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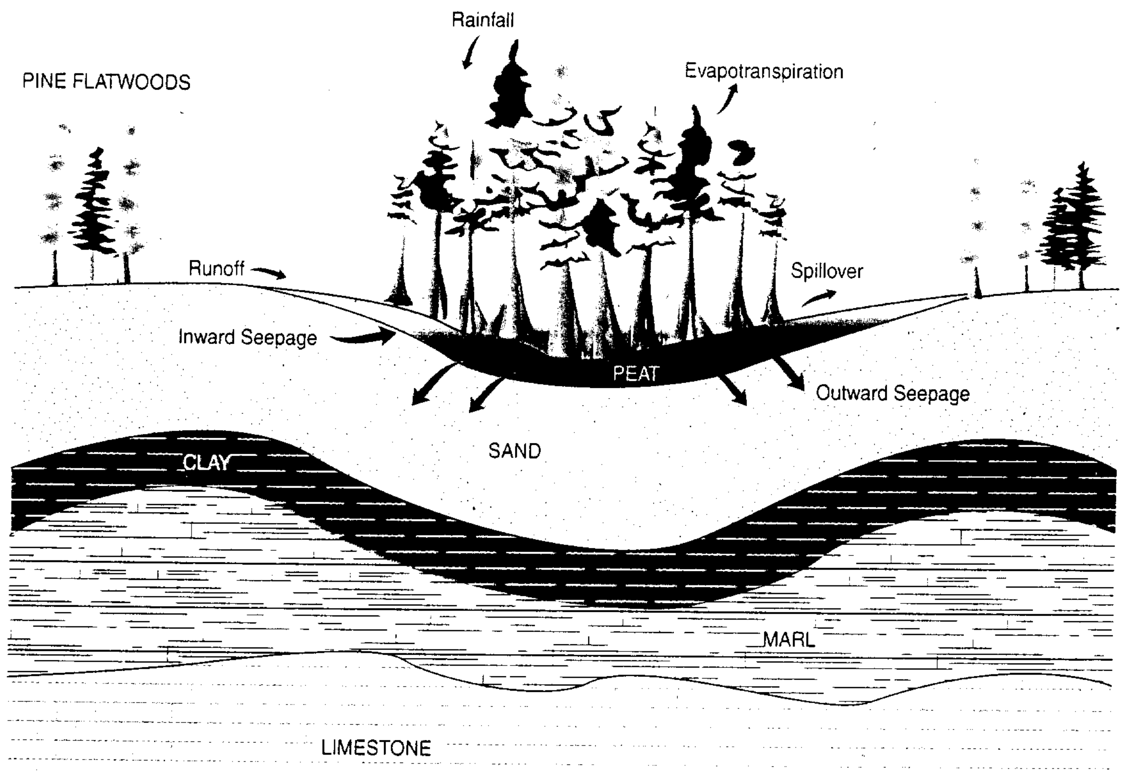
NORTHERN TAMPA BAY WATER RESOURCES ASSESSMENT PROJECT

VOLUME ONE

SURFACE-WATER/GROUND-WATER INTERRELATIONSHIPS



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Resource Evaluation Section
Southwest Florida Water Management District
March 1996

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page No.

TABLE OF CONTENTS (continued)

Page No.

APPENDICES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Figure No. Page No.

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Figure No. Page No.

LIST OF FIGURES (continued)

Figure No. Page No.

LIST OF FIGURES (continued)

Figure No. Page No.

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Figure No. | Page No.

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Figure No. | Page No.

LIST OF TABLES

LIST OF TABLES (continued)

CHAPTER 1 - INTRODUCTION

This report is the first volume of the findings of the Northern Tampa Bay Water Resources Assessment Project (WRAP). The purpose of this volume is to present the results of the analyses of surface-water/ground-water interrelationships and impacts to surface-water features within the study area. Volume Two addresses water quality concerns within the study area, including ground-water contamination and saline water intrusion. The findings within the two volumes and accompanying appendices will be used to help determine safe yield for the study area.

Water use in northwest Hillsborough, northeast Pinellas and Pasco counties has significantly increased since the 1930s. The majority of this use is derived from ground water, which is currently withdrawn at the rate of approximately 255 million gallons per day (mgd). These withdrawals are predominantly from the Upper Floridan aquifer, the principal aquifer in the Southwest Florida Water Management District (SWFWMD). Consequently, the potentiometric levels of the Upper Floridan aquifer and the water table of the overlying surficial aquifer have declined in the areas of large ground-water withdrawals.

The majority of ground-water use in this area is for public supply (Figure 1-1), with at least 75 percent of the public supply use derived from concentrated regional wellfields. In the vicinity of these regional wellfields, observed impacts include lowering of lake levels, reduction in streamflow, and destruction of wetland habitat. In some areas along the coast, lowered ground-water levels have caused water quality degradation.

In response to these observed impacts, the Governing Board of the SWFWMD directed staff to conduct a detailed Water Resource Assessment Project (WRAP) to provide the technical foundation required to address the issue of safe yield in the Northern Tampa Bay area. The Northern Tampa Bay WRAP area (Figure 1-2) was delineated based on a number of factors, including hydrogeologic regime, types of hydrologic effects observed, and regional water use

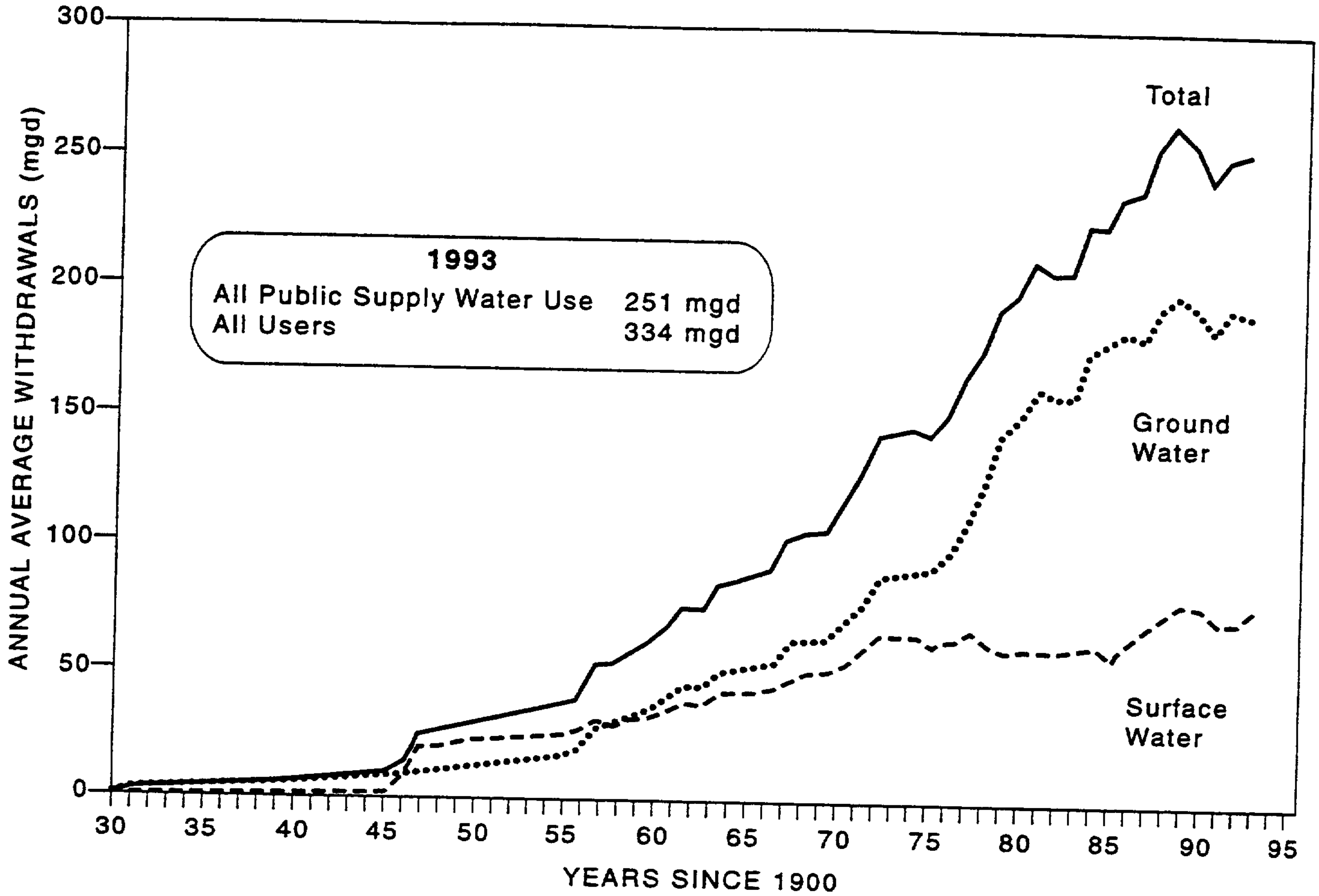


Figure 1-1. Water production of major public suppliers (permits of 1 mgd or greater only) in the Northern Tampa Bay WRAP area.

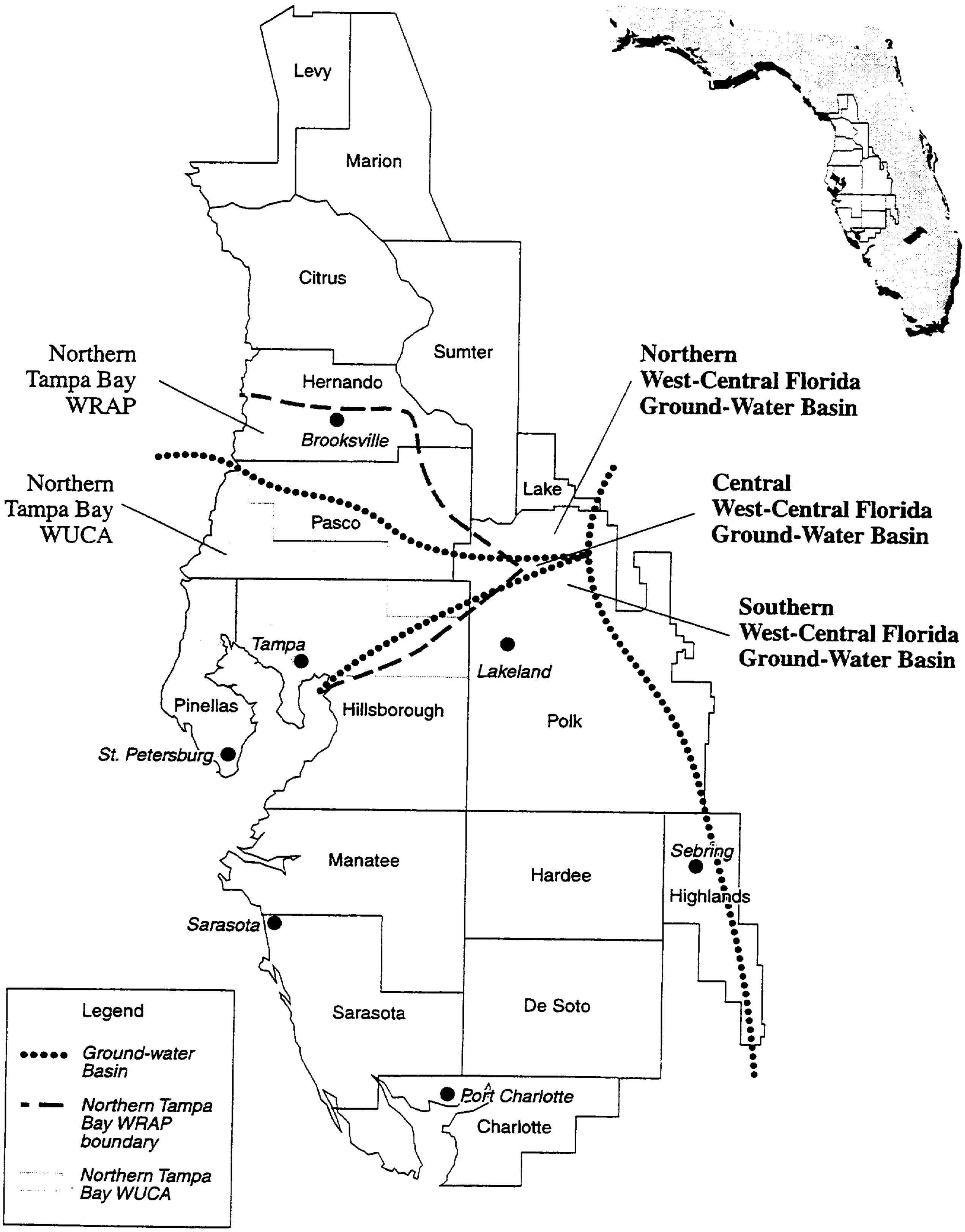


Figure 1-2. Location of the Northern Tampa Bay Water Resources Assessment Project area and the Northern Tampa Bay Water Use Caution Area.

and projected growth. As shown in Figure 1-2, the Northern Tampa Bay WRAP area essentially encompasses the entire Central West-Central Florida Ground-Water Basin (CWCFGWB).

Safe yield, as addressed in this project, is the quantity of water available for man's use without causing unacceptable adverse impacts to the water resources, associated natural systems, and existing legal uses of water. Safe yield may be established by the SWFWMD Governing Board based on a determination of the acceptable levels of impacts. The purpose of the Northern Tampa Bay WRAP is to provide the SWFWMD's Governing Board with the water-resource based technical information and tools necessary to establish safe yield within the project area. The safe yield analysis for ground-water withdrawals must take into account both local and regional cumulative impacts. However, because of the variable nature of the water resource system in the Northern Tampa Bay WRAP area, the impacts from ground-water withdrawals are not reflected regionally. In the Northern Tampa Bay WRAP area, it may not be appropriate to calculate a regional safe yield for the entire study area.

In 1989, the SWFWMD Governing Board declared a region in and around the Northern Tampa Bay WRAP area to be the Northern Tampa Bay Water Use Caution Area (NTBWUCA) (Figure 1-2). In conjunction with declaring the NTBWUCA, the Governing Board implemented a strategy to address the concerns in this area. The strategy consisted of developing and implementing short-, mid-, and long-term measures. The short- and mid-term measures were to be comprehensive in nature and were designed to limit further impacts in the area, based on the best available information at the time (SWFWMD, 1990). These measures included methods to: reduce demand through per capita reduction of public supply, implement water conserving landscape ordinances, further public education, encourage low-volume irrigation, meter water users with cumulative withdrawals higher than 100,000 gallons per day, develop alternative sources of water, halt withdrawals from stressed lakes, and revise the permit process of large ground-water withdrawals. The long-term solutions were to be a refinement of the short- and mid-term measures, and were to be based on the results of the Northern Tampa Bay WRAP.

1.1 Statement of the Problem

The surface-water environment within the Northern Tampa Bay WRAP area is highly interconnected with ground water. Due to the karst geology throughout the Northern Tampa Bay WRAP area, a discontinuous or leaky confining layer provides this relatively good hydraulic connection between the surficial aquifer and underlying Upper Floridan aquifer. Leaky confinement allows water levels of the surficial and Upper Floridan aquifers to fluctuate similarly, and provides the potential for water-level variations in one aquifer to be reflected in the other. Because adequate surface water is necessary to maintain healthy wetlands and lakes, sufficiently high ground-water levels are required to maintain adequate surface-water in these areas of poor confinement.

As in other portions of the SWFWMD, growth in the Northern Tampa Bay WRAP area has accelerated since the 1950s. Agriculture, residential and commercial development, mining, and public water supply development have all had effects on water resources. Conflicting needs for the water have created competition and even confrontation between the different users. Throughout the Northern Tampa Bay WRAP area, problems and concerns have developed over water resource issues due to the large amount of water development.

Due to the combination of increasing ground-water withdrawals and the presence of a leaky confining layer throughout Pasco, Pinellas, and northern Hillsborough counties, effects on surface-water features have been extensively studied since the mid-1960s. The earliest concern was that ground-water withdrawals from the Section 21 and Cosme wellfields were lowering the water levels of surrounding lakes. Reductions of water levels are greatest during dry periods when lake levels and ground-water levels are naturally low, and ground-water withdrawals are usually the greatest. A graph of ground-water levels, lake levels, rainfall, and annual ground-water withdrawals from the Section 21 wellfield (Figure 1-3) shows that since the onset of ground-water withdrawals in 1963, average water levels at the wellfield have significantly decreased, while water level fluctuations have significantly increased. Prior to the commencement of ground-water withdrawals, the Upper Floridan aquifer monitor well (Hillsborough 13) had water levels near 50 feet above the National Geodetic Vertical Datum

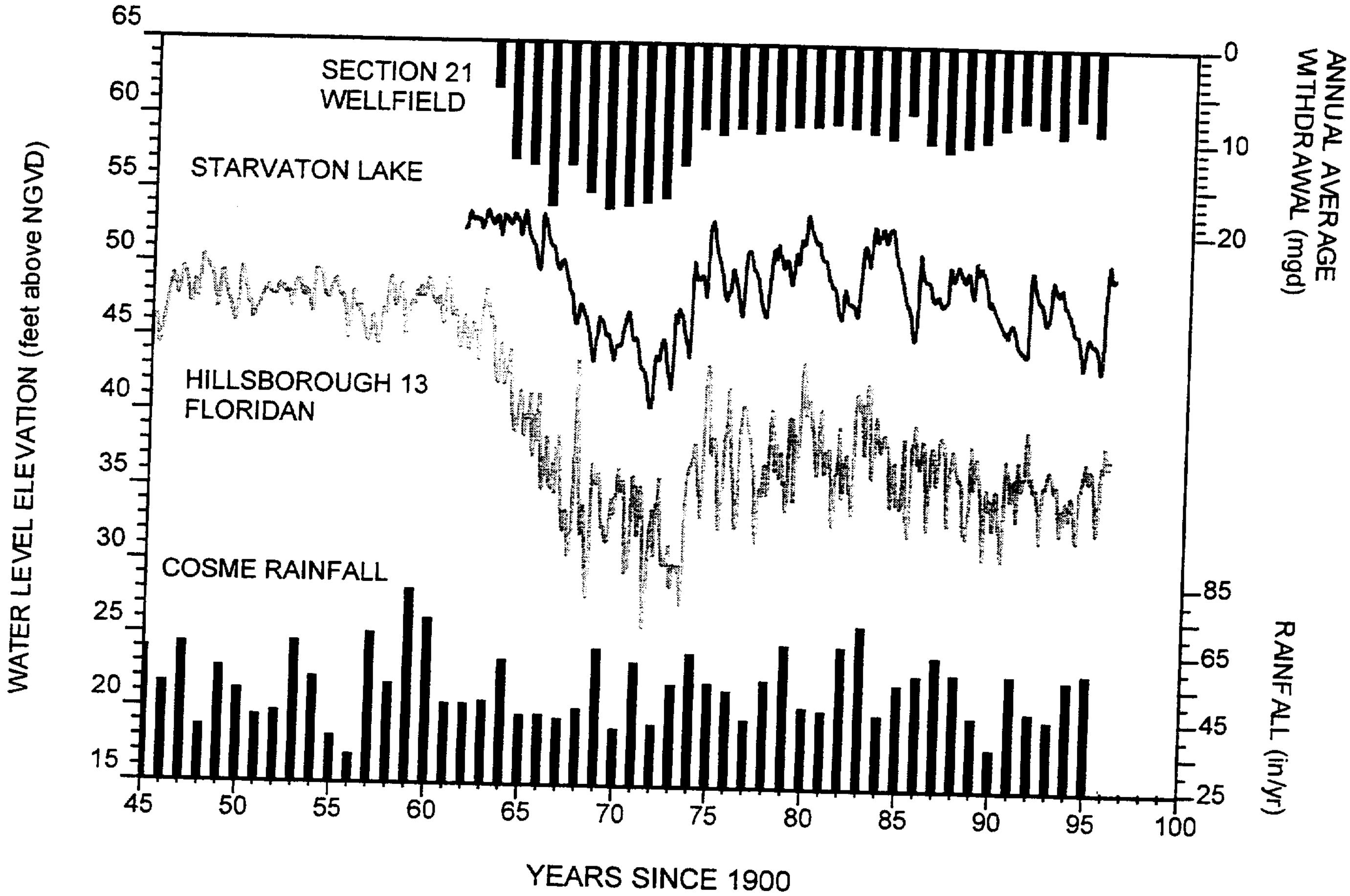


Figure 1-3. Ground-water withdrawal, water levels, and rainfall at the Section 21 wellfield. (rainfall from the Cosme station)

(NGVD). During the late 1960s and early 1970s, water levels in this well declined to an average of approximately 36 feet above NGVD. Effects of ground-water withdrawal reductions in 1974 can be seen in the recovery of water levels in both the Upper Floridan aquifer and Starvation Lake. The data collected at this site clearly demonstrate the principle cause-and-effect relationship between water levels and ground-water withdrawals.

Effects on stream flow from ground-water withdrawals were reported beginning in the early 1970s. Cherry and others (1970) determined that ground-water withdrawals from the Eldridge Wilde, Cosme, and Section 21 wellfields were reducing the flow of Brooker Creek and the Anclote River. Similar effects on these two riverine systems were reported by Parker (1975) and SWFWMD (1984).

Evidence of the effects of historical ground-water withdrawals on wetland conditions has been documented in studies on environmental conditions in and around the Section 21 and Eldridge-Wilde wellfields since the 1960s (Rochow, 1994). Biological investigations in and around the Eldridge-Wilde wellfield documented a number of instances of muck shrinkage, leaning and falling trees, invasion of terrestrial plants, and fire (Courser, 1972, 1973; Black, Crow, and Eidsness, Inc., 1974). Aerial photographic investigations have shown that impacts to isolated wetlands have occurred in the wellfield during periods of intensive wellfield withdrawals.

In addition to surface-water changes, lowered Upper Floridan aquifer water levels have created water-quality concerns. In the coastal margin, sufficient flow of fresh ground water is required to prevent seawater intrusion. Local declines in ground-water levels and the close proximity of ground-water withdrawals to poor quality water near the coast have resulted in some localized seawater intrusion or upconing of seawater. Since the early 1900s, numerous supply wells in coastal areas of Tampa and Pinellas County have been abandoned or capped due to elevated chloride concentrations (Black, Brown, and Pearce, 1954; Black, Crow, and Eidsness, 1974). Many older public-supply wells for the cities of Tarpon Springs, Dunedin, Belleair, Clearwater, New Port Richey, and Port Richey have experienced increases in chloride concentrations. Some of these wells fail to meet potable standards, while others have been retired or modified (Camp, Dresser and McKee, Inc., 1990, 1991).

The karstic nature of the geology in Northern Tampa Bay also makes the Upper Floridan aquifer susceptible to contaminants from the surface waters or the surficial aquifer. The source of this contamination can be from man-made pollutants, or from parameters found naturally within the surficial aquifer. In the presence of drawdowns of the potentiometric surface caused by ground-water withdrawals, the potential for this source of ground-water degradation can increase.

As the population of the Northern Tampa Bay WRAP area grows, the need for additional water supply sources will increase. Future development of ground-water resources can be expected to have similar effects on surface-water features and water quality. Therefore, an important purpose of the Northern Tampa Bay WRAP is to provide a regional understanding of the hydrogeologic system necessary to address the implications of future ground-water development, as well as to further assess the scope of current impacts to the environment and water quality.

1.2 Methods of Investigation

The overall approach of this investigation used two levels of effort in assessing hydrologic and environmental condition. The project began as the Northwest Hillsborough WRAP. Data collection, network expansion, and data analyses were originally focused in the area of northwest Hillsborough, southwest Pasco, and northern Pinellas counties. This area includes the highest density of ground-water withdrawals and long-term environmental impacts. As the project progressed, it became clear that the entire ground-water basin needed to be included in the resource assessment to provide a complete understanding of the hydrogeologic system. Additionally, an understanding of the expanded area would allow an assessment of future regional ground-water withdrawal scenarios. Therefore, the WRAP study area was expanded to include the entire Central West-Central Florida Ground-Water Basin, as well as a bordering section of the Northern West-Central Florida Ground-Water Basin. Portions of the Northern West-Central Florida Ground-Water Basin included in the WRAP are currently providing, or proposed to provide, public water supply to the Northern Tampa Bay WUCA (Figure 1-2). The project was then renamed the Northern Tampa Bay WRAP.

The major objectives of the Northern Tampa Bay WRAP include 1) to describe the hydrogeologic system of the study area, 2) to describe the hydrologic trends within the study area, 3) to estimate the regional extent of impacts, 4) to develop regional relationships between hydrologic parameters, and 5) to provide demonstrative scenarios that can be used to best manage water use in the study area. To accomplish these goals, the Northern Tampa Bay WRAP was divided into five major tasks: 1) preliminary data analysis, literature review, and development of a conceptual model of the hydrogeologic system; 2) development of numerical models to simulate the ground-water flow system and interaction of the freshwater and saltwater flow systems; 3) data network expansion to refine our understanding of the system and to refine the conceptual model; 4) determination of cause-and-effect relationships; and 5) formulation of scenarios to demonstrate water availability alternatives and other appropriate concepts to the SWFWMD's Governing Board.

1.2.1 Preliminary Data Analysis and Literature Review

Basic geologic, hydrologic, biologic, physiographic, climatic, demographic, water use, and water quality data were reviewed and analyzed to describe the study area and to develop a conceptual model. Primary sources of data include water use permit information and data collection networks operated by the SWFWMD; the United States Geological Survey (USGS); the West Coast Regional Water Supply Authority (WCRWSA); the City of Tampa; Hillsborough, Pasco, and Pinellas counties; the United States Weather Bureau; the Florida Agricultural Statistical Service (FASS); the Institute of Food and Agricultural Sciences (IFAS); the State of Florida's Department of Environmental Protection (FDEP); and the State of Florida's Department of Health and Rehabilitative Services (HRS).

Measurement station information for pertinent rainfall, evaporation, streamflow, water level, water quality, and ground-water withdrawal was organized within a spreadsheet data-base system on a personal computer (PC). The Northern Tampa Bay WRAP PC data-base was designed to assist in the requisition and analysis of data throughout the course of the project. The program was designed to allow fast access to project data, and to perform search routines that other existing databases could not handle. The actual hydrologic data was accessed through the

various databases obtained from the agencies listed above. Information on data collection stations used in the study is listed in Appendix A and the Data Appendices of this report.

Analyses performed include hydrographs, hyetographs, hydrostratigraphic cross-sections, flow net analysis, land use maps, biological indices, water use and water quality trend graphs, and various statistical analyses. A detailed literature search was conducted emphasizing previous water resource investigations within the area, and approaches to determine safe yield in other areas.

The results of the data review and analyses were synthesized into a conceptual model of the ground-water flow system in the Northern Tampa Bay area. The system was conceptualized as an aquifer system with ground-water flowing in the Upper Floridan aquifer from Polk, Pasco, and Hernando counties south and west to the Gulf of Mexico. Surficial aquifer flow is more localized, and discharges to lakes, wetlands, streams, and the Gulf of Mexico. The surficial aquifer also recharges the Upper Floridan aquifer. Ground-water flow in the basin originates as rainfall that falls within the basin.

1.2.2 Model Development

A regional quasi-three-dimensional ground-water flow model was developed using the Modular Three Dimensional Finite Difference Ground-Water Flow Model code (MODFLOW; McDonald and Harbaugh, 1988) to further the SWFWMD staff's understanding of the flow system and to help evaluate cause-and-effect relationships of the area's water resources. The model consists of three layers to simulate lateral flow within and between (through vertical exchange) the surficial and Upper Floridan aquifers. The Upper Floridan aquifer is divided into two layers to simulate the Tampa/Suwannee Limestones separately from the Avon Park Formation. The model is also a tool used in demonstrating various ground-water withdrawal scenarios.

Regional water quality relationships were investigated through the use of a quasi-three-dimensional model using the SIMLAS code (HydroGeoLogic, 1994). Specifically, the sharp

interface model was used to quantify the regional rate of movement of seawater intrusion and upconing of mineralized water.

1.2.3 Data Network Expansion

A major task of the Northern Tampa Bay WRAP was to collect additional data where known data deficiencies existed. To accomplish this, a data collection program was established to expand the ground-water level and water-quality monitor network, a wetland health monitoring network was established to observe environmental and hydrologic features, and stream flow data was collected in areas lacking flow information.

The ground-water data collection program included collecting water quality data from the Upper Floridan aquifer, monitoring water levels of the separate aquifers, and determining hydraulic parameters of the system. To collect these data, a comprehensive drilling program was conducted at 40 locations within the Northern Tampa Bay WRAP area. Four of the sites consisted of deep Upper Floridan aquifer test wells, where detailed coring, geophysical logging, and water quality sampling was conducted at each site. On the remaining 36 sites, surficial and Upper Floridan aquifer monitoring wells were drilled and tested. Detailed descriptions of the lithology and permeameter tests of cored sections of confining material were used to establish degrees of confinement. These wells established head differences between the water table and Upper Floridan aquifer potentiometric surface, and allowed estimates of leakance coefficients for the Upper Floridan aquifer semi-confining bed. This data is summarized in Appendix B.

Wetland monitoring was enhanced for the project to address wetland health. A total of 198 isolated wetland sites in the Northern Tampa Bay WRAP area were monitored for field observation of environmental and hydrologic features. Thirty-eight of these sites, 21 of which had surveyed staff gages for water level measurements, were observed and quantitatively ranked. Based upon the established correlation of quantitative ranking and wetland health, the entire 198 wetlands sites were qualitatively ranked. Land use/land cover, soils, depth to water, impervious surface, surface-water drainage, and other descriptors of the entire Northern Tampa Bay WRAP area were discretized from aerial photography and transformed into a Geographical Information

System (GIS) data base. This information was correlated with wetland rankings. This work is discussed in Chapter 4 and Appendix C.

Streamflow data collection was performed in the previously ungaged 24-square mile watershed of the Double Branch Creek system. To quantify surface runoff from this highly developed watershed, three streamflow stations were established. This work is presented in Appendix D. All other major watersheds within the Northern Tampa Bay WRAP study area have been previously gaged.

1.2.4 Cause-and-Effect Relationships

The existing data, literature information, numerical flow and seawater intrusion models, and the results of the data network expansion, were integrated to identify various cause-and-effect relationships. The relationships to be examined are those between the stresses that are applied to the resource and the responses that are being seen in water levels, water quality, ecological health, and surface-water features. The most obvious relationship described was that between ground-water withdrawals and water levels in the Upper Floridan aquifer. Rainfall and drainage alterations were also evaluated as stresses causing water-level declines. Next, the relationships between the lowered water levels and other effects were examined.

The various relationships were assessed through a variety of means, including the use of standard hydrologic and biologic analysis techniques, numerical modeling, and empirical analyses. These tools were used to address the relationship between Upper Floridan aquifer water level declines and the effects on the surficial aquifer, deterioration of water quality, reductions in streamflow, effects on lakes and wetlands, and the relationship between surface-water effects and ecological health.

1.2.5 Management Scenario Runs

Ground-water withdrawal scenarios for the ground-water flow and seawater intrusion models were designed to further refine the cause-and-effect relationships and to determine the limiting

constraints on water availability. The scenarios were initially run using the ground-water flow model, and the results were used as input to the sharp-interface model.

Safe yield is the quantity of water which can be withdrawn from an aquifer system without causing unacceptable impacts. In the Eastern Tampa Bay WRAP analysis, a regional safe yield was determined based on the basin-wide quantity of water that could be withdrawn without causing continuing regional seawater intrusion (SWFWMD, 1993). In the Eastern Tampa Bay area, a regional safe yield could be estimated because withdrawals from throughout the basin were causing the unacceptable water quality changes. In the Northern Tampa Bay WRAP area, the impacts in the surface-water environment are mostly found in the vicinity of the regional public supply wellfields in response to the ground-water withdrawals and associated water level declines. The Northern Tampa Bay WRAP analysis provides documentation of the level of impacts in the region, and provides the tools that are needed to estimate the regional ground-water yield.

The levels of impact for existing withdrawals are determined using the results of the various analyses presented in this report, which include water-table drawdown limits and water quality trends. Favorable locations of possible future ground-water withdrawals are dependent on suitable aquifer characteristics, water quality, and environmental sensitivity. Withdrawal locations are also dependent on land availability, wellhead protection ordinances, and existing water uses.

Prior to final determination of major withdrawal yields, the socioeconomic effects and more localized assessments will be examined in a separate effort, and those effects will be presented to the SWFWMD Governing Board. The permitted quantities associated with the major withdrawals in the Northern Tampa Bay WRAP area will be established by the Board based on a determination of the acceptable level of impacts to the resource, associated systems, existing legal users, and socioeconomic factors.

1.3 Definition of Terms - Regional, Subregional, Local

Throughout this report, the terms "regional", "subregional", and "local" are frequently used to describe the limits of various effects or hydrologic processes. In this report, "regional" is used to describe an effect or process that essentially involves the entire study area. Because the focus of this study was to determine the regional scope of impacts to the hydrogeologic system, regional effects are of primary concern. The term "local" is used to describe an effect of process that involves very site-specific areas, such as an individual lake, wetland, or well, or possibly a small set of such features. The Northern Tampa Bay WRAP includes thousands of features that may be described as local, and it is beyond the scope of this assessment to describe or address all local effects. However, examples of local processes are used or identified as they help define the regional aspects of the WRAP area. The term "subregional" is used to describe effects or processes that involve areas substantially larger than local features, yet do not effect the entire Northern Tampa Bay WRAP area. Because a subregional effect is substantially larger than local effects, these effects are discussed in detail throughout the report.

1.4 Report Contents

The results of the Northern Tampa Bay WRAP are presented in two volumes and several appendices. This report (Volume One) provides the general background of the study area, and presents the results of the analyses of surface-water/ground-water interrelationships and impacts to surficial water resource features. Volume Two presents the results of the analyses concerning water quality and saline water intrusion.

Volume One of this report is divided into six chapters. Chapter 1 is an introduction and discussion of the Northern Tampa Bay WRAP process. Chapter 2 describes the physical framework of the study area, including descriptions of the surface- and ground-water systems, climate, water use, land use, and physiography. Chapter 3 presents the trends in land use, water use, rainfall, evapotranspiration, discharge, ground-water levels, lakes levels, wetland water levels, and wetland health. The cause-and-effect relationships between these parameters are examined in Chapter 4. A summary of the construction of the ground-water flow model is

described in Chapter 5. Also presented is a demonstration of historical impacts to the water resources, and a methodology for determining future water availability and the associated effects on the water resources of the area. Scenarios of possible future water-supply situations are simulated, and suggestions for water management plan applications are presented. Chapter 6 lists the conclusions.

Volume Two of this report is divided into five chapters. Chapter 1 is an introduction and discussion of the Northern Tampa Bay WRAP process as it pertains to water quality analyses. Chapter 2 presents a summary of the Northern Tampa Bay hydrogeologic system, along with a presentation of current ground-water quality and the SWFWMD's monitoring network. Chapter 3 includes a discussion of water-quality degradation from man-made byproducts. Chapter 4 presents analysis pertaining to water-quality trends related to saline water intrusion and upwelling, including a summary of the regional sharp-interface model analysis performed as part of this study. Chapter 5 lists conclusions.

Appendices A through F include discussions of the expansion of the data-base and monitoring network and detailed discussions of some of the technical aspects of the various elements of the study. In addition, Appendices G through J contain graphical and tabular presentations of pertinent hydrologic data contained in the SWFWMD and United States Geological Survey (USGS) data bases for stations within the Northern Tampa Bay WRAP area.

1.5 Acknowledgements

The Northern Tampa Bay Water Resources Assessment Project is an effort of the Resource Evaluation Section of the Resource Projects Department. M.C. Hancock was the project manager under the direction of D.A. Smith. The wetlands monitoring program and analysis was developed by T. Rochow. R.J. Basso was responsible for the description of the hydrogeologic framework of the study area, as well as the water budget analysis, the ground-water model description, and several model scenarios. T.O. Bengtsson was responsible for the original scope of work, and contributed to initial investigations. K. Coates, G.M. Kelley, and R. Schultz were responsible for the water quality analysis. D. Ellison, D. Chan, and M. Beach also contributed

to various hydrologic evaluations. Geographic Information System analysis was performed by the Mapping and GIS Section. The comprehensive well drilling program was conducted by CH2M HILL, Inc. and A. Gilboy of the SWFWMD staff. Regional sharp-interface modeling was performed by HydroGeoLogic, Inc. J.A. Mann was responsible for the stream gage installation and analysis for Double Branch Creek.

Manuscript preparation was provided by F.R. Laushway and L.L. Eichhorn, and graphics support was provided by P. Twardosky and the SWFWMD Graphics Department. This report would not have been possible without the valuable contribution of the SWFWMD Resource Data Department's tremendous data collection effort, the Land Resources Department for acquisition of the many drill sites, the Tampa office of the United States Geological Survey, and the West Coast Regional Water Supply Authority. We also wish to acknowledge the contributions of J. Guida and other Resource Regulation staff for the valuable periodic review of the project results, as well as the advice and review received from the members of the Northern Tampa Bay WRAP Technical Advisory Committee.

CHAPTER 2 - DESCRIPTION OF THE STUDY AREA

2.1 Introduction

A determination of water availability should be based on an understanding of the framework of the water resource system. This chapter includes a description of the water resource system in the Northern Tampa Bay WRAP area. The elements that are described include climate, physiography, geology, ecosystems, surface-water system, ground-water system, land use, and water use.

The Northern Tampa Bay WRAP area encompasses approximately 1,800 square miles of west-central Florida (Figure 2-1). The study area was delineated through the use of the ground-water flow lines in the area and the locations of major ground-water withdrawal areas. Although the Northern Tampa Bay WRAP's main area of focus includes the area of ground-water withdrawals and use, the exact boundaries of the study were determined in the ground-water modeling process. This process is described briefly in Chapter 5 and in detail in the Northern Tampa Bay model report (SWFWMD, 1993a). The study area includes the southwest portion of Hernando County; all of Pasco County, with the exception of the northeast corner east of the Withlacoochee River; a small section of western Polk County; all of Pinellas County; and the northwest portion of Hillsborough County.

Also presented in Figure 2-1 is the delineation of the Northern Tampa Bay WUCA. The WUCA includes the population centers that rely upon the Northern Tampa Bay area for their public water supply. Most of these areas are supplied water under the supervision of the West Coast Regional Water Supply Authority (WCRWSA), although the WUCA also includes service areas supplied by Pasco and Pinellas counties and the cities of Tampa, New Port Richey, Port Richey, Tarpon Springs, Dunedin, Clearwater, Belleair, and other smaller municipal and private utilities. The Northern Tampa Bay WRAP area does not include the southeast corner of the Northern Tampa Bay WUCA in Hillsborough County (Figure 2-1). This area is included, however, within the Eastern Tampa Bay Ground-Water Model (SWFWMD, 1993b).

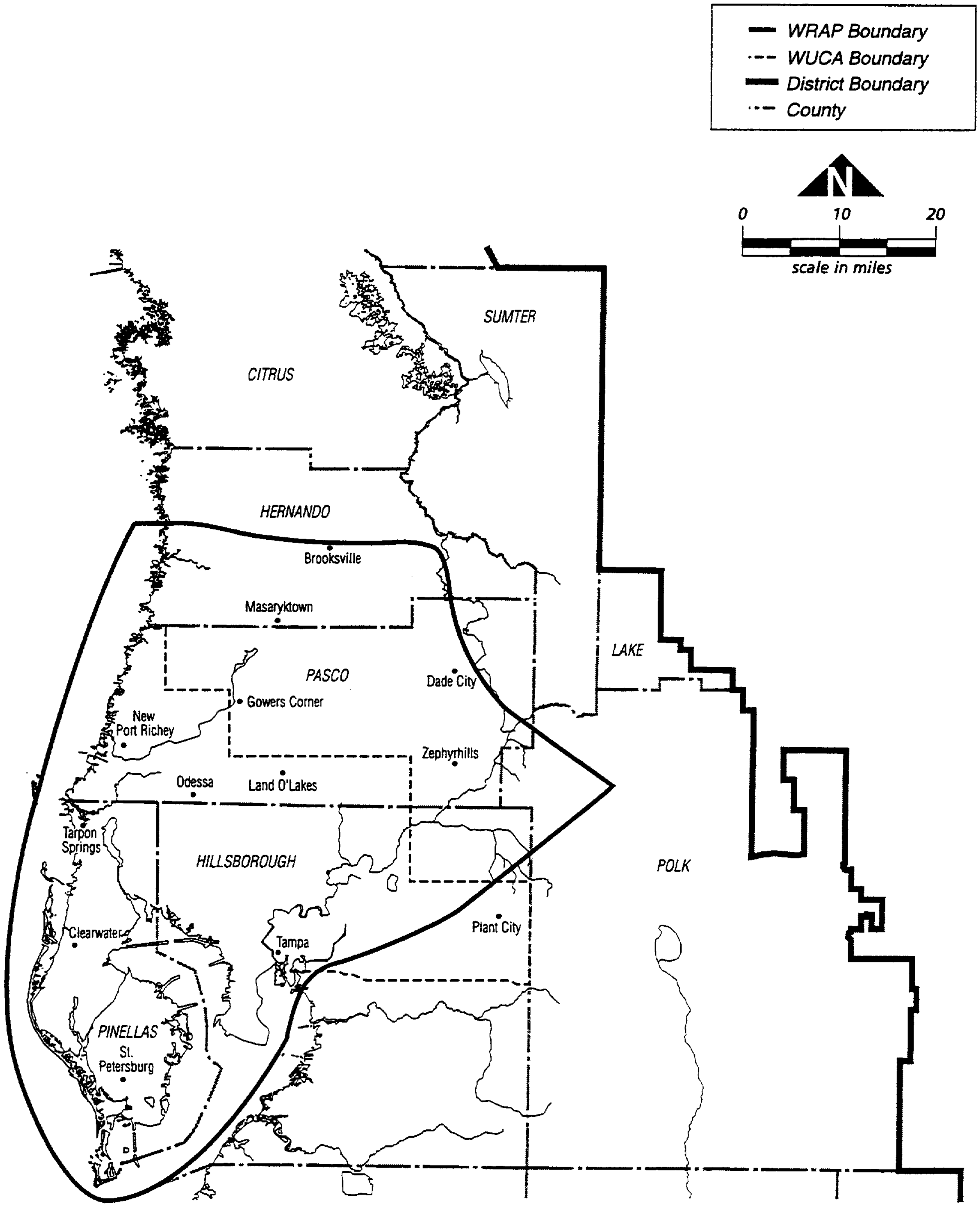


Figure 2-1. Location of the Northern Tampa Bay Water Resources Assessment Project area.

2.2 Climate

The climate of the Northern Tampa Bay WRAP area is humid sub-tropical, characterized by warm, wet summers and mild winters. Some rainfall normally occurs during each month, but a distinct rainy season extends from June through September, and a low rainfall season extends from October through May. On average, about 60 percent of the annual rainfall occurs during the rainy season.

Figure 2-2 represents the average monthly rainfall for the Northern Tampa Bay area based on 38 stations throughout the study area. Although rainfall for any month can be highly variable, the months of greatest rainfall are typically July and August, and the months of least rainfall are typically November, December, and April. Annual rainfall is approximately 52 inches within the Northern Tampa Bay WRAP area. This average is considerably skewed by years of large tropical events, which can result in 80 to 100 inches of annual rainfall at many stations (see Chapter 3). Precipitation is highly variable in frequency, distribution, amount, and intensity due to frontal storms, local thunderstorms, and tropical disturbances. Tropical disturbances include tropical depressions, tropical storms, and hurricanes. These storms can generate heavy precipitation over large or localized areas, usually during August, September, and October (Jordan, 1984). A more complete discussion of rainfall in the Northern Tampa Bay area is found in Chapter 3.

Estimates of evapotranspiration (ET) within the area vary, but a value of approximately 39 inches per year is generally accepted (Hutchinson, 1984). Close to sixty percent of the total ET occurs in the six month period from May to October (SWFWMD, 1988a). The highest ET rates occur in May and June.

Average monthly temperatures within the area range from 61 degrees Fahrenheit in January to 82 degrees Fahrenheit in July and August (NOAA, 1986a). The average annual temperature is 73 degrees Fahrenheit.

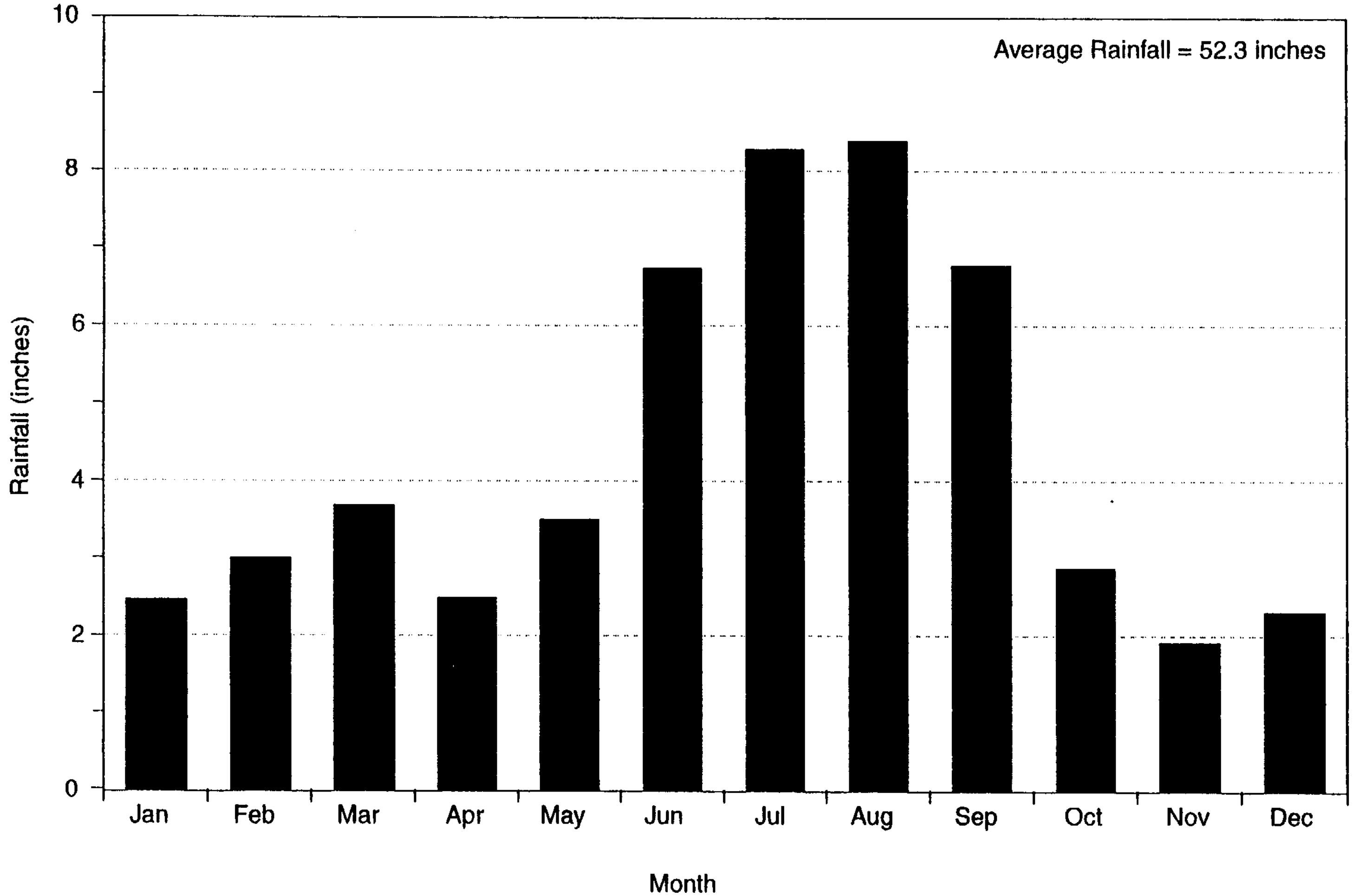


Figure 2-2. Average monthly rainfall for the Northern Tampa Bay WRAP area, based on 38 stations.

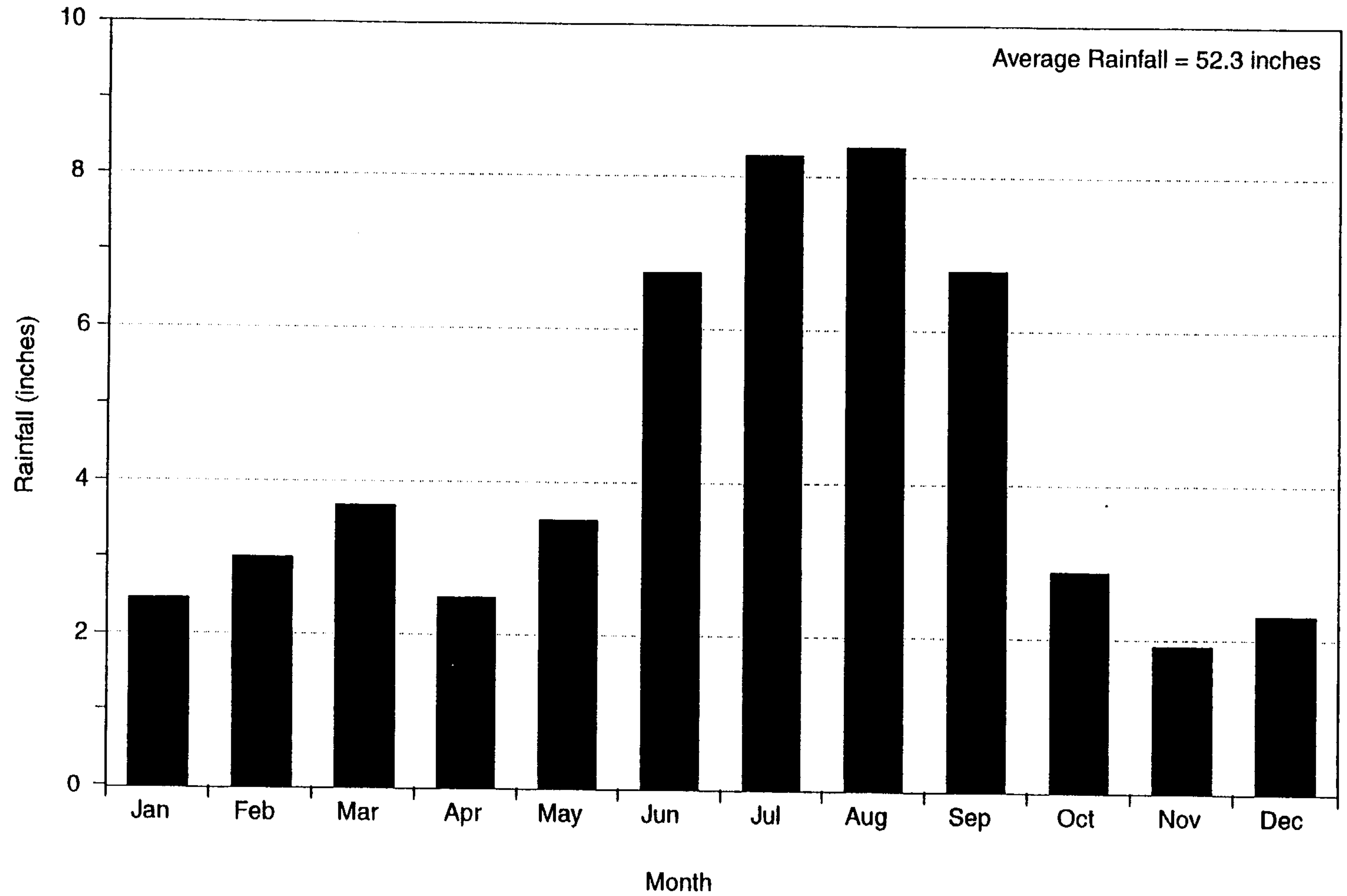


Figure 2-2. Average monthly rainfall for the Northern Tampa Bay WRAP area, based on 38 stations.

2.3 Physiography and Topography

Much of the topography of the Northern Tampa Bay WRAP area is largely a result of limestone dissolution and sediment deposition. Numerous closed depressions and sinkholes throughout the area reflect active dissolution of the underlying limestone. This landscape is termed **karst** topography. Associated with the sinkholes are such features as springs, disappearing streams, and round lakes. Where the depressions are filled with sediment and organic material, they are commonly occupied by cypress communities or exhibit shallow marsh conditions.

The Northern Tampa Bay WRAP area is comprised of five main physiographic provinces (Figure 2-3); the Coastal Swamps, the Gulf Coast Lowlands, the Brooksville Ridge, the Zephyrhills Gap, and the Polk Upland (White, 1970). These provinces are mostly a function of topographic relief and underlying sediments. Topography is presented in Figure 2-4.

The Coastal Swamps province is found in the northwestern portion of the area and generally parallels the coast. This province extends inland about five miles in northern Hernando County. The province consists of tidal marsh and coastal swamp, with elevations ranging from sea level to about 10 feet NGVD. The province contains poorly drained organic soils overlying limestone.

The Gulf Coast Lowlands province lies to the east and south, and encompasses all of Pinellas County, over half of Pasco County, and much of the western areas of Hillsborough and Hernando Counties. Elevations range from near sea level in Pinellas County to 100 feet NGVD in Pasco and Hernando Counties. This province contains sandy soils with little organic material.

The Brooksville Ridge province dominates central Hernando and eastern Pasco Counties. The edges of the Ridge are characterized by deep, sandy soils pocketed with depressions and sinkholes. Soils on the Ridge are mixed, ranging from poorly drained to well drained sandy to clayey soils. The entire Ridge overlies a clayey unit up to 30 feet thick, with localized hydraulic connection to the underlying Upper Floridan aquifer by way of solution features and fractures (Fretwell, 1988). Because of the highly karst nature of the province, the topography is rolling,

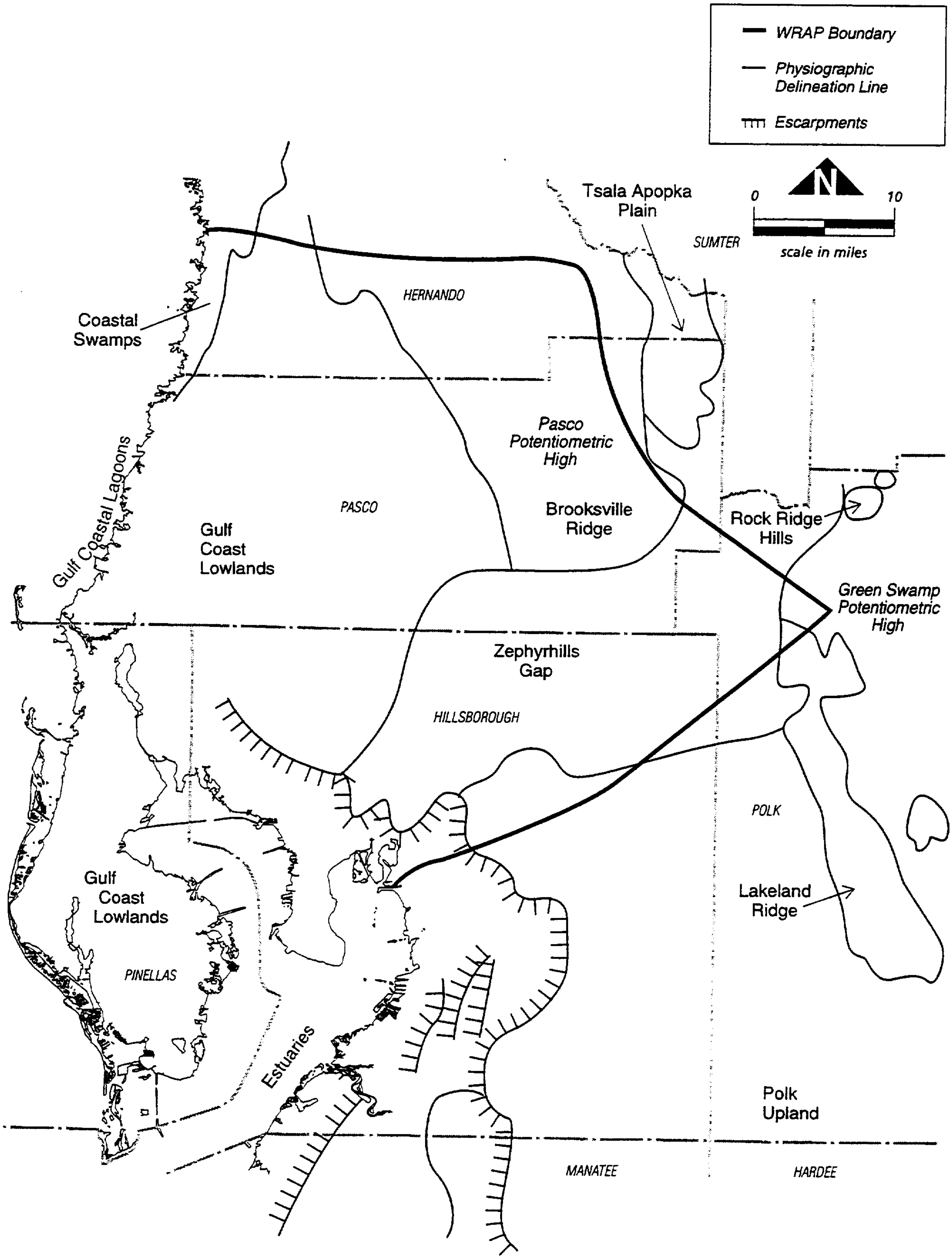


Figure 2-3. Physiographic provinces of the Northern Tampa Bay area (modified from White, 1970).

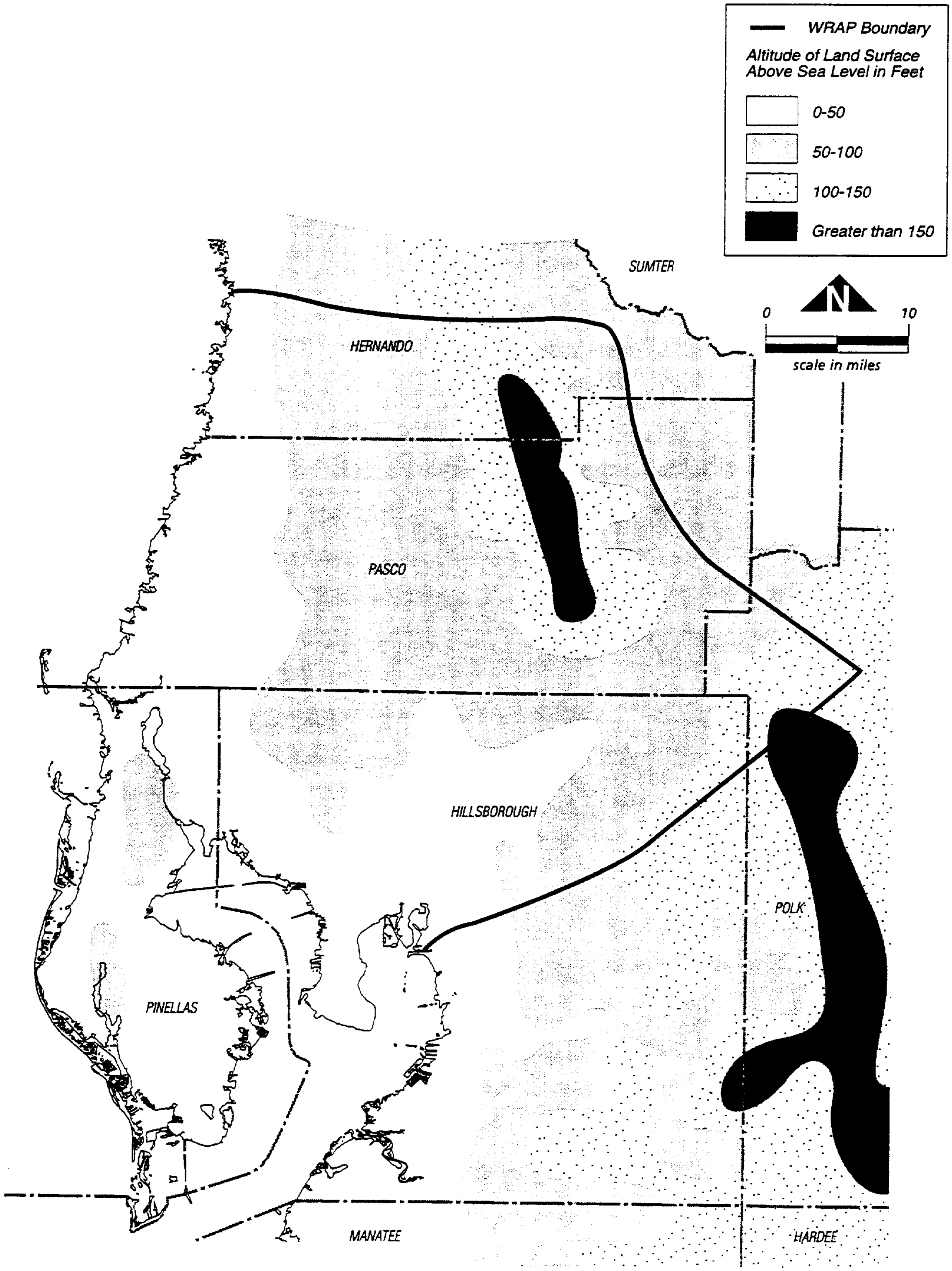


Figure 2-4. Land surface altitude of the Northern Tampa Bay area (modified from Sinclair and other, 1985).

with elevations up to 300 feet NGVD. A significant Upper Floridan aquifer potentiometric high, known as the Pasco High, is located within the Brooksville Ridge province in Pasco County. The Tsala Apopka Plain province lies east of the Brooksville Ridge province, and serves as a portion of the watershed for the Withlacoochee River. The province contains interconnected wetlands, and soils consist of weakly cemented sand mixed with organic material. Elevations range from 75 to 85 feet NGVD. Ocala Limestone outcrops are common in this area.

The Zephyrhills Gap province lies along the eastern border of Hernando and Pasco Counties, and follows the Hillsborough River valley in Hillsborough County. This area is an erosional basin with sluggish surface drainage and many karst features. A thin layer of sand and clay overlie karst limestone, and springs and sinkholes are common. Elevations range from 10 to 140 feet NGVD, with poorly drained swamps and marshes in the low elevations and pine flatwoods in the higher elevations. The Polk Upland province, located to the east of the Zephyrhills Gap province and the Northern Tampa Bay WRAP area, contains the Green Swamp High, the hydrologic peak of the potentiometric surface in central Florida.

Sinkholes occur throughout the Northern Tampa Bay WRAP area as a natural process of dissolution of the limestone by infiltrating rainfall. Ancient cavities created in the limestone with a fragile overlying land surface need a triggering mechanism to cause the collapse. Sinkholes occur naturally when heavy rain or floods cause an increased loading and reduction in the structural strength of the cover over a limestone cavity. Low rainfall periods also stimulate sinkhole activity as ground-water levels lower. This causes the hydraulic gradient between the surficial and Floridan aquifer to increase, which can increase erosional effects and decrease buoyant support of the overburden, prompting a collapse. Relict sinkhole characteristics can be seen as round lakes and cypress domes in the aerial photographs throughout the Northern Tampa Bay WRAP area, although most sinkhole features are covered, and not visible from the surface.

Sinkholes have been reported at an increasing rate during the past few decades. Much of this may be a function of increased data collection, rather than an increase in actual occurrence. However, increased effects by man have been documented to cause some increased level of sinkhole occurrence. The cause of this increase can generally be attributed to loading of the

surficial deposits with retention ponds, buildings, changes in drainage patterns, heavy traffic vibration, or lowering of the ground-water levels by pumping (Sinclair and others, 1985). Usually all of the conditions occur simultaneously in rapidly growing urban areas. Collapses resulting from these effects have been termed **induced sinkholes** (Newton, 1976). Abrupt changes in ground-water levels have been reported to induce sinkholes in northwest Hillsborough County, such as those documented during the initiation of ground-water withdrawals at the Section 21 wellfield in 1963 (Sinclair, 1982). Instances of induced sinkholes during the drilling of public supply or domestic wells in the Northern Tampa Bay area have also been observed. Figure 2-5 displays sinkholes reported to the Florida Sinkhole Research Institute (FSRI) through 1991 that are within or near the Northern Tampa Bay WRAP area.

As part of a study performed by the SWFWMD to prevent stormwater pond collapses due to sinkhole formation (Kelley, 1991), three zones of sensitive karst geology were proposed based on a classification system by Wilson and others (1987):

A. Highest sinkhole hazard [less than 30 ft cover].
B. Low to moderate sinkhole hazard [30 to 200 ft of cover].
C. Little or no sinkhole hazard [more than 200 ft cover].

Figure 2-6 presents these karst sensitivity delineations within the Northern Tampa Bay WRAP area. The delineation generally follows the cover thickness map prepared by Sinclair and Stewart (1985). Due to the karst nature of the study area, there are no areas within the Northern Tampa Bay WRAP area classified as little or no sinkhole hazard.

2.4 Surface Water

2.4.1 Rivers, Streams, and Creeks

The Northern Tampa Bay WRAP area contains all or part of approximately nine significant watersheds or sub-basins, as well as several coastal watersheds drained by many small tidally-influenced or intermittent streams (Figure 2-7). Because of the internally-drained nature of large

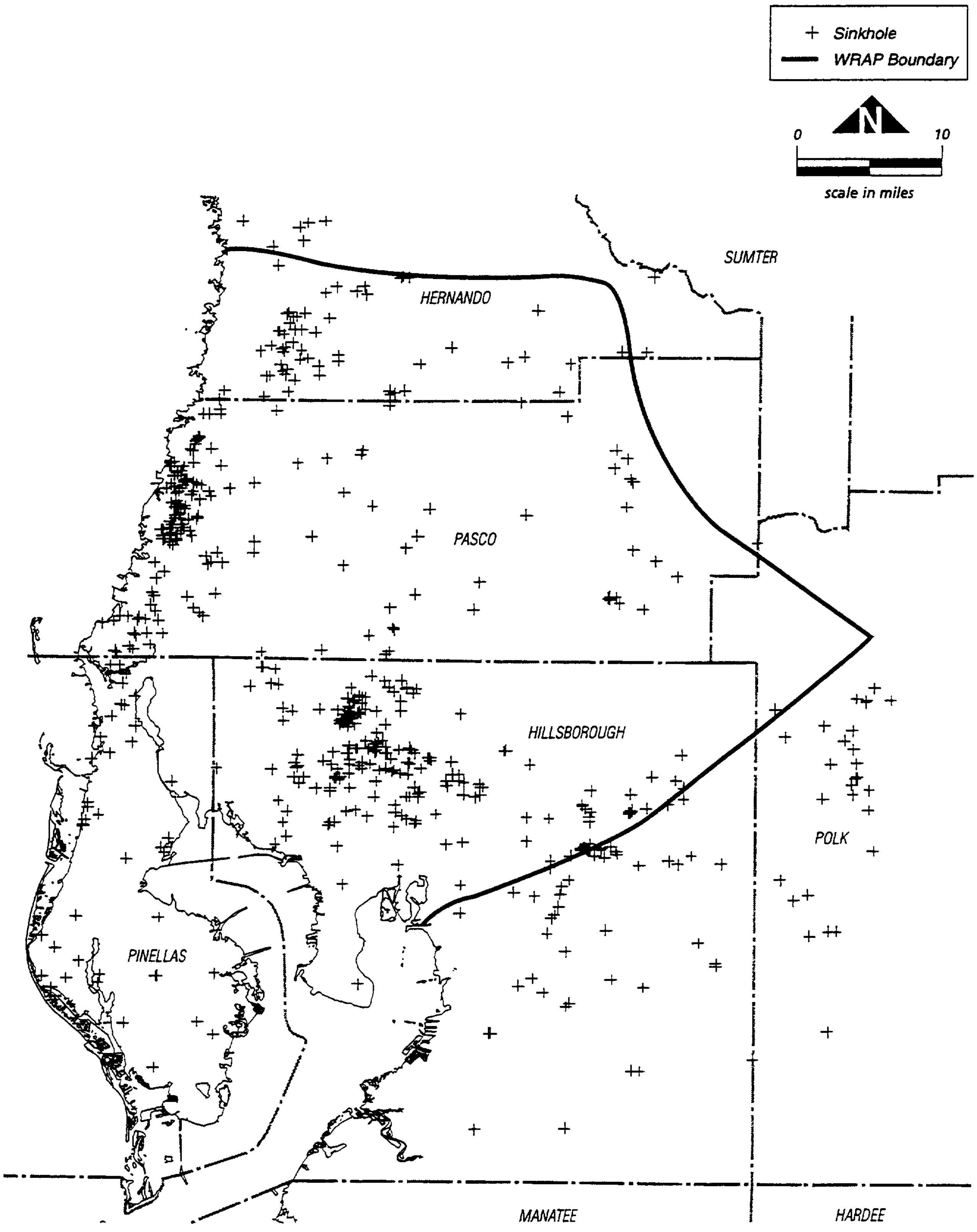


Figure 2-5. Reported sinkholes in the Northern Tampa Bay area.

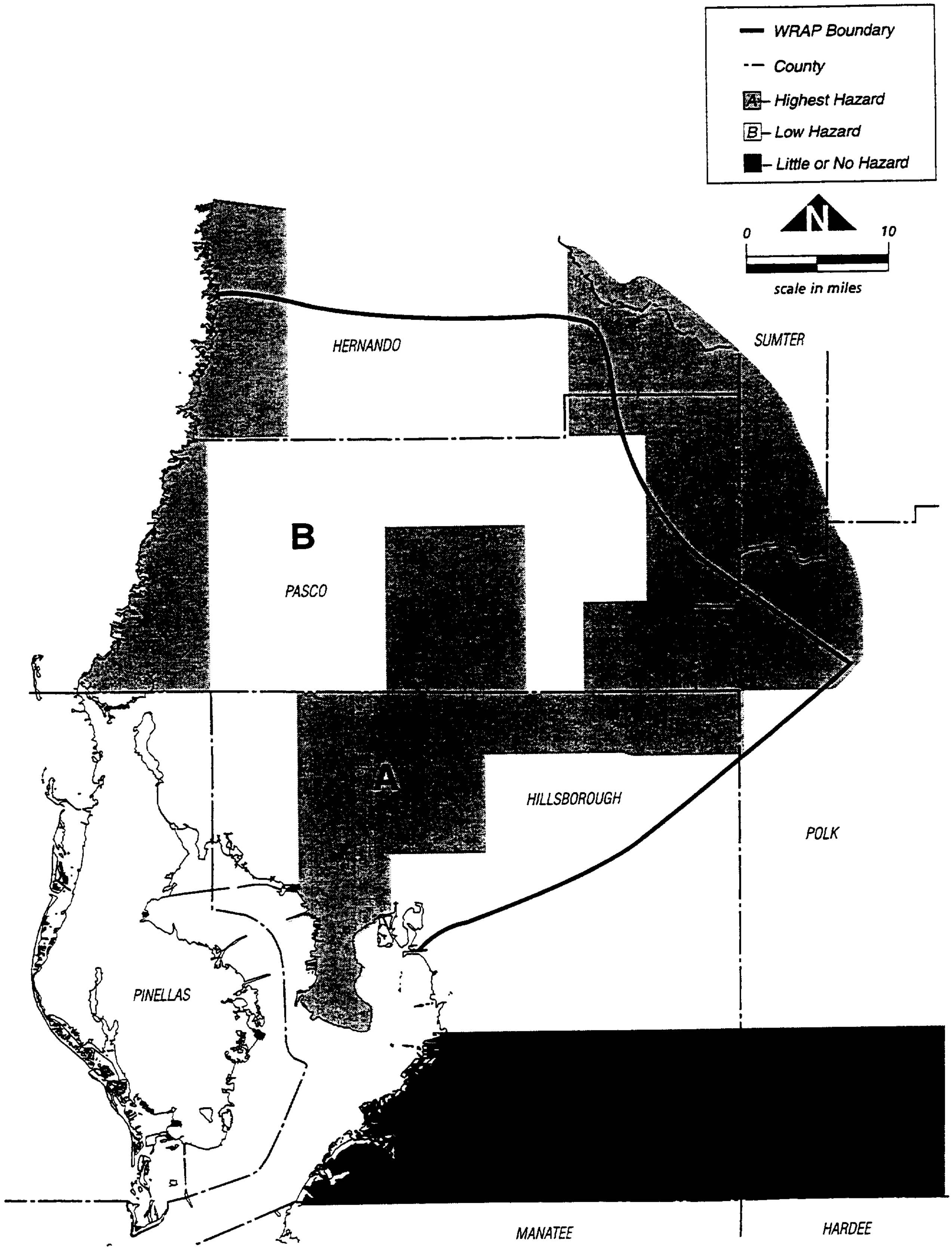


Figure 2-6. Sinkhole hazard areas in the Northern Tampa Bay area.

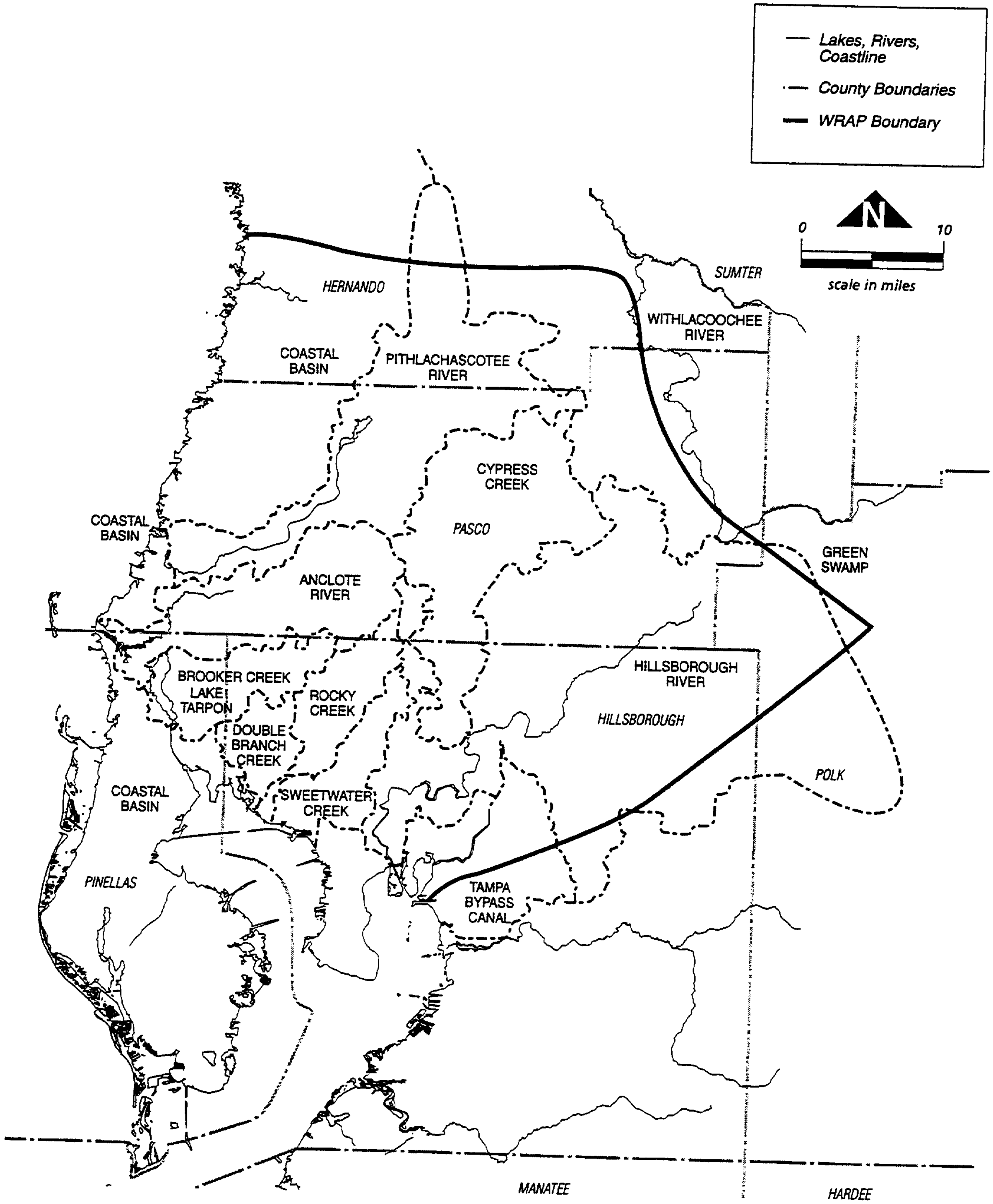


Figure 2-7. Surface-water basins in the Northern Tampa Bay area.

sections of many of the watersheds, particularly in areas north of Hillsborough County, much of the flow in these river systems is derived from ground-water discharge in addition to overland flow. Therefore, a source of flow in some river systems can actually be water that was recharged in another watershed. The major river systems are the Hillsborough River, the Withlacoochee River, the Pithlachascotee River, the Anclote River, Brooker Creek, Double-Branch Creek, Rocky Creek, Sweetwater Creek, and Cypress Creek. Cypress Creek is actually a large sub-basin of the Hillsborough River watershed, but is broken out due to its significance to this study. Most of the peninsular section of Pinellas County is drained by intermittent or low flowing streams, supplied by surface-water runoff. Hydrographs for all streamflow gages on each river system can be found in the Data Appendices of this report.

The most hydrologically significant river within the study area is the Hillsborough River, with a watershed of approximately 650 square miles. The interactions between the Hillsborough River watershed and the Upper Floridan aquifer are quite complex, and result in large wetland areas that act as ground-water discharge points in some areas, and perched surface-water storage basins in others.

Although most of the river systems in the Northern Tampa Bay WRAP area are fed almost totally by overland flow or surficial aquifer discharge, the Hillsborough River receives significant contributions from the Upper Floridan aquifer. The river system originates in the Green Swamp, but much of the baseflow entering the river is discharged from the Upper Floridan and surficial aquifers along the course of the river. Several reaches of the river have direct contact with the Upper Floridan aquifer, and many springs are found along the bottom and banks. The banks of the Hillsborough River have been developed for residential use in lower reaches of the river, and the river is dammed for public water supply ten miles upstream from its mouth. The greater part of the headwaters and upper reaches of the river is undeveloped. The USGS estimates the average flow at the reservoir to be 464 cfs (300 mgd) (SWFWMD, 1988a).

Crystal Springs, located just north of the Hillsborough County line (Figure 2-9), contributes a large amount of flow to the river, averaging over 57 cfs (37 mgd) (USGS, 1990). The

percentage of flow in the upper portions of the river contributed by the spring has been as much as 80 percent (SWFWMD, 1988c), thus creating a significant and constant baseflow. In the lower reaches of the watershed, the Tampa Bypass Canal System was built by the U.S. Army Corp of Engineers to provide flood protection for the Tampa metropolitan area. The canal system was completed in 1984, and extends 18 miles from the Trout Creek area to McKay Bay. The canal system breaches the Upper Floridan aquifer in some areas, and acts as a conduit for ground-water exchange to and from the canal.

The largest tributary to the Hillsborough River system is Cypress Creek. Cypress Creek's watershed is approximately 160 square miles, and is mostly undeveloped or agricultural land. Average discharge at the most downstream gage is approximately 86 cfs (56 mgd). The channel is poorly defined throughout most of the watershed. Flow originates from low sand hills and karst areas in northern Pasco County, and travels through large wetland systems toward the Hillsborough River. Like many of the creek systems in the study area, several reaches exhibit no flow during the dry season, but unlike most other creek systems, it is estimated that the Upper Floridan aquifer contributes about 20 percent of the total flow of the creek in the middle reaches of the system (Cherry and others, 1970).

The northeast corner of the study area consists of the Withlacoochee River watershed. This is the largest watershed in the area, consisting of over 2,000 square miles, but only a small portion is located within the study area (Figure 2-7). Like the Hillsborough River, the Withlacoochee River originates in the Green Swamp. The Withlacoochee River flows generally northwest to the Gulf of Mexico. The average flow in the river at its confluence with Blue Run, which conveys the discharge of Rainbow Springs to the river, is about 2,000 cfs (1,293 mgd) (SWFWMD, 1987a). The Withlacoochee River also has many areas of direct connections to the Upper Floridan aquifer. Since such a small part of the river is within the study area, the Withlacoochee River system does not play a large role in this investigation.

The northwest quarter of the study is dominated by several small coastal systems (including the Weeki Wachee Spring system discussed later) and the Pithlachascotee River system, which rises in south-central Hernando County and flows southwestward toward the Gulf of Mexico. The

watershed of the Pithlachascotee River is approximately 195 square miles, of which about 150 square miles is comprised of the river's headwaters north of Crews Lake. The main channel of the river begins below the lake. The last non-tidally influenced gaging station before the river's mouth has an average flow of approximately 30 cfs (19 mgd). This station does experience no flow days seasonally. The elevation of the potentiometric surface is very close to the elevation of the water table in this area, so ground-water contribution is minimal, and varies from reach to reach. Flows are relatively low in the river because much of the watershed is internally drained, with several small streams terminating in sinkholes. Much of the watershed is either undeveloped or agricultural land, with concentrated areas extensively developed with urban and commercial areas in the coastal sections.

The northwest Hillsborough County area contains all or part of five watersheds (Figure 2-7): the Anclote River basin (120 square miles), the Brooker Creek basin (42 square miles), the Brushy/Rocky Creek basin (41 square miles), the Sweetwater Creek basin (26 square miles), and the Double Branch Creek basin (24 square miles). Several other small creek systems are located in this area, including the Dick Creek Basin and basins of several drainage canals along Hillsborough and Old Tampa Bays.

The swampy terrain that once prevailed near the headwaters of these creeks and rivers provided the water with the physical and chemical characteristics of blackwater streams. The headwaters of all four major basins consist of many lakes, wetlands, and intermittent streams. Many of these lakes and wetlands have manmade control structures. The Brushy/Rocky Creek and Sweetwater Creek basins have experienced extensive land development in the past twenty-five years. The Anclote River and Brooker Creek basins, however, have only recently seen increased development. All of the watersheds are similar, and the flow in each system is almost entirely originated by surface-water runoff or short-term surficial aquifer baseflow. With the exception of Brooker Creek, the larger downstream sections of each system are tidally influenced.

The Sweetwater Creek basin begins just south of the Pasco County line in Hillsborough County, and drains southwesterly towards Hillsborough Bay. The drainage basin of Sweetwater Creek

is approximately 26 square miles, and is extensively developed with residential and commercial land uses. Like many of the rivers and streams in the area, the topography of the headwaters is very flat and largely internally drained. Of the five major watersheds in Northwest Hillsborough County, Sweetwater Creek has been subject to the most manmade alterations. Between 1967 and 1972, Channels G and H were dug from the mouth of Sweetwater Creek up to an area just south of Waters Avenue (Corral and Thompson, 1988). Since 1970, flow from Sweetwater Creek has been diverted through Channel G to the lower section of Rocky Creek. Although a gaging station with a period of record of over 40 years exists along the creek (average flow less than 7 cfs, or 4.5 mgd), a control structure upstream of Gunn Highway has affected flow since 1953. Other changes to the watershed include the diversion of flow from Curiosity Creek (in the Hillsborough River basin) to Sweetwater Creek during flood events, and the diversion of a portion of the northern Sweetwater Creek watershed to Brushy Creek, via an interceptor canal constructed in 1960. Due to alterations and other impacts to the watershed, portions of Sweetwater Creek are often dry.

The Brushy/Rocky Creek basin drains to the southwest from southern Pasco County, discharging into Channel A and Hillsborough Bay. Channel A, constructed along with Channels G and H in the late 1960s, reaches almost to Linebaugh Avenue. The basin consists of flows from both Brushy and Rocky Creeks, which converge south of Gunn Highway. The total watershed area is about 41 square miles, and is mostly developed with residential land uses.

The headwaters of Brushy and Rocky Creeks consist of many lakes and wetlands. Water levels in many of the lakes and some wetlands are regulated by manmade control structures. Some of the structures are operable by the SWFWMD, and are adjusted in accordance with adopted lake levels and operating schedules. An interceptor canal east of the natural basin, built in 1960, diverts some flow from the Sweetwater basin to Brushy Creek (Camp, Dresser & McKee, 1986a). Although many lakes have control structures, and many land use changes have occurred, the stream beds of Brushy and Rocky Creeks remain relatively unchanged. The channelization of the lower portion of the watershed occurred downstream of the last recording gage, and does not alter flow at the gage. Average discharge at the gage is over 38 cfs (25

mgd) (USGS, 1991). All of the man-made control structures are in the very northern sections of the system, so the main course of both creeks flow rather naturally.

The Brooker Creek basin begins along the boundary of Pasco and Hillsborough Counties, and drains in a westerly direction towards Lake Tarpon, into which it discharges. Although the area has only recently experienced residential development, the streambed has been affected by agricultural practices for many years. Several sections of the creek are channelized, and the natural drainage patterns of many of its contributing interconnected wetlands have been altered. The current drainage basin is about 42 square miles, with an average discharge of less than 20 cfs (13 mgd) (USGS, 1991).

A stop-log control structure, installed in 1955, regulates the flow out of Keystone Lake, the largest lake located along the main channel of Brooker Creek. This structure was replaced with a lift-gate structure in 1974. Island Ford Lake, located immediately downstream of Lake Keystone, received a concrete and steel sheet pile control structure in 1975 (Briley, Wild & Assoc., 1978).

The Anclote River basin drains westerly beginning in south-central Pasco County, discharging to the Gulf of Mexico at Tarpon Springs. The headwaters are poorly defined, and consist of mostly agricultural and natural lands. The lower one-third of the watershed is heavily developed with residential dwellings (SWFWMD, 1988c). This watershed is about 120 square miles, and contains several recording stations with long-term streamflow data. The average discharge at the most downstream gaging station is 68 cfs (44 mgd) (USGS, 1991). Like Brushy and Rocky Creeks, the Anclote River flows rather naturally, and like the Pithlachascotee River, does have some connections to the Upper Floridan aquifer in its lower reaches.

The remaining watershed in the northwest Hillsborough County area is the Double Branch Creek system. This watershed consists of approximately 24 square miles, and prior to this study was ungaged. To quantify surface runoff from this watershed, three streamflow measuring stations were established in Double Branch Creek as part of this study. A discussion of this work is included in Appendix D.

2.4.2 Lakes

There are over 150 named lakes located in the Northern Tampa Bay WRAP area with significant records of lake level data (Figure 2-8), although hundreds of open water areas and wetlands dot the landscape. Many lakes were formed by sinkhole activity and retain a hydraulic connection to the Upper Floridan aquifer, while some are surface depressions perched on relatively impermeable materials and reflect the water table levels. Many of the lake systems are internally drained, while others are connected to river systems through natural streams or manmade canals. Several lakes have been altered by water level control structures, water level maintenance through augmentation from the Upper Floridan aquifer, and dredging. The SWFWMD has set lake management levels that apply to 152 of the lakes within the Northern Tampa Bay WRAP area. Table 2-1 lists the largest lakes within the Northern Tampa Bay WRAP area.

Table 2-1. Large lakes within the Northern Tampa Bay WRAP area.

Lake	Size (acres)
Lake Tarpon	2,534
Lake Thonotosassa	824
Crews Lake	749
Seminole Lake	684
Lake Hancock	519
Lake Keystone	417
Lake Pasadena	373
Hunters Lake	302
Big Fish Lake	270
Mud Lake	266
King (East) Lake	263
Lake Magdalene	238
Neff Lake	226
Middle Lake	215
Moody Lake	205
Lake Padgett	200

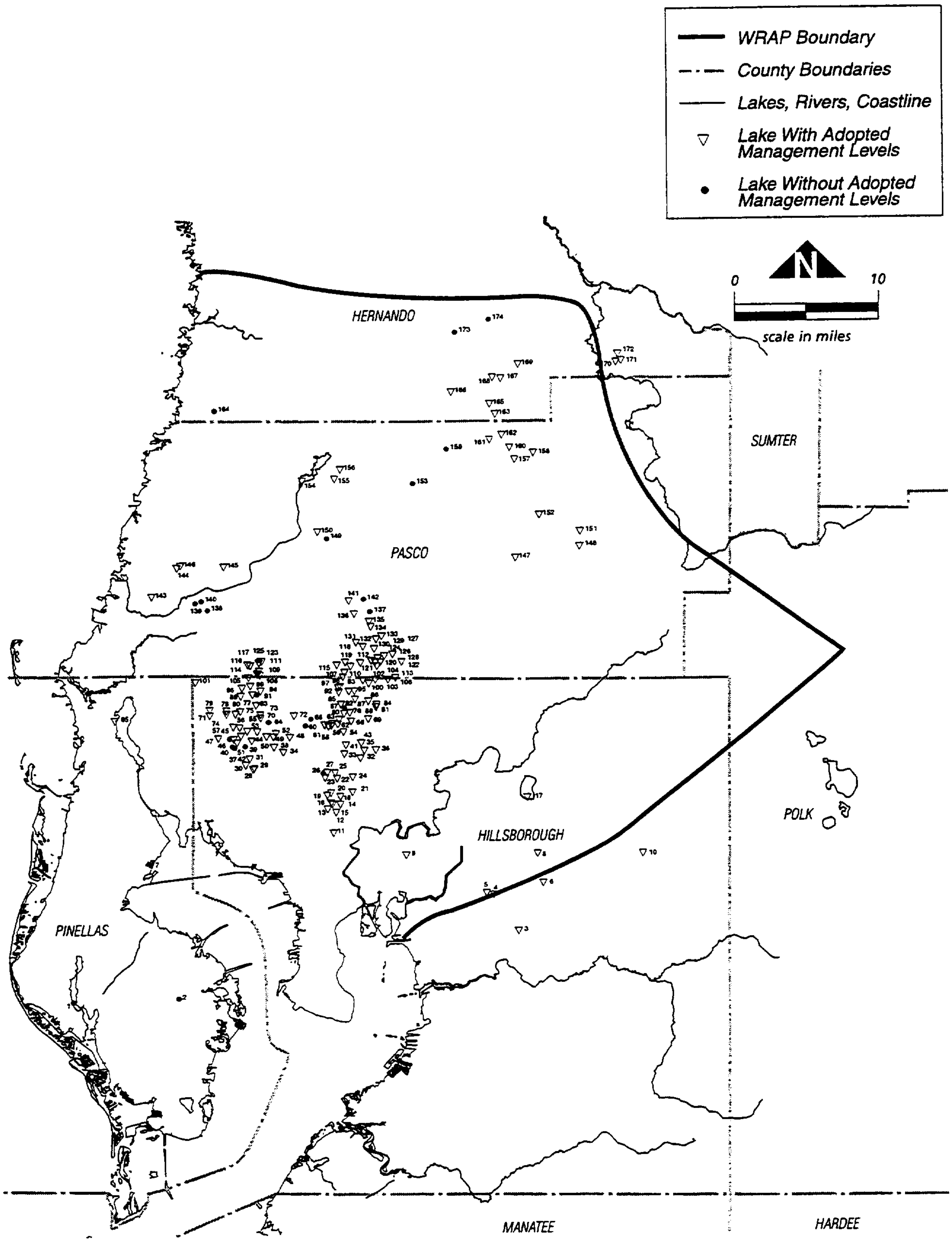


Figure 2-8. Location of lakes with collected data within the Northern Tampa Bay WRAP area. (Lake names listed in Appendix A).

Lake Tarpon is the largest lake in the study area, with a surface area of approximately 2,500 acres, and a drainage basin of approximately 60 square miles. Most of the lake is very shallow, and water surface elevations fluctuate between two to three feet NGVD. The principal surface-water inflow to the lake is Brooker Creek. Historically, a large sinkhole to the west of the lake periodically drained the lake. The sinkhole is connected via a conduit to Spring Bayou, located along the tidal portion of the Anclote River to the north. At times, the flow would reverse, and seawater would contaminate the freshwater in the lake. In 1969, the SWFWMD constructed a dike which disconnected the sink from the lake. The lake is located in a large fracture system of the Floridan aquifer, however, so although the main conduit is detached, some interaction with the underlying aquifer remains. Since 1971, the lake's main outfall is the Lake Tarpon Outfall Canal to the south, and is controlled by a structure operated by the SWFWMD.

2.4.3 Springs

Several major springs are located within the Northern Tampa Bay WRAP area, including: Weeki Wachee Spring and Mud Springs in Hernando County, Crystal, Unnamed Number 3, Salt, Horseshoe, and Magnolia Springs in Pasco County, Health Spring in Pinellas County, and Lettuce Lake and Sulphur Springs in Hillsborough County (Figure 2-9). The most productive is Weeki Wachee Spring, a first magnitude spring that has discharged from approximately 101 cfs (65 mgd) to 275 cfs (177 mgd) for the period of record (1931 - present). The average discharge is about 175 cfs (113 mgd). Spring discharge is related to the gradient of the potentiometric surface. Correlation studies have shown that the flow in Weeki Wachee Spring increases or decreases by approximately 12.5 cfs (8.1 mgd) for every foot of water level increase or decrease in the potentiometric surface, respectively (Yobbi, 1992). Since most spring discharge in the region originates from deep Floridan aquifer sources, spring discharge does not typically fluctuate drastically like the region's stream flow. Although recharge is a major driving force in spring discharge rates, there is a delay in response to rainfall due to the depths of spring discharge origination. Higher spring discharges usually occur in late fall, with low discharges in late spring. Spring discharge can also be affected by ground-water lowering caused by withdrawals, or, in springflows originating from shallow Floridan or surficial aquifer, can be affected by land use activities and drainage. Some springs in the study area, including

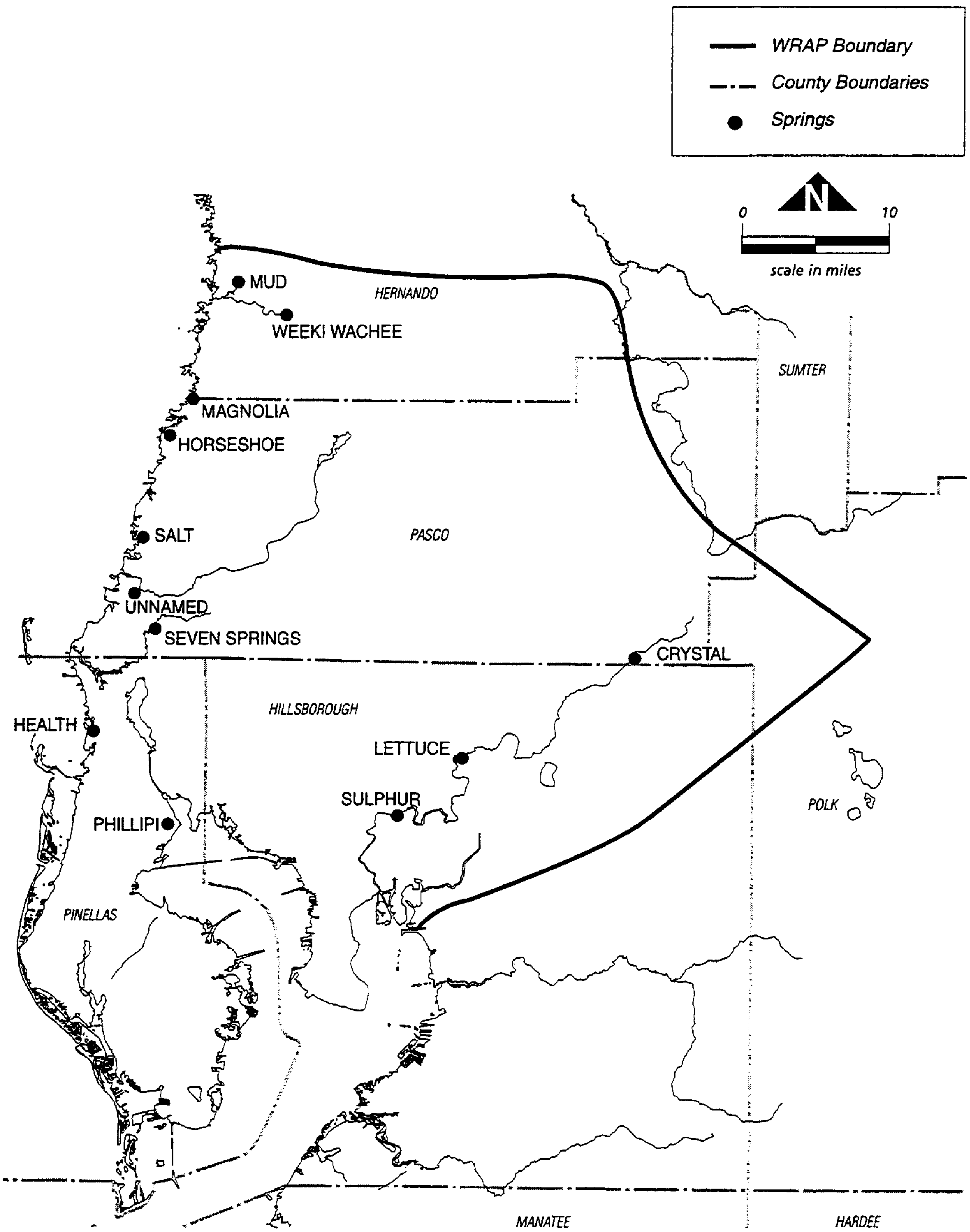


Figure 2-9. Location of major springs within the Northern Tampa Bay area.

Seven Springs in Pasco County and Phillipi Spring in Pinellas County (Figure 2-9), no longer flow.

Several second magnitude springs are located in this area, the largest of which include Crystal Spring and Sulphur Spring. Both springs discharge into the Hillsborough River. Crystal Spring is located in Pasco County near Zephyrhills, and is one of the principle sources of the Hillsborough River's headwaters. Measured flow has ranged from 20 cfs (13 mgd) to 147 cfs (95 mgd) for the period of record (1934 to present), and has averaged 57.6 cfs (37.2 mgd). Upward leakage of ground-water in the wetland areas of the Hillsborough River's headwaters accounts for much of the remaining baseflow. One direct withdrawal is permitted from the spring, which pumps at a rate of less than 0.2 mgd for any month. Sulphur Spring, which derives much of its flow from relatively shallow ground-water sources, discharges near the mouth of the Hillsborough River, about one mile south of the City of Tampa's dam. Measured flow has ranged from near zero to 111 cfs (72 mgd) for the period of record (1959 - present). The average discharge is about 40.4 cfs (26.1 mgd), but has shown declines in recent years. Sulphur Springs is used by the City of Tampa as a supplement to its public water supply. In the last ten years, the City has withdrawn at a rate as high as 20 mgd for one month, but typically averages less than three mgd as an annual average. These withdrawals are not included in the discharge data collected for the spring.

Many second, third, and lesser magnitude springs have been identified within the study area (Rousenau and others, 1977; Wright, 1974; and Ryder, 1982). Most of the other springs are coastal, and discharge directly to the Gulf of Mexico.

2.5 Ecosystems

Southwest Florida has an abundance of natural and man-influenced ecosystems. Because of the large number of systems, it is most useful for project objectives to focus on the systems most sensitive to changes in hydrology. Due to their shallow water depths, the most sensitive ecological systems to changes to water level fluctuations are wetlands. Figure 2-10 presents the current spatial distribution of wetlands throughout the Northern Tampa Bay WRAP area.

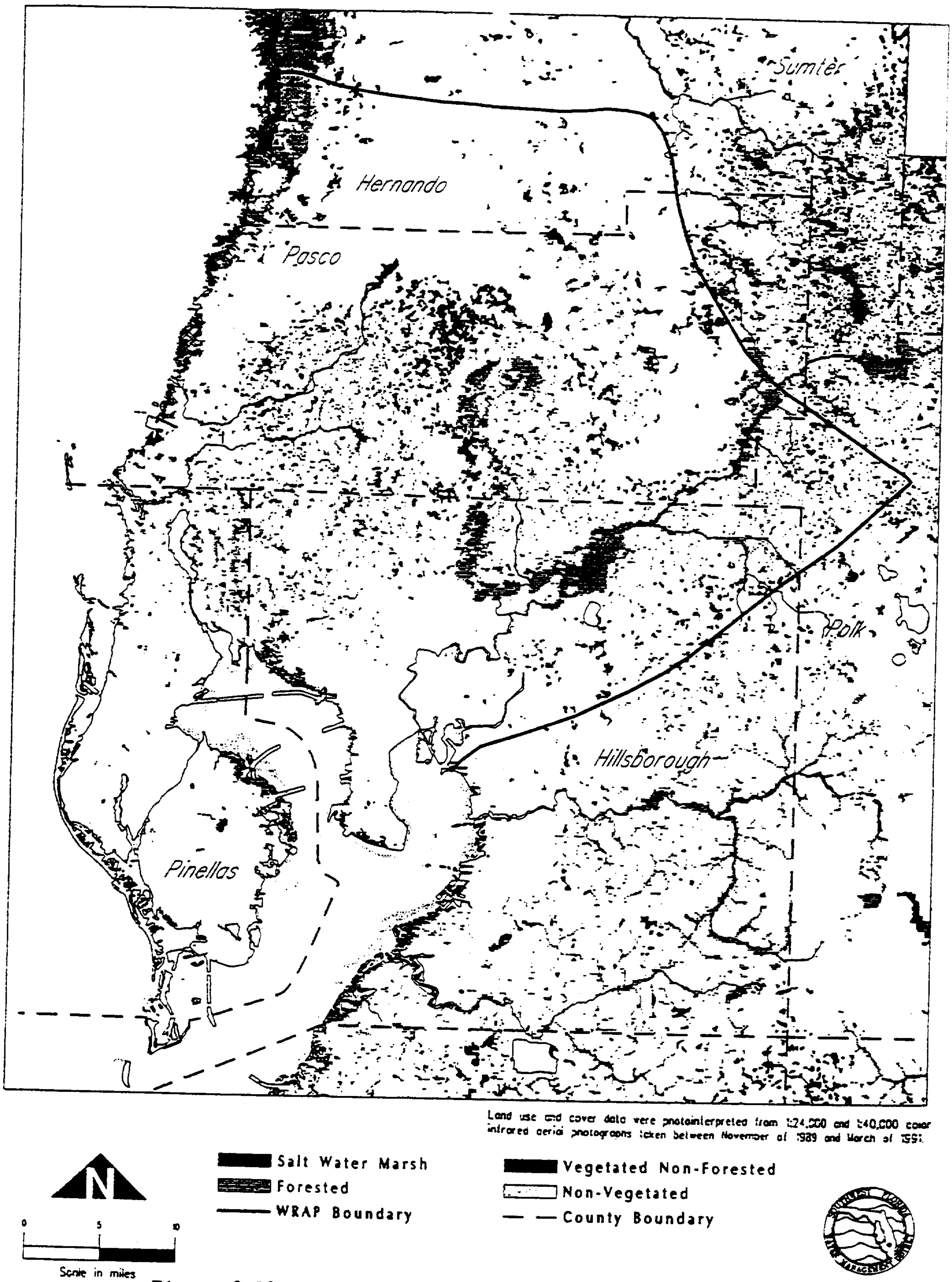


Figure 2-10. Wetland distribution of areas of ten acres or more in the Northern Tampa Bay WRAP area.

Historically, Florida has ranked either first or second among the fifty states in percentage of land surface occupied by wetlands (Dahl, 1990). Prior to significant development, approximately 54 percent of the state was wetlands. However, due to wetland loss, only about 30 percent of the state currently is wetlands. Major wetlands in southwest Florida include estuaries, hardwood-cypress swamps, and marshes.

Estuaries are coastal landscape features with brackish waters formed by the mixing of fresh ground- and surface-water discharge and seawater. Estuaries along the northern coastline in southwest Florida are easily recognized by expanses of black needlerush marshes adjacent to open-water areas. Along the southern coastline, several species of mangroves become important in the vegetational composition of estuaries. There are many estuaries of various sizes along the coastal area of the Northern Tampa Bay WRAP area. By far the largest is Tampa Bay, with an area of approximately 400-square miles. Fresh surface-water contributions to the Bay from the project area come from the Hillsborough River, Sweetwater Creek, Rocky/Brushy Creek, and the Lake Tarpon Outfall Canal. Sizable estuaries are also associated with the Anclote River, Pithlachascotee River, and Weeki Wachee River.

Two major freshwater wetland systems are the hardwood-cypress swamps and marshes. Both of these systems are found either bordering lake/river systems or standing alone as isolated wetlands. The hardwood-cypress swamps are forested systems with water at or above ground for a considerable portion of the year. The amount of time that water is found above land surface within a wetland is known as the wetland's **hydroperiod**. Bald cypress, gum, pop ash, and red maple are common tree species within hardwood-cypress swamps. A characteristic type of isolated swamp within the Northern Tampa Bay area is the cypress dome. Pond cypress rather than bald cypress is dominant in these isolated swamp areas, which generally have hydroperiods of six to twelve months in a year (Ewel and Smith, 1992). Assessment in the Northern Tampa Bay area has found typical hydroperiods in healthy cypress domes to average approximately seven months (Ormiston, 1993). Marshes are generally treeless wetlands with a typically abundant vegetational cover of grasses, sedges, and forbs. Assessment of healthy marsh systems in the Northern Tampa Bay area has found hydroperiods to range from seven to

ten months (Ormiston, 1993). Common marsh types include sawgrass marshes, flag marshes, and cattail marshes.

Although swamps, marshes, and other wetlands are distinctly different ecological systems, they are all dependent on adequate amounts of water, which varies depending on the season. Similarly, all wetlands provide important environmental functions in maintaining natural hydrologic conditions, improving water quality, and sustaining wetland wildlife.

Unlike the wetlands, the more upland types of ecological systems are less dependent on water table levels, and therefore less affected by alterations in water levels. For this reason they are mentioned here only briefly. The most important upland ecosystems are the hardwood hammock, mixed hardwood-pine, pine flatwoods, sand pine scrub, and sandhill communities. Although they are less dependent on high ground-water levels, upland ecosystems interact biologically and hydrologically with wetlands, so they are dependent on wetland health.

2.6 Geology

The Northern Tampa Bay WRAP area is underlain by a thick sequence of sedimentary rocks that can be divided into an upper zone of unconsolidated sediments, and a lower zone of consolidated carbonate rock. The geologic framework has been described in detail in various published reports (Heath and Smith, 1954; Wetterhall, 1964; Menke and others, 1964; Stewart, 1968; Cherry and others, 1970; Mann, 1972; Sinclair, 1974; Geraghty and Miller, 1976; Hutchinson and others, 1981; Hutchinson, 1984; Hutchinson, 1985; Miller, 1986; Fretwell, 1988; CH2M Hill, 1988; Dames and Moore, 1988, and Scott, 1988). Cross sections depicting the stratigraphy of the Northern Tampa Bay WRAP area are presented in Figure 2-11 and 2-12. The location of each line-of-section is shown in Figure 2-13.

More recently, CH2M Hill (1990a,b) completed four deep test borings into the middle confining unit of the Upper Floridan aquifer as part of a test program for the Northern Tampa Bay WRAP. Table 2-2 summarizes the geology and aquifer systems based on this data and other

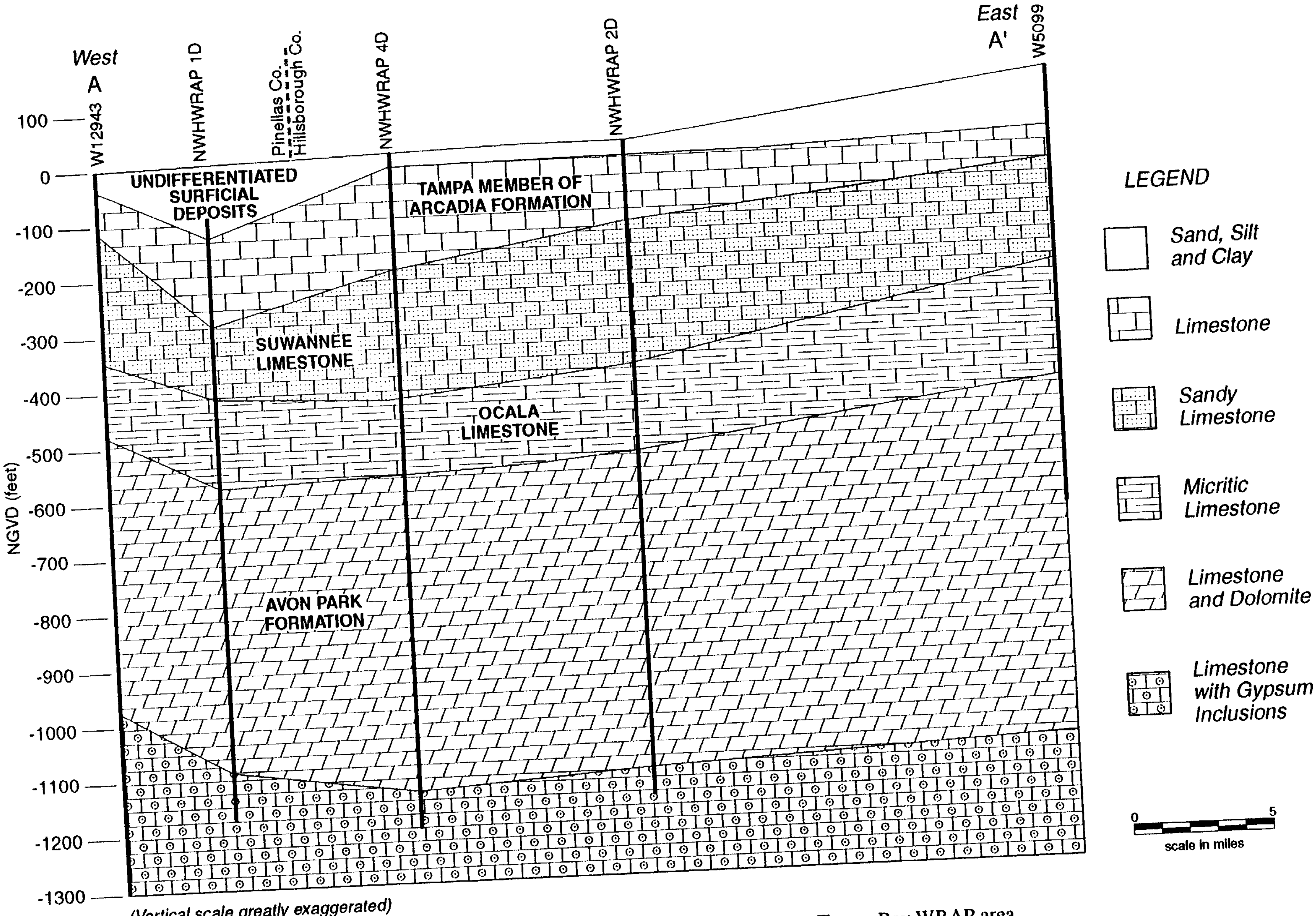


Figure 2-11. West to east geologic section across the Northern Tampa Bay WRAP area.

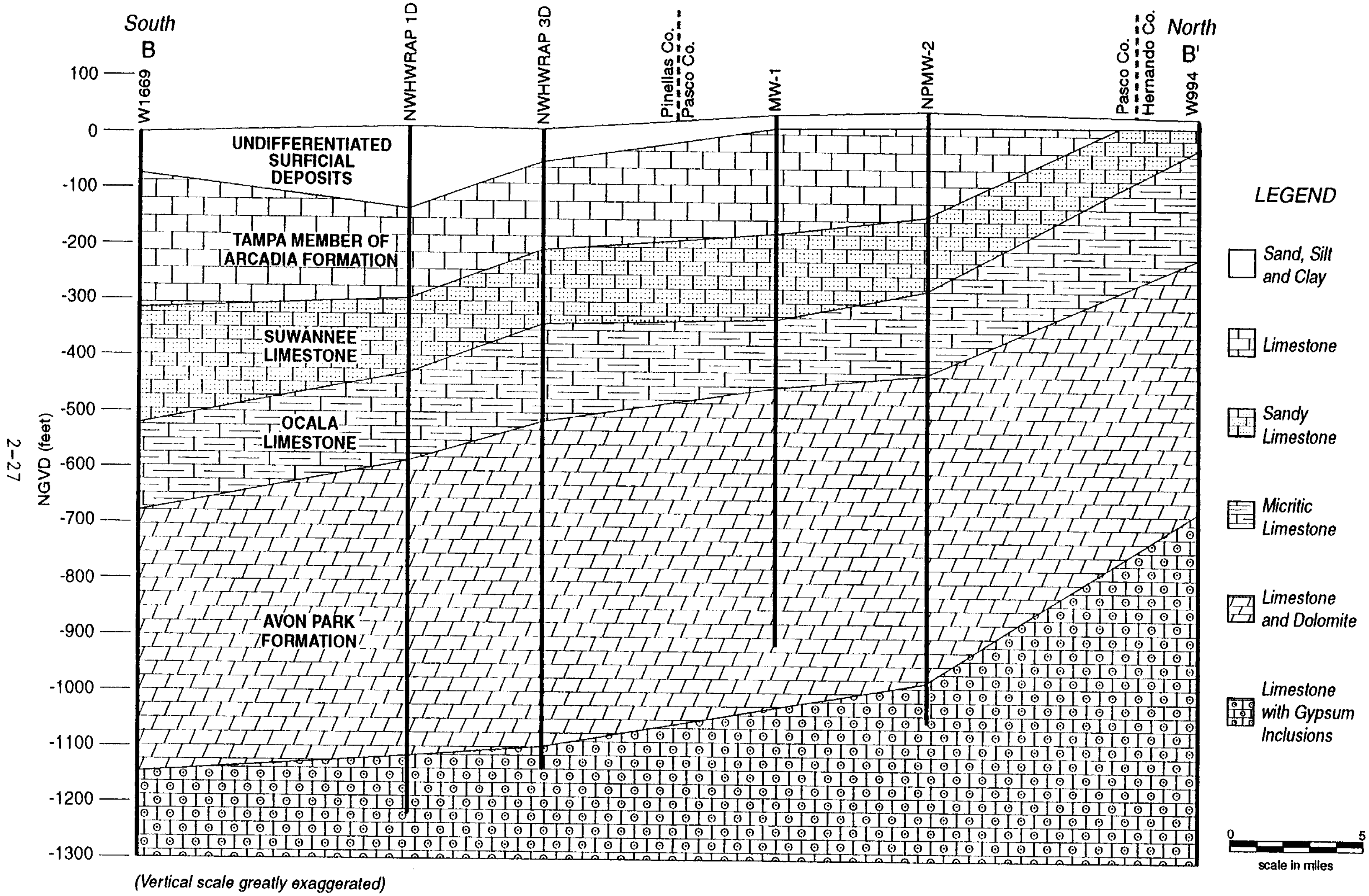


Figure 2-12. South to north geologic section across the Northern Tampa Bay WRAP area.

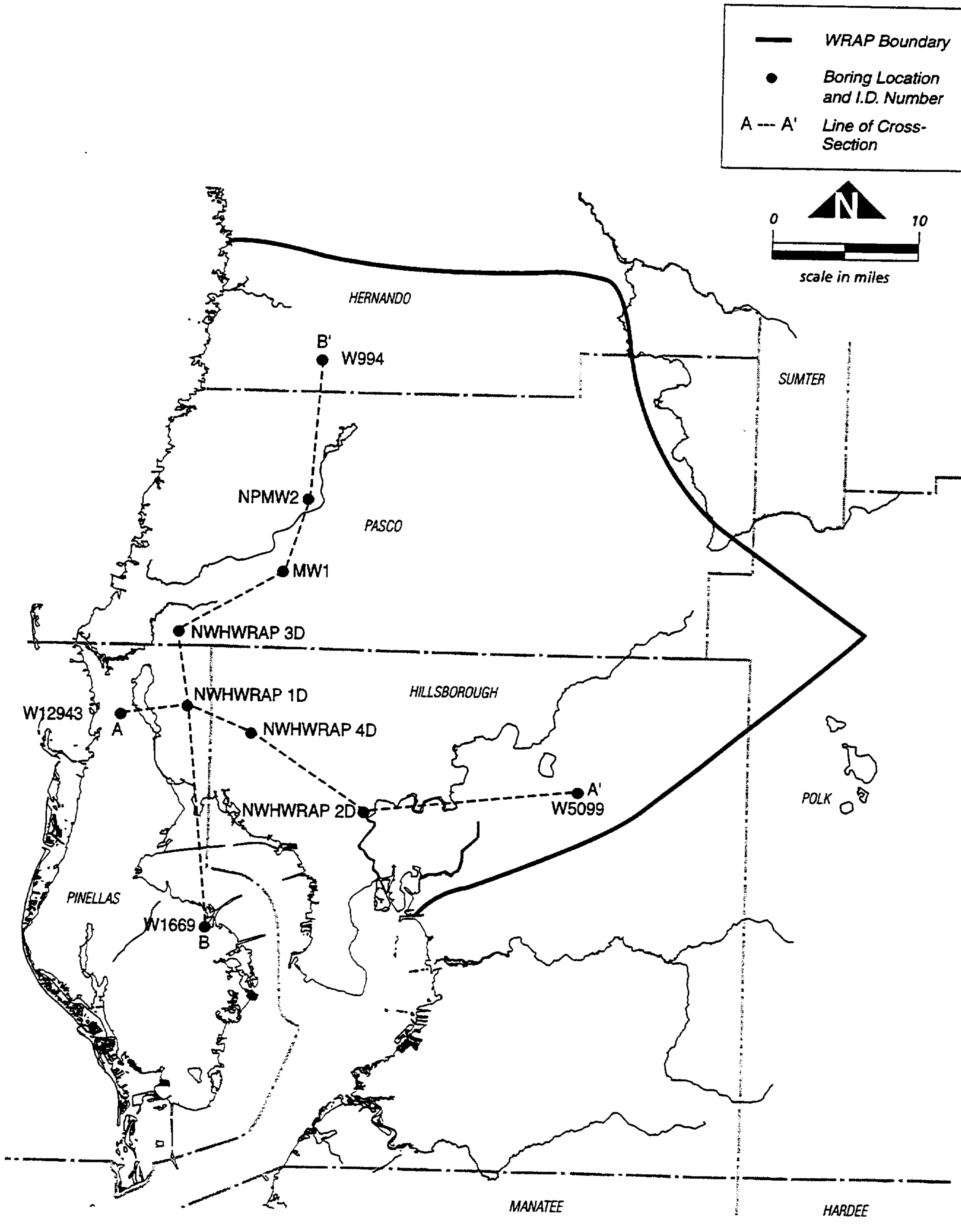


Figure 2-13. Location of geologic cross-sections A-A' and B-B' in the Northern Tampa Bay WRAP area.

Table 2-2. Geologic and hydrogeologic units in the Northern Tampa Bay WRAP area (modified from Miller, 1986 and Scott, 1988).

<table>
<tr><th>Series</th><th colspan="3">Stratigraphic Unit</th><th>Hydrogeologic Unit</th><th>Lithology</th></tr>
<tr><td>Holocene to Pliocene</td><td colspan="3">Undifferentiated Surficial Deposits</td><td>Surficial Aquifer</td><td>Sand, silty sand, clayey sand, peat, and shell</td></tr>
<tr><td rowspan="4">Miocene</td><td rowspan="4">Hawthorn Group</td><td colspan="2">Peace River Formation</td><td rowspan="3">Upper Semi-Confining Unit</td><td rowspan="2">Predominantly phosphatic clay, gray to green to brown, plastic, ductile, minor sand, residual limestone</td></tr>
<tr><td rowspan="3">Arcadia Formation</td><td></td></tr>
<tr><td rowspan="2">Tampa Member</td><td rowspan="2">Limestone, gray to tan, sandy, soft, clayey, minor sand, phosphatic. Chert found locally</td></tr>
<tr><td rowspan="4">Upper Floridan Aquifer</td></tr>
<tr><td>Oligocene</td><td colspan="3">Suwannee Limestone</td><td>Limestone, cream to tan, sandy, vuggy, fossiliferous</td></tr>
<tr><td rowspan="3">Eocene</td><td colspan="3">Ocala Limestone</td><td>Limestone, white to tan, friable to micritic, fine-grained, soft, abundant foraminifera</td></tr>
<tr><td colspan="3" rowspan="2">Avon Park Formation</td><td rowspan="2">Limestone and dolomite. Limestone is tan, recrystallized Dolomite is brown, fractured, sucrosic, hard. Peat found locally at top. Interstitial gypsum in lower part.</td></tr>
<tr><td>Middle Confining Unit</td></tr>
</table>

published information. Detailed lithologic descriptions of each boring are included in Appendix B.

At land surface, undifferentiated sediments comprised of silt, sand, and clay form surficial deposits that vary in thickness from less than 10 feet in coastal areas to over 100 feet in paleo-karst depressions or sand ridges. The typical thickness of these sediments varies from 20 to 50 feet. In low-lying areas near lakes and streams, thin layers of organic material mix with unconsolidated sediments near the upper part of this zone. Pleistocene Series terrace sands underlie the uppermost sediments. These sands are fine to very fine-grained and are comprised mostly of quartz. Underlying these sands are Pliocene Series silts and clays which form the base of the undifferentiated surficial deposits. These silts and clays were formed as a result of shallow marine conditions or due to weathering of the underlying Hawthorn Group.

Underlying the undifferentiated sediments is the phosphatic clay and limestone of the Hawthorn Group which includes the uppermost Peace River Formation and the lowermost Arcadia Formation (Scott, 1988). In the Northern Tampa Bay region, the Peace River Formation is largely absent. The Arcadia Formation, which comprises most of the Hawthorn Group sediments in the area, includes the Tampa Member (formerly designated the Tampa Limestone) in the middle and lower portion.

Lithologically, the upper portion of the Arcadia Formation (Hawthorn Group) contains mostly sili-clastic clayey materials that grade into a carbonate sequence (Scott, 1988). These sediments were formed largely as a result of terrestrial and marine depositional mechanisms during the Miocene epoch. However, a significant portion of these clayey materials are residual products created during the Pliocene epoch as a result of physical and chemical weathering of the upper limestone surface. The middle and lower portion of the Arcadia Formation consists chiefly of limestone and dolomite containing various amounts of quartz sand, clay, and phosphate grains. Thin beds of quartz sand and clay that are generally very calcareous or phosphatic are often scattered throughout the section (Scott, 1988).

In areas where the clayey sediments of the Upper Hawthorn Group are absent (due to breachment by sinkholes or differential weathering), unconsolidated sands overlie the Tampa Member of the Arcadia Formation. At well site NWHWRAP 1-D, drilled two miles east of Lake Tarpon in northeast Pinellas County, approximately 140 feet of undifferentiated sediments were found overlying the Tampa Member. At another project well (WRAP-56F), located about 500 feet away from NWHWRAP 1-D, the Tampa Member was encountered at a depth of 50 feet. Due to the presence of paleo-sinkholes in the project area, the depth to the top of carbonate formations may vary up to 100 feet in a short lateral distance (Nettles and Vandor, 1989). In addition to paleo-karst features, a series of coastal sand dune deposits exist inland and parallel to the coast. These relict dunes also contribute to increased thickness of unconsolidated sediments which overlie the Hawthorn Group.

Underlying the surficial sands and clays are a series of Tertiary limestone and dolomite units that form the carbonate platform of peninsular Florida. The sequence of carbonate rocks include, in descending order, the following members or formations: Tampa Member of the Arcadia Formation, Suwannee Limestone, Ocala Limestone, and the Avon Park, Oldsmar, and Cedar Keys Formations. A lithologic change from limestone and dolomite to a sequence of gypsiferous dolomite begins in the lower portion of the Avon Park Formation and continues into the Oldsmar and Cedar Keys Formations. The top of this lithologic change marks the middle confining layer of the Floridan aquifer system. The middle confining unit is generally considered the base of the freshwater production zone of the Upper Floridan aquifer. Lithologic descriptions of the Oldsmar and Cedar Keys Formations are not discussed in this report.

This entire carbonate series thickens and dips toward the southwest. The total thickness of the Upper Floridan aquifer marine sequence varies from 950 to 1,200 feet (Miller, 1986). Included below, in descending order, are detailed geologic descriptions of each of the units that comprise the Upper Floridan aquifer.

The Tampa Member of the Arcadia Formation is a white to light-gray, sandy, hard to soft, locally clayey, fossiliferous (pelecypod and gastropod casts and molds) limestone that contains phosphate and chert in places. The phosphate content of the Tampa Member is low, in

comparison to the remainder of the Hawthorn Group. Foraminifera fossils place the age of the Tampa Member in the early Miocene epoch. The Tampa Member ranges from 0 to 200 feet in thickness.

The Suwannee Limestone consists of two rock types; the upper portion is a cream to tan, crystalline, highly vuggy limestone containing prominent gastropod and pelecypod molds, and the lower portion is a white to cream, finely pelletal limestone containing foraminifera and pellets of micrite bound together in a finely crystalline limestone matrix. The Suwannee Limestone varies from 150 to 300 feet in thickness and is Oligocene in age (Miller, 1986).

The upper portion of the Ocala Limestone is a white, generally soft, somewhat friable, porous coquina composed of large foraminifera, bryozoan fragments, and partial or full echinoid remains, all loosely consolidated in a matrix of micritic limestone. Abundant *Lepidocyclina sp.* and *Nummulites sp.* formanifera are commonly found within the formation. The lower part of the unit consists of cream to white, fine-grained, soft to semi-indurated, micritic limestone. The lower portion of the Ocala contains plentiful miliolid remains and scattered foraminifera. The Ocala Limestone is late Eocene in age and ranges in thickness from 90 to 300 feet (Miller, 1986).

The Avon Park Formation is comprised of a light to dark brown, highly fossiliferous, soft to well-indurated, chalky limestone and a gray to dark brown, very fine to microcrystalline dolomite. The dolomite is slightly vuggy, fractured in some places, with a sucrosic to argillaceous texture. The dolomite contains porous fossil molds, thin beds of carbonaceous material, and peat fragments. Locally, thin striations of organic peat and abundant *Dictyoconus sp.* foraminifera serve to mark the top of the formation. The lower portion of the formation consists of a rather impermeable, dark-colored, dolomitic limestone that contains intergranular gypsum and anhydrite. The Avon Park Formation ranges from 300 to 500 feet in thickness and is middle Eocene in age (Miller, 1986).

2.7 Ground Water

The hydrogeologic conditions of the project area have been evaluated based on information collected from hundreds of wells (including the 36 monitor well nests and four deep test wells constructed as part of the WRAP project) as well as various published reports. Appendices A and B include the construction data and other information for these wells, as well as geologic and hydraulic information for the Northern Tampa Bay WRAP test wells. Additional information concerning the ground-water system is contained in various published reports of the USGS, Florida Geological Survey, and numerous ground-water consulting firms (such as Heath and Smith, 1954; Wetterhall, 1964; Menke and others, 1964; Stewart, 1968; Cherry and others, 1970; Mann, 1972; Sinclair, 1974; Geraghty and Miller, 1976; Hutchinson and others, 1981; Hutchinson, 1984; Miller, 1986; Fretwell, 1988; CH2M Hill, 1988; Dames and Moore, 1988; and Swancar and Hutchinson, 1992).

Figure 2-14 represents a generalized cross section of the hydrogeology of the entire SWFWMD. As seen in this figure, the Central West-Central Florida Ground-Water Basin (CWCFGWB), where the majority of the Northern Tampa Bay WRAP area is located, constitutes a hydrogeologic transition zone between the southern and northern parts of the SWFWMD. In the southern portion of the District, a regionally extensive intermediate confined aquifer subdivides the surficial and Upper Floridan aquifers. Near the southern boundary of the Northern Tampa Bay WRAP area, this aquifer system and its associated clay confining units thin and eventually become a single confining unit that hydrologically separates the surficial and Upper Floridan aquifers. Further northward, in the central and northern portions of the CWCFGWB, this single confining unit becomes discontinuous and eventually disappears entirely in the northern part of the District. Toward the northern boundary of the Northern Tampa Bay WRAP area, the Upper Floridan aquifer is subregionally unconfined. Therefore the regional north to south trend is one of a well-confined three aquifer system in the southern portion of the SWFWMD to a much less-confined two aquifer system in the northern portion of the SWFWMD.

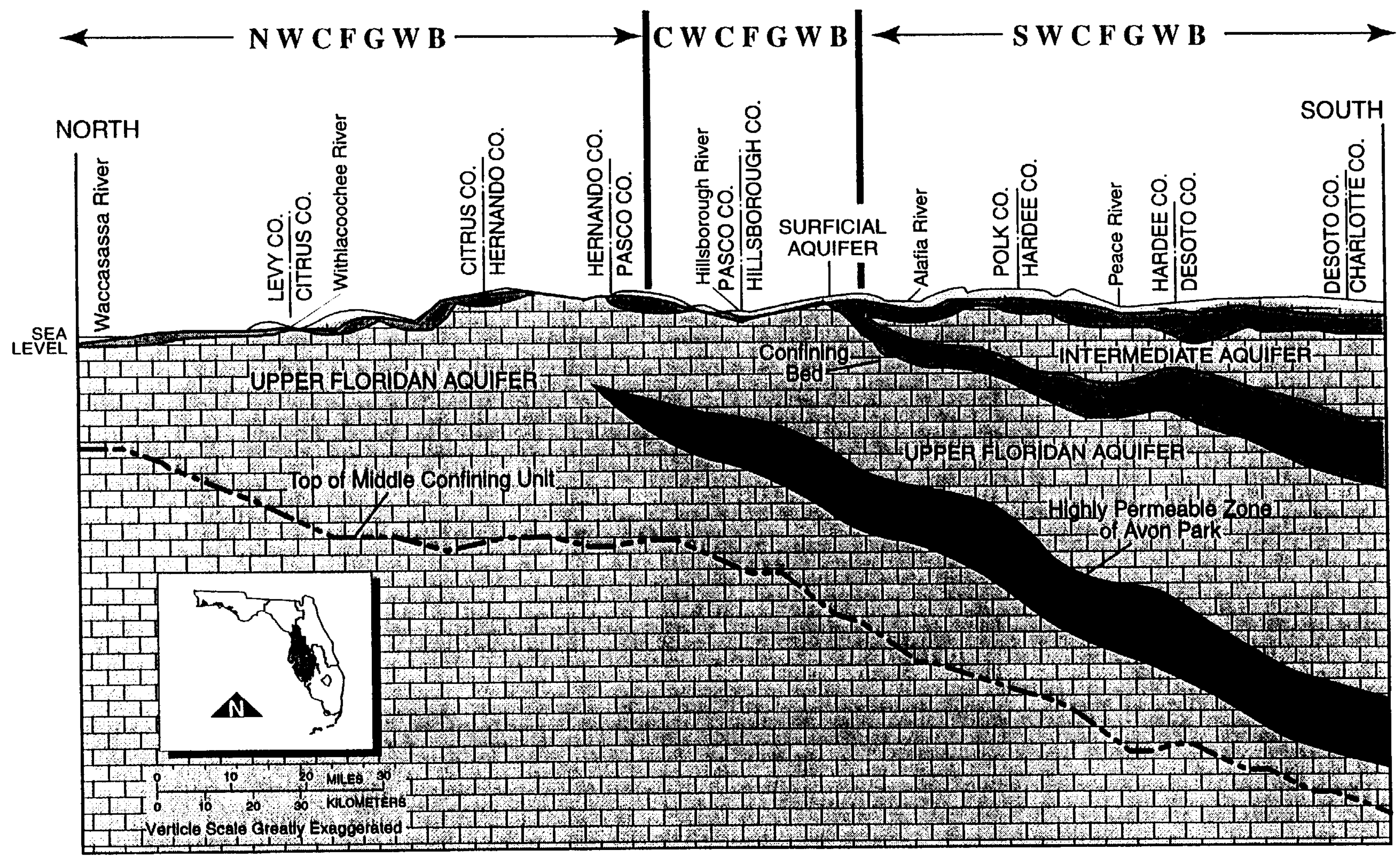


Figure 2-14. Hydrogeologic cross-section of the SWFWMD.

2.7.1 Surficial Aquifer

The surficial aquifer is comprised primarily of unconsolidated deposits of fine-grained sand, silt, and clayey sands with an average thickness of 30 feet. Figures 2-15 and 2-16 show the thickness of sand based on exploratory drilling information. Due to the karst geology of the region and the existence of relict marine terraces, thickness of the sand is highly variable and ranges from less than five feet to over 90 feet. On a regional basis, sand thickness is greater along the marine terraces in northern Pinellas County and the along the Brooksville Ridge physiographic province.

The elevation of the water table ranges from less than five feet NGVD near the coast to greater than 100 feet NGVD in north-central Pasco County (Figure 2-17). Depth to the water table ranges from near or at the land surface in wetlands areas to greater than 15 feet along sand ridges. Typically, the depth to the water table averages from two and five feet below land surface. The hydraulic gradient (change of elevation per unit length) ranges from a few feet per mile to about ten feet per mile.

The water table elevation is influenced by rainfall, with annual highs occurring during the end of the wet season in September, and seasonal lows developing near the end of the spring dry period in May. The ground-water flow direction varies locally and is significantly controlled by the topography of land surface and the karst geology. Additionally, the unconsolidated materials that comprise the surficial aquifer are generally low in permeability, especially when compared to the underlying Upper Floridan aquifer. Therefore, the surficial aquifer system neither yields or transmits significant quantities of water. Considering these factors, surficial aquifer ground-water flow is localized in nature, is often intercepted as Floridan aquifer recharge vertically before it travels very far horizontally, and it is not considered a regional flow system like the Upper Floridan aquifer. Of more hydrologic significance in the Northern Tampa Bay ground-water system, the surficial aquifer provides a source of water that recharges the Upper Floridan aquifer via downward vertical leakage across the semi-confining unit. Because of the large degree of hydraulic connection between the surficial and underlying Upper Floridan aquifers, water table elevation is significantly affected by changes in the underlying Upper

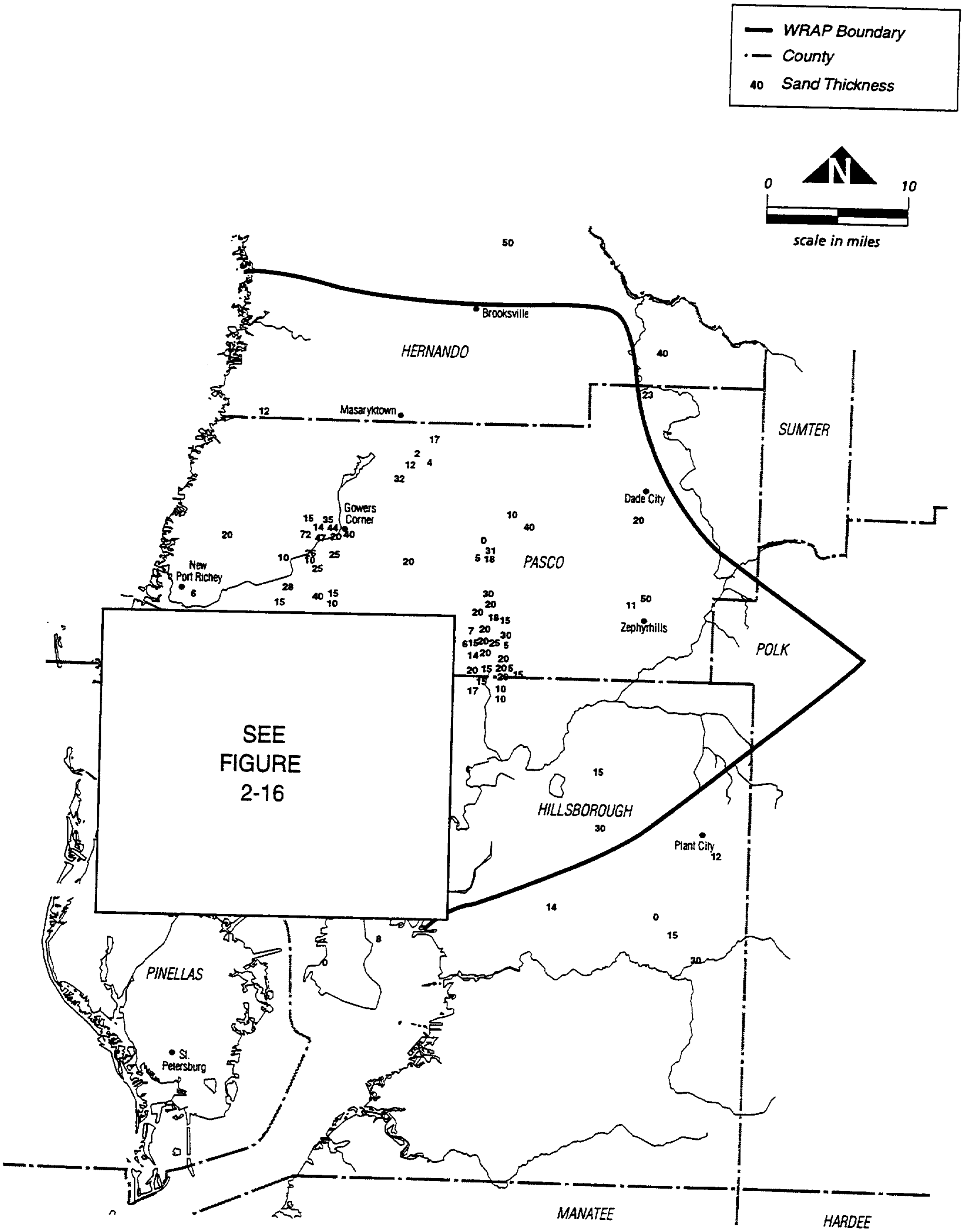


Figure 2-15. Thickness of sand at individual exploratory drilling sites outside of the tri-county region.

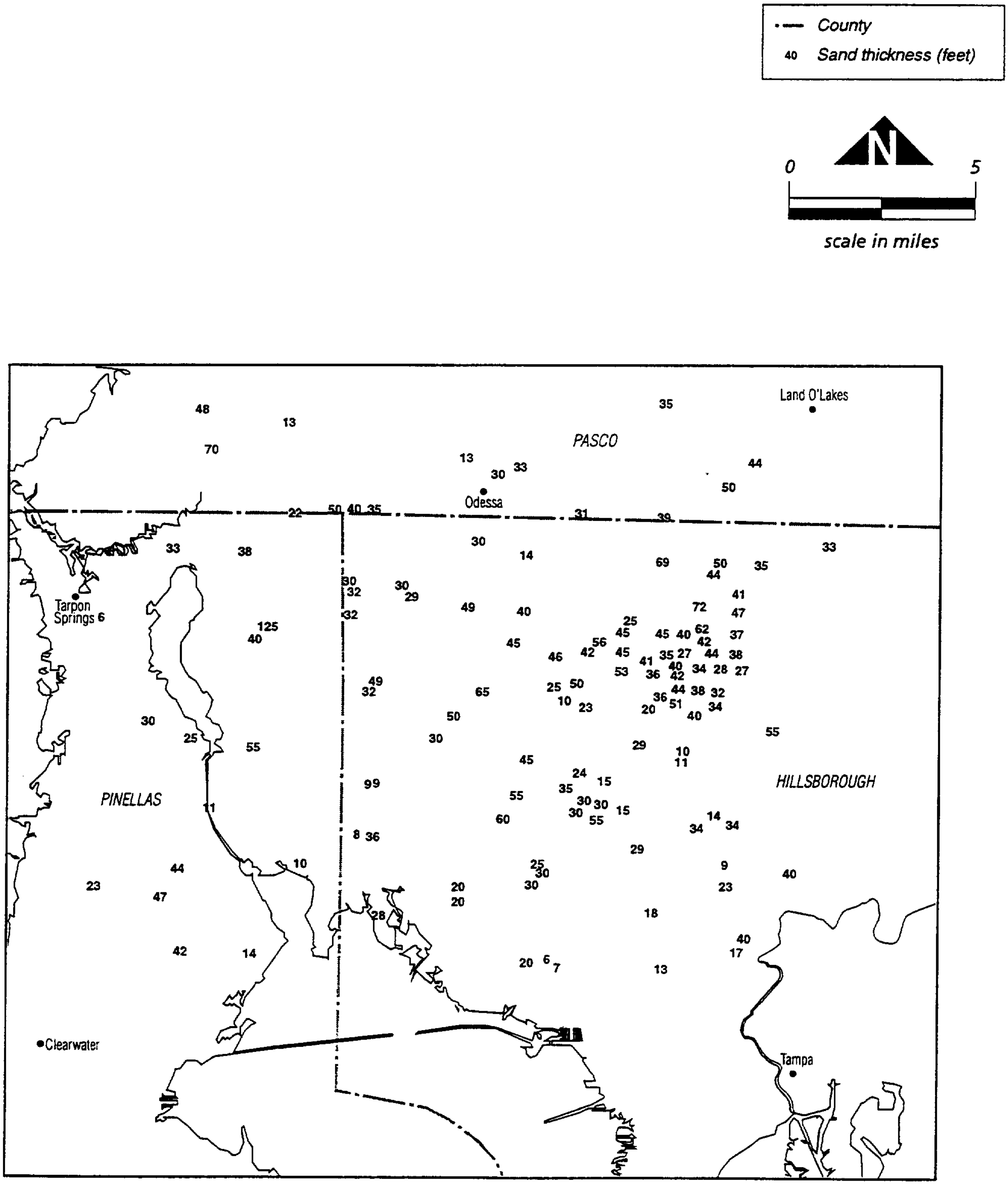


Figure 2-16. Thickness of sand at individual exploratory drilling sites in the tri-county region.

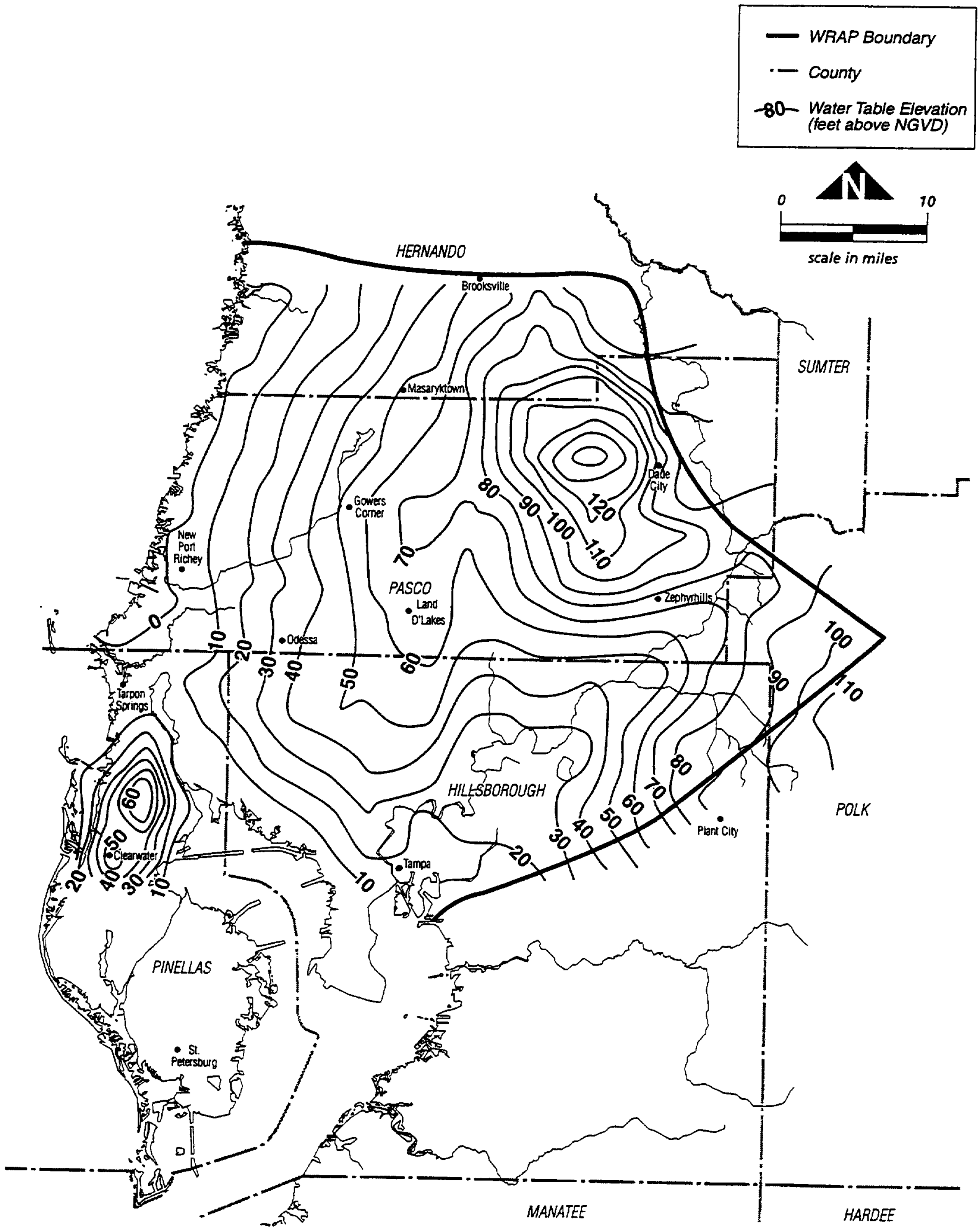


Figure 2-17. May 1989 water table elevation within the Northern Tampa Bay WRAP area.

Floridan aquifer potentiometric surface. Therefore, the contours in Figure 2-17 represent the topographic influence on surficial aquifer flow, but do not account for the influence of the karst geology and the Upper Floridan aquifer.

Ground water derived from this aquifer is used most often for lawn irrigation and watering livestock. Typical surficial aquifer wells yield less than 20 gallons per minute. Horizontal hydraulic conductivity of the surficial aquifer varies from three to 40 feet/day (Appendix B). Cherry and others (1970) reported vertical hydraulic conductivity ranging from 1.34×10^{-4} feet/day to 28.1 feet/day with porosity averaging 39 percent. Effective porosity is about 25 percent (Cherry and Brown, 1974).

2.7.2 Semi-Confining Zone

Below the surficial aquifer is a semi-confining unit comprised chiefly of clay, silt, and sandy clay that retards the movement of water between the overlying surficial aquifer and the underlying Upper Floridan aquifer. The confining materials are comprised of blue-green to gray, waxy, plastic, sandy clay and clay. The upper portion of the Arcadia Formation (Hawthorn Group) typically forms the semi-confining layer. The middle and lower parts of the Acadia Formation contain the predominately carbonate Tampa Member that is typically in direct hydraulic connection with the underlying limestone units. Regionally, the thickness of the unit varies from essentially zero to more than 60 feet. Although the clay thickness generally follows the regional trend of being thicker in the southern portions and thin or absent in the northern portions of the Northern Tampa Bay WRAP area, the karst geology of the area creates a highly variable confining unit locally, ranging in thickness from zero to more than 60 feet. Figures 2-18 and 2-19 illustrate the variability of the thickness of clay from exploratory drilling data.

In the Northern Tampa Bay area, leakage from the surficial aquifer into the Upper Floridan aquifer occurs by infiltration across the semi-confining layer or through fractures or secondary openings in the semi-confining unit caused by chemical dissolution of the underlying limestone. Due to the highly karstic nature of the geologic system, the clay semi-confiner can be absent in one area, but be tens of feet thick a very short distance away. These localized karst features,

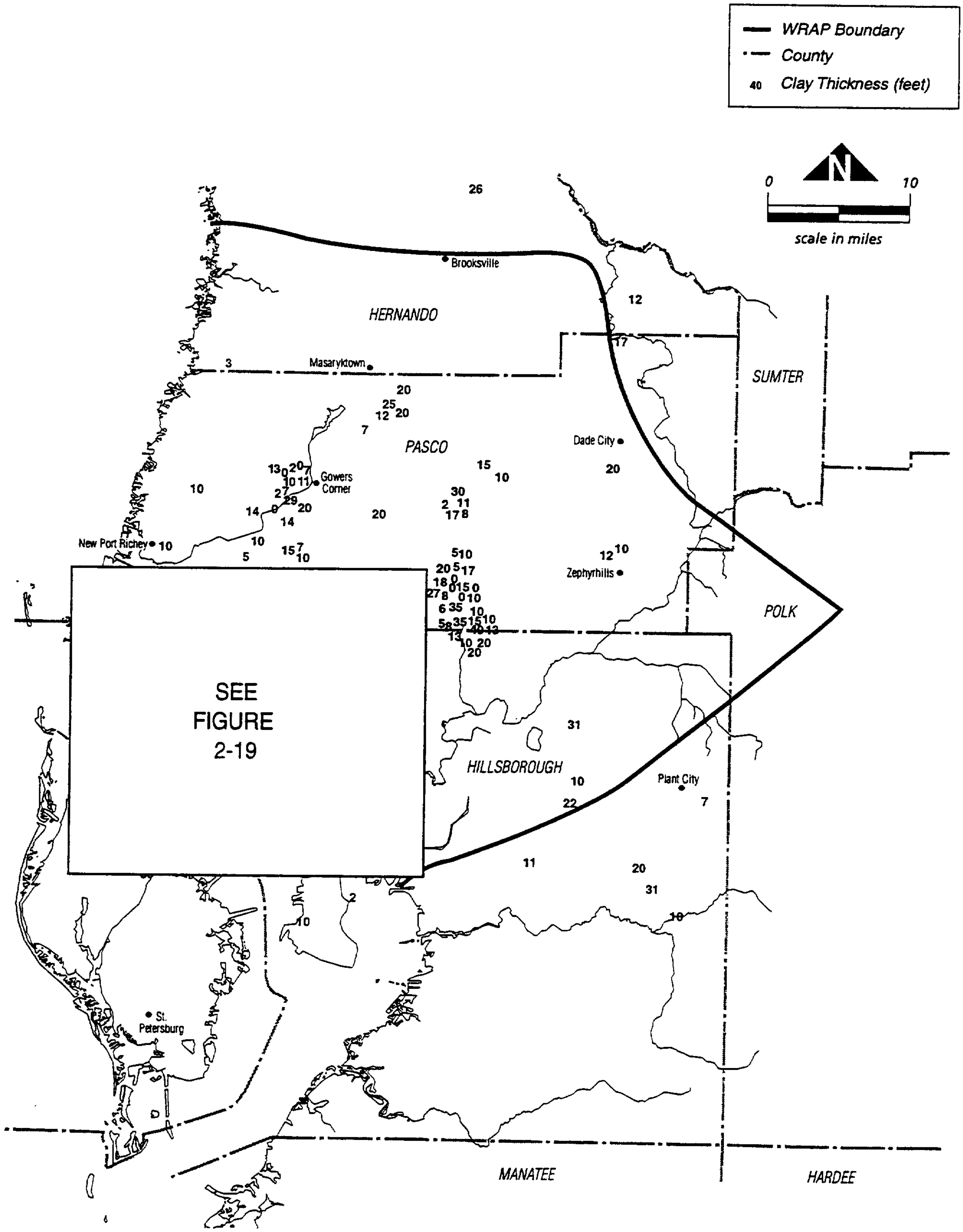


Figure 2-18. Thickness of clay at individual drilling sites outside of the tri-county region.

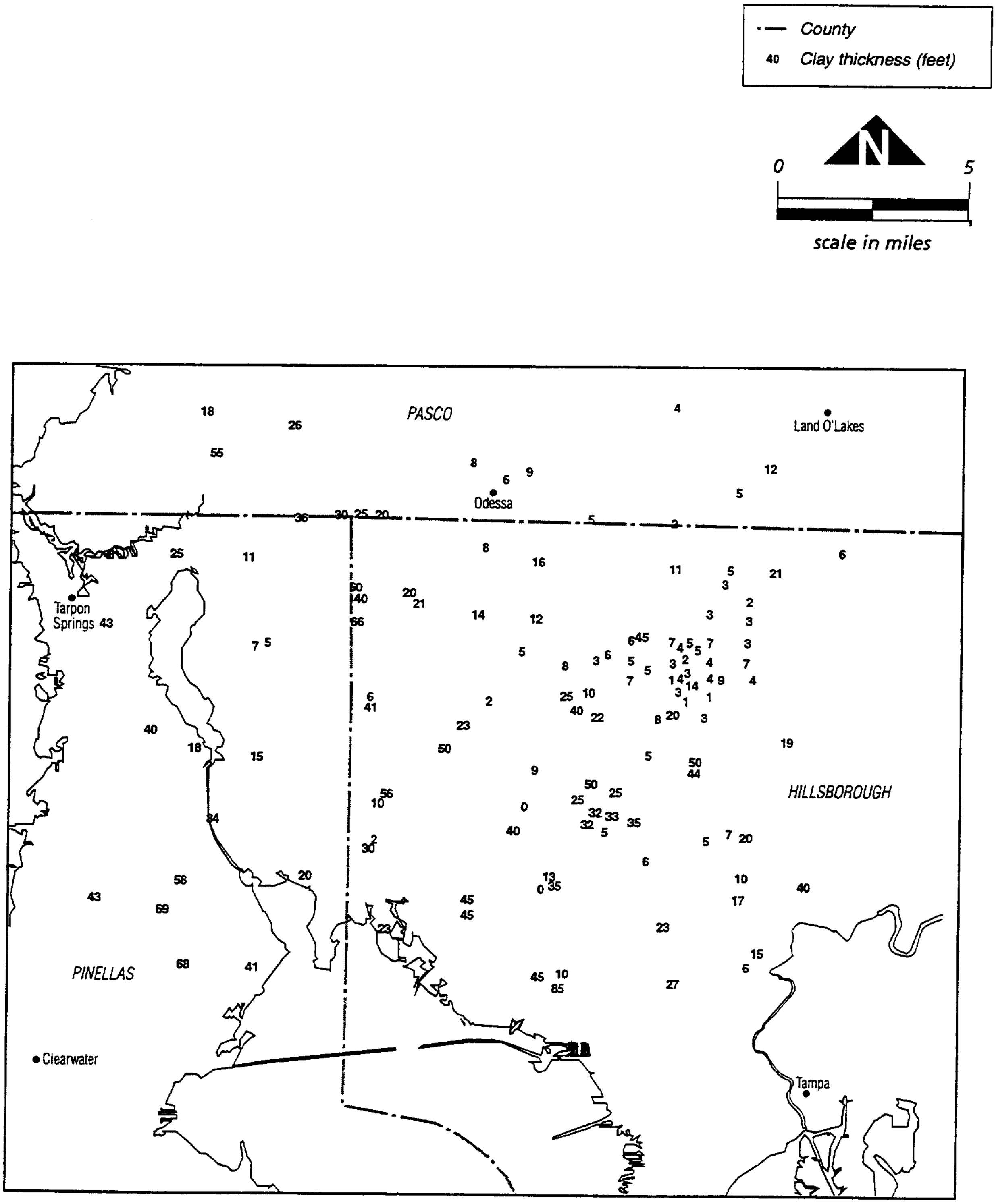


Figure 2-19. Thickness of clay at individual drilling sites in the tri-county region.

where the clay semi-confining layer is breached or missing, significantly increase hydraulic connection between the two aquifers.

The vertical hydraulic conductivity of the semi-confining unit, measured from laboratory tests on core samples collected during the installation of the shallow project well nests, varied from 3.94×10^{-6} feet/day to 7.03 feet/day, and averaged 1.22×10^{-3} feet/day (Appendix B). In the Northern Tampa Bay area, however, the majority of leakage occurs through fractures or karstic collapses in the confining unit, rather than through the clay material itself. Leakance coefficients (vertical conductivity/thickness) of the semi-confining unit determined from 22 aquifer performance test sites ranged from 2.7×10^{-3} ft/day/ft (day^{-1}) to 4.7×10^{-6} day^{-1}, and averaged 2.3×10^{-4} day^{-1} (Appendix B). In local areas of breached confinement, leakance coefficients may be much larger than these values.

2.7.3 Upper Floridan Aquifer

The Upper Floridan aquifer consists of a continuous series of carbonate units that include portions of the Tampa Member of the Arcadia Formation, Suwannee Limestone, Ocala Limestone, and Avon Park Formation. Except in the extreme northern portions of the project area, ground water within the Upper Floridan aquifer is pressurized or under artesian conditions. Near the base of the Avon Park Formation lies the middle confining unit of the Floridan aquifer. It is an evaporite sequence of very low permeability that is composed of gypsiferous dolomite and dolomitic limestone. Figures 2-20 and 2-21 display the elevation of the top of the limestone or Upper Floridan aquifer based on exploratory drilling information. On a regional basis, the top of the limestone dips toward the southwest in the project area. The general thickness of the Upper Floridan aquifer in the study area is shown in Figure 2-22.

The middle confining unit generally delineates the boundary between the freshwater Upper Floridan aquifer and the brine saturated Lower Floridan aquifer. The evaporites function as a lower confining unit and retard vertical flow across the boundary. Based upon data collected from packer tests on the upper portion of the evaporite sequence from the four Northern Tampa Bay WRAP deep test borings (Table 2-3), horizontal hydraulic conductivity varies from 0.01 to

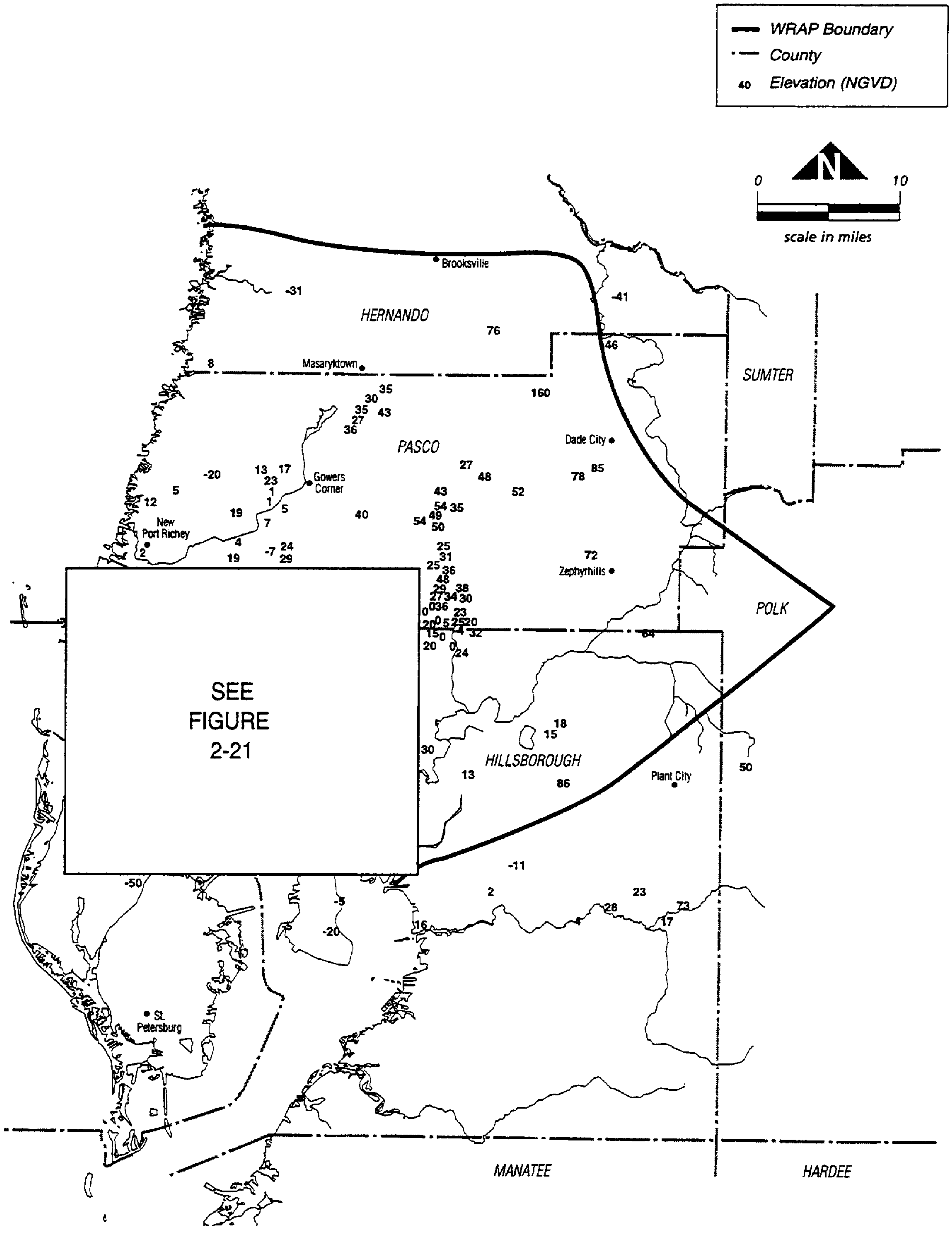


Figure 2-20. Elevation of the top of the limestone at individual drilling sites outside of the tri-county region.

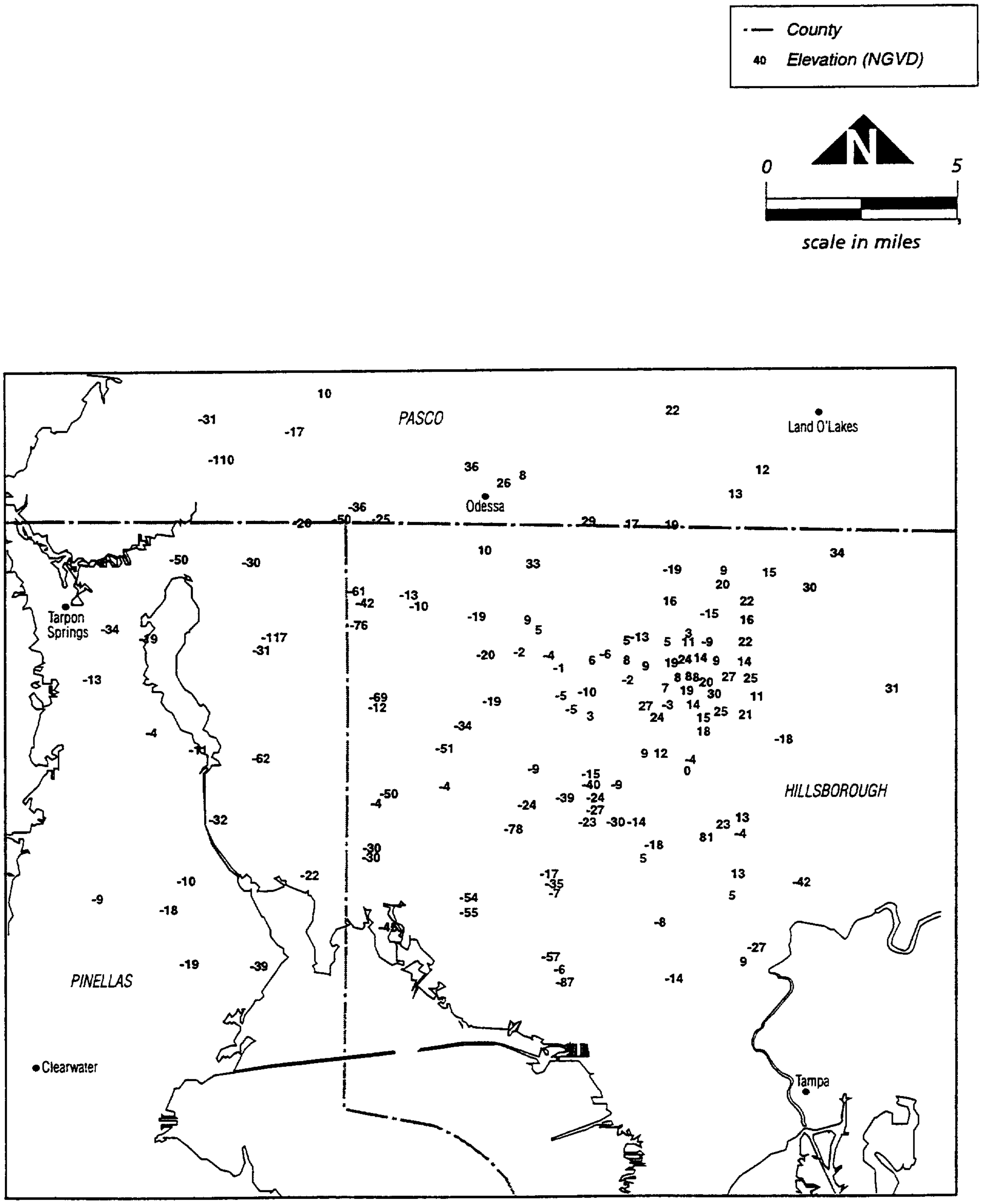


Figure 2-21. Elevation of the top of limestone at individual drilling sites in the tri-county region.

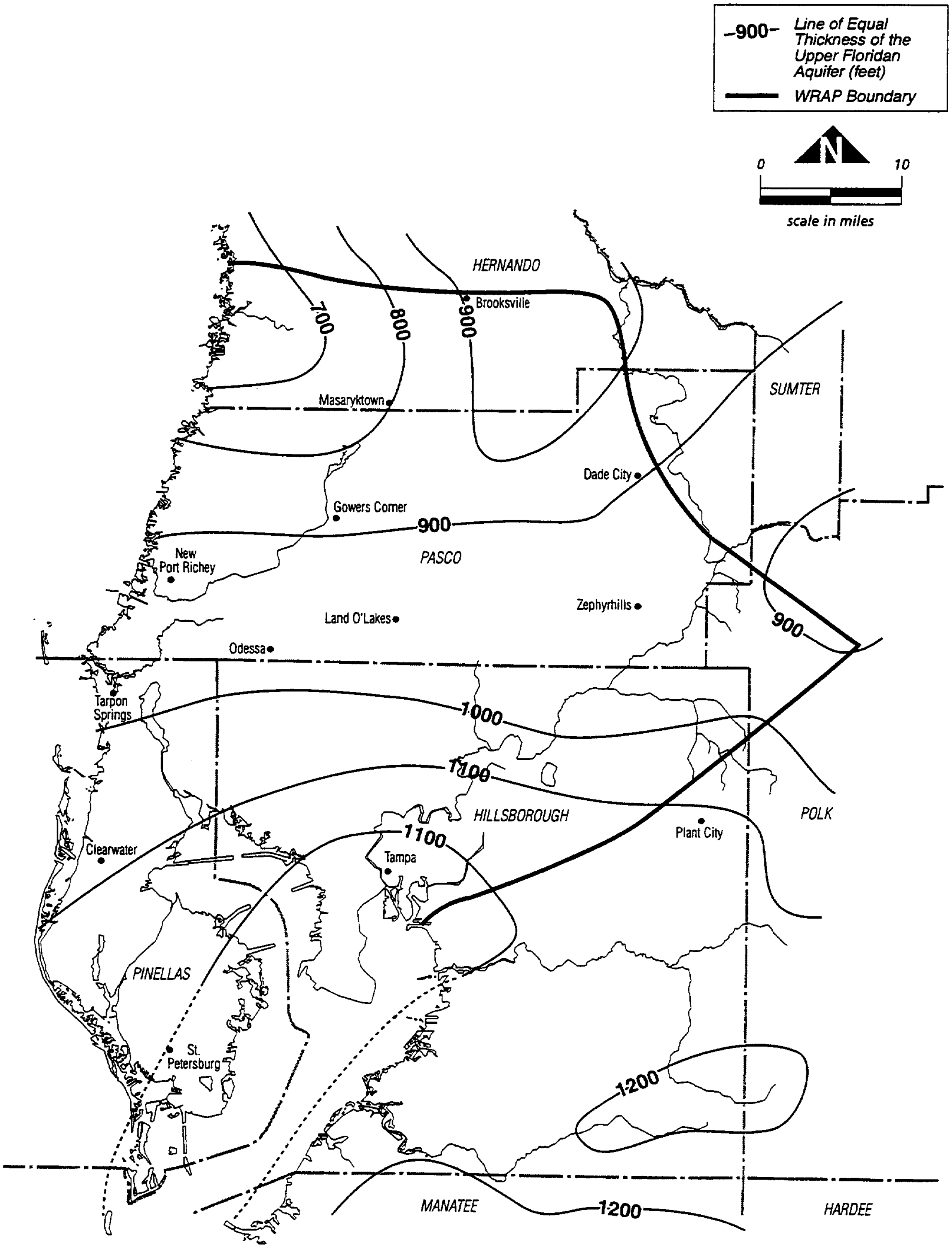


Figure 2-22. Thickness of the Upper Floridan aquifer within the Northern Tampa Bay area (modified from Miller, 1986).

Table 2-3. Summary of hydraulic data from Drilling Sites 1D through 4D.

PACKER AND AQUIFER TEST DATA

WELL#	FORMATION OR UNIT	DEPTH INTERVAL (feet bls)	K(horizontal) average (ft/d)	TRANSMISSIVITY (FT^2/day)	TEST TYPE (A,P)*
1D	OCALA LS	391-473	12.2	997.1	A
	OCALA LS	464-470	0.6	3.8	P
	AVON PARK FM	660-691	5.4	168.3	P
	EVAPORITE	1146-1210	0.1	6.4	P
2D	SUWANNEE-	175-530	2.6	923	A
	OCALA LS	370-530	0.4	70.4	P
	AVON PARK FM	719-769	2.4	120	P
	EVAPORITE	1140-1180	0.07-.017	4	P
3D	SUWANNEE-	173-500	9.2	3008.4	A
	OCALA LS	380-398	3.9	70.2	P
	OCALA LS	473-500	9.2	248.4	P
	UPPER FL	173-1132	57.5	55,142.5	A
	EVAPORITE	1061-1107	0.05-.08	2.99	P
4D	SUWANNEE-	180-579	19.4	7740.6	A
	OCALA LS	437-579	2	284	P
	EVAPORITE(1)	1192.5-1234	0.01-0.022	0.7055	P
	EVAPORITE(2)	1192.5-1234	0.01-0.012	0.4565	P
	EVAPORITE(3)	1237.5-1285	0.044-0.065	2.6125	P
	EVAPORITE(4)	1237.5-1285	0.045-0.048	2.2325	P

(1) - Submersible Pump (3) - Air-line, tube in P - Packer test
(2) - Air-line (4) - Air-line, tube out A - Aquifer test

CORE TEST DATA

WELL#	FORMATION OR UNIT	DEPTH INTERVAL (feet bls)	K(vertical) average (ft/d)
1D	OCALA LS	451	.012
	OCALA LS	467	.033
	OCALA LS	505	.671
	EVAPORITE	1170	2.96E-06
	EVAPORITE	1189	.060
2D	OCALA LS	432	2.82
	OCALA LS	472	0.05
	OCALA LS	500	5.9
	EVAPORITE	1147	.088
	EVAPORITE	1165	0.0002
3D	OCALA LS	360	0.005
	OCALA LS	400	0.79
	OCALA LS	450	0.008
	EVAPORITE	1063	0.0014
	EVAPORITE	1084	5E-06
	EVAPORITE	1114	0.006
4D	OCALA LS	445	0.219
	OCALA LS	505	0.008
	OCALA LS	550	0.03
	EVAPORITE	1186	0.001
	EVAPORITE	1214	0.058

0.17 feet/day and averages 0.06 feet/day (CH2M HILL, 1990a,b). Vertical hydraulic conductivity, based on an analysis of core permeability tests from the same wells (Table 2-3), ranges from 5.0 x 10^{-6} to 0.09 feet/day and averages 0.018 feet/day (CH2M HILL, 1990a,b). Assuming the average thickness of the evaporitic sequence is 600 feet, and the average vertical hydraulic conductivity obtained from the upper 100 feet is comparable to the entire sequence, the leakance coefficient for the middle confining zone is estimated at 3.0 x 10^{-5} day^{-1}.

In relative terms, the permeability of the Upper Floridan aquifer is moderate in the Tampa Member and Suwannee Limestone, somewhat lower in the Ocala Limestone, and very high in portions of the Avon Park Formation (Figures 2-11 and 2-12). The limestone and dolomite beds produce significant quantities of water due largely to numerous solution openings along bedding planes and fractures. Reported transmissivity of the Tampa/Suwannee part of the aquifer, varies from 18,700 feet squared per day (ft^2/day) to 73,500 ft^2 /day and averages 40,100 ft^2 /day (Dames and Moore, 1988). The transmissivity of the entire thickness of the Upper Floridan aquifer, determined from a short-term aquifer test on NWHWRAP 3-D in southwest Pasco County, was 55,000 $feet^2$/day, while estimates from various aquifer tests throughout the study area generally range from 18,700 $feet^2$/day to over 130,000 $feet^2$ /day (Appendix B). Figure 2-23 presents an areal distribution of transmissivity values from wells open to a variety of formations within the Upper Floridan aquifer, based on published reports in the area.

Specific capacity tests, completed at every drill stem change during the drilling of the deep test borings, generally increased significantly once the fractured zone within the Avon Park Formation was encountered (Figures 2-24 and 2-25). The largest increase occurred at sites NWHWRAP 1-D and NWHWRAP 3-D, located in northeast Pinellas and southwest Pasco Counties, respectively. At both of these sites, specific capacity increased from less than 50 gallons per minute per foot of drawdown (gpm/ft drawdown) in the Tampa/Suwannee Limestones, to more than 200 gpm/ft drawdown in the Avon Park Formation.

The Ocala Limestone is less transmissive than the Tampa/Suwannee or Avon Park Formations, and is generally a layer of lower permeability within the Upper Floridan aquifer. Vertical

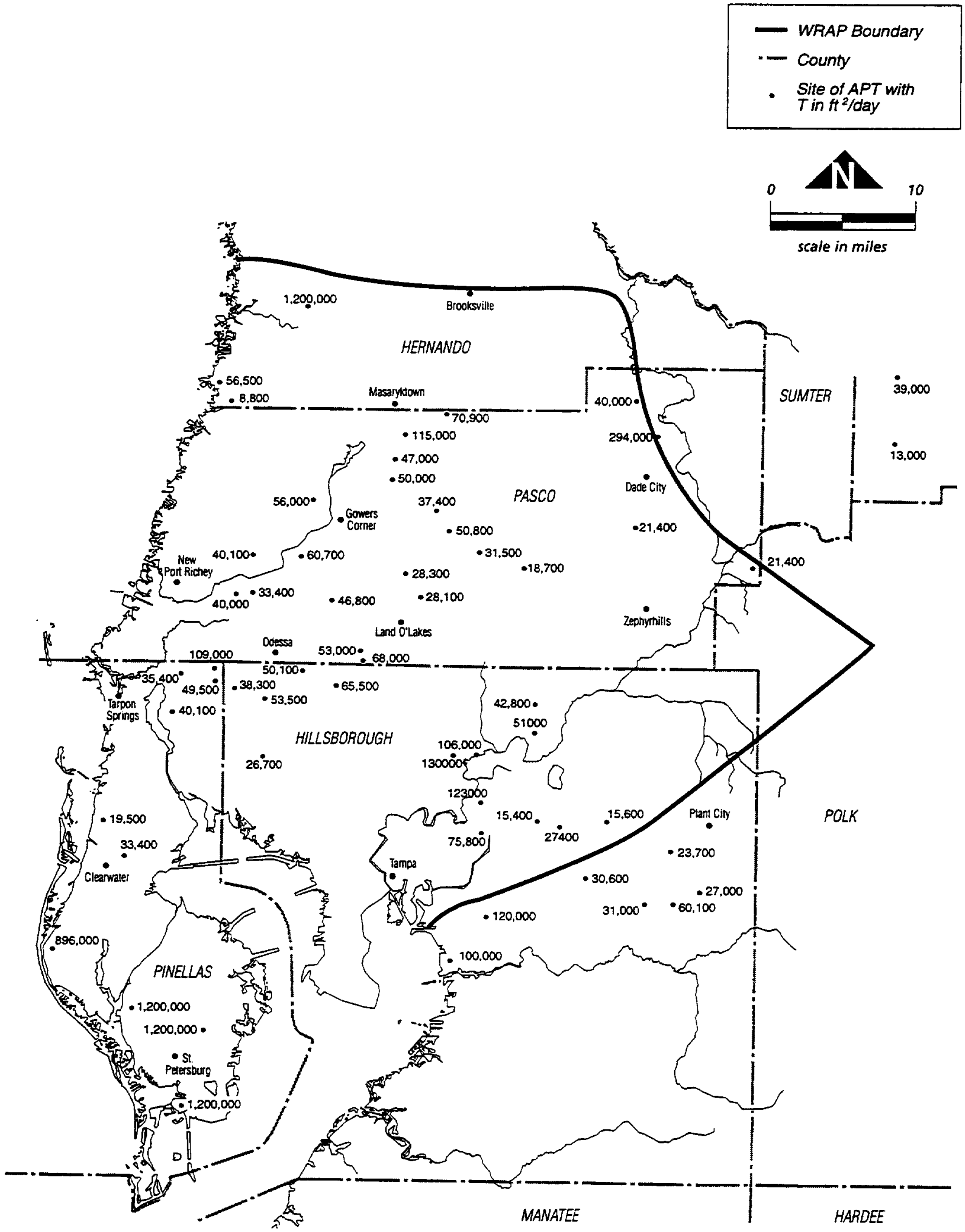
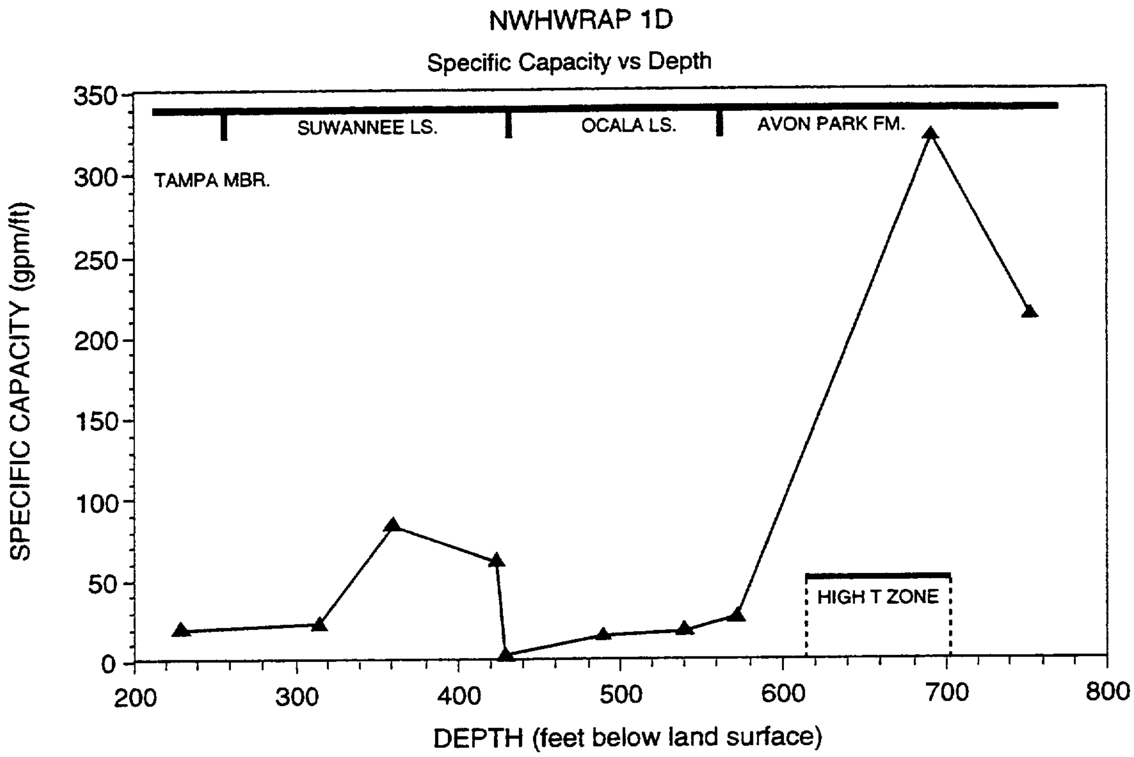


Figure 2-23. Reported transmissivity values of the Upper Floridan aquifer in the Northern Tampa Bay WRAP area.



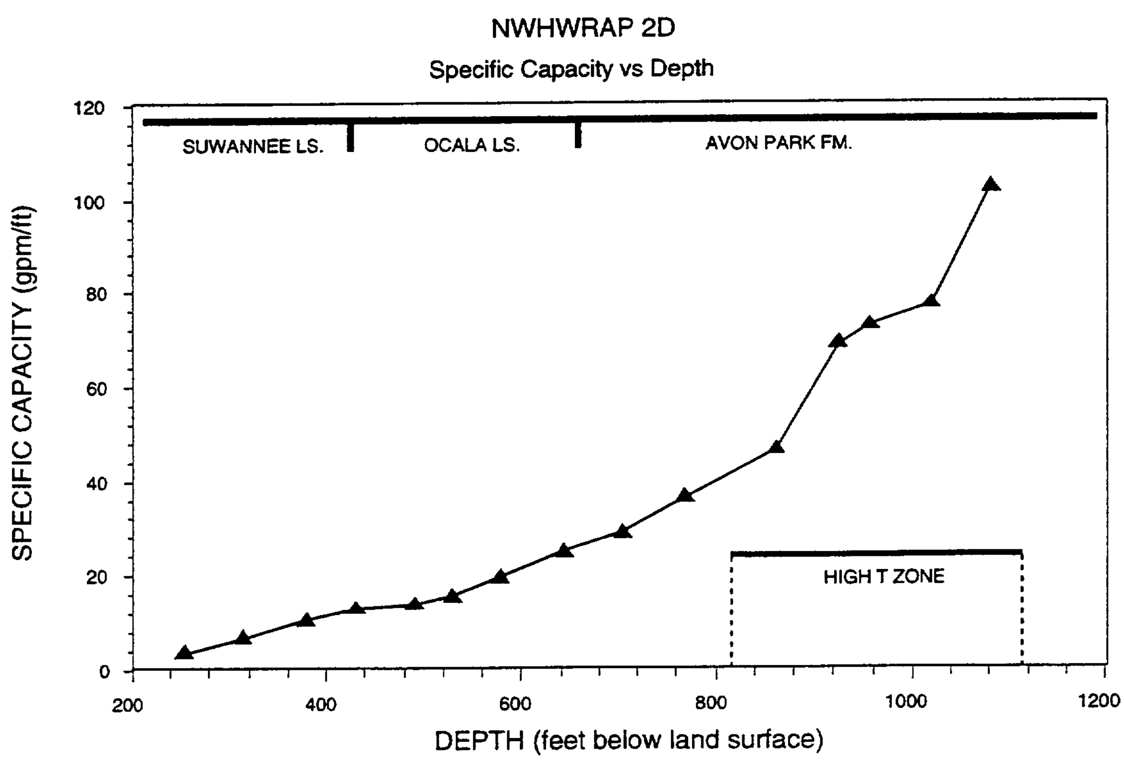
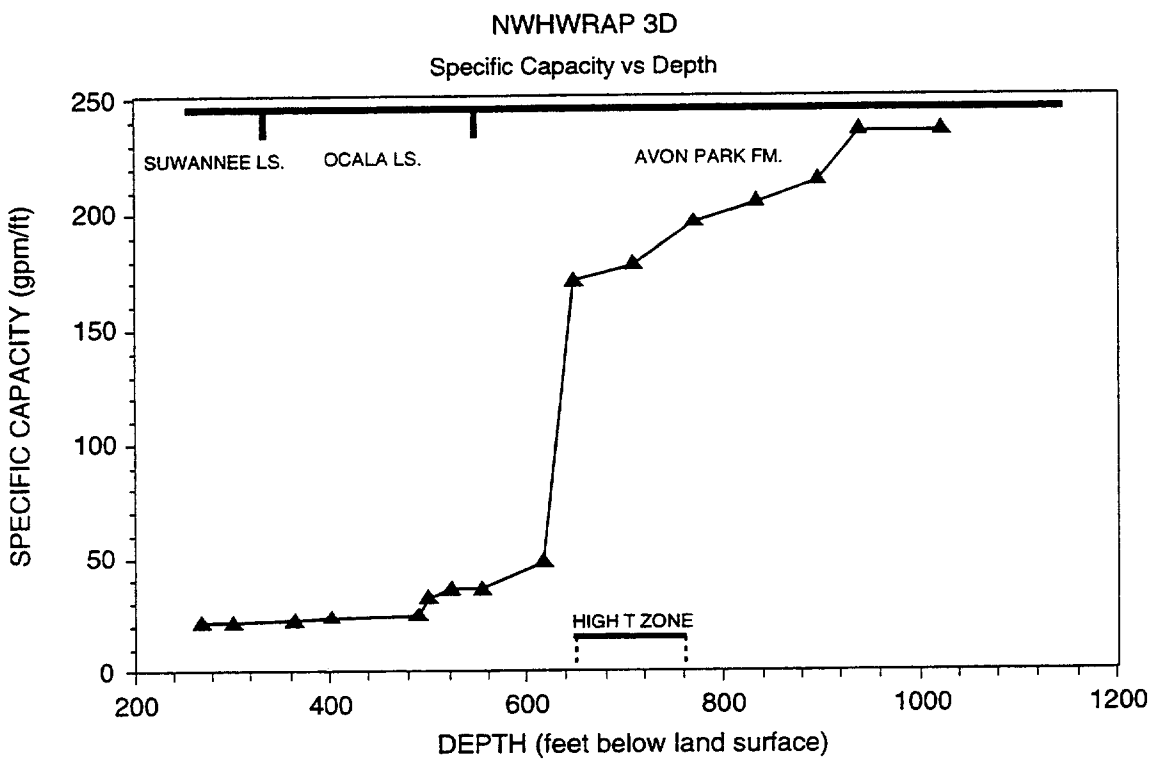


Figure 2-24. Specific capacity vs. depth at sites 1D-2D.



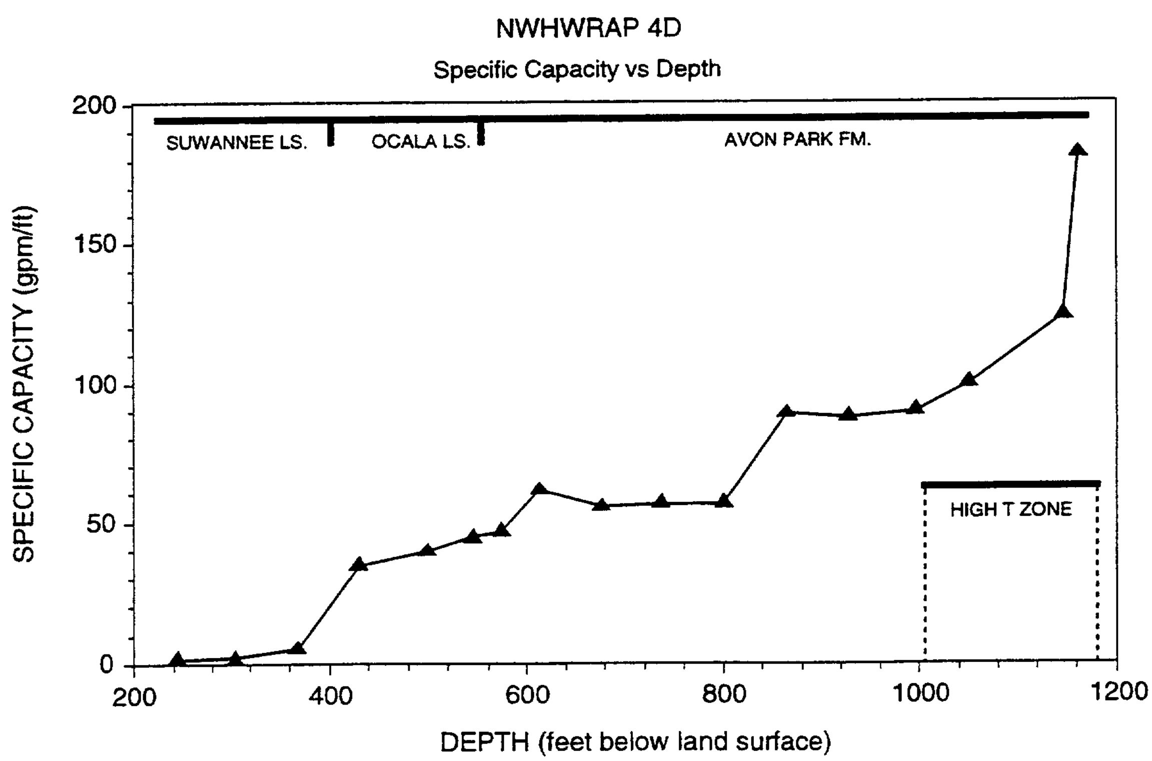


Figure 2-25. Specific capacity vs. depth at sites 3D-4D.

hydraulic conductivity values on 13 cores from the Suwannee and Ocala Limestones collected in Pinellas County range from 1.34 x 10^{-3} feet/day to 2.5 feet/day and average 0.6 feet/day (Hickey, 1981). However, analysis of geophysical temperature and flow meter logs, plus short-term hydraulic tests from the four deep test sites, indicate that significant permeability exists in distinct sections within the Ocala Limestone. This may be due to localized solution features or fractures that tend to increase secondary porosity of the formation. Packer tests conducted on discrete zones within the Ocala Limestone yielded horizontal hydraulic conductivity values that varied from 0.4 to 6 feet/day and averaged 1.7 feet/day (Table 2-3). Vertical hydraulic conductivity of the Ocala Limestone, based on an analysis of core samples from the four deep test wells, ranged from 5.0 x 10^{-3} to 5.9 feet/day and averaged 0.9 feet/day (CH2M HILL, 1990a,b).

Transmissivity of the Avon Park Formation is very high due to the fractured nature of the dolomite zones. The full range of variability of the Avon Park Formation has not been determined in this region, however, since most wells penetrate shallower portions of the Upper Floridan aquifer. Transmissivity values from six Avon Park aquifer tests ranged from 98,000 ft^2/day to 1,200,000 ft^2/day (Dames and Moore, 1988). The storage coefficient of the Upper Floridan aquifer varies from 8 x 10^{-3} to 6 x 10^{-5} and averages 1 x 10^{3} (Appendix B).

The potentiometric surface represents levels to which ground water would rise in tightly cased wells that are completed into the Upper Floridan aquifer. If water levels in these wells rise above the base of the confining material, the system is termed artesian, or confined. The altitude of the potentiometric surface of the Upper Floridan aquifer for May 1989, representing dry season conditions, ranged from 100 feet National Geodetic Vertical Datum (NGVD) in Polk County to less than five feet NGVD along the west coast of Pasco County (Barr, 1989). Figure 2-26 shows the potentiometric surface of the Upper Floridan aquifer in May 1989. The altitude of the potentiometric surface of the Upper Floridan aquifer for September 1989 (Figure 2-27), representing wet season conditions, is similar to May 1989 (Knockenmus and Barr, 1990).

Ground-water flow in the Floridan aquifer originates as rainfall that percolates downward from the surficial aquifer. In areas where the Upper Floridan aquifer is near the surface or

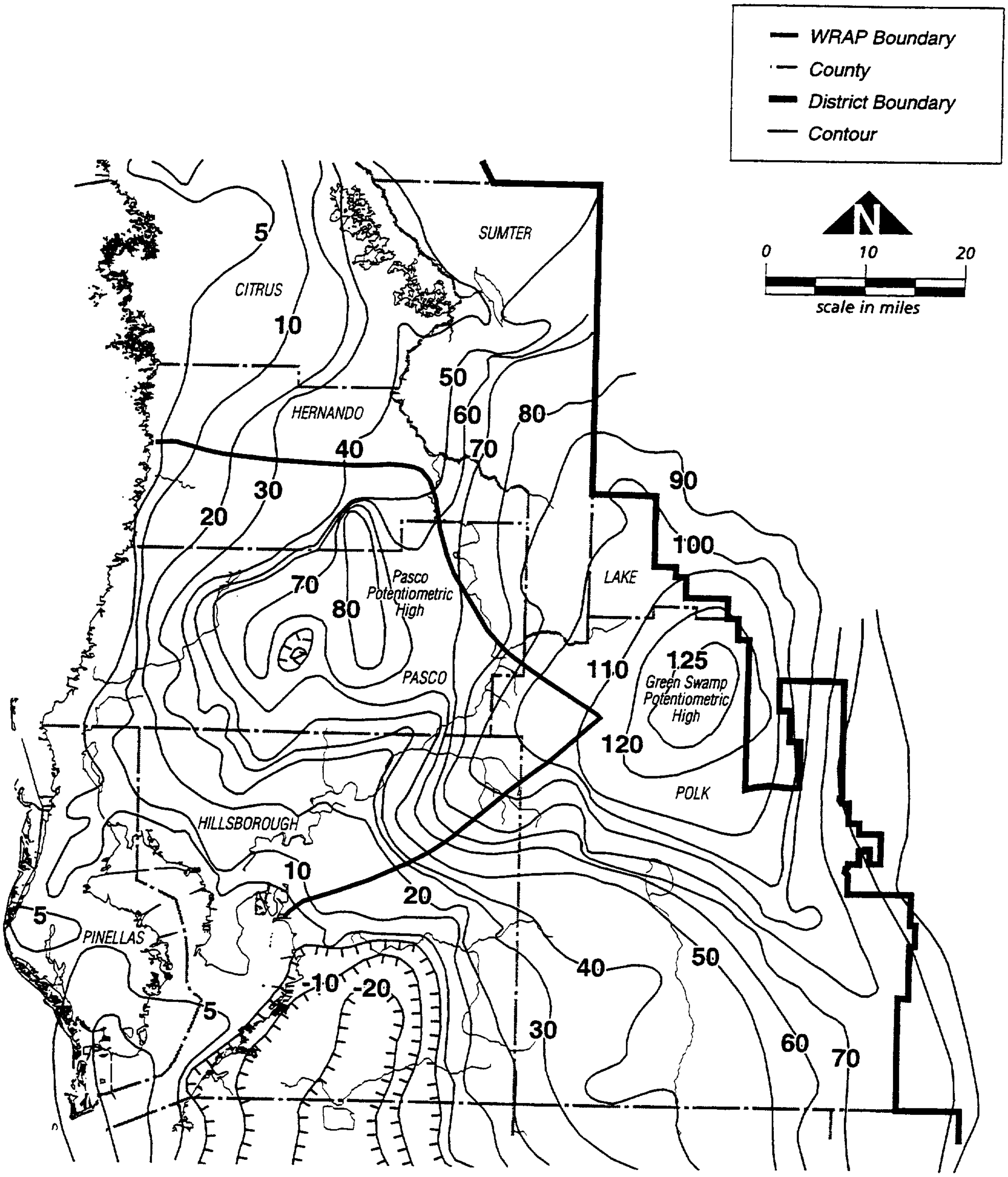


Figure 2-26. Potentiometric surface of the Upper Floridan aquifer, May 1989, within the Northern Tampa Bay WRAP area.

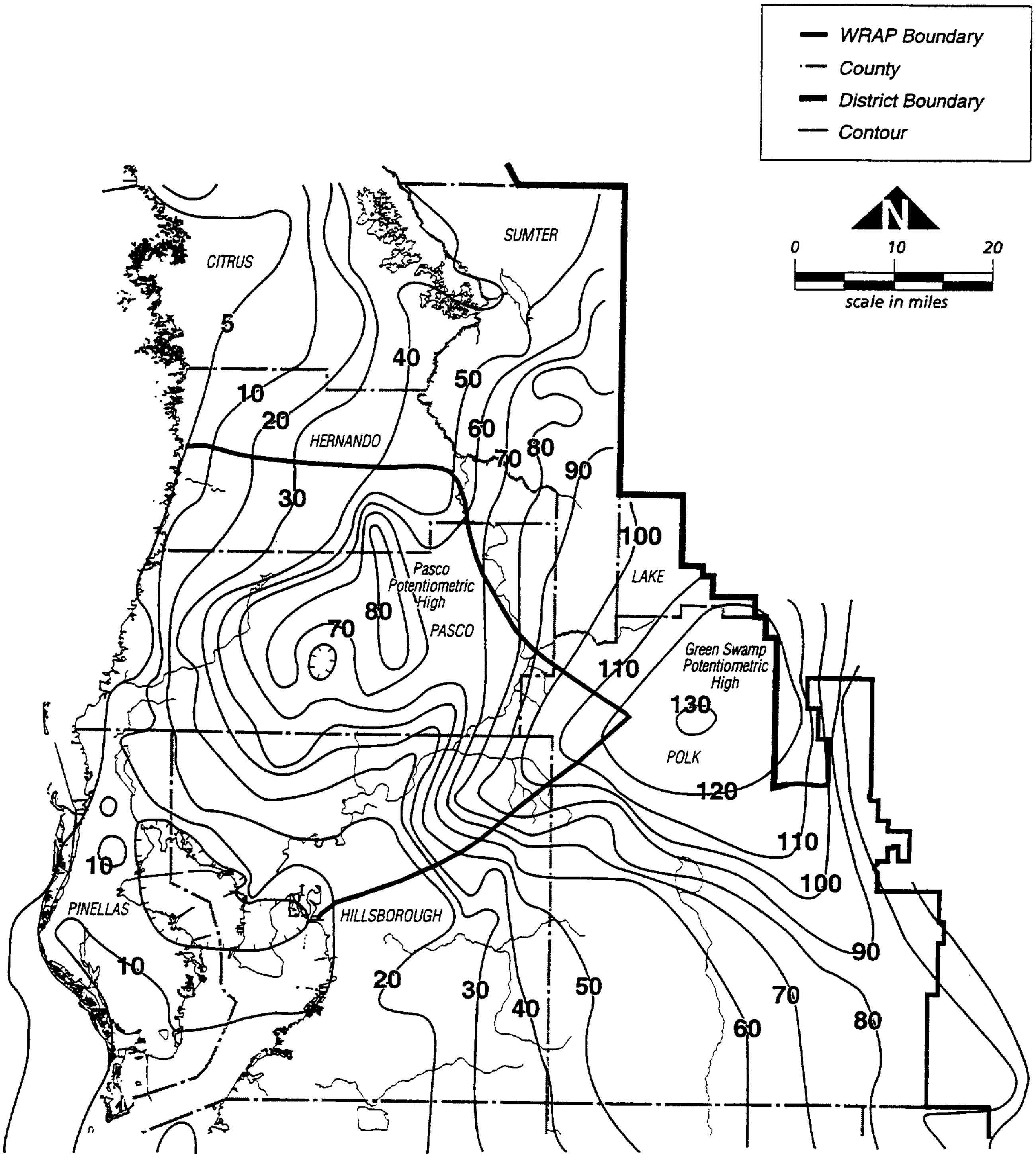


Figure 2-27. Potentiometric surface of the Upper Floridan aquifer, September 1989, within the Northern Tampa Bay WRAP area.

unconfined, this recharge can be direct. Recharge can also be high in areas of thicker confinement if the confining layer is breached with sinkholes. Recharge rates are generally higher in the northern portion of the Northern Tampa Bay WRAP area. Aucott (1988) reported recharge to be greater than 10 inches per year in the north-central portion of Hernando and Pasco Counties. Ryder (1985) indicates recharge rates from 14 to 22 inches per year in north-central Pasco and central Hernando Counties from a 1976 model simulation of the Upper Floridan aquifer. Similar rates were determined by SWFWMD (1993), although they were spatially variable. Recharge can be highly variable throughout the area due to karst geology and induced leakage caused by ground-water withdrawals. Along the coast, water levels in the Upper Floridan aquifer are higher than in the surficial aquifer, creating areas of diffuse upward leakage. Swancar and Hutchinson (1992) found discharge along coastal areas to vary from one to five inches per year along the Gulf of Mexico and Tampa Bay, with somewhat higher rates along Hillsborough Bay.

Figure 2-28 depicts areas of recharge and discharge to the Upper Floridan aquifer for predevelopment hydrologic conditions as determined by Aucott (1988). Although this pattern is generally reasonable, Aucott's determination of recharge was highly dependent on the thickness of the confining unit. Swancar and Hutchinson (1992), in performing an assessment to determine areas of potential Floridan aquifer contamination, developed a map that more accurately demonstrates areas of recharge within the Northern Tampa Bay area (Figure 2-29). By sampling water-quality constituents taken from various Floridan aquifer monitor wells, Swancar and Hutchinson were able to determine water age, and thus a measure of water movement into the Floridan aquifer. Figure 2-29 shows that recharge, and thus contamination potential, is not only a factor of the thickness of the confining unit, but also the integrity of the confinement and the head difference between the surficial and Floridan aquifers. Thus, areas around the Brooksville Ridge, where the confinement is thick but breached, and the head difference is large, show a high potential for Floridan aquifer contamination, and therefore recharge. Alternatively, the Green Swamp shows a much lower potential for contamination. Although the confining unit is thin or absent in this area, the transmissivity of the Upper Floridan aquifer is low, and the vertical head difference between the surficial and Upper Floridan aquifers is small, so the recharge is low. Much of the rainfall in the Green Swamp

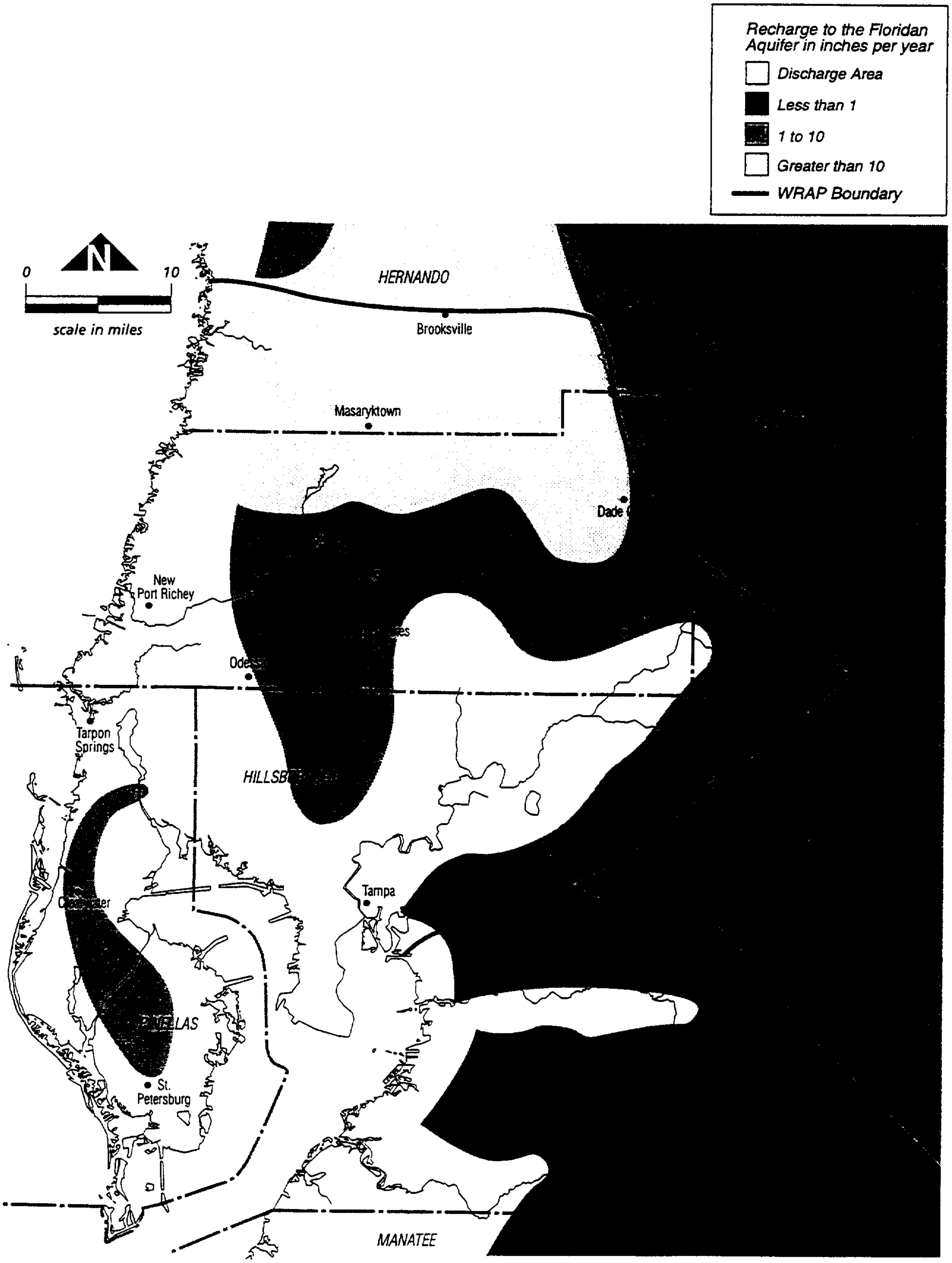


Figure 2-28. Upper Floridan aquifer recharge/discharge areas for predevelopment conditions within the Northern Tampa Bay area. (modified from Aucott, 1988).

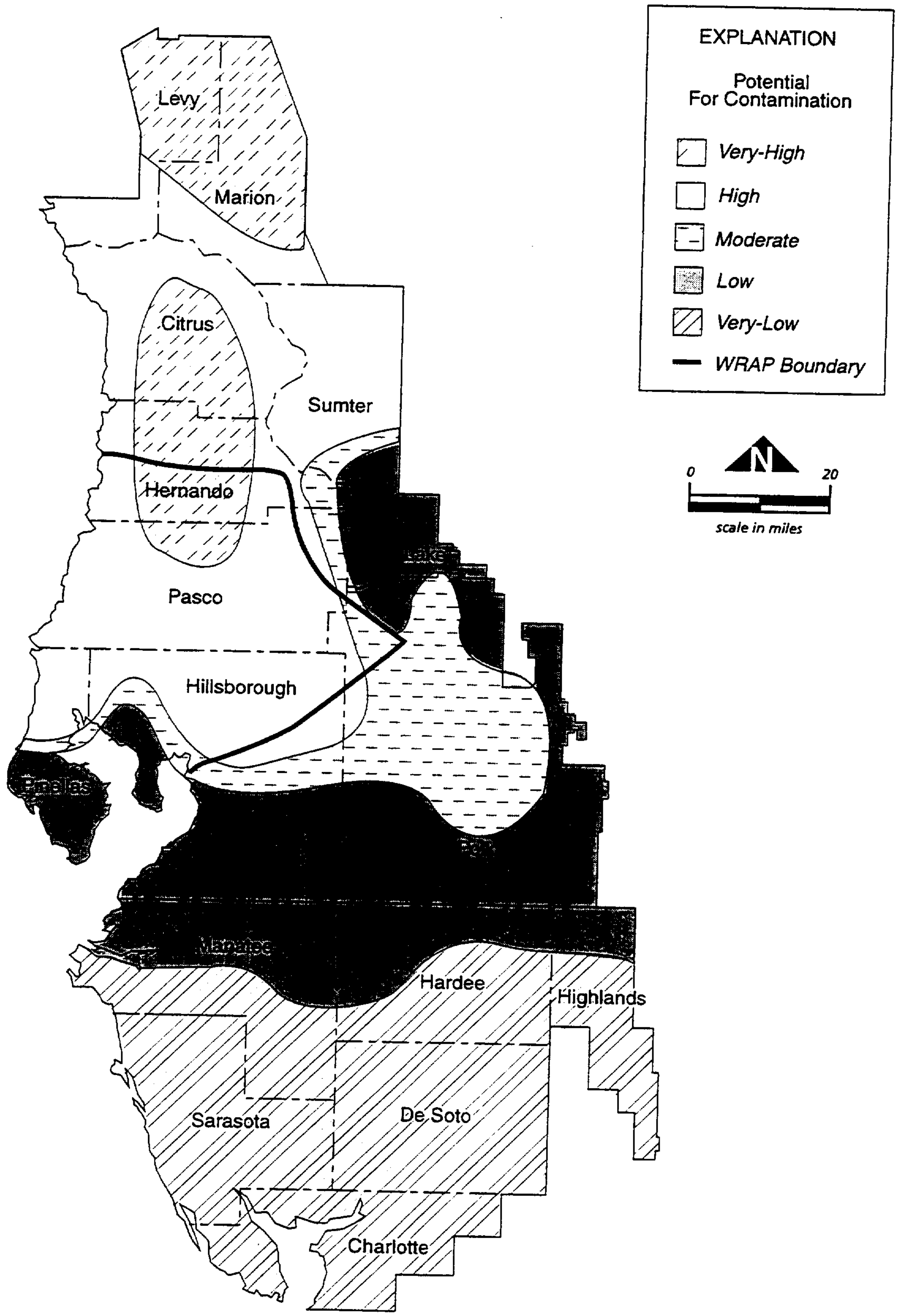


Figure 2-29. Potential for contamination of the Upper Floridan aquifer. (modified from Swancar and Hutchinson, 1992)

provides a source of water for the headwaters of the Hillsborough, Withlacoochee, Peace, and Oklawaha Rivers.

Figure 2-29 is a regional map of recharge potential, and there are localized areas of low confinement, or areas were the head difference between the surficial and Floridan aquifer has been increased through ground-water withdrawals from the Floridan aquifer, that can have greater recharge than is shown. Note that much of the area of northwest Hillsborough and southern Pasco Counties lies within an area of highly variable recharge.

The regional hydraulic gradient and direction of flow in the Upper Floridan aquifer is generally toward the south and west. Two potentiometric highs, the Pasco and Green Swamp potentiometric highs (Figures 2-26 and 2-27), influence the direction of regional ground-water flow in the area. The Pasco High is located between the towns of San Antonio and Zephyrhills in Pasco County. The high reaches an elevation of about 85 feet NGVD. The Green Swamp High is centered in northern Polk County. The elevation of this high rises to greater than 130 feet NGVD. Ground-water flow radiates outward from these potentiometric surface highs, generally toward the west and south. A trough in the potentiometric surface, oriented in a north-south direction, is located between the two highs in the Dade City area of Pasco County. The trough is theorized to exist because of a north-south oriented area of high transmissivities and fractures, as well as the existence of springs, Gator Hole Slough spring to the north and Crystal Springs to the south, on either end of the trough (Tibbals and others, 1980).

2.8 Land Use

Land use in the Northern Tampa Bay WRAP area is dominated by urban areas. Pinellas County is almost entirely urbanized, as is much of northwest Hillsborough County, and southwestern Pasco County. Inland areas of both Pasco and Hernando Counties are rapidly becoming urbanized, such as in Dade City, Zephyrhills, Land O' Lakes, Brooksville, and Spring Hill. Citrus groves and nurseries are also a major land use in Pasco and Hernando Counties, especially in the areas surrounding Dade City and Zephyrhills.

Land use in the Northern Tampa Bay areas can be characterized by four major categories: wetlands/water, upland forest/rangeland, agricultural, and urban/mining/recreation (Figure 2-30).

Acreages in the region associated with these uses are presented in Table 2-4. These categories were delineated based on aerial photography collected by the SWFWMD during 1989-1990. The largest classification is urban/mining/recreation, which accounts for over 37 percent of the land use within the 1,800 square mile area. Urban areas are mostly located along the Gulf coast, with the major metropolitan areas being Tampa, St. Petersburg, Clearwater, and New Port Richey. Brooksville, Dade City, Temple Terrace, and Zephyrhills are the largest population centers located inland. Mining areas are associated with limestone and sand production, and are located mostly in Pasco and Hernando Counties. Mining land use comprises a very small portion of the urban/mining/recreation land use category.

Table 2-4. Land use in the Northern Tampa Bay WRAP area (acres)

	Hillsborough	Pinellas	Pasco	Hernando	Polk	Total
Agriculture	63,451	3,711	140,755	33,906	12,619	254,442
Upland/ Rangeland	40,944	12,943	97,306	49,995	8,758	209,946
Urban/ Mines/Rec	143,824	139,187	95,075	44,765	7,020	429,871
Wetlands/ Water	82,574	42,871	102,626	22,904	10,312	261,287
TOTAL	330,793	198,712	435,762	151,570	38,709	1,155,546

The second largest land use is water and wetlands, which accounts for 23 percent of the area. The Northern Tampa Bay WRAP area is covered with many cypress domes and lakes, as well as tidal marshes, riverine forests, and to the northeast, the Green Swamp. Together, the many scattered wetlands combine to form a large land coverage. Agricultural land use is relatively similar in scope to water/wetlands, comprising 22 percent of the land area. Agricultural land use is dominated by citrus, particularly in northeastern Pasco County. The final land use type, upland/rangeland, comprises approximately 18 percent of the area.

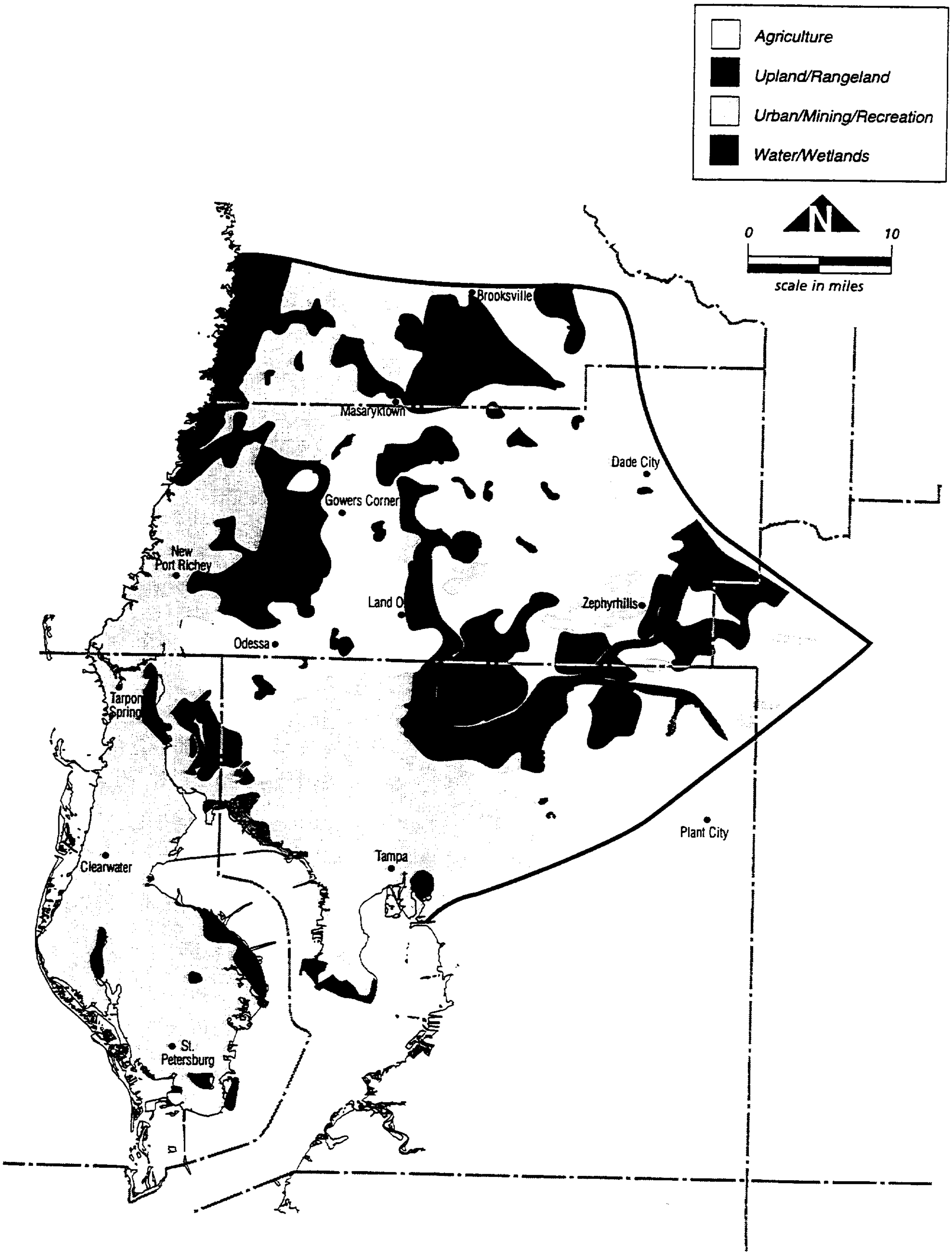


Figure 2-30. Generalized land use of the Northern Tampa Bay WRAP area.

Approximately 28 percent (329,050 acres) of the land in the Northern Tampa Bay WRAP area is already associated with an active water use permit (Table 2-5). Although the total represents all land within a permittee's boundary, not all acreage associated with the permit is irrigated or supplied water. These permitted lands include all land use classes: agriculture, rangeland and upland forest, urban and built-up areas, and wetlands and water bodies.

Table 2-5. Land use in the Northern Tampa Bay WRAP area associated with Water Use Permits (WUPs), in acres.

	Associated with a Water Use Permit	No Permit	Total
Agriculture	120,852	133,590	254,442
Rangeland/Upland	66,845	143,101	209,946
Urban/Mines/Rec	65,845	364,026	429,946
Wetlands/Water	75,508	185,779	261,287
TOTAL:	329,050	826,496	1,155,546

2.9 Water Use

In the Northern Tampa Bay WRAP area, the 1993 annual-average quantity of water withdrawn for all users was estimated to be 334 million gallons per day (mgd), including 246 mgd of ground-water and 88 mgd of surface-water. Most water withdrawn is for public supply (Figure 2-31). Public supply accounted for 75 percent of the estimated total water use and 74 percent of the estimated ground-water use in the Northern Tampa Bay WRAP area in 1993. Public supply ground-water withdrawals are almost entirely derived from the Upper Floridan aquifer.

Approximately 27 percent of the total public supply water use in 1993 was derived from two surface-water sources: the City of Tampa reservoir on the Hillsborough River and the City of Tampa withdrawals from the Tampa Bypass Canal. The remainder of public supply water in the WRAP area is derived from the Upper Floridan aquifer. Agricultural irrigation water use, the second largest water use in the WRAP area, accounts for approximately 10 percent of the total water withdrawn, and is also derived almost entirely from the Upper Floridan aquifer.

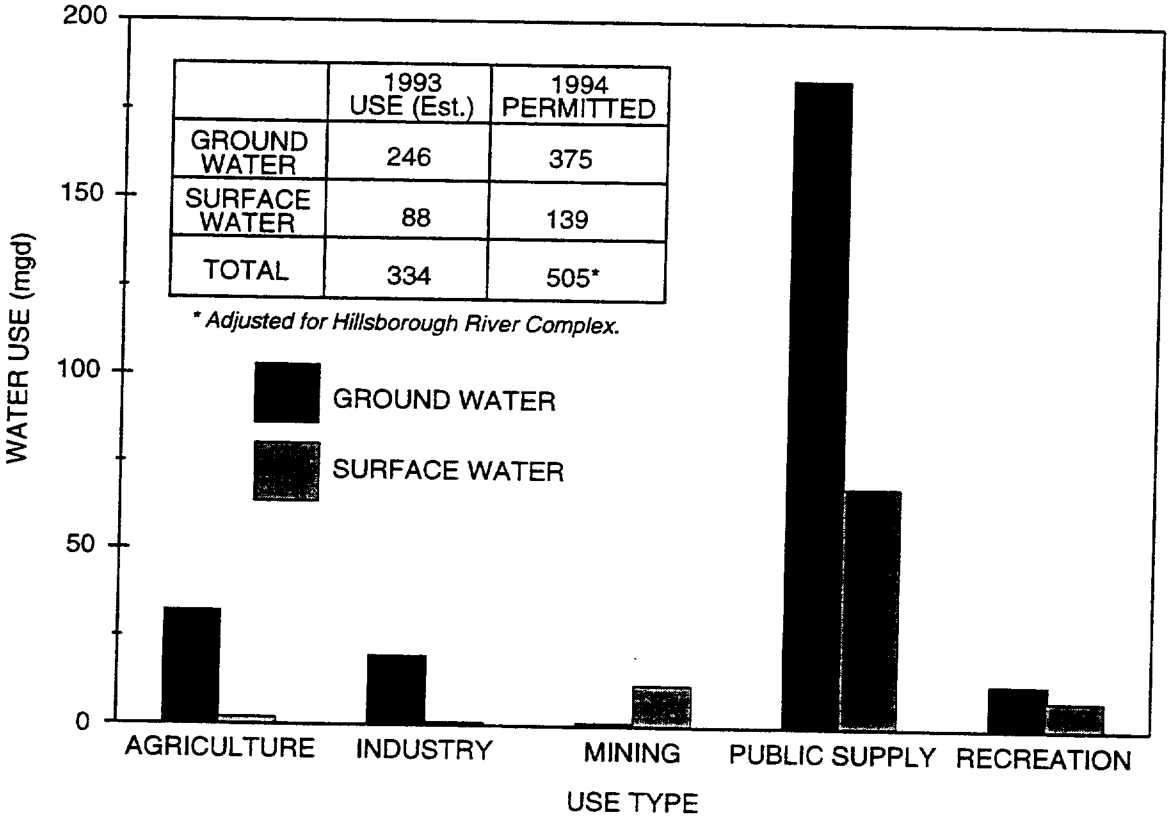


Figure 2-31. Estimated water use in the Northern Tampa Bay WRAP area (1993).

The following discussion includes both permitted and estimated water use. The summary of permitted use includes all permits of record as of November 1994. The most current information for estimated actual use for the Northern Tampa Bay WRAP area is for 1993. Where available, the estimates are based on metered quantities. Estimates for non-metered withdrawals in each major category are derived through use of the ratio of actual withdrawals to permitted withdrawals for all metered users in each category. Within the Northern Tampa Bay WRAP area, approximately 85 percent of the total estimated water use was metered as of 1990 (83 percent of the ground-water use and 93 percent of the surface-water use). Public supply, industrial, mining, and recreational estimated water uses are based on reported withdrawals for those permits required to submit withdrawal reports. A complete description of the water use estimation methodology is found in Tsai and others (1994).

2.9.1 Permitted Water Use

As of November 1994, there were 1,213 water use permits in the Northern Tampa Bay WRAP area. The 1994 annual-average permitted use equals approximately 505 mgd. As shown in Table 2-6, public supply accounts for 70 percent of the permitted quantity. The agriculture permitted water use accounts for 13 percent of the total permitted use. All other uses combined add up to the remaining 17 percent. Note that the permitted water use by county is the allowable maximum annual-average amount of water to be withdrawn from that county. Because of inter-county water transfers, the amount actually consumed by each individual county varies. Also note that actual and average water use can be much less than the permitted use, for several reasons that are discussed in the next section.

Most of the permitted water use in the study area is derived from ground water. Ground-water withdrawals are permitted for 375 mgd, or approximately 74 percent of the total permitted quantities. Public supply and agriculture permitted ground-water use is 263 mgd and 61 mgd, respectively.

Most of the permitted water use in the Northern Tampa Bay WRAP area is associated with individual users that are permitted for at least 0.5 mgd (Table 2-8 and Tables 2-10 through 2-

13). These 65 permittees represent approximately 82 percent (416 mgd) of the total permitted water use. Conversely, most of the users (1148 or 95 percent of the total) are permitted for less than 0.5 mgd. Together, these smaller users comprise only about 89 mgd, or 18 percent of the total permitted use.

Table 2-6. Permitted water withdrawals in the Northern Tampa Bay WRAP area as of November 1994 (mgd).

	Hillsborough	Pinellas	Pasco	Hernando	Polk	Total
Agriculture	22.0	0.7	34.8	3.7	2.2	63.4
Industry	9.3	0.3	17.7	0.0	0.0	27.3
Mining	1.5	0.2	11.2	7.0	5.0	24.9
Public Supply	150.6	56.3	129.3	18.2	0.8	355.2
Recreation	14.3	7.7	6.9	4.7	0.3	33.9
TOTAL:	197.7	65.2	199.9	33.6	8.3	504.7

2.9.2 Estimated Water Use

The quantity of water that is being used in the Northern Tampa Bay WRAP area is estimated to be approximately 34 percent less than the permitted quantity (Table 2-7). The most current estimates of actual water use are for calendar year 1993. Estimated water use in the Northern Tampa Bay WRAP area in 1993 is 334 mgd, with 74 percent of the use from ground-water withdrawals.

There are many reasons why actual use can be significantly less than permitted use. One reason is the fact that permitted quantities are issued for water use that is expected to occur within the six or 10 year duration of a permit. For many permits, the need for the water use may not have occurred as of 1993 (or any given year). For agricultural uses, permitted amounts are often determined on the basis of a 2 in 10-year drought, and on seasonal crops, so the permitted use would not be expected to be applied on an annual basis. In addition, withdrawal quantities on all permits are controlled by water quality and environmental parameters, and, in some cases,

minimum Upper Floridan aquifer levels (regulatory levels) that are established in the permits. Therefore, depending on hydrologic and other conditions, permitted quantities may not always be achievable. Finally, in the case of Table 2-7, some new permits have been issued (or expired) in the Northern Tampa Bay WRAP area between 1993 and 1994.

Table 2-7. Permitted and estimated water withdrawals in the Northern Tampa Bay WRAP area (mgd).

	1994 Permitted			1993 Estimated		
	SW	GW	TOTAL	SW	GW	TOTAL
Agriculture	2.5	60.9	63.4	1.3	31.6	32.9
Industry	0.5	26.8	27.3	0.2	18.9	19.1
Mining	24.6	0.3	24.9	11.1	0.3	11.4
Public Supply	102.0	262.6	355.2[1]	67.8	183.3	251.1
Recreation	9.5	24.4	33.9	7.5	12.0	19.5
TOTAL:	139.1	375.0	504.7[1]	87.9	246.1	334.0

Figures 2-32 and 2-33 present the distribution, quantity, and major use-types of estimated water use from both ground and surface water in 1993. As shown, ground-water use is dominated by concentrated public supply withdrawals, located mostly in the central portion of the Northern Tampa Bay WRAP area. Individual industrial users also account for some larger ground-water withdrawals, although the total industrial use is significantly smaller than total public supply water use. While agricultural water is the second largest use type in 1993, individual withdrawal points are spread over a large area. The majority of surface-water use is controlled by the public supply water facility at the Hillsborough River, and some dewatering operations for mining, mostly in the eastern portion of the WRAP area. As discussed earlier, a large majority of both the estimated surface-water and ground-water use within the Northern Tampa Bay WRAP area is controlled by a small number of permits.

[1] adjusted for the Hillsborough River complex. The complex consists of ground-water withdrawals at the Morris Bridge wellfield, as well as surface-water withdrawals from the Hillsborough River. Although the wellfield is permitted with an annual average of 15.5 mgd, and the river is permitted with an annual average of 82.0 mgd, the combined total can not exceed 88.1 mgd. Therefore, the individual permitted surface-water and ground-water uses do not equal the total permitted amount.

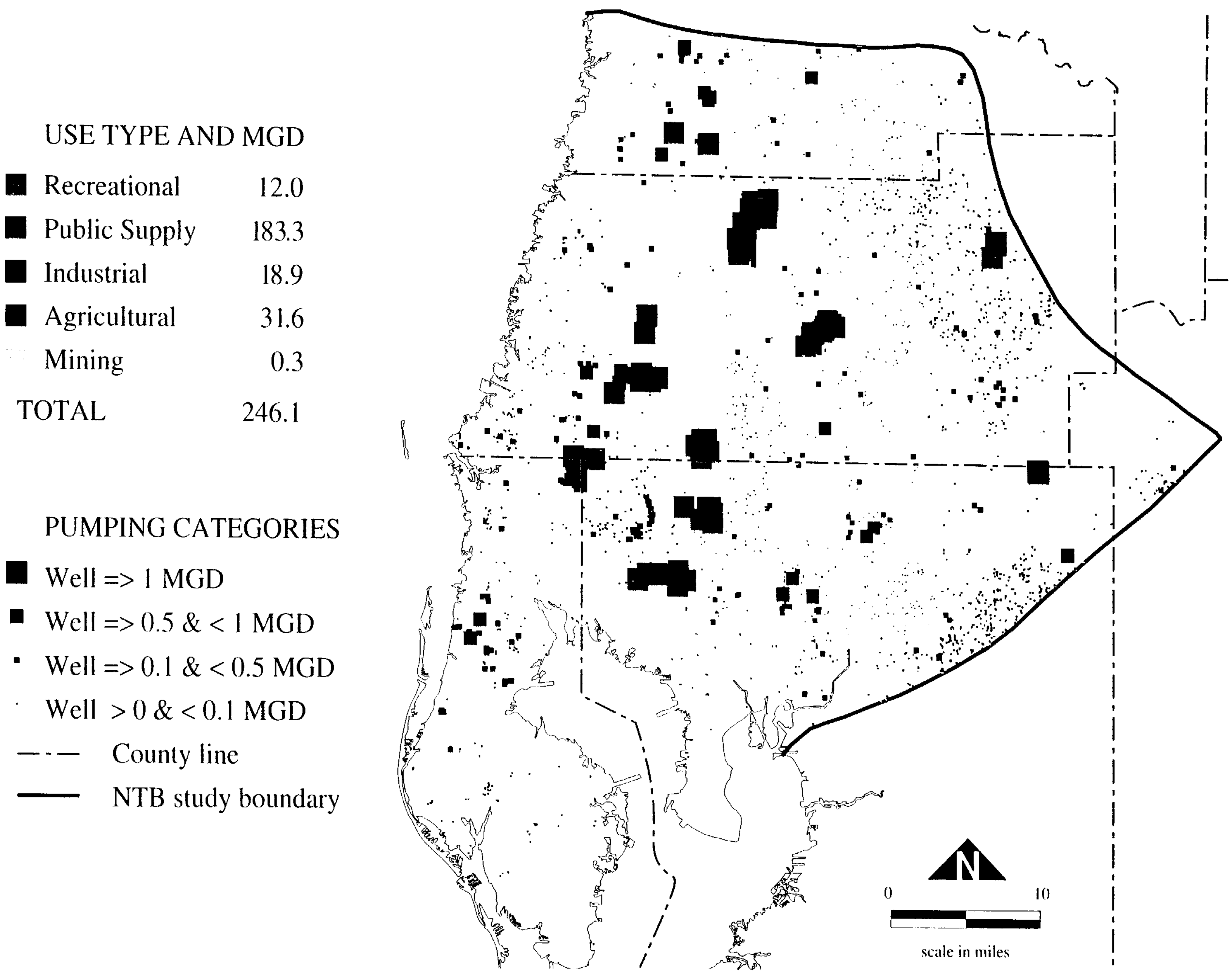


Figure 2-32. Ground-water withdrawals and use types within the Northern Tampa Bay WRAP area in 1993.

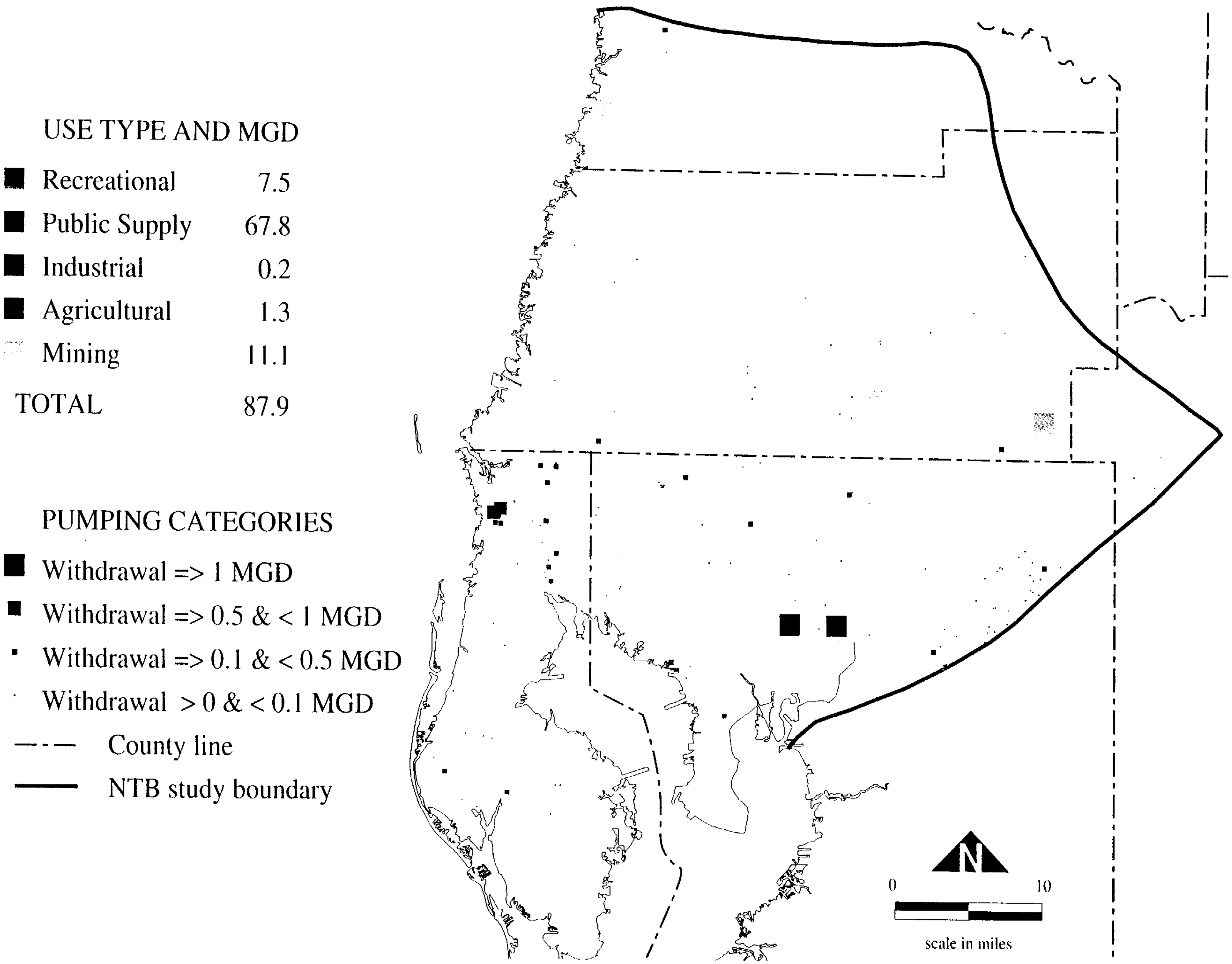


Figure 2-33. Surface-water withdrawals and use types within the Northern Tampa Bay WRAP area in 1993.

The largest difference between permitted and estimated use, 104 mgd, is for public supply, although the percentage of estimated public supply withdrawals in 1993 versus permitted amounts was approximately 70 percent. The difference occurs because most major wellfields have been permitted to account for future population growth, or have been limited by regulatory levels in the Upper Floridan aquifer. Public supply also represents the largest permitted use type. There are 210 permits in the Northern Tampa Bay WRAP area that list public supply as the major use type. Total permitted withdrawals in 1994 for public supply in the Northern Tampa Bay WRAP area are 355.2 mgd. By county, these permitted withdrawals are distributed with 56.3 mgd in Pinellas, 150.6 mgd in Hillsborough, 129.3 mgd in Pasco, 18.2 mgd in Hernando, and 0.8 mgd in Polk County. In contrast, the estimated 1993 public supply withdrawals were 251.1 mgd. Approximately 74 percent of the permitted public supply use is derived from ground-water withdrawals. Table 2-8 lists the 32 largest public supply permits in the Northern Tampa Bay WRAP area. The location of these withdrawals is shown in Figure 2-34. These permits account for 245 mgd (97 percent) of the estimated 1993 public supply water use. The data in this table indicate that reported public supply use for the largest users in 1993 was about 72 percent of the 1994 permitted public supply use. Note that a significant amount of water withdrawn as public supply is actually used for non-residential uses, such as industrial and recreational purposes. Therefore, the water use tabulated for industrial and recreational use below includes only those users with separate permits for water use.

Much of the public supply water withdrawals in Pasco, Hillsborough, and Pinellas Counties enters a regional system of intercounty transfers. Therefore, a significant amount of water withdrawn from Pasco and Hillsborough Counties is not actually consumed in those counties. In 1993, approximately 174 mgd entered the regional public supply system (Tsai, 1995). Nearly 108 mgd was derived from Pasco County, nearly 30 mgd was derived from Hillsborough County (including from areas outside of the Northern Tampa Bay WRAP area), and over 37 mgd was derived from Pinellas County. In return, approximately 47 mgd was distributed to Pasco County, 17 mgd was distributed to Hillsborough County, and nearly 110 mgd was distributed to Pinellas County.

Table 2-8. Permitted and estimated water use for Public Supply (permitted for 0.5 mgd or greater in the Northern Tampa Bay WRAP area, rounded to nearest tenth).

WUP Nº.	Name	1994 Permitted (mgd)	1993 Reported (mgd)	
02062	City of Tampa	88.1[1]	67.1[1]	SW/GW[2]
02673	Pinellas Co. - Eldridge Wilde	35.2	27.6	GW
04290	WCRWSA - Cross Bar	30.0	29.9	GW
03650	WCRWSA - Cypress Creek	30.0	25.1	GW
06675	City of Tampa Bypass Canal	20.0[1]	5.7[1]	SW
03647	St. Petersburg - South Pasco	16.9	12.3	GW
04446	WCRWSA - Starkey	15.0	12.0	GW
00003	WCRWSA - Section 21	12.0	9.4	GW
00004	WCRWSA - Cosme	12.0	5.7[3]	GW
04842	Spring Hill Utilities	10.3	9.3	GW
06676	WCRWSA -NW Hillsborough	8.8	9.4	GW
10051	WCRWSA - North Pasco	8.5	2.7	GW
02981	City of Clearwater	8.0	3.2	GW
08426	WCRWSA - Cypress Bridge	8.0	1.1	GW
02980	City of Dunedin	7.1	4.9	GW
02983	Hernando Co. - Brookridge	4.9	4.5	GW
00450	City of Temple Terrace	4.6	3.7	GW
04391	Pinellas Co. - East Lake	3.0	0.0	GW
00266	Pasco Co. - West	2.6	0.8	GW
	Continued next page			

[1] This is part of the Hillsborough River Reservoir Complex. The permitted and estimated withdrawal rates include ground-water withdrawals from the Morris Bridge Wellfield. The City of Tampa also has a permit #06675 which allows up to an annual average of 20 mgd of withdrawals from the Tampa ByPass Canal to be pumped into the Hillsborough River. The Hillsborough Reservoir permit (#02062) also allows for up to an annual average of 5.0 mgd of water to be similarly diverted from Sulphur Springs, although no water was withdrawn for this purpose in 1993. The permit allows for up to 82 mgd of reservoir withdrawals, and up to 15.5 mgd of ground-water withdrawals from the Morris Bridge wellfield, but the total can not exceed 88.1 mgd. In 1993, 5.0 mgd was withdrawn from the wellfield, and 62.1 mgd was withdrawn from the reservoir, for a total of 67.1 mgd.

[2] SW = surface water, GW = ground water

[3] Due to metering inaccuracies between January 1988 and April 1993, these values have been adjusted up by 2.0 mgd prior to April, 1993.

Table 2-8 (continued). **Permitted and estimated water use for Public Supply (permitted for 0.5 mgd or greater in the Northern Tampa Bay WRAP area, rounded to nearest tenth).**

WUP N°.	Name	1994 Permitted (mgd)	1993 Reported (mgd)
01631	City of Dade City	2.2	1.5 GW[1]
06040	City of Zephyrhills	2.7	1.6 GW
03182	Aloha Utility	2.0	2.0 GW
07627	City of Brooksville	1.5[2]	1.0[2] GW
00742	City of Tarpon Springs	1.4	0.4 GW
07692	Town of Belleair	1.3	1.1 GW
05245	Pasco Co. - New River	1.0	0.5 GW
05886	Florida Cities Utility	0.8	0.6 GW
04352	WCRWSA - S. Central	0.8[2]	0.0[2] GW
04669	Hudson Water Works	0.8	0.6 GW
06505	Polk County - North	0.7[2]	0.4[2] GW
03132	Pebble Creek	0.7	0.4 GW
09870	WCRWSA - NE Brandon	0.6[2]	0.0[2] GW
	TOTAL	341.5	244.5

Agriculture represents the second largest permitted use type. There are 758 permits in the Northern Tampa Bay WRAP area that list agriculture as the primary use. Annual-average permitted use for agriculture in the Northern Tampa Bay WRAP area totals 63.4 mgd. By county, this use is distributed with 0.7 mgd in Pinellas, 22.0 mgd in Hillsborough, 34.8 mgd in Pasco, 3.7 mgd in Hernando, and 2.2 mgd in Polk County. Approximately 96 percent of the permitted agricultural use is derived from ground-water withdrawals. Estimated agricultural water use in 1993 was 32.9 mgd. The percentage of estimated actual agricultural withdrawals in 1993 versus permitted amounts was approximately 52 percent. The crop type with the largest estimated use is citrus, estimated to use about 14 mgd (Table 2-9). The 11 largest permitted agricultural uses (Table 2-10) account for approximately 3.8 mgd or 12 percent of the estimated

[1] SW = surface water, GW = ground water

[2] includes the portion of the permit within the Northern Tampa Bay WRAP area only.

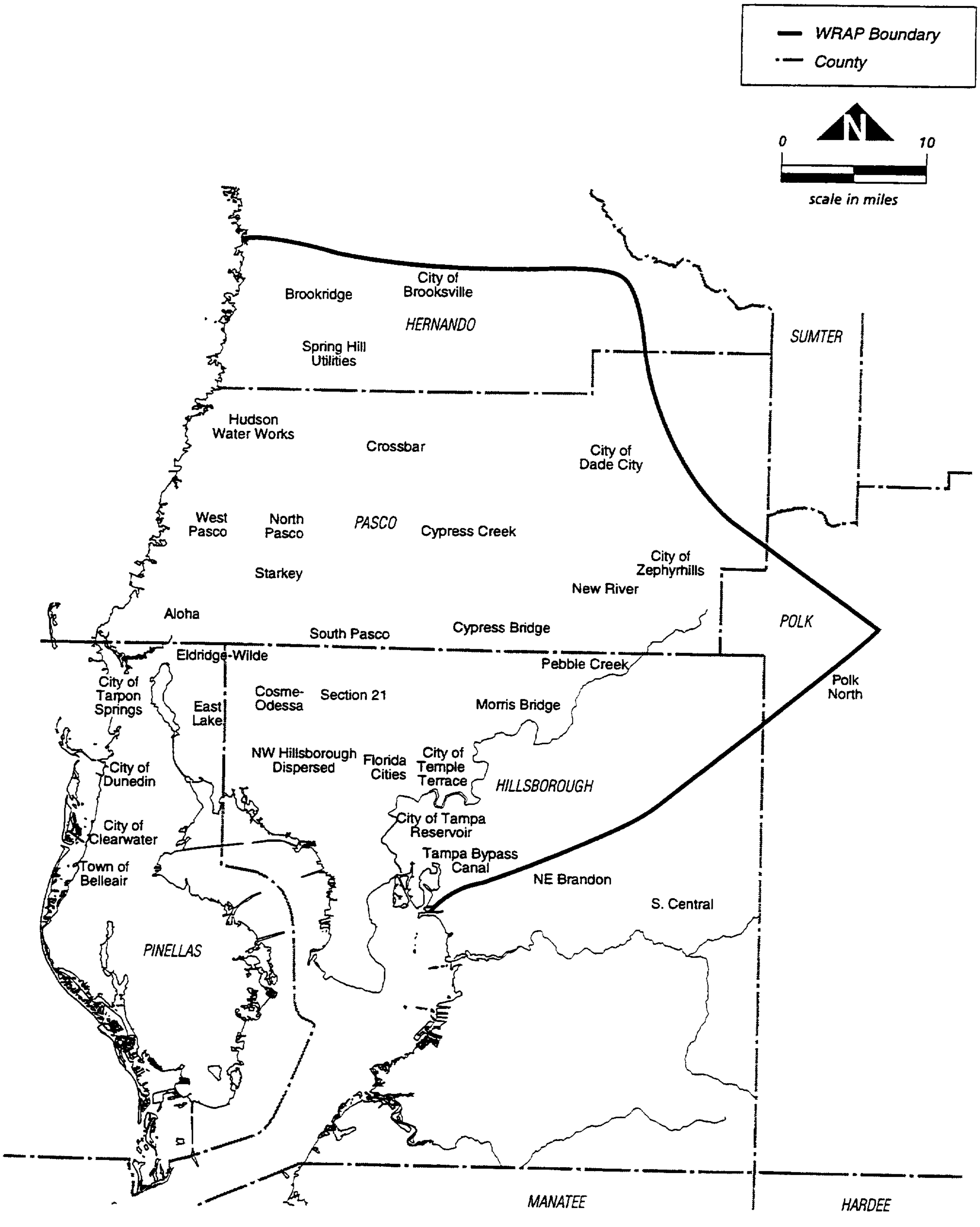


Figure 2-34. Location of major public supply wellfields within the Northern Tampa Bay WRAP area.

Table 2-9. Permitted and estimated Agricultural water use in the Northern Tampa Bay WRAP area (mgd, rounded to nearest tenth).

	1994 Permitted	1993 Estimated
Citrus	23.0	14.1
Nursery	6.8	3.7
Pasture	10.8	1.4
Sod	1.3	0.5
Vegetables	5.2	3.7
Strawberries	4.3	2.3
Miscellaneous	12.0	7.2
TOTAL	63.4	32.9

Table 2-10. Permitted and estimated water use for Agriculture (permitted for 0.5 mgd or greater in the Northern Tampa Bay WRAP area, rounded to the nearest tenth).

WUP Nº.	Name	1994 Permitted	1993 Reported Use	
03468	S.C. Bexley, Jr.	3.2	0.0	GW[1]
02479	Wiregrass Ranch	2.8	0.2	GW
06431	Freeman F. Polk	2.0	0.8[2]	GW
01367	Two Rivers Ranch	1.5	0.2[2]	GW
07686	The Larkin Company	1.2	0.6[2]	GW
08825	James Tokey Walker	1.0	0.3	GW/SW
03391	Evans Properties Inc.	1.0	0.8	GW
09194	R.P. Company, Inc.	1.0	0.5	GW
03389	Evans Properties Inc.	0.7	0.2	GW
02698	Sid Larkin & Son Inc.	0.7	0.1	GW
01580	Anclote River Ranch	0.5	0.1	GW
	TOTAL	15.6	3.8	

[1] SW = surface water, GW = ground water

[2] estimated

agricultural withdrawals in 1993. The data in this table indicate that reported agricultural use for the largest users in 1993 was about 24 percent of the 1994 permitted agricultural use. The general locations of these withdrawals appear in Figure 2-35.

There are 55 permits in the Northern Tampa Bay WRAP area that list industry as the primary use, totaling 27.3 mgd. Within the Northern Tampa Bay WRAP area, permitted use is 0.3 mgd in Pinellas, 9.3 mgd in Hillsborough, 17.7 mgd in Pasco, and near zero mgd in both Hernando and Polk Counties. Estimated industrial use within the Northern Tampa Bay WRAP area was 19.1 mgd in 1993. The percentage of estimated actual industrial withdrawals in 1993 versus permitted amounts was approximately 70 percent. The five largest permitted industrial uses (Table 2-11) accounted for 17.1 mgd, or 90 percent of the industrial use in 1993. The data in this table indicate that reported industrial use for the largest users in 1993 was about 71 percent of the 1994 permitted industrial use. The general locations of these withdrawals are found in Figure 2-36. Note that the public water supply utilities in the tri-county area of Hillsborough, Pinellas, and Pasco Counties also provide over 15 mgd of water to industrial/commercial users in this area (Ostow, 1995). Although this value includes southern Hillsborough County water use, which is not within the Northern Tampa Bay WRAP area, the portion that is applicable to the WRAP area is not reflected in the industrial water use category (but would be included in the public supply values).

There are 15 permits in the Northern Tampa Bay WRAP area with mining as the primary use type. All of the mining permitted use is for sand, limestone, or peat mining, and most of the water use consists of dewatering with onsite discharge. Total permitted mining use is 25.1 mgd. Within the Northern Tampa Bay WRAP area, permitted use is 0.2 mgd in Pinellas, 1.5 mgd in Hillsborough, 11.4 mgd in Pasco, 7.0 mgd in Hernando, and 5.0 mgd in Polk County. Estimated mining use in the Northern Tampa Bay WRAP area for 1993 was 11.4 mgd, of which nearly all consisted of surface-water withdrawals. The percentage of estimated actual mining withdrawals in 1993 versus permitted amounts was approximately 46 percent. The four largest permitted mining uses (Table 2-12) account for approximately 10.3 mgd in 1993, or 90 percent of the total mining water use. The data in this table indicate that reported mining use for the

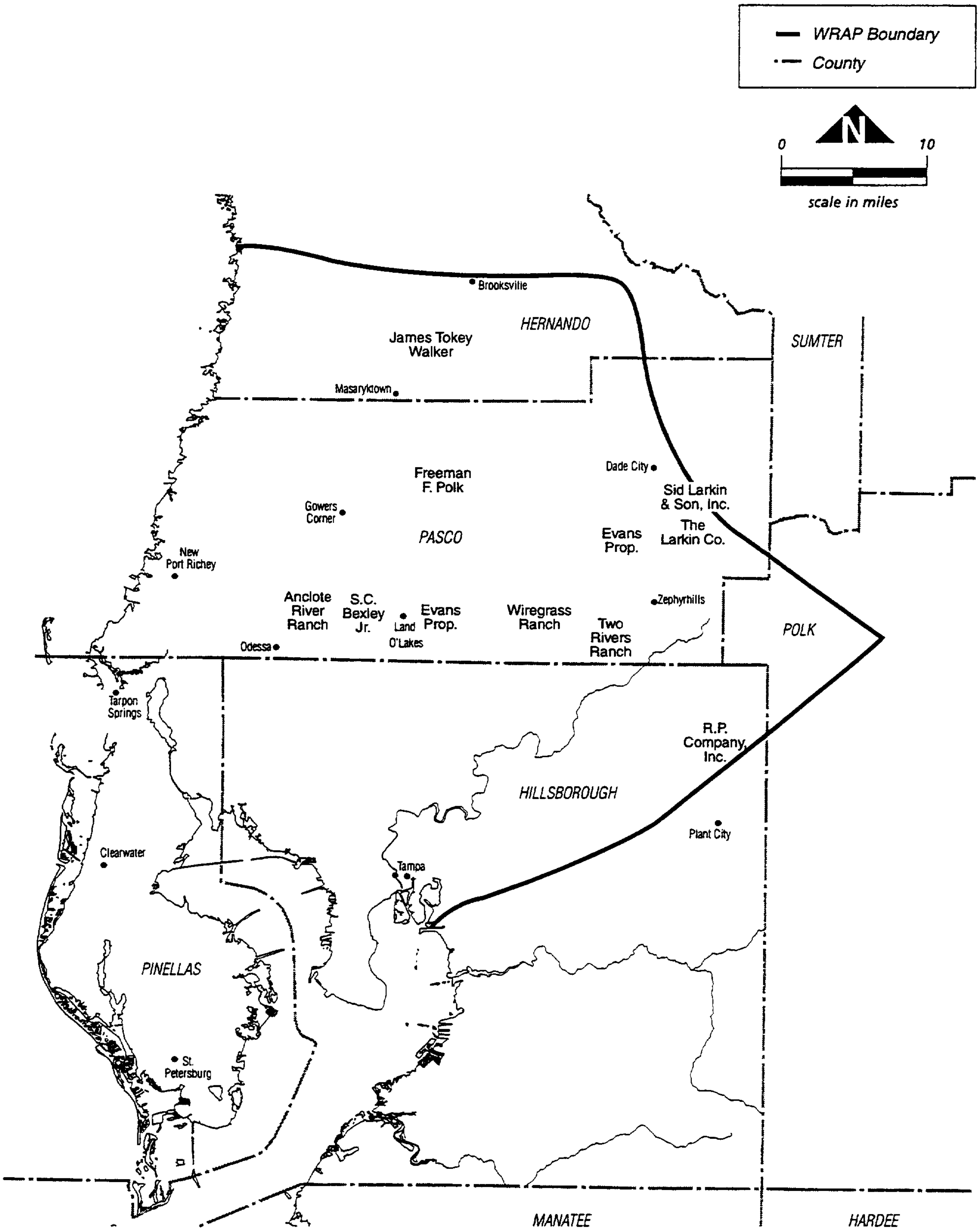


Figure 2-35. Location of major agricultural water users within the Northern Tampa Bay WRAP area.

Table 2-11. Permitted and estimated water use for Industry (permitted for 0.5 mgd or greater in the Northern Tampa Bay WRAP area, rounded to the nearest tenth).

WUP Nº.	Name	1994 Permitted	1993 Reported Use	
00451	Lykes Pasco Inc.	15.5	10.2	GW
01415	CF Industries Inc.	6.4	5.2	GW
10413	Pasco Cogeneration	0.8	0.4	GW
09087	Pasco County Solid Waste	0.7	0.7	GW
00148	Stroh Brewery Company	0.7	0.6	GW
	TOTAL	24.1	17.1	

Table 2-12. Permitted and estimated water use for Mining (permitted for 0.5 mgd or greater in the Northern Tampa Bay WRAP area, rounded to the nearest tenth).

WUP Nº.	Name	1994 Permitted	1993 Reported Use	
04826	Plaza Materials Corporation	8.9	9.1	GW/SW[1]
01929	Oman Construction Company	7.0	1.1	SW
07095	Howard Bros. Mining & Materials	5.0	0.0	SW/GW
10679	Cone Corporation	1.4	0.1	SW
	TOTAL	22.3	10.3	

largest users in 1993 was about 46 percent of the 1994 permitted mining use. The general locations of these withdrawals are found in Figure 2-37.

There are 175 permits in the Northern Tampa Bay WRAP area with recreation as the primary use type. Total permitted recreational use is 33.9 mgd. Within the Northern Tampa Bay WRAP area, permitted use is 7.7 mgd in Pinellas County, 14.3 mgd in Hillsborough, 6.9 mgd in Pasco, and 4.7 mgd in Hernando, and 0.3 mgd in Polk County. Estimated recreational use in the Northern Tampa Bay WRAP area for 1993 was 19.5 mgd. The percentage of estimated actual recreational withdrawals in 1993 versus permitted amounts was approximately 58 percent. The largest 13 permits

[1] SW = surface water, GW = ground water

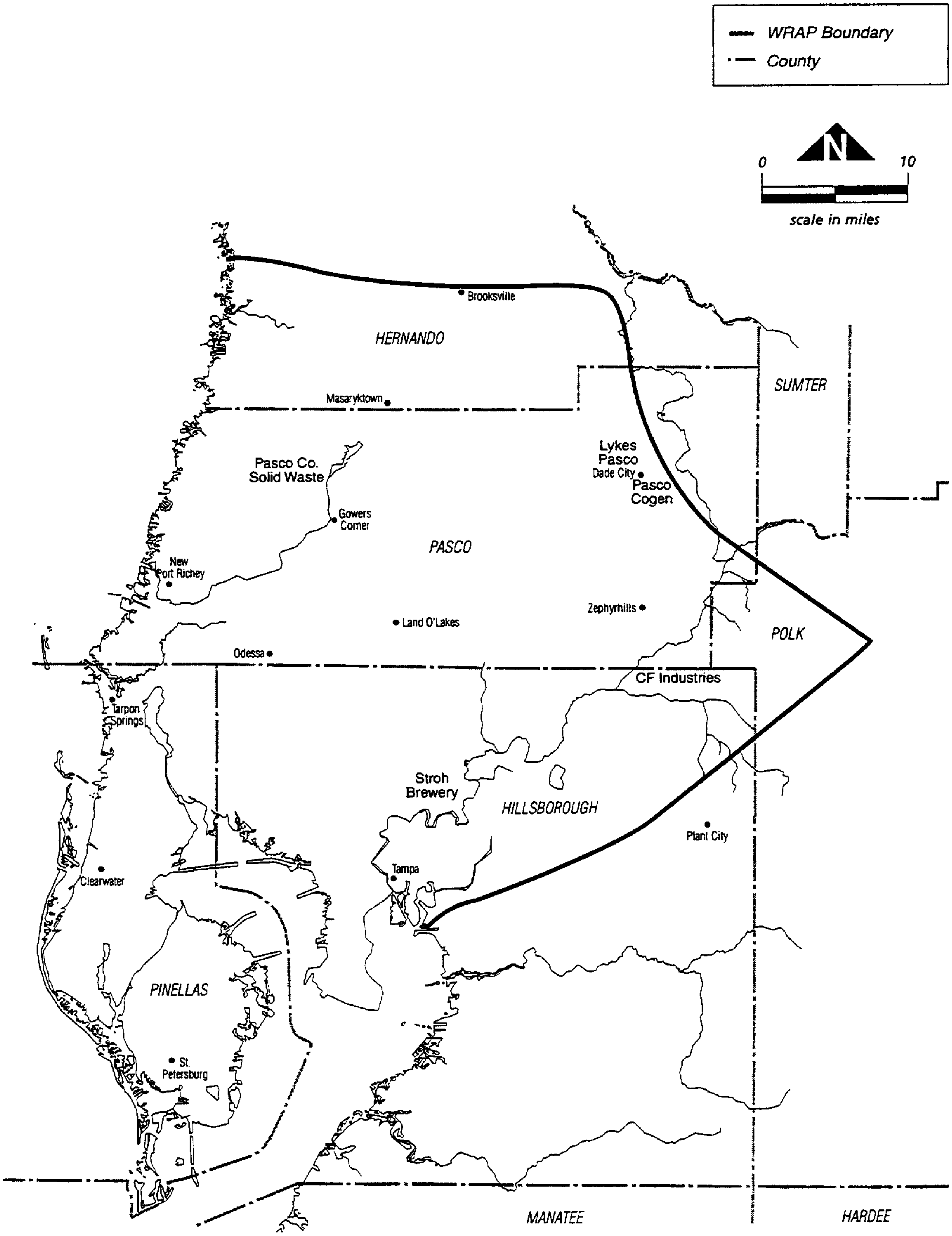


Figure 2-36. Location of major industrial water users within the Northern Tampa Bay WRAP area.

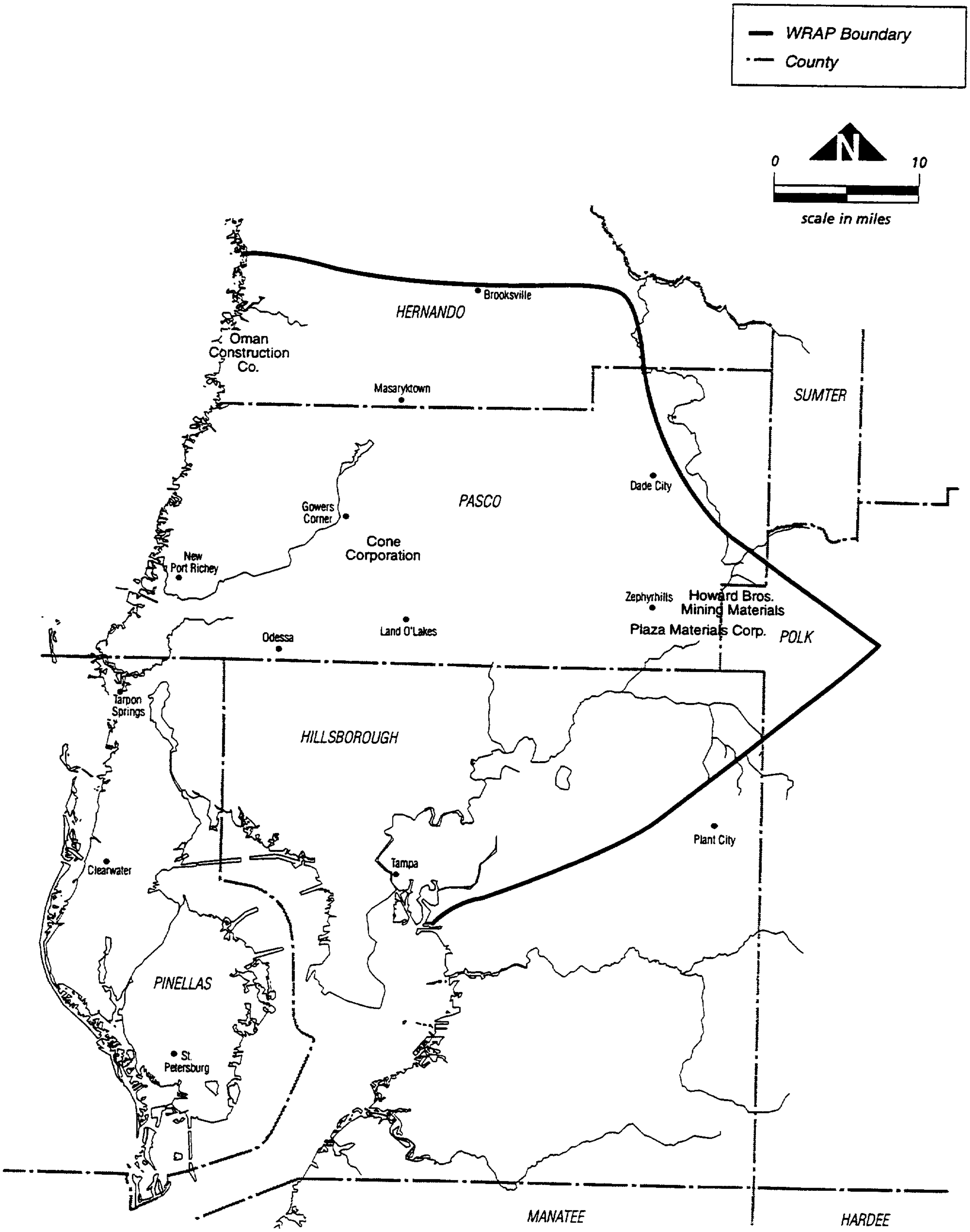


Figure 2-37. Location of major mining water users within the Northern Tampa Bay WRAP area.

(Table 2-13) account for 6.3 mgd, or only 32 percent of the total 1993 water use. The data in this table indicate that reported recreation use for the largest users in 1993 was about 51 percent of the 1994 permitted recreation use. The general locations of these withdrawals are found in Figure 2-38.

Table 2-13. Permitted and estimated water use for Recreation (permitted for 0.5 mgd or greater in the Northern Tampa Bay WRAP area, rounded to the nearest tenth).

WUP №.	Name	1994 Permitted	1993 Reported Use
01960	University of South Florida	2.9	1.3 SW/GW
02320	Busch Entertainment Corp.	1.8	1.6 SW/GW
07437	East Lake Woodlands LTD.	1.0	0.7 SW/GW
09042	Markborough Florida Inc.	0.9	0.2 SW/GW
06960	William L. Jacobsen	0.9	0.2 SW/GW
05755	Scarborough/Sembler Joint	0.8	0.0 SW
06113	Saddlebrook Resorts Inc.	0.7	0.3 SW/GW
02705	Westchase Associates	0.7	0.3 SW/GW
08639	Timber Pines Community	0.6	0.5 GW
03707	Bardmoor/Bayou Club	0.6	0.5 SW/GW
04874	SICO Inc.	0.5	0.2 SW/GW
10199	Sherman Hills Golf Club, Inc.	0.5	0.4 GW
00620	The Eagles, LTD.	0.5	0.1 SW/GW
	TOTAL	12.4	6.3

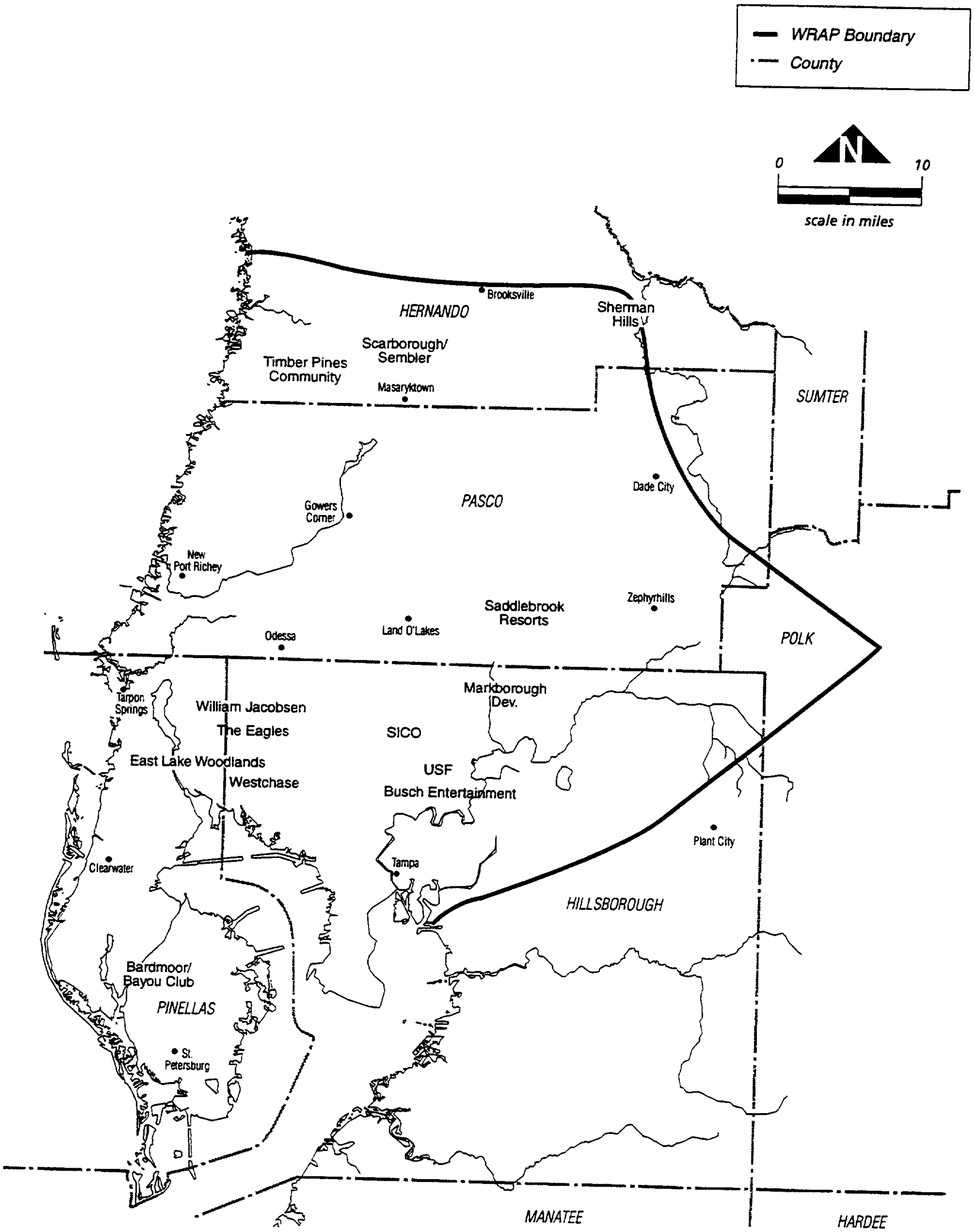


Figure 2-38. Location of major recreational water users within the Northern Tampa Bay WRAP area.

CHAPTER 3 - TREND ANALYSIS

The critical concern of the Northern Tampa Bay WRAP is to determine the regional causes of impacts to the water resources of the area. As discussed earlier, the most important of these impacts are lowered surficial and ground-water levels, degradation of biological health, and the degradation of ground-water quality through seawater intrusion. Determining the causes of these impacts is complicated by the numerous variables involved in the hydrologic cycle. For example, aquifer levels are dependent on recharge from rainfall, rates of ground-water withdrawals, changes in land use, alterations to surface-water drainage, as well as other atmospheric variables. To attribute the cause of the lower water levels to any one factor without considering all of the variables involved may lead to a wrong conclusion.

With the numerous variables involved in the water resource system, ascertaining which variables are causing the impacts observed requires an understanding of changes which have taken place in the past. This chapter presents a discussion of historical trends for land use, water use, rainfall, evapotranspiration, surface-water flows, surface- and ground-water levels, and biological health. Water quality trends are presented in Volume Two of this report. The goal of the trend analysis is to present changes in each variable in a manner that will facilitate an understanding of the cause-and-effect relationships between the variables. In Chapter 4, the cause-and-effect relationships are discussed.

3.1 Land Use

Changes in land use through the years have resulted in some profound changes in the demand for water in the Northern Tampa Bay WRAP area. Future changes will add an additional burden on the water supply. One of the most significant trends in the Northern Tampa Bay WRAP area is the increase in urban/commercial land use. The Florida Department of Transportation (FDOT, 1985) estimated that between 1973 and 1984, urban/commercial land use increased by approximately 50,000 acres in Hillsborough County; 35,000 acres in Pinellas County; 37,000 acres in Hernando County; 48,000 acres in Pasco County; and 113,000 acres in Polk County. This trend has continued through the 1980s. In 1990, urban/commercial land

use accounted for approximately 430,000 acres, or over 37 percent, of the Northern Tampa Bay WRAP area.

The evaluation of historical trends in agricultural acreage of the Northern Tampa Bay WRAP area was based on information provided by the Florida Agricultural Statistics Service (FASS). Citrus is the predominant crop in the Northern Tampa Bay WRAP area. Citrus data has been published biennially by the FASS since 1966. The total citrus acreage in the Northern Tampa Bay WRAP area has decreased from over 80,000 acres in 1968 to a low of approximately 12,000 acres in 1986 (Figure 3-1). The large decrease was caused by freeze damage in the mid-1980s. As of 1992, citrus acreage in the Northern Tampa Bay WRAP area had increased to approximately 18,000 acres. Based on previous estimations of irrigated acreage, the total citrus acreage has decreased over the past thirty years, while the percentage of acreage that is irrigated has increased (Gerber, 1973, and Marella, 1988).

Although citrus dominates the agricultural acreage, other crop types, such as nursery and vegetables, have increased over the last 12 years. The total nursery acreage in the Northern Tampa Bay WRAP area has increased from approximately 500 acres in 1980 to approximately 1,300 acres in 1992 (Figure 3-2). Vegetable acreage data for the counties included in the Northern Tampa Bay WRAP area are available by county since 1986 (Figure 3-3). Vegetable data are reported as a combination of fall and successive spring (e.g. the 1990/1991 report contains the data for Fall 1990 and Spring 1991, presented as one value per county). Each bar presented on Figure 3-3 represents the combined value for the spring of that year and the previous fall. The major vegetable crops in the Northern Tampa Bay WRAP area are tomatoes, strawberries, melons, cucumbers, and peppers. The total vegetable acreage in the Northern Tampa Bay WRAP area has increased from approximately 600 acres in 1986 to almost 700 acres in 1991.

Citrus acreage has decreased in the last 10 years, but the acreage is projected to increase in the next thirty years. Nursery and vegetable acreage has been increasing since 1980 and 1986, respectively, and are expected to increase in the next thirty years. In support of the SWFWMD's Needs and Sources Plan development, the Institute of Food and Agricultural

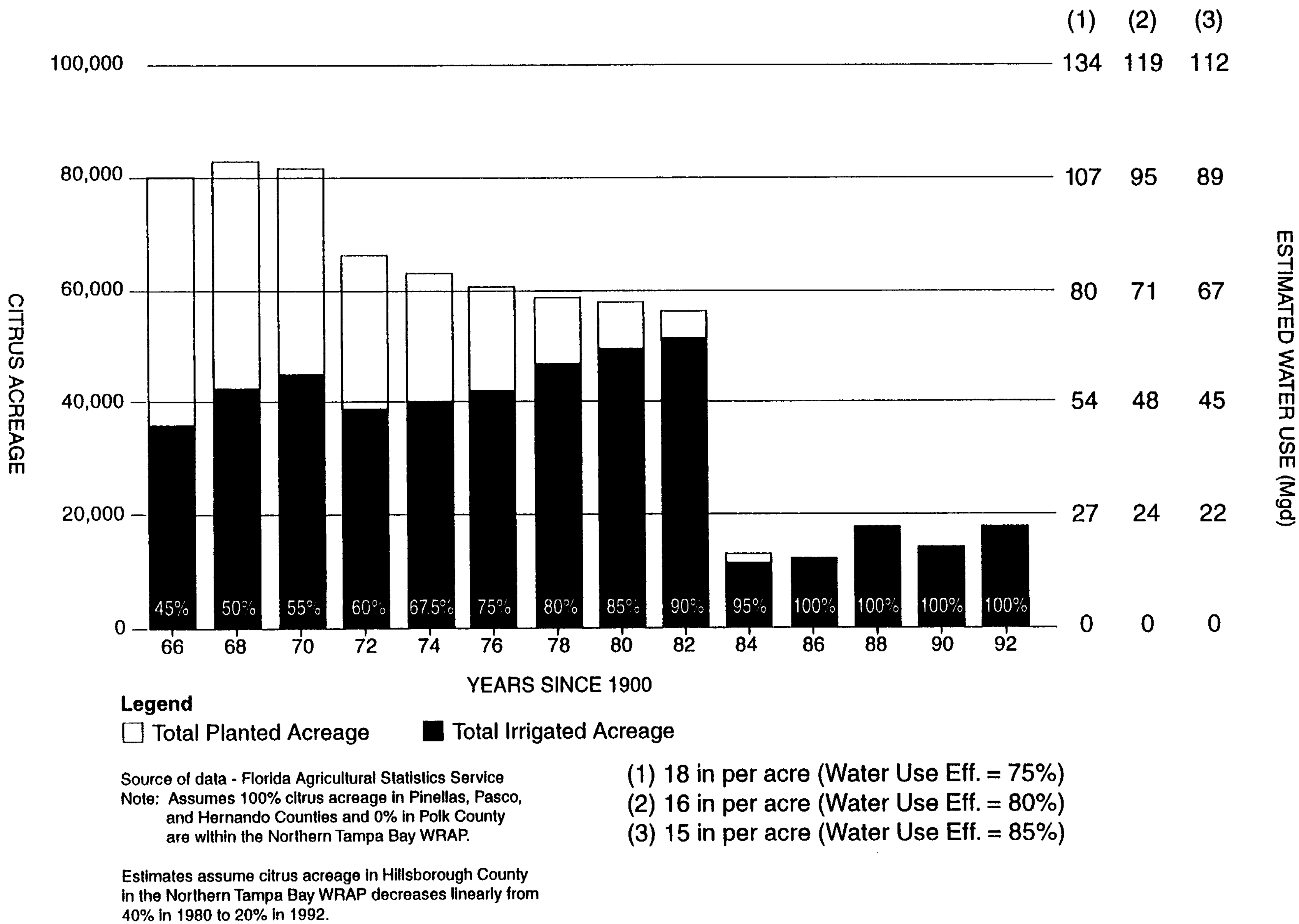
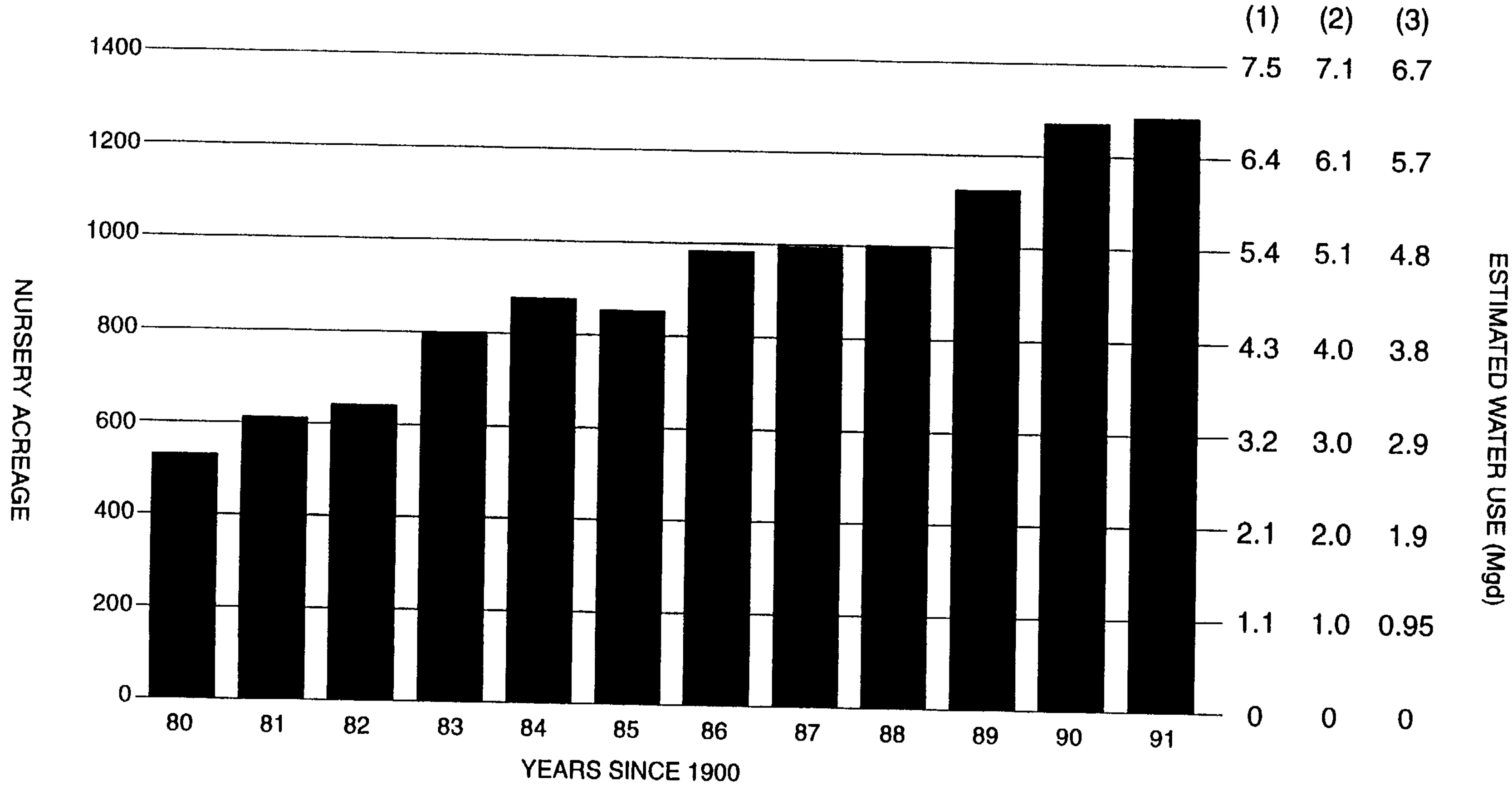


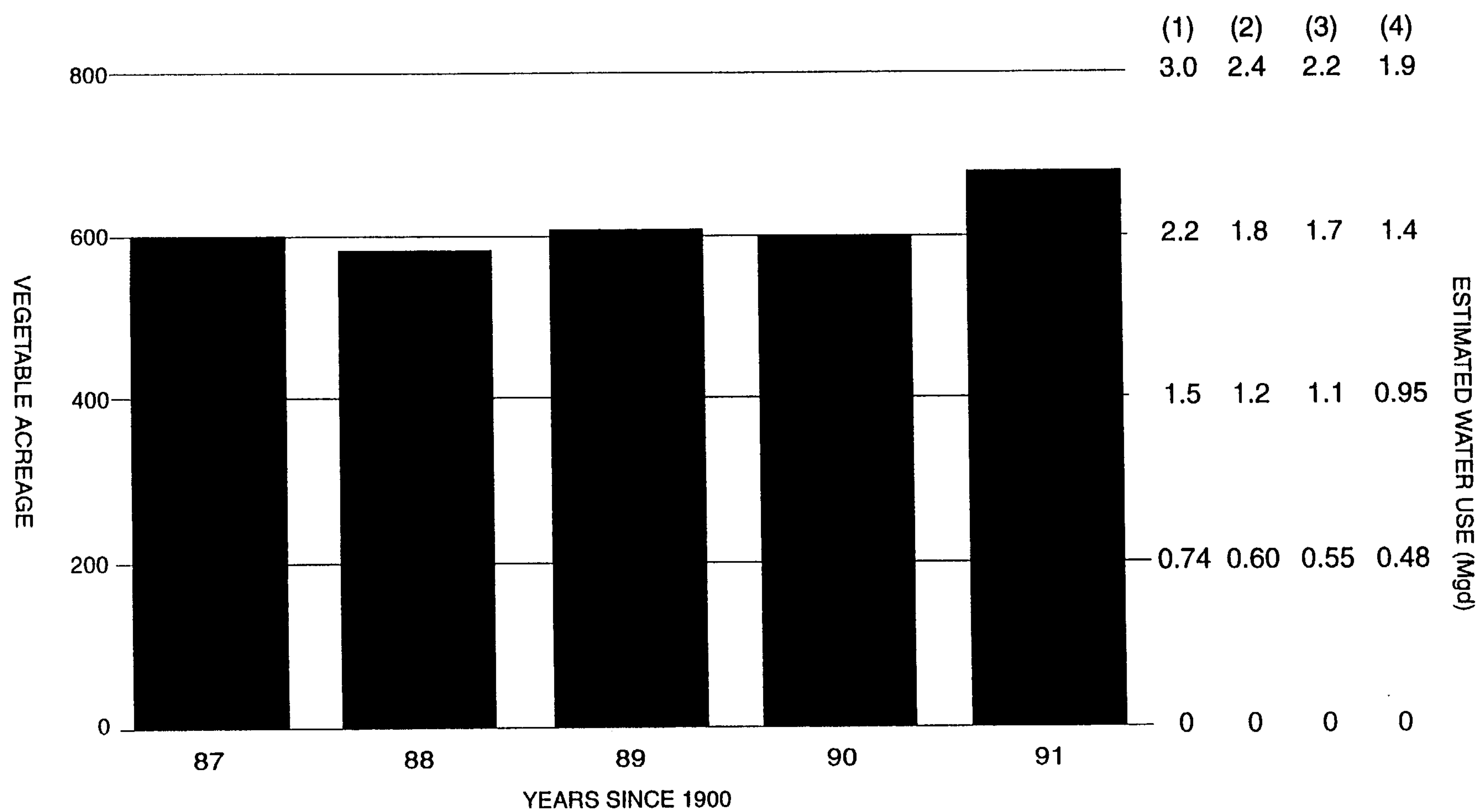
Figure 3-1. Estimated acreage and water use for citrus in the Northern Tampa Bay WRAP.



Source of data - Florida Agricultural Statistics Service
Note: Assumes 100% in Pinellas, Pasco, and Hernando Counties, 20% in Hillsborough County and 0% in Polk County are within the Northern Tampa Bay WRAP.

(1) 72 in per acre (Water Use Eff. = 75%)
(2) 68 in per acre (Water Use Eff. = 80%)
(3) 64 in per acre (Water Use Eff. = 85%)

Figure 3-2. Nursery acreage and estimated water use in the Northern Tampa Bay WRAP.



Source of data - Florida Agricultural Statistics Service
Note: Assumes 100% vegetable acreage in Pinellas and Pasco Counties, 1% in Hillsborough County, 2% in Polk County, and 20% in Hernando County are within the Northern Tampa Bay WRAP.

Amounts include Fall and Spring acreage (e.g., 1987 includes Fall 1986 and Spring 1987 acreage).

(1) 50" per acre (Water Use Eff. = 45%)
(2) 40" per acre (Water Use Eff. = 60%)
(3) 37" per acre (Water Use Eff. = 70%)
(4) 32" per acre (Water Use Eff. = 85%)

Figure 3-3. Vegetable acreage and estimated water use in the Northern Tampa Bay WRAP.

Sciences (IFAS) estimated irrigated acreage for all crops in the SWFWMD (Reynolds and others, 1990).

IFAS estimated that in 1990, there were 47,671 irrigated acres in Hillsborough County, 10,455 irrigated acres in Pasco County, and 1,787 irrigated acres in Hernando County. By the year 2020, the IFAS projects the irrigated acreage to increase to 63,191 acres in Hillsborough; 23,755 acres in Pasco; and 2,061 acres in Hernando Counties. Insignificant agricultural growth is expected in Pinellas County. Note that these values are for the entire area of each county, and that only a portion of most counties lie within the Northern Tampa Bay WRAP area.

3.2 Water Use

Water-use data in the SWFWMD have been collected by two agencies: the SWFWMD and the United States Geological Survey (USGS). Prior to 1977, water-use data was collected by the USGS as part of their national program of estimating water use every five years. In 1977, the USGS began collecting annual data, but turned this responsibility over to the SWFWMD in 1982. The USGS continues to produce water use estimates every five years. Each agency has used comparable methodologies to collect this data, but some differences do exist.

Water use within the Northern Tampa Bay WRAP area was initially concentrated along the coastal areas, and then expanded or moved to inland areas. During the early-1900s, ground-water withdrawals were limited and widespread compared to today's usage. The cities of St. Petersburg, Clearwater, Tampa, and other coastal communities had municipal supply wells, but water use data for this period is limited. Based on available data, a few small capacity irrigation and domestic wells were in use. The primary agricultural use was citrus farming and cattle ranching, however, historical trends indicate these activities used small quantities of water.

As a result of seawater intrusion in Pinellas County during the 1920s, St. Petersburg developed the Cosme wellfield in northwest Hillsborough County in 1929 (Figure 2-34). In 1937, Pinellas County developed a county-wide water supply system to provide the Gulf beach communities with potable water. A reservoir was developed in Pinellas County on McKay Creek, and by 1952, had a storage capacity of 450 million gallons. Clearwater, Dunedin, and Tarpon Springs

all had municipal supply wells, however, poor quality water was detected in some of these wells. Average-daily water use in 1947 was 7.1 mgd for St. Petersburg, 1.5 mgd for Clearwater, 0.65 mgd for unincorporated Pinellas County, and 1.43 mgd for all other communities in Pinellas County (Florida Board of Health, 1948).

During the early-1900s, the City of Tampa had artesian wells located downtown near City Hall that were used to fill surface reservoirs. Due to water quality deterioration in these wells, they were capped in 1924. Following the loss of these wells, the Tampa reservoir on the Hillsborough River became the principal source of Tampa's municipal water supply. Hillsborough County supplied water to areas surrounding the City of Tampa using ground water from their Drew Field wellfield, located to the west of downtown Tampa. In 1942, ground-water withdrawals were discontinued at the wellfield due to high chloride concentrations. At this time, several private utilities and subdivisions supplied water to local areas. Water supply to the city was consolidated so that much of the water came from the Hillsborough River. In 1947, annual-average withdrawals from the river increased from 3.0 mgd to 14 mgd.

In the 1950s and 1960s, several significant events occurred. In 1956, Pinellas County began pumping from the Eldridge Wilde wellfield (Figure 2-34), replacing the Harn, Blackburn, and Coachmann wellfields. Water use increased in Pinellas County from approximately 14 mgd in 1951 (Heath and Smith, 1954), to nearly 50 mgd by 1966 (Stewart, 1968). Water use from the Tampa reservoir increased to approximately 36 mgd by 1966 (Stewart, 1968). The cities of Port Richey and New Port Richey had small municipal supplies in addition to many other private suppliers or smaller communities. St. Petersburg developed the Section 21 wellfield in 1963, continuing their exportation of water from Hillsborough County. During the early-1960s, irrigation of citrus was discovered to enhance crop production (Koo, 1963). By 1966, about 4,240 acres in the northwest Hillsborough County area were irrigated with an annual-average of 2.0 mgd of water pumped from ground water and lakes (Stewart, 1966).

Low rainfall and increases in water use created problems, conflicts, and concerns in the early-1970s. At an administrative hearing conducted in 1973, the SWFWMD Governing Board formally adopted Order 73-1D, which established the northwest Hillsborough County area as a Water Shortage Area. Resulting from this action were special restrictions to regulate ground-

water withdrawals, irrigation, drilling of wells, and wastewater disposal. During this time, the SWFWMD began issuing consumptive use permits (CUPs[1]) to regulate water use throughout its jurisdictional area. Section 21, South Pasco, Cosme, and Eldridge Wilde wellfields were assigned minimum water levels (also known as regulatory levels) in several Upper Floridan aquifer monitor wells, which limited the quantities of water that could be withdrawn from these wellfields.

The West Coast Regional Water Supply Authority (WCRWSA) was created shortly after the SWFWMD began issuing CUPs in 1974, and was established to develop and manage water supplies for Hillsborough, Pinellas, and Pasco Counties. To meet the demands of an expanding urban area, the WCRWSA developed three wellfields during the late-1970s and early-1980s. Cypress Creek wellfield came on-line in 1976, and by 1979 was pumping 30 mgd, partly to meet the demand left by withdrawal cutbacks at the South Pasco wellfield. In the mid-1970s and early-1980s, respectively, the Starkey and Cross Bar Ranch wellfields were developed by the WCRWSA to increase the supply of water to Pinellas and Pasco Counties. The WCRWSA also consolidated many Hillsborough County and private subdivision wells into the Northwest Hillsborough Dispersed wellfield using an improved distribution system. Interconnection between most of the major wellfields was completed during the late-1980s, though some of the connections were limited by pipe diameter and other hydraulic factors. This resulted in the ability to shift ground-water withdrawals from one wellfield to another in response to environmental conditions near wellfields.

Public supply is the major water demand in the Northern Tampa Bay WRAP area. Figure 3-4 displays the water production record of the major public water-supply sources of the Northern Tampa Bay WRAP area from 1930 to the present. The figure also shows the breakdown of surface- and ground-water use. Surface-water use consists of water pumped from the Hillsborough River Reservoir (since 1930) and the Tampa Bypass Canal (since 1985). As shown, public-supply water use has increased by over 400 percent from 1960 to 1993, increasing from just over 60 mgd to about 251 mgd. The last few years of data show a pattern of stabilization, largely due to water conservation practices and increased water reuse.

[1] Currently referred to as Water Use Permits (WUPS).

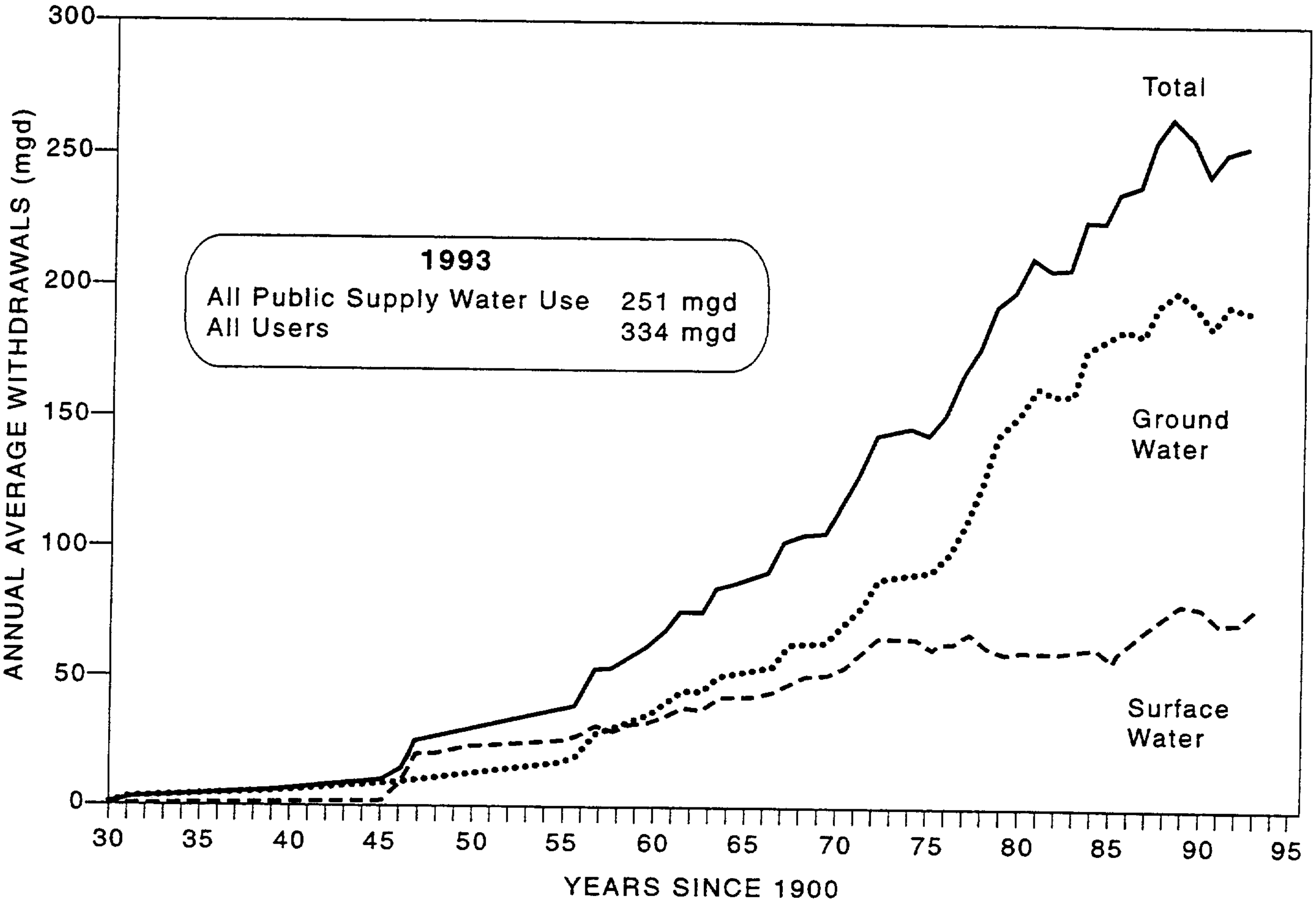


Figure 3-4. Water production of major public suppliers (permits of 1 mgd or greater only) in the Northern Tampa Bay WRAP area.

Historical water use records for non-public supply purposes are not readily available, however, as mentioned in the previous section, FASS has published citrus data since 1966, and several larger non-public supply users have kept some records. Figure 3-5 presents estimated historical non-public supply water use from ground water based upon this limited available data, along with the ground-water withdrawals for public supply (as previously included in Figure 3-4). Public supply ground-water use for major users is also shown on this figure for comparison purposes. Note that the non-public supply water use information begins in 1966, which is the limit of FASS data, and that a small amount of the water use estimated from the FASS acreages may actually have been withdrawn form surface-water sources, such as lakes. Little water use is reported for other than citrus and public supply in these early years, and it was estimated by Menke and others (1961) that irrigation throughout Hillsborough County prior to this time was less than 15 mgd. This does not include the entire Northern Tampa Bay WRAP area, but does include the southern portion of Hillsborough County outside of the WRAP area, and therefore provides some assurance that non-public supply water use was small prior to 1960. The estimated historical non-public supply water use shown in Figure 3-5 is dominated by citrus irrigation in the 1970s. A sharp decline is noted in the early-1980s associated with the citrus freeze that destroyed most trees in the Northern Tampa Bay area. The increase in recent years is due mainly to increased industrial water use and replanting of citrus, although the total non-public supply water use remains about one-third of the public supply ground-water use.

Since historical agricultural water-use records in the Northern Tampa Bay WRAP area are generally unavailable, water-use estimates based upon crop acreage are considered to be more representative of historical water use. Figures 3-1 through 3-3, included in the previous section, present historical citrus, nursery, and vegetable acreage for the Northern Tampa Bay WRAP area. Also presented are levels of water-use efficiencies with associated estimated water use based on a modified Blaney-Criddle formulation (Cohen, 1992). Efficiency is defined as the ratio of the volume of water beneficially used (delivered to the crop's root zone) to the volume delivered from the irrigation system. A range of efficiencies are listed since different irrigation systems are operated at different efficiencies. However, overall irrigation efficiencies have improved over the years.

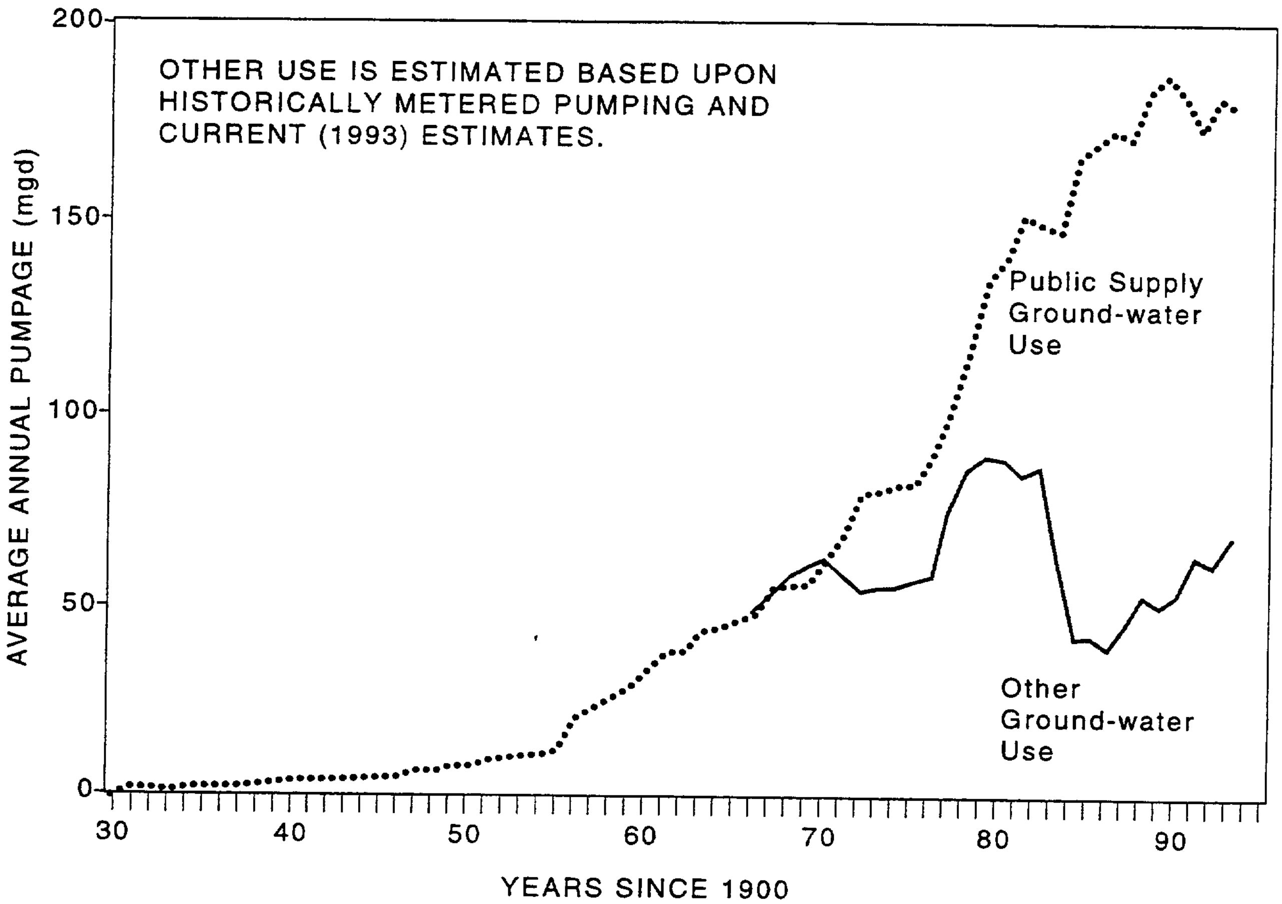


Figure 3-5. Ground-water production of major public suppliers (permits of 1mgd or greater only) and other users in the Northern Tampa Bay WRAP area.

As discussed earlier, citrus acreage has decreased by over 50 percent since the 1960s, although some increase has been observed recently. Although citrus acreage has decreased, the percentage of irrigated acres has risen from less than 50 percent in the 1960s to nearly 100 percent currently. Using the 75 percent efficiency assumption as a "worst-case" scenario, estimated water use for citrus irrigation in the Northern Tampa Bay WRAP area increased from about 48 mgd in 1966 to about 70 mgd in 1982. Using the same efficiency, the loss of citrus to freeze damage has caused the citrus irrigation water use to fall to less than 30 mgd in the 1990s. This rate is probably high (1993 estimate is approximately 14 mgd, see Chapter 2), since overall irrigation efficiencies have increased throughout the years. However, using the IFAS projections for citrus acreage in 2020, citrus acreage in the Northern Tampa Bay WRAP area would increase to almost 40,000 acres. This acreage would require an estimated 54 mgd of irrigation water use at 75 percent efficiency.

Although citrus irrigation is the major agricultural water use, nursery acreage has increased by over 120 percent since 1980. Nursery acreage has increased from approximately 500 acres in 1980 to almost 1,300 acres in 1991. Using an efficiency of 75 percent, estimated water use for nursery irrigation has increased from approximately three mgd in 1980 to almost seven mgd in 1991. The IFAS projections indicate that nursery acreage will increase to over 4,400 acres within the Northern Tampa Bay WRAP area by 2020 (Reynolds and others, 1990). This acreage would require an estimated 24 mgd of irrigation water use at 75 percent efficiency.

By 2020, the IFAS projects an overall increase in agricultural acreage within Hillsborough, Pinellas, Pasco, and Hernando Counties of over 150 percent from 1990 (Reynolds and others, 1990). Using the 1990 estimated agricultural water use of about 33 mgd for the Northern Tampa Bay WRAP area, 2020 water use could be over 82 mgd.

By determining the ratio of current Northern Tampa Bay WRAP water use to county-wide water use, and applying this ratio to total county water use projections for 2020, as determined by the SWFWMD's Needs and Sources document (SWFWMD, 1992), 2020 water use for the Northern Tampa Bay WRAP was determined (Table 3-1). This methodology includes the following assumptions: 1) the current ratios of surface-water use versus ground-water use will continue in the future, 2) a rate based upon the 2-in-10 year drought is used for agricultural water use

projections, 3) historical per capita water use rates for public supply will continue, and, 4) no alternative sources replace the current water supply sources.

Although inherent errors are unavoidable in this calculation, the projections show a decrease in industrial and mining use, and increases in public supply, agricultural, and recreational use, mostly in response to urbanization of the area. Note that because current surface-water withdrawals for public supply use in the Northern Tampa Bay WRAP area are limited to one source, the Hillsborough River, the current ratio of surface-water to ground-water use may not apply in the future. Therefore some of the approximately 102 mgd of projected surface-water withdrawals for public supply may be attributable to other sources. The largest increase, about 156 mgd, is expected for public supply use. Approximately a 60 percent increase is projected in total water use within the Northern Tampa Bay WRAP area by 2020. However, reductions in per capita water use, increased efficiencies, and alternative sources of water supply will reduce much of the surface- and ground-water demand presented in Table 3-1.

Table 3-1. Estimated and projected water withdrawals in the Northern Tampa Bay WRAP area (mgd).

	1993 Estimated			2020 Projected		
	SW	GW	TOTAL	SW	GW	TOTAL
Agriculture	1.3	31.6	32.9	4.1	79.9	84.0
Industry	0.2	18.9	19.1	0.4	15.2	15.6
Mining	11.1	0.3	11.4	2.6	0.0	2.6
Public Supply	67.8	183.3	251.1	101.9	305.4	407.3
Recreation	7.5	12.0	19.5	15.5	25.5	41.0
TOTAL:	87.9	246.1	334.0	124.5	424.6	549.2

3.3 Rainfall

Since rainfall is the driving force of Florida's hydrologic cycle, it is necessary to evaluate rainfall to develop an understanding of the hydrologic system. The relationship between rainfall

trends and effects to the water resource system will be discussed in Chapter 4. There are many influences on rainfall, some of which are not well understood. Although local rainfall throughout Florida may be affected by variations in land use, temperature, coastal proximity, elevation, and percentage of water cover, much of the state's rainfall pattern is controlled by regional and global weather patterns. Wet and dry periods in Florida have been linked to activity in the Pacific Ocean (Quiroz, 1983), continental air mass trends, and, of course, tropical storm and hurricane activity. Therefore, to discuss rainfall in the SWFWMD or Northern Tampa Bay WRAP area, it is necessary to begin by describing rainfall patterns for the entire state.

3.3.1 Florida Rainfall

The climate of Florida is generally described as humid subtropical, but weather patterns are not uniform throughout the state. Although temperatures are somewhat uniform throughout the state during the summer months, temperature variation is more pronounced in the winter. Mean daily maximum summer temperatures range from 88 to 91 degrees Fahrenheit throughout the state, while mean daily maximum winter temperatures range from 60 degrees Fahrenheit in the western panhandle to 75 degrees Fahrenheit in southern Florida (Jordan, 1984). The reason for this difference is related to the frequency of cold continental and warm maritime air masses influencing different parts of the state. During the winter months, cold fronts move into northern Florida from the northwest, but stagnate or weaken as they move towards the southern half of the state. These cold fronts account for the secondary rainfall peak usually seen around March at northern rainfall stations. Conversely, warm maritime air masses in the summer approach from the south or southwest, influencing these areas more than the northern areas. Concurrently, during the summer months a more northerly positioning of the Bermuda high pressure system prevents frontal systems from reaching Florida.

Another weather event that can greatly affect rainfall amounts is the occurrence of tropical storms and hurricanes, which occur almost exclusively during the months of June through November. These events are much more random than convective and frontal events, and often make the interpretation of rainfall data difficult. Although all of Florida is susceptible to hurricanes, frequencies are higher in the panhandle area and in southern Florida. However,

hurricane and tropical storm strength is not necessarily correlated with rainfall amounts, and many weak tropical storms or frontal events have produced much more rainfall than some large-scale hurricanes (Jordan, 1984).

Figure 3-6 shows the annual-average rainfall in Florida from 1951 to 1980 (Jordan, 1984). Although the time period is limited, analysis of the complete period of record shows the same spatial patterns. As the figure shows, the greatest annual rainfall is in the panhandle and southeast Florida. This is possibly related to tropical storm frequency. Other patterns that can be seen are lesser rainfall amounts along the immediate coastal areas. Theories explaining this include the lack of rain gages on the immediate coast, the effects of sea breezes, and the fact that thunderstorms lose most of their moisture over land masses (Jordan, 1984; Pardue and others, 1982). These theories may partially explain why areas such as Tampa, Daytona Beach, and Key West do not historically record as much rainfall as those areas several miles inland. Although rainfall along the immediate coast is often low, the outer portions of the state historically receive more rainfall than the central strip of the peninsula. Many convective storms form over central Florida, but do not result in rainfall until they reach the leading edge of the sea breezes.

Another aspect of Florida weather that must be considered is the apparently random spatial variability of convective rainfall. This concept, coupled with gaps in the data collection network (as well as normal data collection error), causes short-term and long-term data discrepancies. It is not uncommon for two rain gages located within a few miles of one another to record significantly different rainfall amounts for a day, a month, or even a year. Although thunderstorm formation over large areas may be partially controlled by regional or global influences, individual thunderstorms are often very localized. The pattern of rainfall amounts appears random from one station to the next, and makes data interpretation difficult. One extreme example occurred at the Cross City station in Dixie County in 1985. In August of that year, the Cross City station recorded 31.95 inches of rainfall, caused by many convective events and Hurricane Elena. Other stations nearby recorded only 15 or 16 inches. This variability in data is difficult to fully explain, but is related to the high variability of local rainfall events. This concept will be further illustrated later.

Figure 3-6. Average annual rainfall in Florida from 1951 to 1980. (modified from Jordan, 1984.)

Finally, there are some areas that exhibit long-term anomalies. These areas consistently receive high or low amounts of rainfall with no apparent explanation. These areas include the Tampa and Bradenton areas. The Tampa station consistently receives low rainfall amounts, while gages in the Bradenton area consistently receive high rainfall amounts when compared to surrounding rainfall stations. There may be many reasons for this, including urban heating effects, coastal proximity, instrument error, or true local weather anomalies. No single reason has been established for these and other areas, so these stations must be carefully incorporated into any analysis.

3.3.2 SWFWMD Rainfall

As rainfall data in the SWFWMD is analyzed, the information presented in the previous section must be considered. If rainfall data is evaluated for a single station, without accounting for the regional trends, the results may be misleading.

The SWFWMD lies in a subtropical divide, i.e., a border area (latitude 27°N to 29°N) where there is a transition between frontal and convective influences. There is a hypothesis that Florida is experiencing a period where frontal influences have been moving further south. Chen and Gerber (1985) found a decreasing trend in minimum temperature observations throughout the last 80 to 100 years in Florida, especially in northern Florida, although the reason is not yet clear. This could have a significant affect on rainfall patterns. However, this occurrence may just be one swing of a long-term oscillation in the data.

Table 3-2 presents a summary of rainfall statistics for 46 rainfall stations in and around the SWFWMD. These stations are those rainfall collection points with 30 or more years of data. Some relatively remote stations, such as Miami and Tallahassee, were included for comparison purposes.

Spatial Trends - Table 3-3 displays minimum and maximum annual rainfall amounts for the 46 stations listed in Table 3-2, for the period of 1901 to 1995. The average range of annual rainfall for these stations is about 32 inches. Thus, in any given year, the difference between the station

Table 3-2. Annual rainfall statistics for 46 stations in the vicinity of the SWFWMD.

Station	Period of Record	No. of years (1)	Min.	Max.	Mean	Median	Standard Deviation
Arcadia	1908-1994	87/83	30.75	80.11	52.23	51.62	10.27
Avon Park	1902-1994	93/86	34.86	80.08	52.56	52.08	10.07
Babson Park	1956-1991	36/36	31.16	67.63	49.88	50.14	9.21
Bartow	1901-1995	95/93	35.31	83.44	54.18	52.48	9.66
Bradenton	1911-1995	85/84	29.45	93.28	54.45	52.95	9.65
Brooksville	1901-1994	94/92	37.46	80.17	55.70	55.16	10.13
Bushnell	1937-1994	58/48	35.60	77.11	52.27	52.85	8.93
Clermont	1901-1994	94/91	32.28	68.09	50.62	50.64	7.85
Cosme	1945-1995	51/51	33.19	82.17	54.43	54.20	10.44
Crescent City	1913-1994	82/68	37.42	75.03	53.04	51.58	9.15
Cross City	1942-1994	53/50	33.04	85.22	57.93	57.87	12.84
Daytona Beach	1951-1994	44/44	31.36	79.29	48.74	46.54	11.07
Fort Green	1956-1994	39/35	35.94	78.87	53.70	53.08	10.61
Fort Myers	1901-1995	95/95	32.83	80.17	53.32	52.43	9.93
Gainesville	1901-1995	95/95	32.79	76.95	51.39	49.98	8.67
Haynesworth	1929-1995	67/65	31.32	72.35	51.42	53.39	9.48
High Springs	1945-1994	50/47	32.90	71.04	53.34	52.63	8.34
Inverness	1901-1994	94/94	28.45	87.27	53.35	52.30	9.67
Jacksonville	1951-1994	44/44	31.20	79.63	53.15	52.13	10.28
Kissimmee	1901-1995	95/83	28.07	80.38	49.24	47.78	10.06
Labelle	1929-1995	67/60	36.83	73.83	51.62	51.07	8.41
Lake Alfred	1924-1995	71/70	35.62	76.47	51.38	51.77	8.97
Lakeland	1915-1995	81/79	34.93	70.24	50.48	49.78	8.66
Melbourne	1951-1994	44/43	31.97	69.85	49.11	47.96	9.13
Miami	1951-1994	44/44	37.00	89.33	57.84	57.38	12.79
Moore Haven	1918-1995	78/66	29.63	78.48	48.74	47.83	9.34
Mountain Lake	1935-1995	60/60	32.77	74.92	51.27	49.62	9.47
Myakka River	1943-1995	53/48	36.97	80.36	56.24	56.06	11.01
Naples	1951-1944	44/44	33.02	72.50	52.97	55.54	9.53
Ocala	1901-1995	95/95	33.94	74.71	53.36	53.02	8.73
Orlando	1901-1995	95/90	31.68	74.89	51.10	50.76	8.38
Plant City	1901-1995	95/89	32.96	86.68	53.68	52.81	10.58
Punta Gorda	1914-1995	82/81	30.03	88.10	50.84	50.25	10.94
Sebring	1951-1993	43/41	35.26	77.60	51.08	52.04	10.05
St. Pete	1914-1995	82/81	30.51	87.62	51.77	52.03	11.27
St. Leo	1902-1995	94/93	36.61	81.98	55.02	53.47	8.98
Section 21	1966-1995	30/30	34.46	74.76	48.43	48.42	8.27
Tallahassee	1951-1994	44/43	30.98	104.18	63.22	62.07	13.86
Tallevast	1950-1992	43/41	25.49	106.70	57.67	54.05	15.10
Tampa	1901-1995	95/95	28.89	76.57	47.31	45.46	9.48
Tarpon Springs	1901-1995	95/95	27.54	83.20	51.67	50.26	10.28
Titusville	1951-1994	44/44	40.15	81.74	56.18	54.29	11.17
Venice	1955-1995	41/39	30.07	80.12	49.75	45.87	11.73
Wauchula	1933-1993	61/61	36.66	83.48	52.99	51.80	9.46
West Palm Beach	1951-1994	44/44	37.31	85.89	61.36	61.15	12.86
Winter Haven	1941-1994	53/50	35.26	73.28	50.35	49.44	9.23

(1) a/b; a=total number of years; b=number of years with no more than five percent of daily values missing.

Table 3-3. **Rainfall extremes from 1901 to 1994 using 46 stations throughout Florida.**

Area	Maximum Annual Rainfall	Minimum Annual Rainfall	Maximum Rainfall Range [(1)]	Minimum Rainfall Range [(1)]	Average Rainfall Range [(1)]
FLORIDA (46 stations)	106.7 1959 Tallevast (of 43 stations)	25.5 1984 Tallevast (of 46 stations)	72.9 1964 Tallahassee, 104.2 Punta Gorda, 31.3 (of 43 stations)	11.1 1907 Clermont, 49.8 Tarpon Spgs, 39.7 (of 10 stations)	32.0 (for 1901-1995)
SWFWMD (27 stations)	106.7 1959 Tallevast (of 24 stations)	25.5 1984 Tallevast (of 27 stations)	40.9 1962 Punta Gorda, 77.9 Lake Alfred, 37.0 (of 24 stations)	8.5 1913 Tampa, 44.4 Tarpon Sprgs, 52.9 (of 9 stations)	26.4 (for 1901-1995)
NTBWRAP (6 stations)	87.6 1959 St. Petersburg (of 5 stations)	28.9 1956 Tampa (of 5 stations)	31.8 1988 Section 21, 37.7 St. Petersburg, 69.6 (of 6 stations)	6.0 1958 Cosme, 54.2 St. Petersburg, 60.2 (of 5 stations)	16.8 (for 1901-1995)

Notes:
Rainfall units are inches.
(1) The range is the difference in rainfall between the station with maximum rainfall and the station with the minimum rainfall, in any one year. A minimum of five stations in each year were required for comparison.

with the highest rainfall amount and the station with the lowest, averages about 32 inches with a period of record range from over 11 to just under 73 inches. Within just the SWFWMD, the average is reduced to over 26 inches, with a period of record range of approximately 9 to 41 inches. Therefore, annual rainfall is far from uniform throughout Florida or the SWFWMD. On shorter time scales, the variability can be greater.

As can be seen in Figure 3-6, however, on average, there are certain areas that consistently receive higher rainfall than others. In the northern half of the SWFWMD, from Levy County to Hillsborough County, annual-average rainfall values show a decreasing spatial trend from north to south, with Brooksville recording the highest amounts, and Tampa the lowest. The southern part of the SWFWMD has a more uniform annual-average rainfall coverage, with one high area around Bradenton.

Temporal Trends - Several previous studies of rainfall trends have been performed in the SWFWMD. As part of the SWFWMD's Highlands Ridge hydrogeologic investigation (Barcelo and others, 1990), a rainfall study was performed for 21 rainfall stations throughout central Florida. A comparison of annual-average rainfall prior to 1961 to annual-average rainfall between 1961 and 1987, indicated a rainfall deficit for the latter years (up to six inches at some stations). The annual-average rainfall of all stations shows a decrease of almost three inches from the first period to the second. These numbers may be dependent on the way stations were chosen for analysis, and more importantly, on the year chosen as a division between periods. The high rainfall from 1957 to 1960, which included large rainfall events associated with Hurricane Donna, increases the average rainfall for the pre-1961 period by as much as two inches for individual stations, and may exaggerate the differences between the two time periods.

Another pertinent rainfall investigation in the SWFWMD is Heaney and others (1986), which studied the Cypress Creek watershed in central Pasco County. As part of this study, various statistical analyses were performed on selected long-term rainfall stations to detect any trends. The study found no statistically significant upward or downward trends in period of record rainfall time series, although certain periodicities were noted. A five-to-seven year rainfall cycle has been observed in other studies in central and south-eastern Florida (Thomas, 1974; Huber

and others., 1982), and may be linked to tropical storm frequency (Khanal and Hamrick, 1982). Heaney and others (1986) noted this periodicity in data from the St. Leo rain gage in central Pasco County. Other rainfall cycles, ranging from a few years to 40,000 years, have been suggested. As the Cypress Creek study points out, these cycles are not regular and cannot be used for predicative purposes.

If the theory of rainfall cycles is accepted, then rainfall data can be following a downward or upward trend at any given time. Analysis of rainfall data from many stations has shown this to be accurate. Analysis of the shorter cycles is of interest to most studies, since it is desirable to know whether apparent rainfall increases or decreases are part of a long-term or short-term trend. However, to determine whether rainfall over a specific region at any particular time is on an upward or downward curve is difficult. Figure 3-7 presents five-year moving averages of the Lakeland and Plant City rainfall gages, located approximately 10 miles apart. The five-year average was chosen to better visualize the five-to-seven year periodicities documented in previous studies.

In the Plant City graph, the period from the mid-1910s to about 1930 shows a significant increasing trend, while the same period in Lakeland shows a slight decreasing trend. Similar discrepancies can be seen in other periods. Thus, a study of rainfall over an area near one of these stations may reach a variety of conclusions on short-term rainfall trends, depending on the stations chosen.

Figure 3-8 presents five-year moving average plots of five stations spread throughout the SWFWMD and nearby area. General similarities can be seen, but short-term trends differ at various points in time, and long-term trends are not apparent. The Gainesville station, located just to the north of the northern boundary of the SWFWMD, shows a long-term increasing trend through the 1960s, a decreasing trend in the 1970s, and then a continuous increasing trend in the 1980s. Tarpon Springs also shows an increasing trend, although not as great, and without the large decrease observed in the Gainesville station during the 1970s.

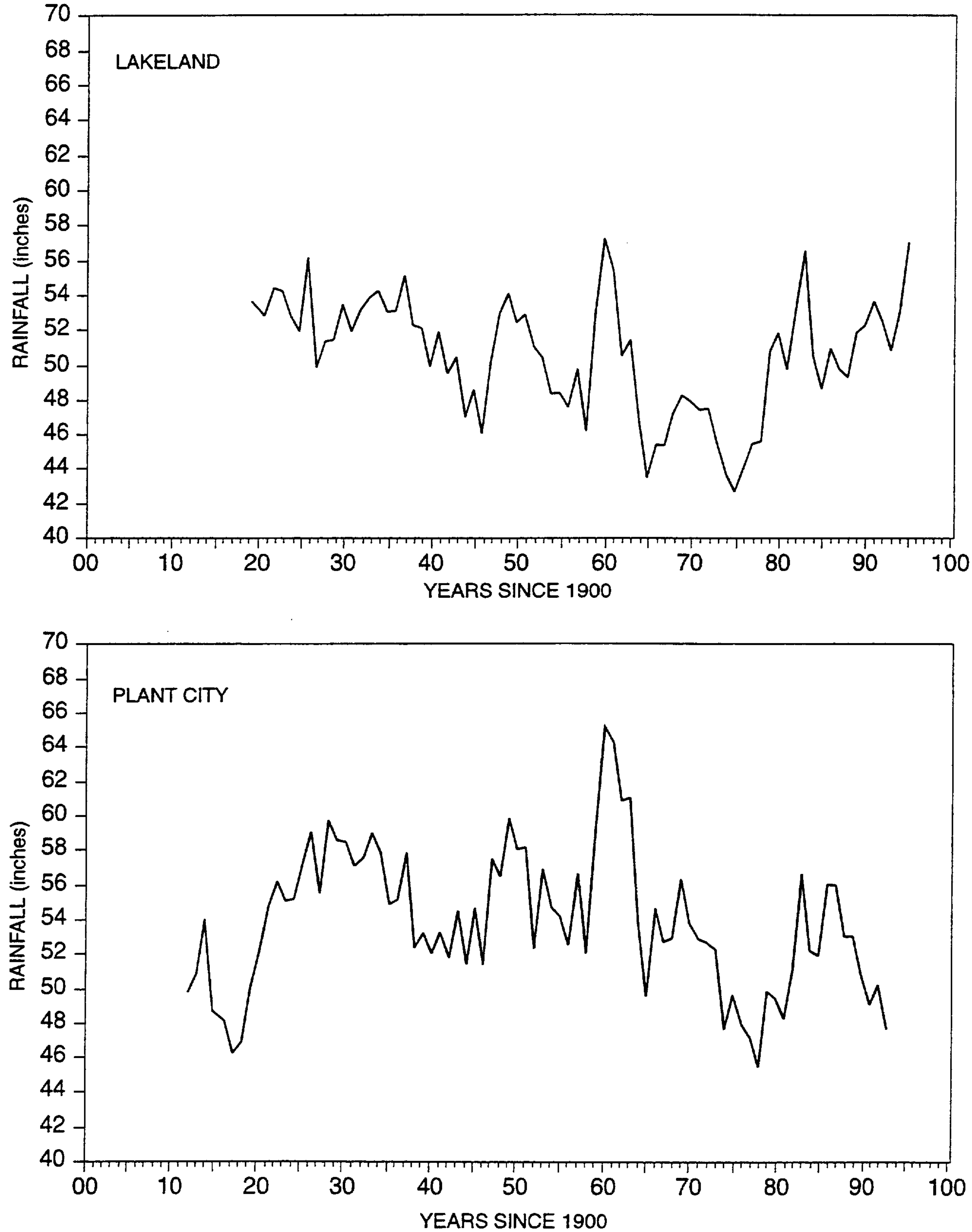


Figure 3-7. Five-year moving average of the Lakeland and Plant City rainfall data.

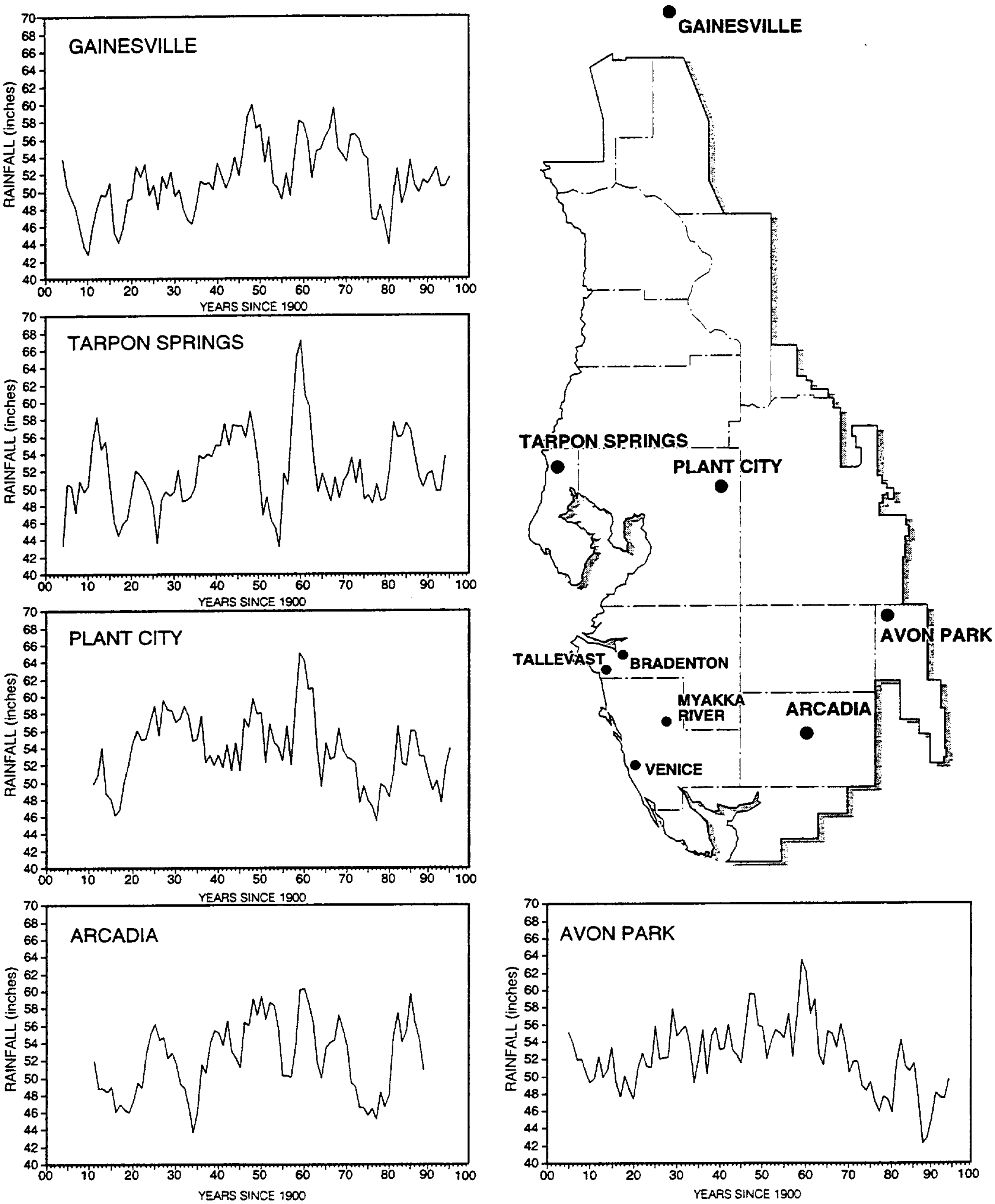
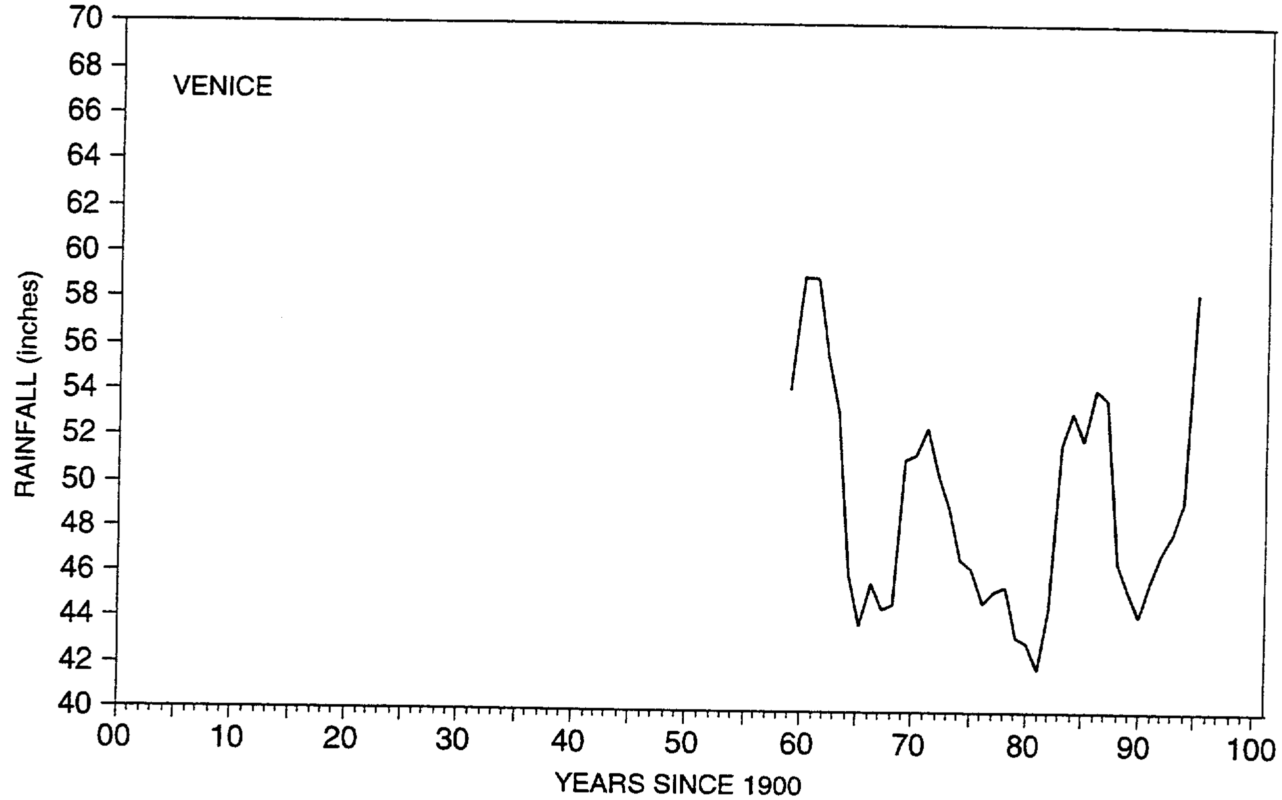


Figure 3-8. Five-year moving average of rainfall data from five stations throughout the SWFWMD area.

The Plant City rain gage and the Avon Park rain gage are located in the central part of the District. Avon Park also shows an increasing trend throughout most of the period of record, although Plant City looks more like the Tarpon Springs plot, with a rather flat slope throughout most of the period of record. Rainfall at both the Plant City and Avon Park stations shows a strong decreasing trend in the 1960s. The Plant City plot reaches a low similar to that of the 1910s, but increases to near average in the 1980s. Avon Park lows during the 1970s and late-1980s surpass previously recorded lows. Finally, the Arcadia plot shows a slight positive trend, with highs in the 1980s comparable to those at any other time. However, the data throughout the period of record at Arcadia appears to be the most variable.

Can we say that there are any downward or upward trends in the rainfall for a region based upon these plots? Some qualitative observations can be made, but quantification is very difficult. As was noted earlier, the main reason for this difficulty is the spatial variability of the data. Although the Arcadia station shows a flat to upward slope in the 1980s data (Figure 3-8), other stations in the general area show other trends. Figure 3-9 presents five-year moving averages of data from the Venice and Myakka River stations, located to the west of the Arcadia station (Figure 3-8). The record does not begin as early as the Arcadia station, but the trend for each of these stations moves often in different directions. Figure 3-10 shows five-year moving average plots for the Bradenton and Tallevast stations, located less than five miles apart. These plots also show that trends since the 1970s are apparently moving in different directions. Therefore, the choice of stations for even small-scale areas can affect the interpretation of results.

Figure 3-11 presents five-year moving averages from six long-term rainfall stations throughout the central portion of the SWFWMD; the area that is the focus of this study. The plots show variable upward and downward slopes throughout the period of record, and the effects of high rainfall events of the 1950s and 1960. After a decline in rainfall in the late-1960s and early-1970s, most of the stations appear to have an upward trend until the late-1980s. Tarpon Springs appears to have a long-term upward trend, while St. Petersburg shows a consistent upward trend from the 1960s through the 1980s.



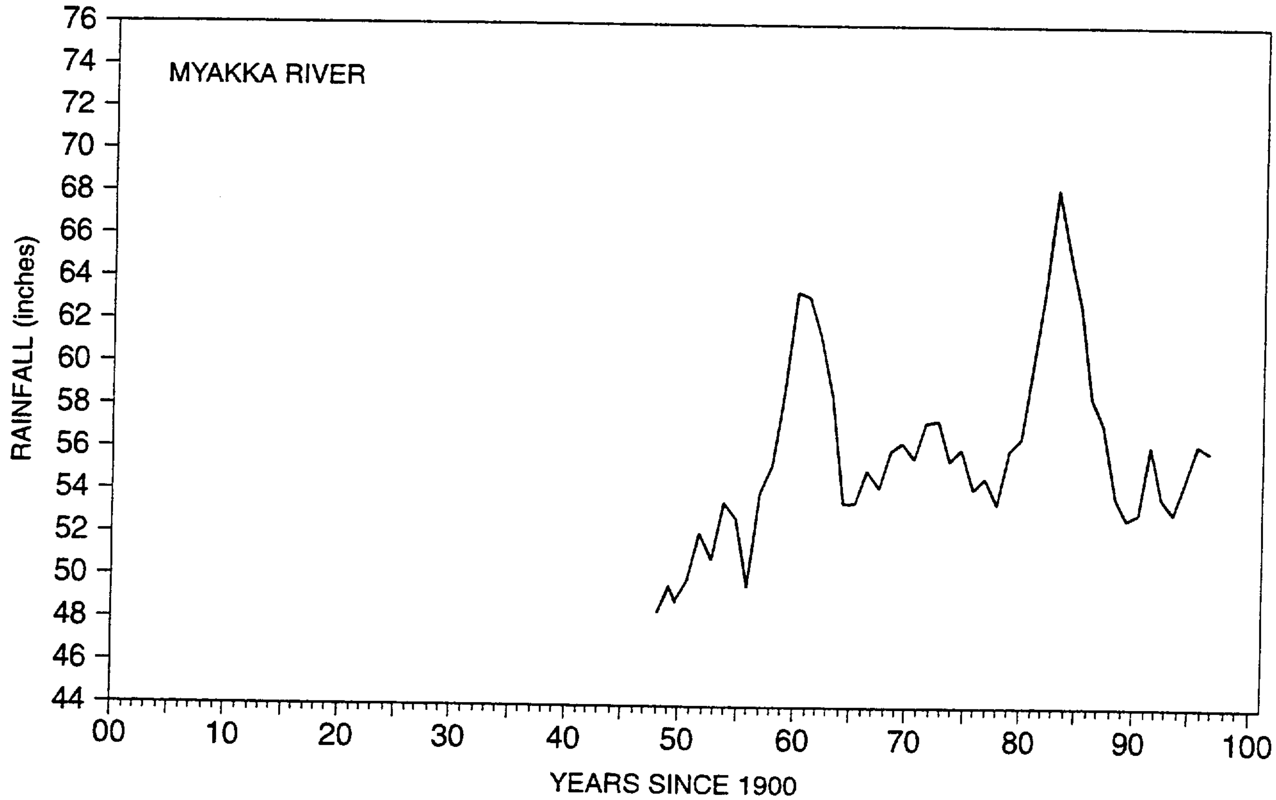
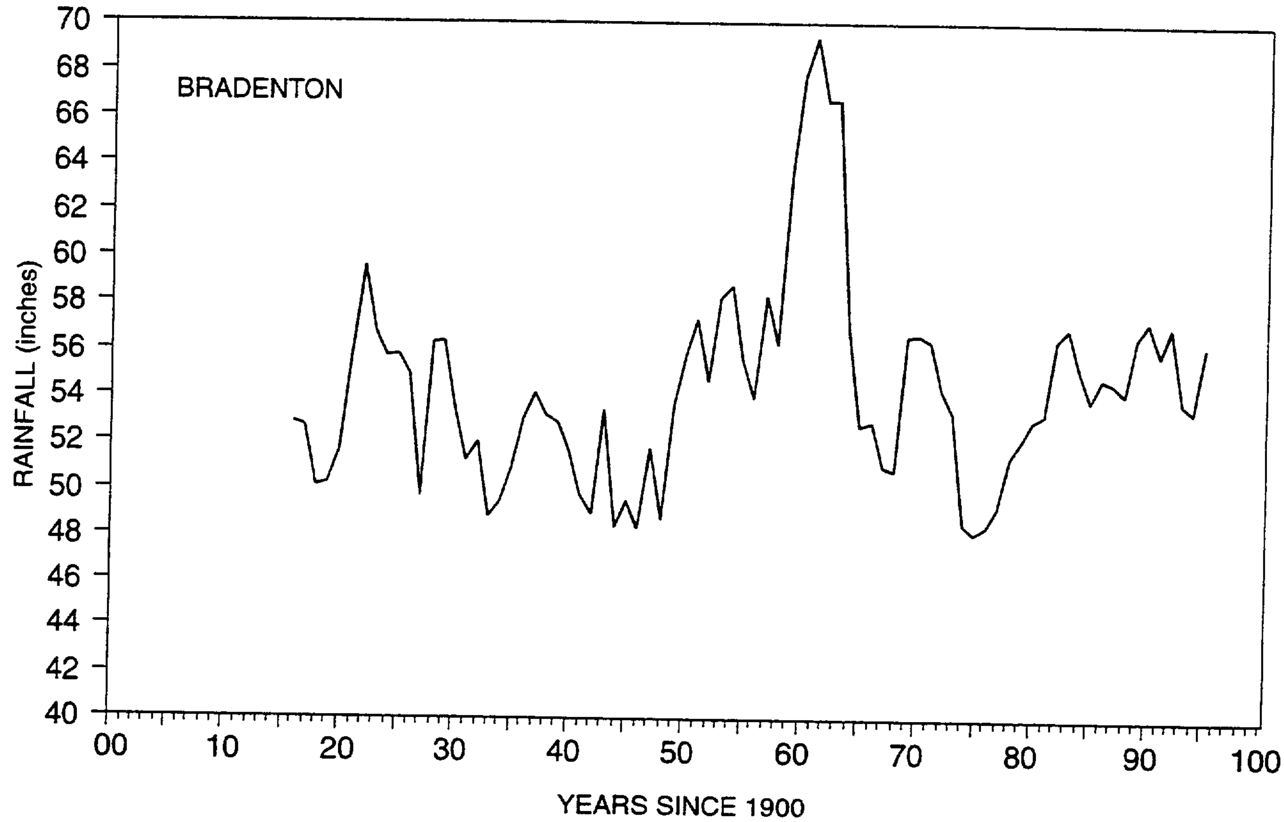


Figure 3-9. Five-year moving average of the Venice and Myakka River SP rainfall data.



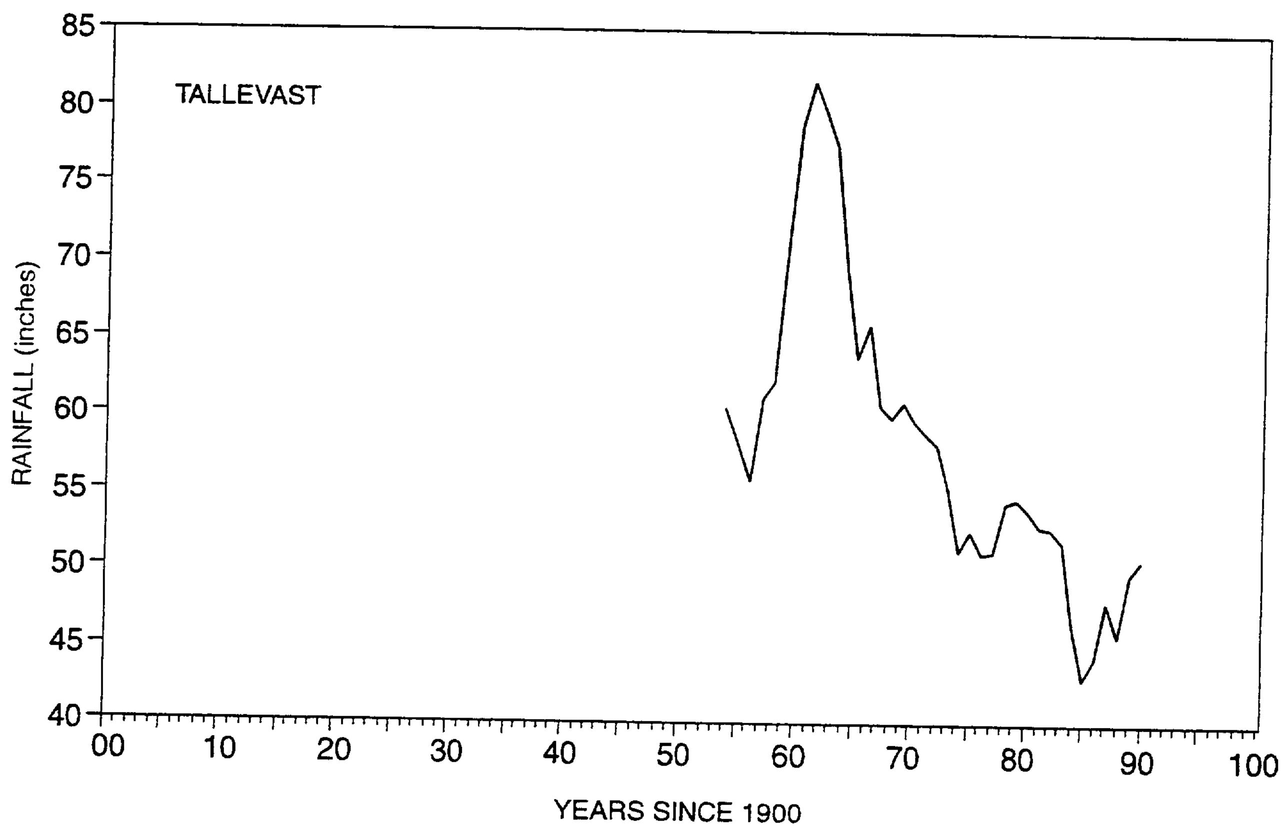


Figure 3-10. Five-year moving average of the Bradenton and Tallevast rainfall data.

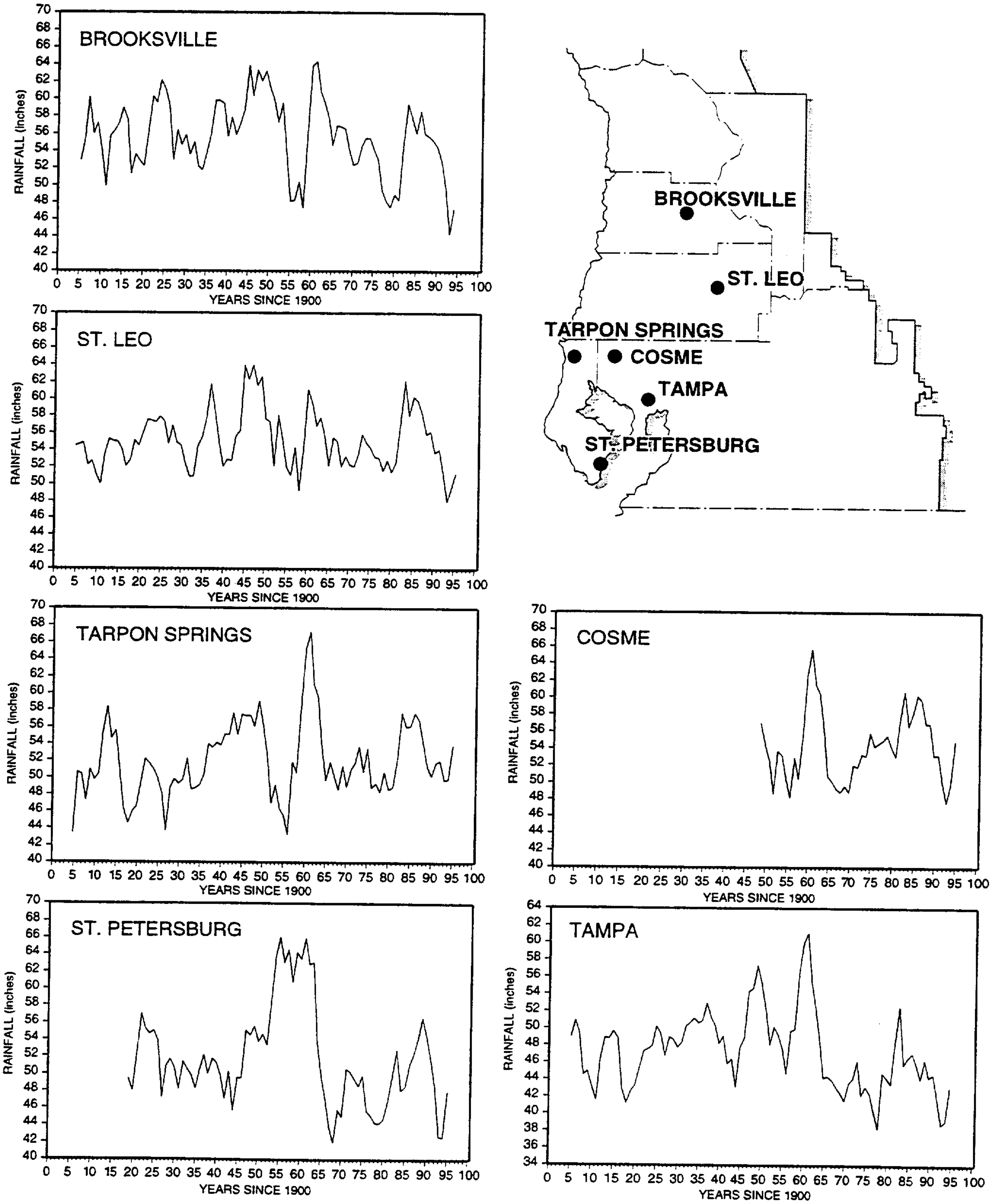


Figure 3-11. Five-year moving average of rainfall data from the central portion of the SWFWMD.

To attempt to evaluate these trends in the entire region, Table 3-4 presents the cumulative rainfall deviations of the post-1961 period (1961 to 1994) to the pre-1961 average and the period of record average, similar to that performed earlier by Barcelo and others (1990). Figure 3-12 presents some of this data graphically. The stations represent those with longer periods of record (approximately 60 to 90 years). Since the records of all stations do not begin on the same year, some error is introduced in the pre-1961 average. The year 1961 was chosen since it has been reported that many stations demonstrate lower rainfall amounts beginning around this year, although some variations do exist (Barcelo and others, 1990). Although the actual numbers should be viewed qualitatively only, an apparent congregation of low numbers is evident in the central part of the SWFWMD. Analysis of rainfall along the east coast, beyond the eastern boundary of Figure 3-12, shows similar below average rainfall. Below average values are not seen toward the north and south. The low numbers in the center of the SWFWMD suggest less rainfall over the last 30 years than over the previous periods' averages for this area. With some exception, this low rainfall area generally diminishes north and south of Hillsborough and Polk Counties.

The comparison of the pre-1961 rainfall data with the post-1961 data must be done with some care. Note that these numbers do not imply a downward trend in rainfall since 1961, but do indicate a lowered average since 1961. In fact, inspection of many of the rainfall graphs presented earlier reveals that many stations appear to have an increasing trend since the mid-1960s. In many cases, the rainfall average for the pre-1961 period is based upon 60 years of data whereas the post-1961 period is less than 35 years, so as the post-1961 data is expanded over time, the average may change. Additionally, since the longest period of record is about 95 years of data, it is unknown if the pre-1961 rainfall was higher, lower, or about average when compared to a long-term average that is based on several hundred years of data. Although the values should not be interpreted as the amount of rainfall that is "missing" from the system, the analysis does provide some measure to compare rainfall received at various stations. A more representative way of viewing the data may be to compare the post-1961 rainfall data with the long-term average of each station (Table 3-4).

Table 3-4. Results of cumulative rainfall analysis.

Station	Pre-1961 Average	Post-1961 Average	Period of Record Average	Cumulative Post-1961 Rainfall Compared to Pre-1961 Average	Cumulative Post-1961 Rainfall Compared to Period of Record Average
Lakeland	51.79	48.84	50.48	-103.01	-57.38
Plant City	55.24	51.29	53.68	-138.21	-83.86
Gainesville	51.18	51.75	51.39	19.91	12.57
Tarpon Springs	51.79	51.48	51.67	-10.68	-6.75
Arcadia	52.76	51.30	52.23	-43.69	-27.90
Avon Park	53.99	50.03	52.56	-122.87	-78.58
Bradenton	54.76	54.00	54.45	-26.74	-15.60
Brooksville	57.17	53.18	55.70	-135.81	-85.62
St. Leo	55.82	53.70	55.02	-73.93	-46.11
St. Pete	54.23	48.54	51.77	-199.10	-113.07
Tampa	49.36	43.79	47.31	-194.93	-123.11
Bartow	56.33	50.60	54.18	-200.53	-125.06
Clermont	50.68	50.52	50.62	-5.41	0.00
Ft. Myers	52.84	54.15	53.32	46.11	29.12
Inverness	53.21	53.58	53.35	12.68	0.00
Haynesworth	54.37	48.56	51.42	-191.56	-94.30
Kissimmee	50.69	47.15	49.24	-120.16	-70.94
Labelle	52.12	51.18	51.62	-30.09	-14.04
Crescent City	54.11	51.61	53.04	-72.53	-41.60
Lk. Alfred	53.19	49.56	51.38	-127.00	-63.50
Moore Haven	50.97	46.23	48.75	-146.93	-77.92
Mountain Lake	54.63	48.70	51.27	-201.90	-87.49
Ocala	54.83	51.11	53.36	-126.57	-76.53
Orlando	52.38	48.78	51.10	-115.23	-74.26
Wauchula	56.15	50.31	52.99	-192.87	-88.53
Punta Gorda	51.47	50.01	50.84	-50.90	-28.91

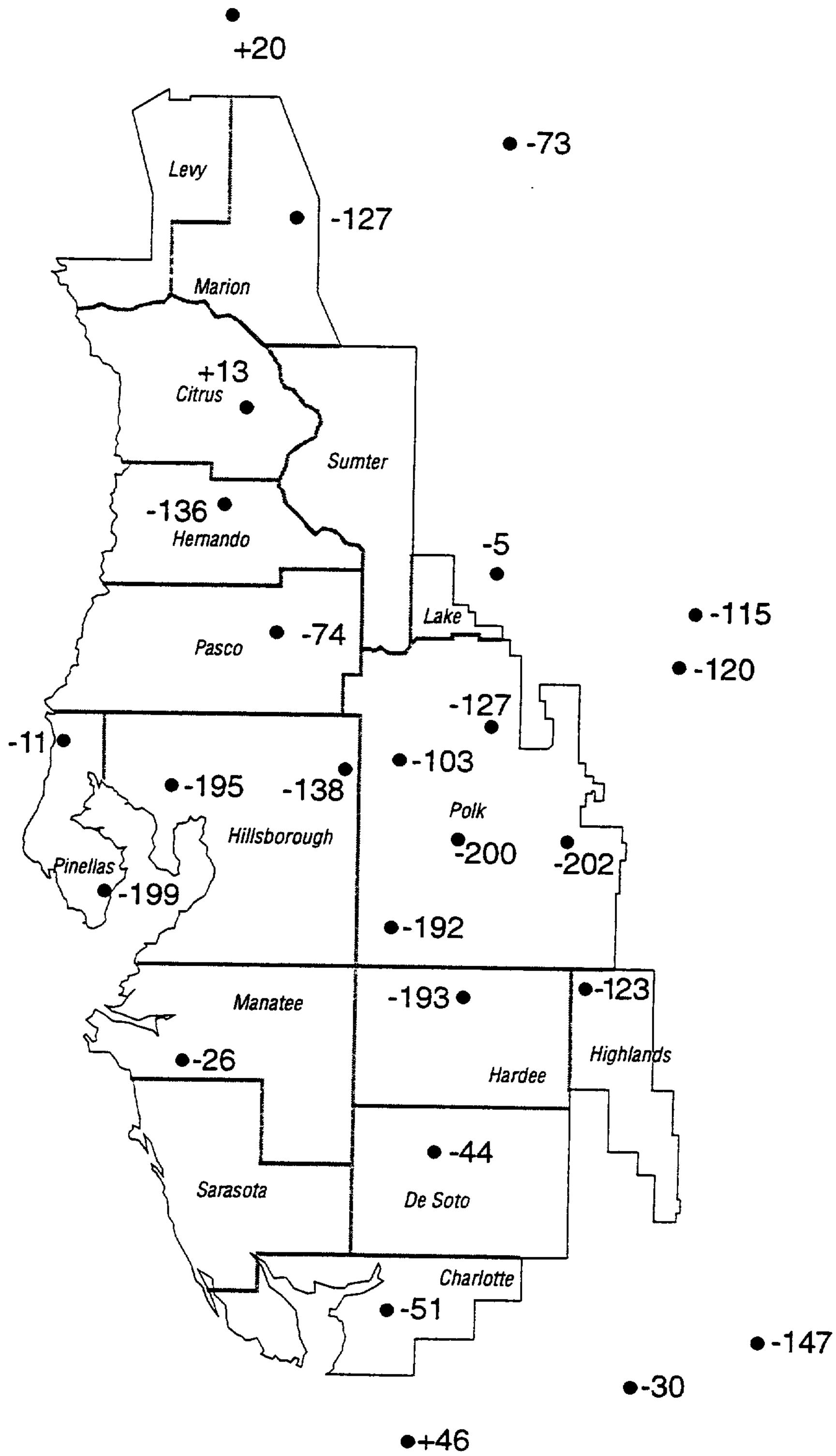


Figure 3-12. Cumulative rainfall deviation from pre-1961 average since 1961 to 1994.

The difference in rainfall amounts between the two time periods may be influenced by the recent decline in major tropical storm occurrence in the last 20 to 30 years. Figure 3-13 presents the frequency of tropical storm occurrence (including tropical depressions, storms, and hurricanes) in peninsular Florida by decade for the current century. The 1970s and 1980s had fewer tropical events compared to other decades, which may account for some of the lower rainfall average during this period. Note that the several tropical storms experienced in Florida in 1994 and 1995 are not included in this figure. Although tropical storms are identified by wind speed rather than rainfall, tropical storms are usually associated with high rainfall.

To explain any possible seasonal changes in rainfall pattern, Figure 3-14 presents five-year moving averages of the Avon Park station, with the convective and frontal seasons separated. It is assumed that most convective events occur from June to October. As the plot shows, most of the rainfall occurs during the convective events of the summer. Although the convective plot still retains the downward slope seen from the 1950s to the present in the total five-year moving average plot (Figure 3-8), the frontal plot appears fairly stable. Figure 3-14 also presents a similar plot for the Lakeland station, located to the west but also within the apparent low rainfall area. This plot shows less clear trends, but does also show a downward slope in the convective plot, and a more stable frontal plot. Although an analysis of this type based on only two stations is not conclusive, it suggests that the lower rainfall in the last 30 years in the central part of the SWFWMD may be due to a decrease in convective and/or tropical rainfall. No sign of increased rainfall from frontal events is evident. The possible southward movement of frontal influences (as suggested by Chen and Gerber (1985)), does not appear to be reflected in the rainfall amounts of these two stations.

3.3.3 Northern Tampa Bay WRAP Area Rainfall

Rainfall investigations in the Northern Tampa Bay area include Heaney and others (1986), which studied the Cypress Creek watershed in Pasco County, Fernandez, Jr. (1990), which studied the Anclote River watershed, and Law Environmental, Inc. (1994), which studied the northwest Hillsborough County area. As part of these studies, various statistical analyses were performed on selected long-term rainfall stations to detect any trends. As discussed earlier, the Cypress

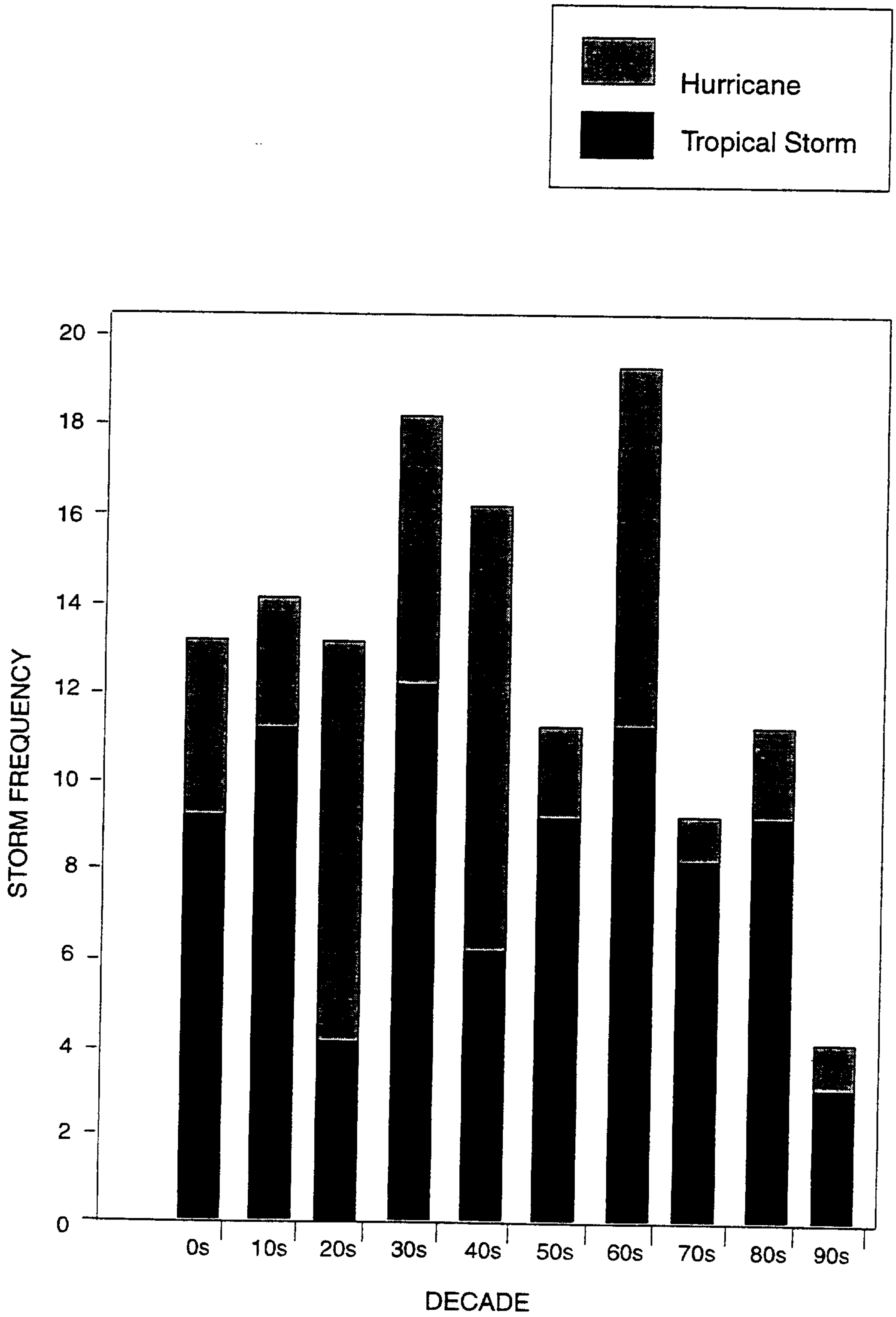


Figure 3-13. Frequency of tropical storm occurence in peninsular Florida as of January 1, 1994.

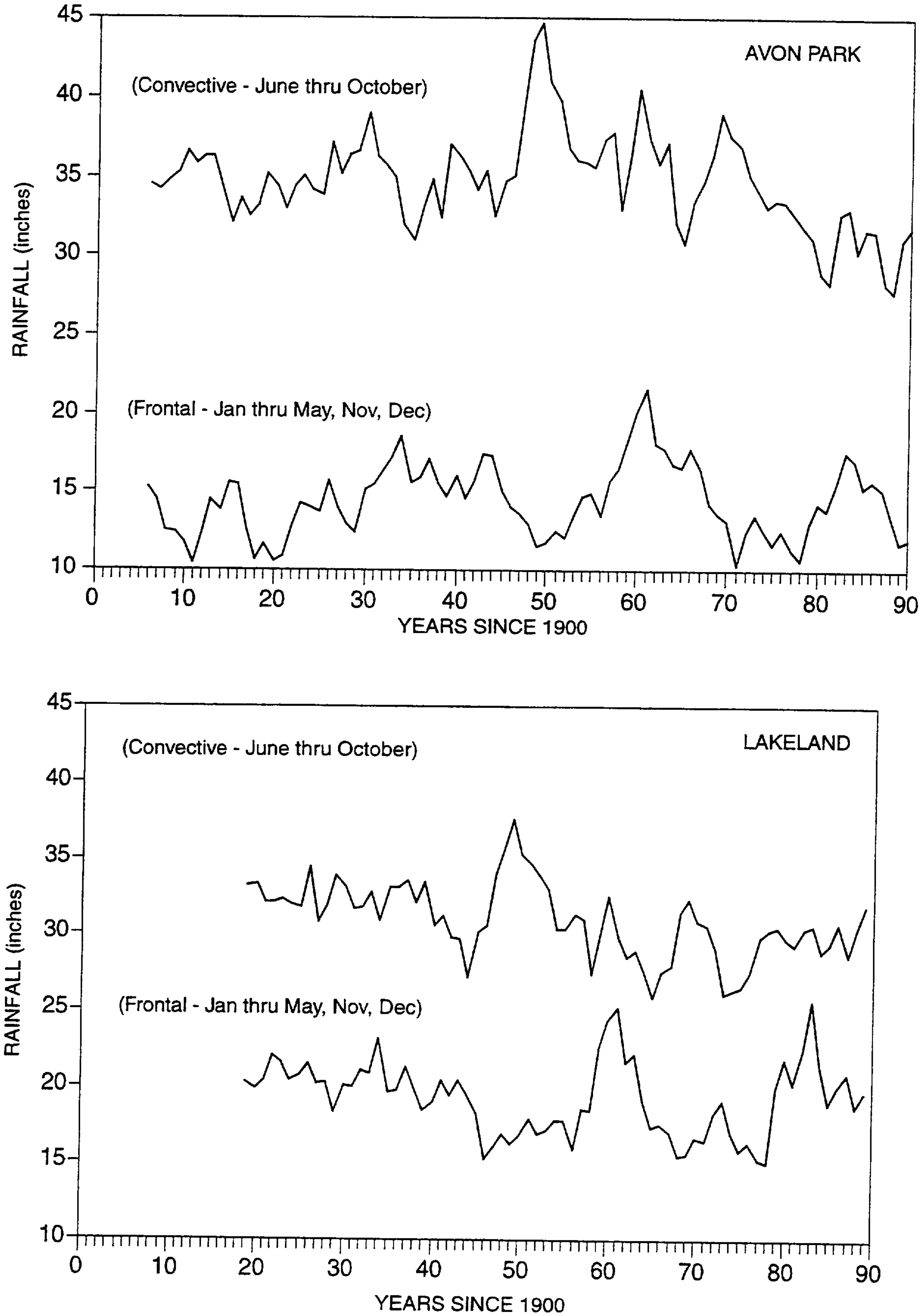


Figure 3-14. Five-year moving average of convective and frontal rainfall periods for the Avon Park and Lakeland rain stations.

Creek study found no statistically significant upward or downward trends in rainfall time series, although certain periodicities were noted. The Anclote River and northwest Hillsborough studies also found no significant long-term trends in the local rainfall data of these respective areas (Fernandez, 1990; Law Environmental, Inc., 1994).

Figure 3-15 presents annual rainfall for the Northern Tampa Bay area, determined through the average of 38 stations throughout the study area. Regression analysis of the annual rainfall data from 1915 to 1995 has determined no statistically significant long-term trend in the data, which is consistent with other previously cited studies in the area. The average of this data is 52.3 inches per year, however, the average rainfall is not the best representation of "normal" rainfall. Annual and cyclic variability in the data is obvious, so the amount of rainfall received in any given year is variable. The total range of annual rainfall in this data set is from 35.4 to 79.7 inches, with 90 percent of the data within the range of approximately 42 to 68 inches. Therefore, based on the average of these 38 stations, rainfall in any given year can range within about 10 inches below or about 16 inches above the average rainfall, and would still be considered "normal" or "expected" rainfall. In other words, for any given year, annual rainfall anywhere within a wide range can be expected, at least based upon the period of rainfall record for the Northern Tampa Bay area.

As in the previous discussions, rainfall is temporally variable in the Northern Tampa Bay WRAP area. Figure 3-16 is a five year moving average of annual rainfall from the 38 stations located within and immediately outside of the Northern Tampa Bay WRAP area. These stations are identified in Appendix A. For the period of record, the lowest rainfall periods generally occurred during the late-1920s, mid-1950s, mid- to late-1960s, mid- to late-1970s, and early-1990s. The combined period around the late-1960s and 1970s represents the longest period of low rainfall using the five-year moving average. The five-year period average ending in 1970 was 47.6 inches, which represented a cumulative departure of 23.5 inches or 4.7 inches below the annual average of 52.3 inches. The years 1976, 1977, and 1978 had five-year averages of 47.6 inches each, which were similar to 1970. The five-year period ending in 1993 represented the single driest five-year interval in the period of record. The cumulative deficit over the five-year period ending in 1993 was -33 inches or about 6.6 inches below the average.

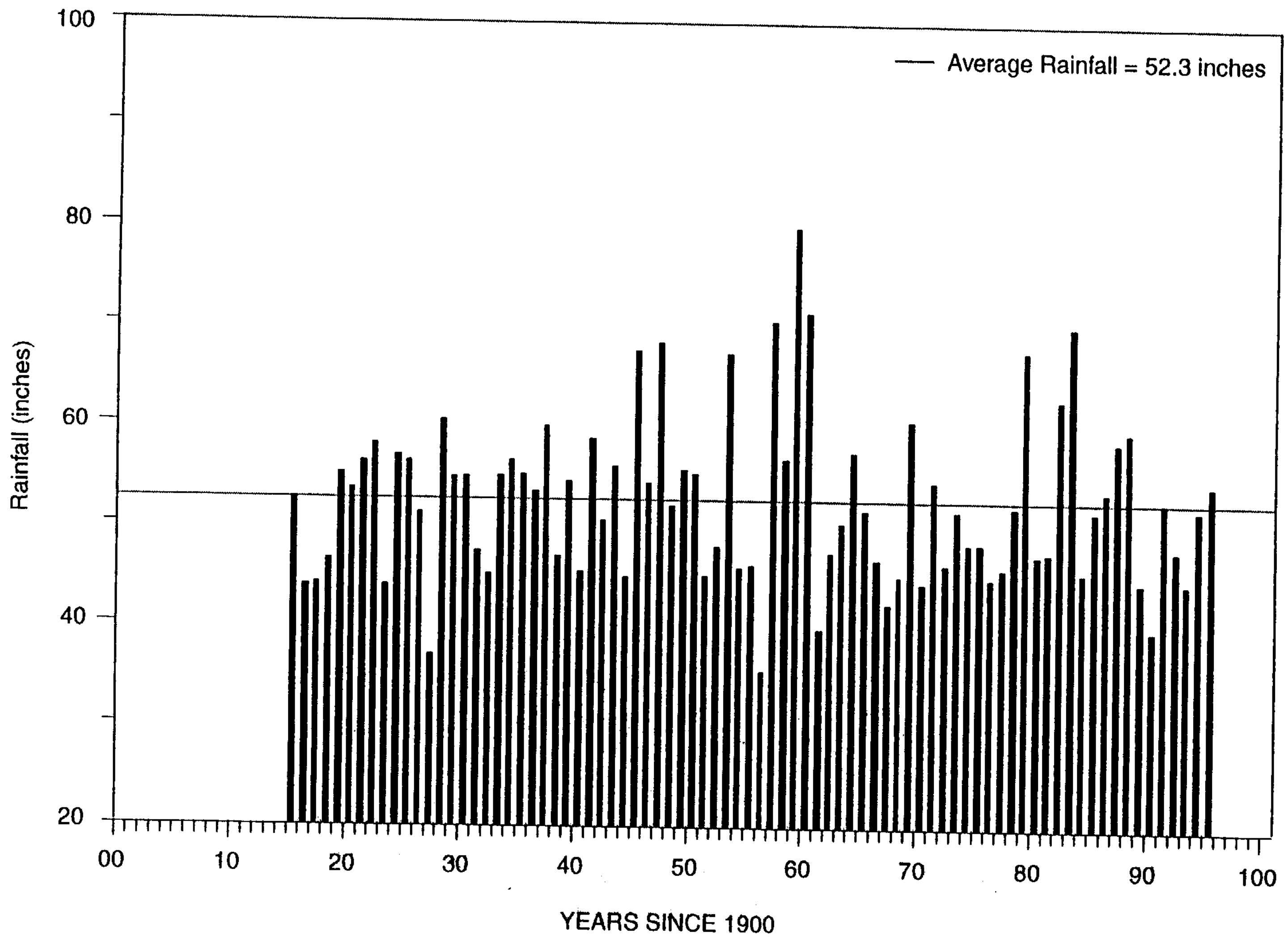


Figure 3-15. Annual rainfall for the Northern Tampa Bay WRAP area based on the average of 38 stations.

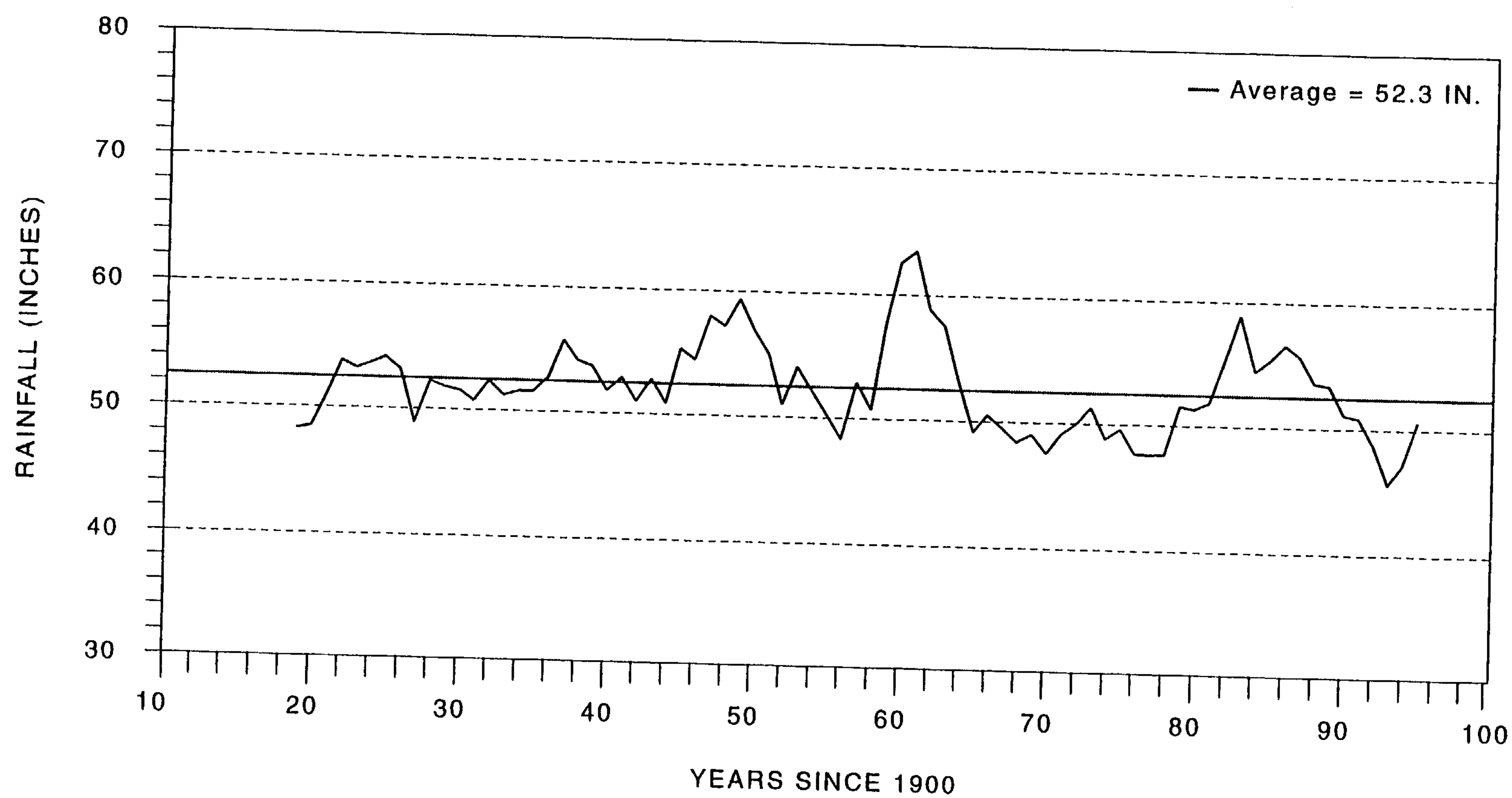


Figure 3-16. Five-year moving average of rainfall in the Northern Tampa Bay Area (based on 38 stations).

If smaller time intervals are examined, the mid-1950s represent the most severe drought period (three years or less), with an average rainfall of 42.3 inches per year. The three-year period ending in 1956 had a cumulative departure of -30 inches, or nearly 10 inches below average. This rainfall departure is close to the five-year departure recorded at the end of 1993, but it occurred over a shorter duration. The single driest year on record is 1956 with an annual rainfall of 35.4 inches (averaged from 38 stations).

Conversely, the highest rainfall periods occurred over three periods in the last 50 years: the mid- to late-1940s, the late-1950s and early-1960s and the early- to mid-1980s. The first two periods correspond to increased tropical storm activity, with 1960 representing the year of Hurricane Donna, an intense storm that caused severe flooding across the peninsula. Examining the five-year moving average, the period ending in 1961 was the highest at 63.4 inches per year. The cumulative departure during this period was a surplus of 55.5 inches. The five-year period ending in 1949 had an average of 59.4 inches per year or a cumulative surplus of 35.5 inches. Likewise, the five-year period ending in 1983 had an average of 58.9 inches per year or a cumulative surplus of 33 inches. If one to three-year averages are reviewed, these same time periods remain the highest rainfall events. On a three-year average, 1960 is the highest at 69.1 inches per year with 1959 and 1961 ranked second and third. 1947 is ranked fourth at 63.2 inches per year and 1983 is ranked fifth highest of the three-year averages at 60 inches per year. The single wettest year is 1959 with an annual rainfall of 79.9 inches (averaged from 38 stations).

It is important to note that multi-year averaging of data tends to smooth short-term periodicity so that long-term trends become more apparent. Greater variability along with higher maximum and minimum values occur with shorter term averaging. Longer term averaging diminishes year-to-year variability. An analysis of three, four, five, six, and seven-year moving averages was completed on annual rainfall data from the St. Leo rainfall station (Figure 3-17). The higher amplitude line corresponds to the shorter term average, in this case three years. The least variation occurs from the seven-year moving average. The most significant point, however, is that the cyclic pattern of low and high rainfall intervals is generally consistent whether it is a

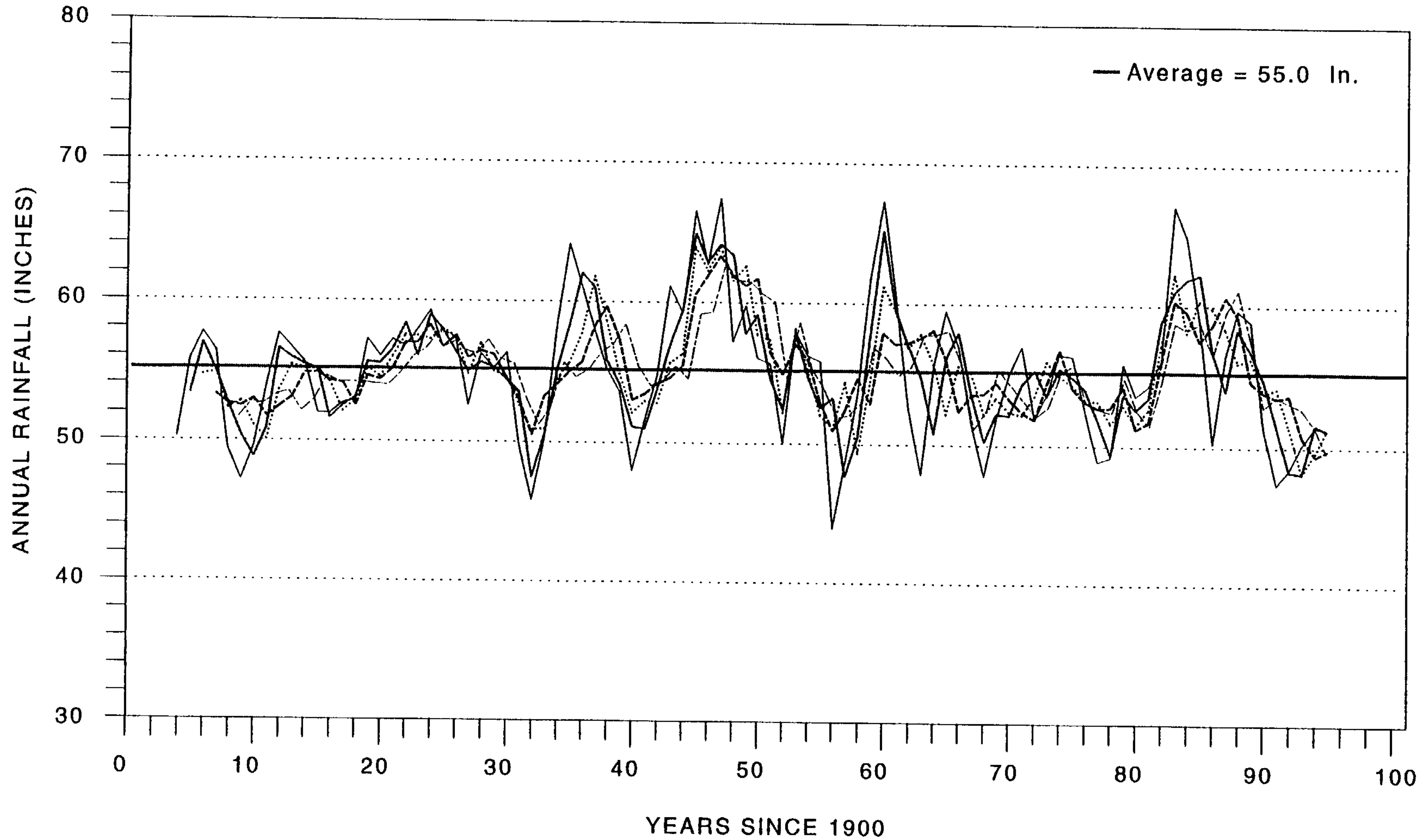


Figure 3-17. Three, four, five, six and seven-year moving average from the St. Leo rainfall station.

three-year or seven-year moving average. These troughs and peaks in the data describe alternate dry and wet periods throughout the record, regardless of the moving average value.

Long-term spatial variability of long-term average rainfall are evident throughout west-central Florida. This spatial variability in annual average in the area can be demonstrated by observing long-term average rainfall from four stations with that have equivalent long periods of record; Brooksville NWS, Tarpon Springs NWS, Tampa NWS, and the St. Leo NWS. The Brooksville station has the highest average (55.8 inches) and Tampa the lowest (47.5 inches). The data from the Tampa station, as mentioned earlier, are consistently lower than that of other surrounding rain stations, possibly due to the station's proximity to Tampa Bay.

As in the rest of the District, short-term spatial variations in rainfall between stations located within the Northern Tampa Bay WRAP area can often appear to be random. As an example, based on the same 38 stations, the average rainfall amount of all stations in the Northern Tampa Bay WRAP area in 1989 (60 stations) is 44.4 inches. The extremes, however, range from 35.3 inches at the Hillsborough River SP station to 60.7 inches at the Lowry Park station. These two stations are relatively close to one another (less than 15 miles). Similarly, the average rainfall in 1994 for the same 38 stations was 51.7 inches, which is very close to the period-of-record average. The extremes in this year ranged from 39.7 to 61.1 inches, again at two stations located within 15 miles of one another.

Two stations located even closer together are the Cosme and Section 21 rainfall stations. Although the two stations are located less than five miles apart, they often have drastically different annual, monthly, and daily rainfall amounts. With some exceptions, the Cosme station usually has higher annual rainfall than the Section 21 station, and has over 5.5 inches higher annual-average rainfall (53.9 inches versus 48.3 inches). Figure 3-18 shows these large differences in rainfall amounts on an annual basis between the two stations. Several years have a difference of over 10 inches, with the Section 21 rain gage consistently recording less than Cosme in all but one of the last sixteen years. Therefore, rainfall can be variable from one location to another for any given year, potentially due to local conditions surrounding each rain gage, the variability of summer rainfall, human error, and other reasons.

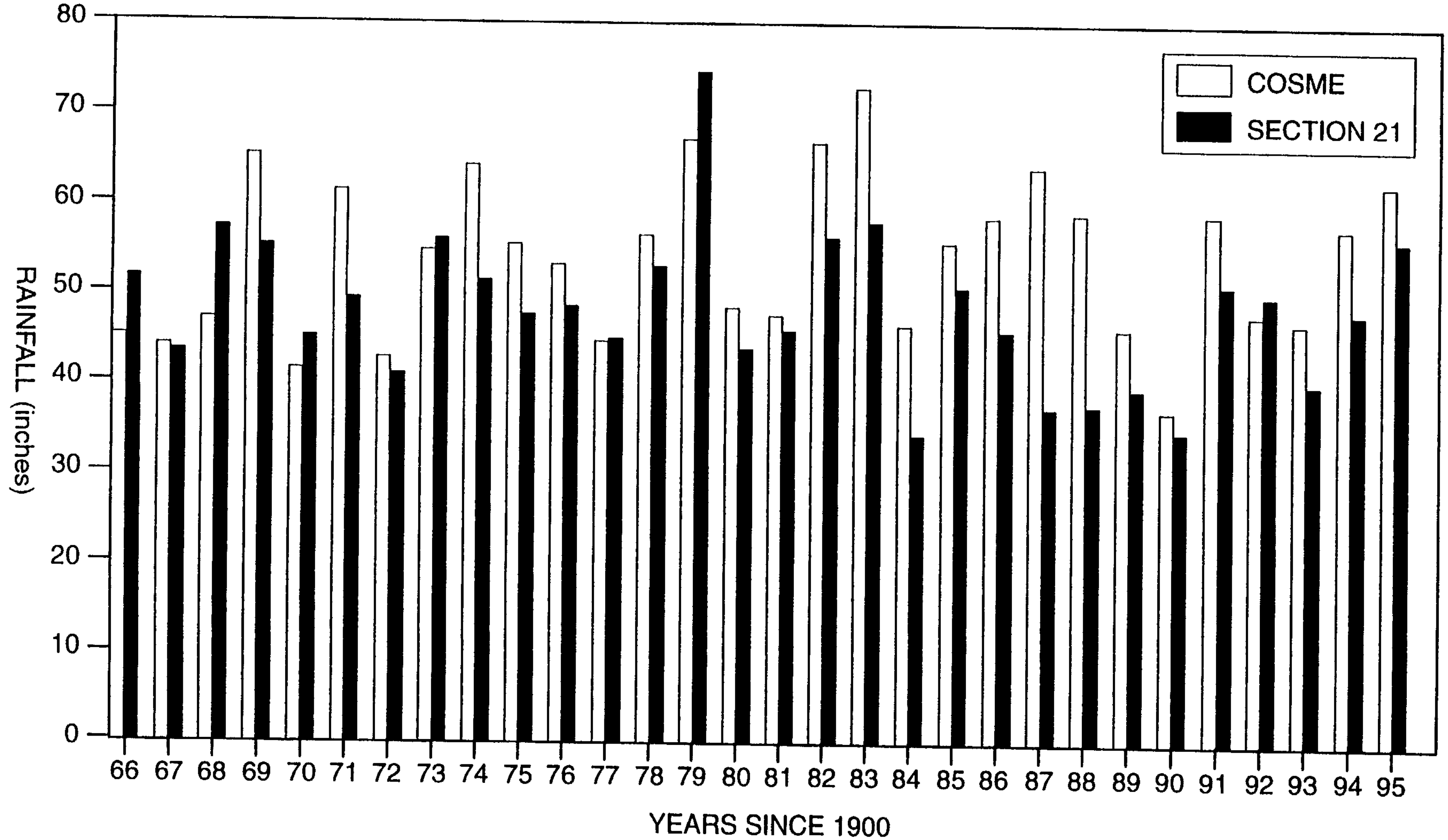


Figure 3-18. Comparison of annual rainfall at the Cosme and Section 21 gauges.

3.4 Evapotranspiration

Trends in the rate of evapotranspiration (ET) have not been widely analyzed, largely due to measurement difficulties. Basically, ET can be estimated by measuring pan evaporation in inches, and applying coefficients to estimate potential and actual evapotranspiration. Since a shallow pan is not a good representative of a lake or water table, a coefficient (K1) is applied to convert pan evaporation to potential evapotranspiration (PET). PET is the upper limit of evapotranspiration. A second coefficient (K2) is then applied to convert PET to ET. This coefficient is based upon various local parameters, including vegetation, average water-table level, soil types, and others. Gibney (1983) suggests values of 0.70 for K1 and 0.89 for K2 as averages in Florida. Therefore, an annual pan evaporation measurement of 60 inches would convert to

$$K1 * K2 * PE = ET$$

$$0.70 * 0.89 * 60 = 37.4 \text{ inches}$$

Since pan evaporation is proportional to PET, it can be studied for any atmospheric changes or trends that may be occurring. Care should be taken to extrapolate any trends identified in pan evaporation to ET, since ET rates are also determined by water-table levels, and land use.

Figure 3-19 shows daily pan evaporation rates at the Bradenton ET station from 1986 to 1989. Seasonal trends are obvious. Like rainfall, pan evaporation increases in the summer months, and decreases in the winter months. This is due to the higher solar radiation levels associated with summer. Although seasonal PET trends can be identified, accurate analysis of long-term regional ET trends will not be achievable until better measurement techniques are developed and historical data collected.

3.5 Discharge

As described in Section 2.4.1, the Northern Tampa Bay WRAP area contains all or part of approximately nine significant watersheds or sub-basins, as well as several coastal watersheds drained by many small tidally-influenced or intermittent streams (Figure 2-7). Most of the

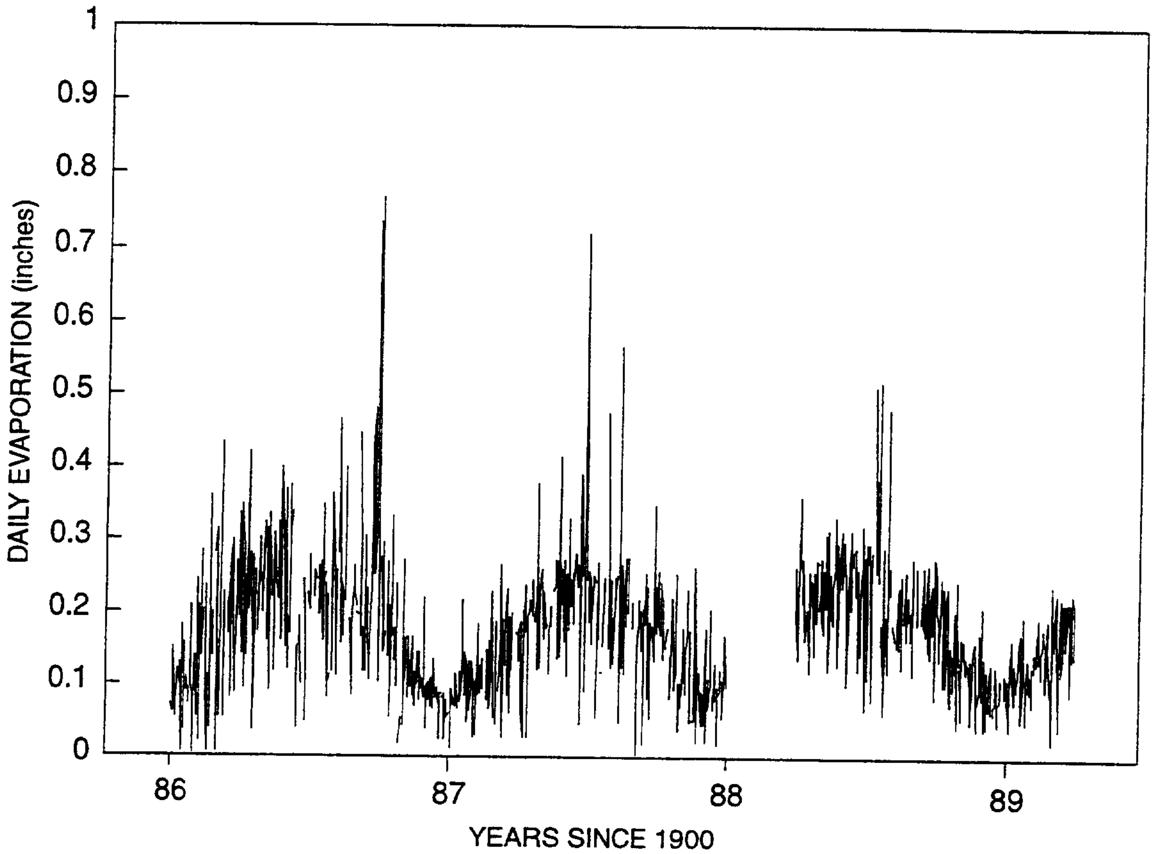


Figure 3-19. Daily pan evaporation at Bradenton (1986-1989).

stream systems throughout the study area receive a majority of their flow from overland flow and surficial aquifer discharge, and naturally reach near zero discharge during periods of low rainfall. Some systems, such as the Hillsborough River, receive a significant supply of baseflow from Upper Floridan aquifer discharges.

The annual discharge quantities at gaging stations in three watersheds are presented in Figures 3-20 through 3-22. These three watersheds were selected since they are located within the portion of the Northern Tampa Bay WRAP area with the highest concentration of public supply ground-water withdrawals. To facilitate the comparison, discharge quantities are expressed in inches per year for the contributing watershed. When displayed this way, all three watersheds should have approximately equivalent runoff amounts if all characteristics of each watershed are the same and they all receive equivalent precipitation. Since the three watersheds are adjacent, they should be exposed to similar atmospheric conditions and topography (although, as discussed earlier, temporal and spatial variability in rainfall should be acknowledged). In the reach above each stream gage, these rivers receives a major portion of their flow from the surficial aquifer and overland flow. Coastal sections of the Anclote River (below the gage) do receive some discharge from the Upper Floridan aquifer.

As can be seen from the annual runoff hydrographs, all three watersheds track very closely until the mid-1970s, when Rocky Creek shows increasing runoff volume. Discharge from at least one treatment plant may explain some of the increase. The location of the Rocky Creek flow gage, as well as the control structure which regulates flow in the creek, changed during March 1971 to a site 1,500 feet upstream of the former location. The structure's effect on the flow is not clear, but the gage is approximately 75 feet upstream from the control structure. The change in the gaging location did slightly reduce the size of the contributing basin, but only changes in watershed characteristics could explain the increasing runoff with time. Therefore, Rocky Creek's increased flow is of interest.

The cyclic nature of flow in each of the watersheds originates from cycles of rainfall, as exhibited in each of the hydrographs. Note that although each hydrograph appears to follow a loose cycle of high and low flows, Brooker Creek has a very regular cycle, with a four to six

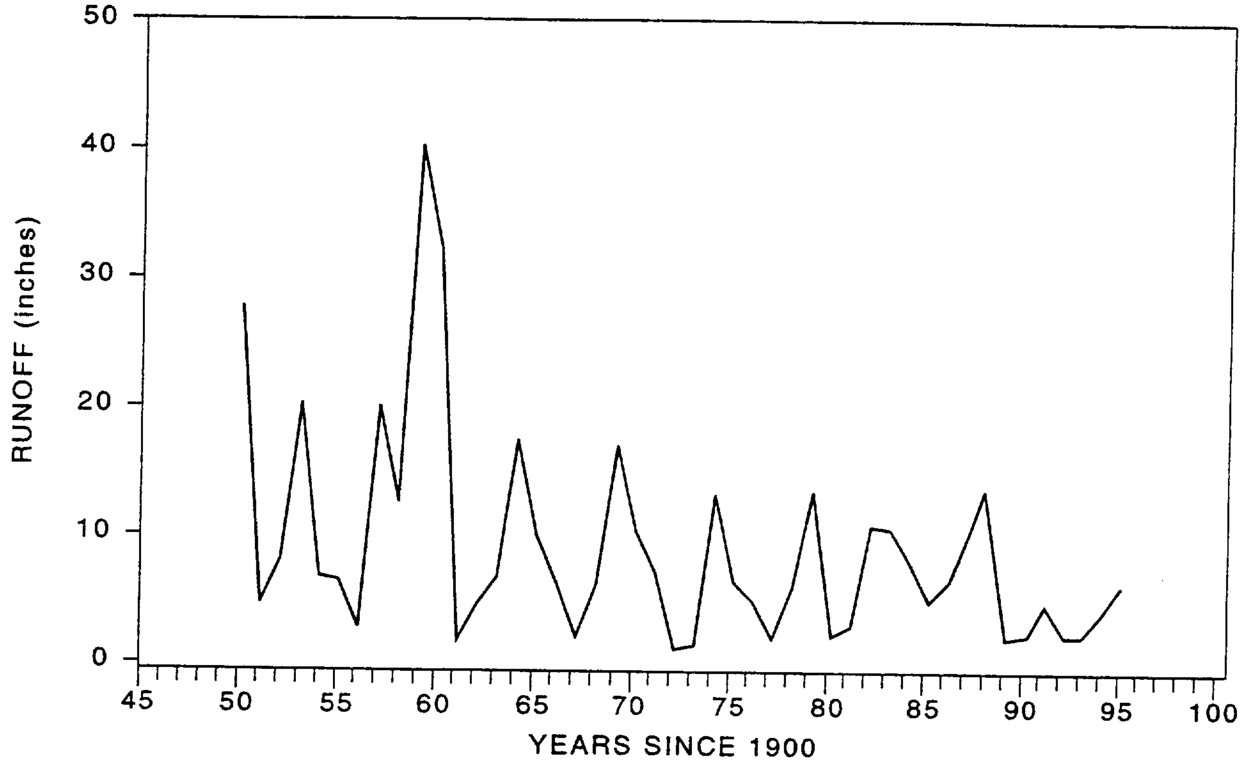


Figure 3-20. Runoff at Brooker Creek near Tarpon Springs.

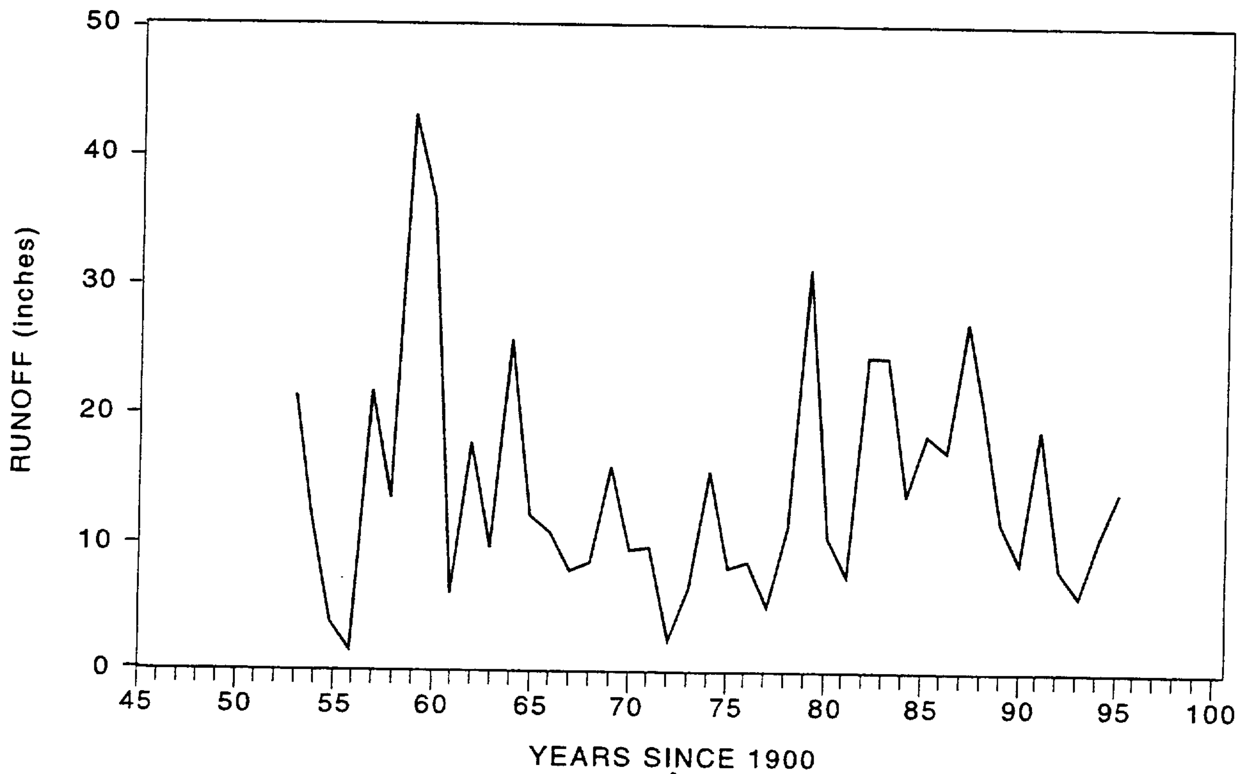


Figure 3-21. Runoff at Rocky Creek near Sulphur Springs.

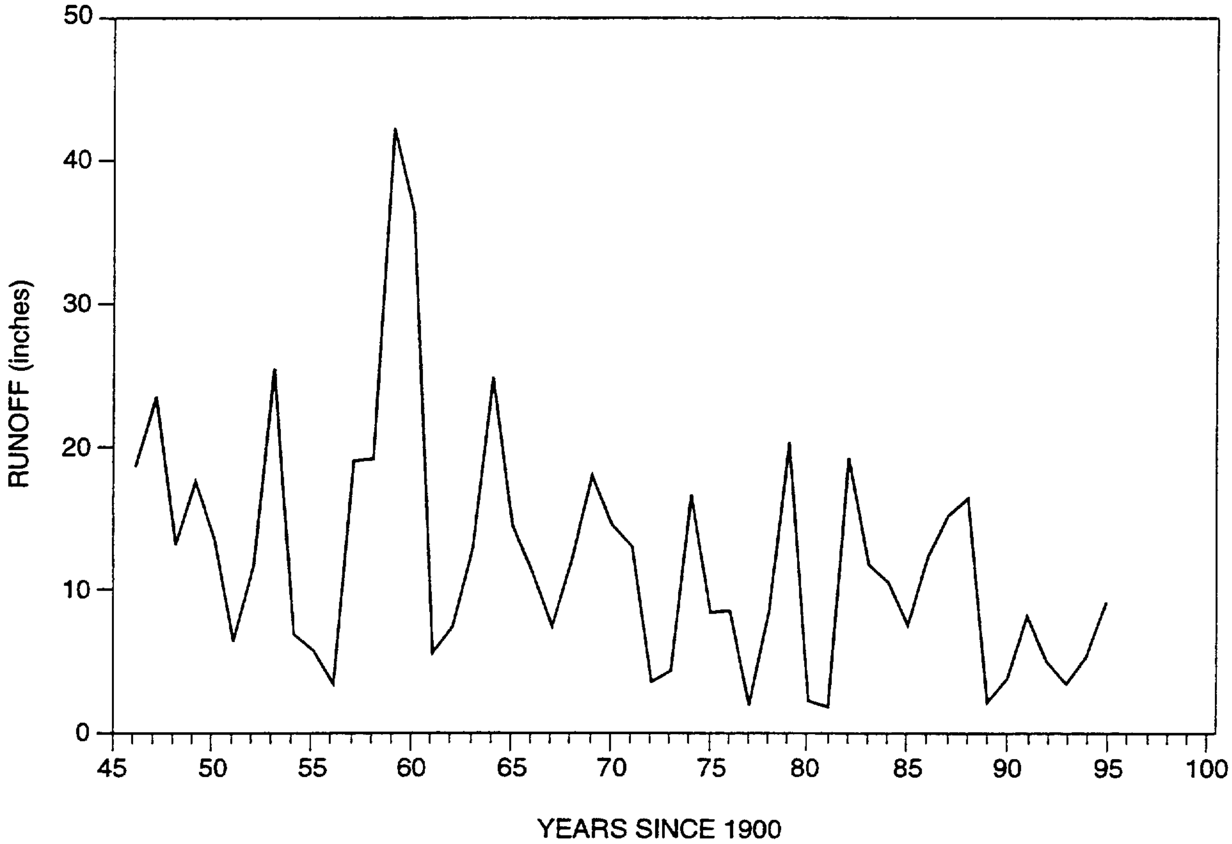


Figure 3-22. Runoff at Anclote River near Elfers.

year return and period. The amplitude of flow in Brooker Creek also shows a slight decreasing trend through the period of record. The annual runoff hydrographs indicate an apparent increase in flow in Rocky Creek and a slight reduction of volume and amplitude in Brooker Creek. No trend is apparent in the runoff hydrograph of the Anclote River. Similar conclusions were found by other investigations (Cherry and others, 1970; Parker, 1975; Briley, Wild, and Associates, 1978; SWFWMD, 1984; SWFWMD, 1987b, Law Environmental, 1994).

One methodology used to help visualize the possibility of trends in the streamflow is the examination of flow frequencies. Figures 3-23 and 3-24 display bar graphs of Rocky Creek and Brooker Creek flow distributions for the last four decades of data. Rocky Creek (Figure 3-21) shows an increasing trend in the number of days with flows of 10 cubic feet per second (cfs) or less during the 1950s, 1960s, and 1970s, but shows an abrupt decrease in the number of low flow days (or increase in the number of high flows) during the 1980s. The Brooker Creek graph (Figure 3-22) shows a more pronounced but similar increase in low flow frequencies, but does not have the large increase in high flows during the 1980s that was observed at Rocky Creek.

Figures 3-25 and 3-26 present continuous time series of the log (base ten) of flow in Rocky Creek and the Anclote River. These graphs allow us to see the minimum flows for the period of record, assumed to be the baseflow. As was seen in the frequency distribution, the Rocky Creek figure shows an apparent decrease in low flow rates though the 1970s. Log flows average about 0.5 to 0.8 (3.0 to 6.0 cfs) in the 1950s and 1960s, and -0.3 to 0.6 (0.5 to 4.0 cfs) in the 1970s. An increasing trend in the baseflow of Rocky Creek is apparent in the 1980s. Because of the highly urbanized landscape, flow in the Rocky Creek system is derived from a rapidly declining series of surface-water flow events and a declining amount of baseflow. The smaller average flows (0.5 to 6 cfs) are probably more representative of the true baseflow of the system. The Anclote River series shows no apparent trend in baseflow. This methodology does not work for Brooker Creek since low flows have been zero throughout the period of record.

Figure 3-27 presents annual discharge data from the Cypress Creek gauging station located at Worthington Gardens along State Road 54 in Pasco County. No apparent trend is discernable in this data, although the largest flow occurred on the first data point in 1974. An analysis of

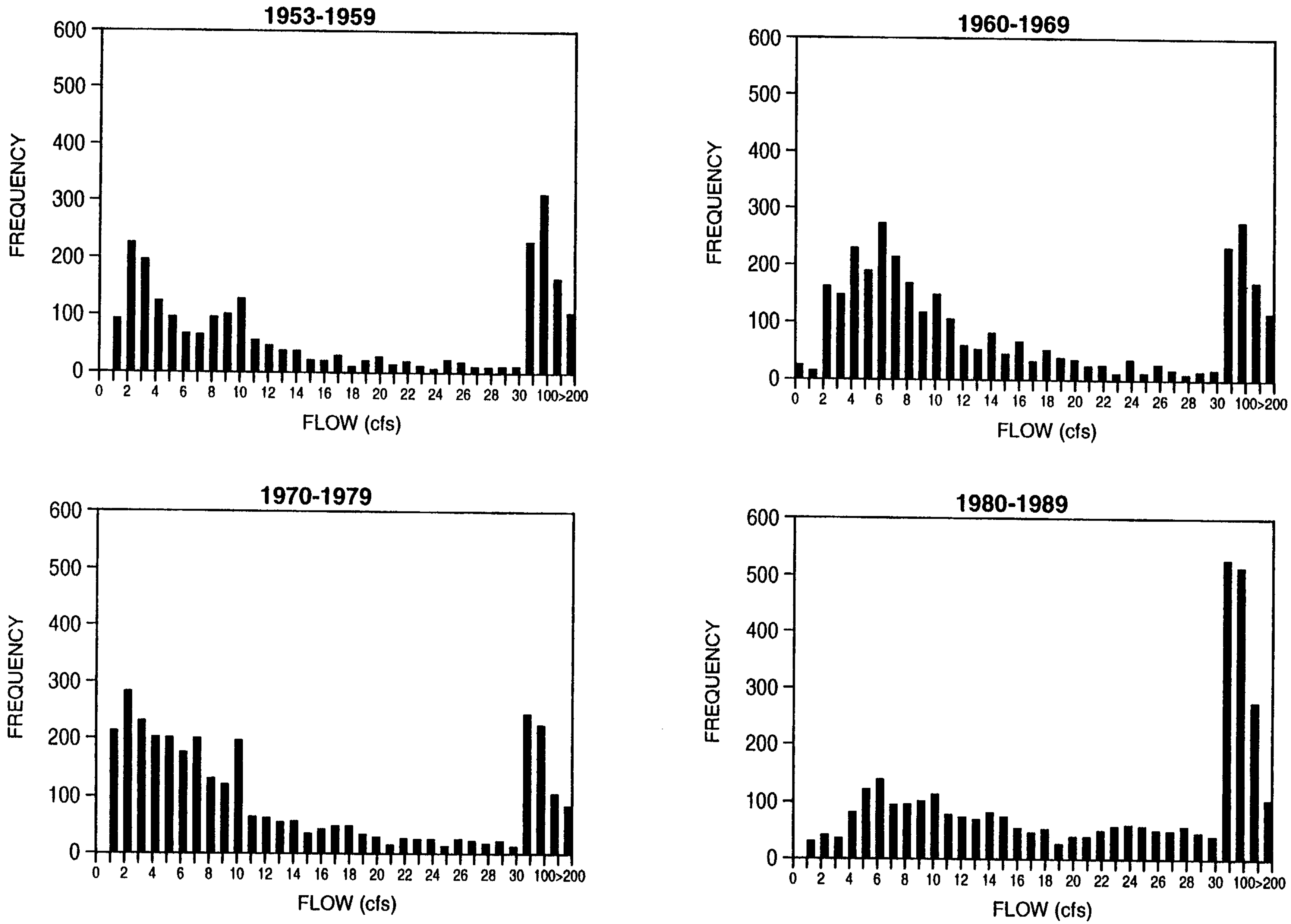


Figure 3-23. Flow distributions of Rocky Creek near Sulphur Springs.

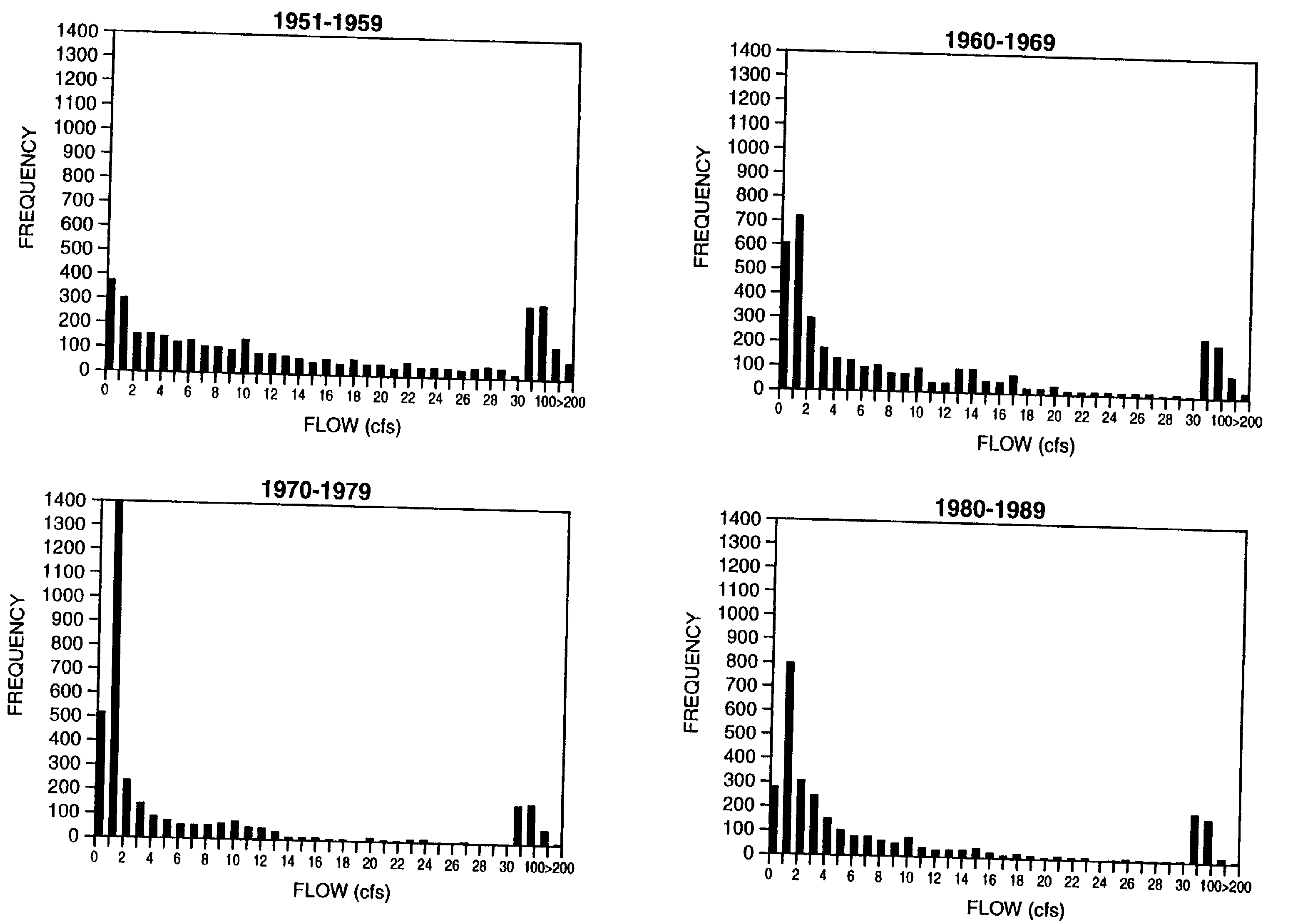


Figure 3-24. Flow distributions of Brooker Creek near Tarpon Springs.

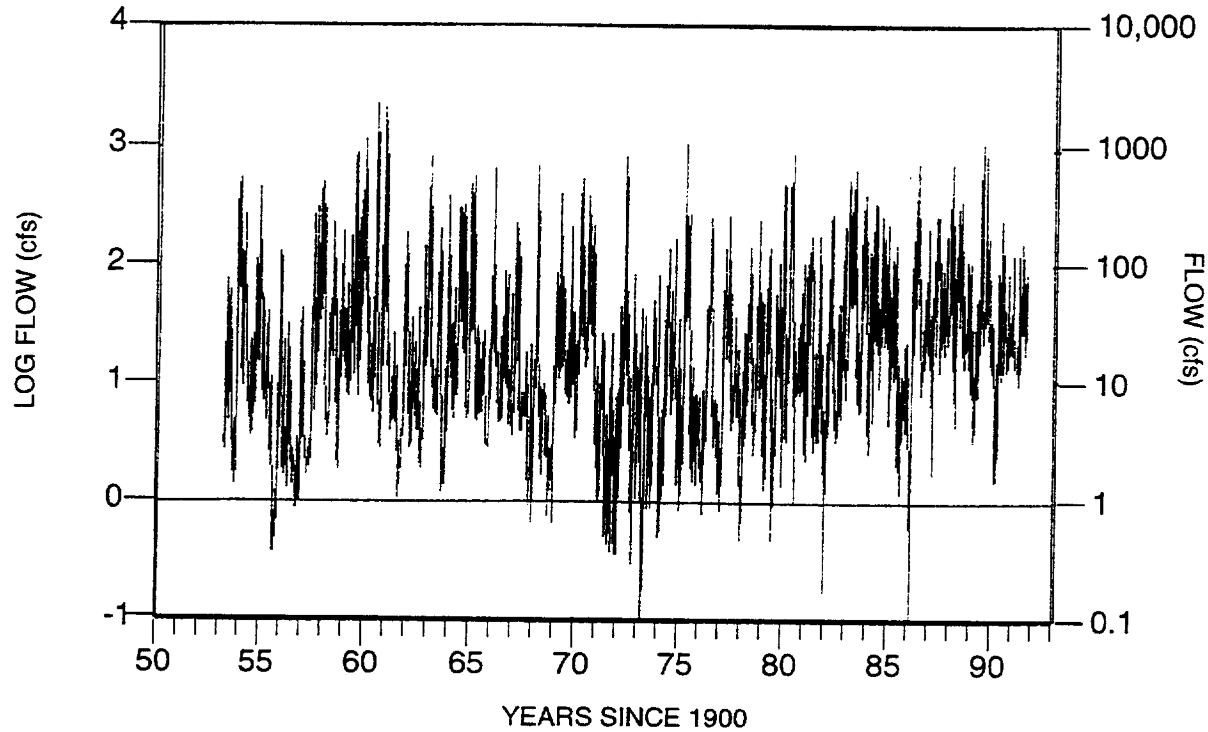


Figure 3-25. Baseflow analysis of Rocky Creek near Sulphur Springs.

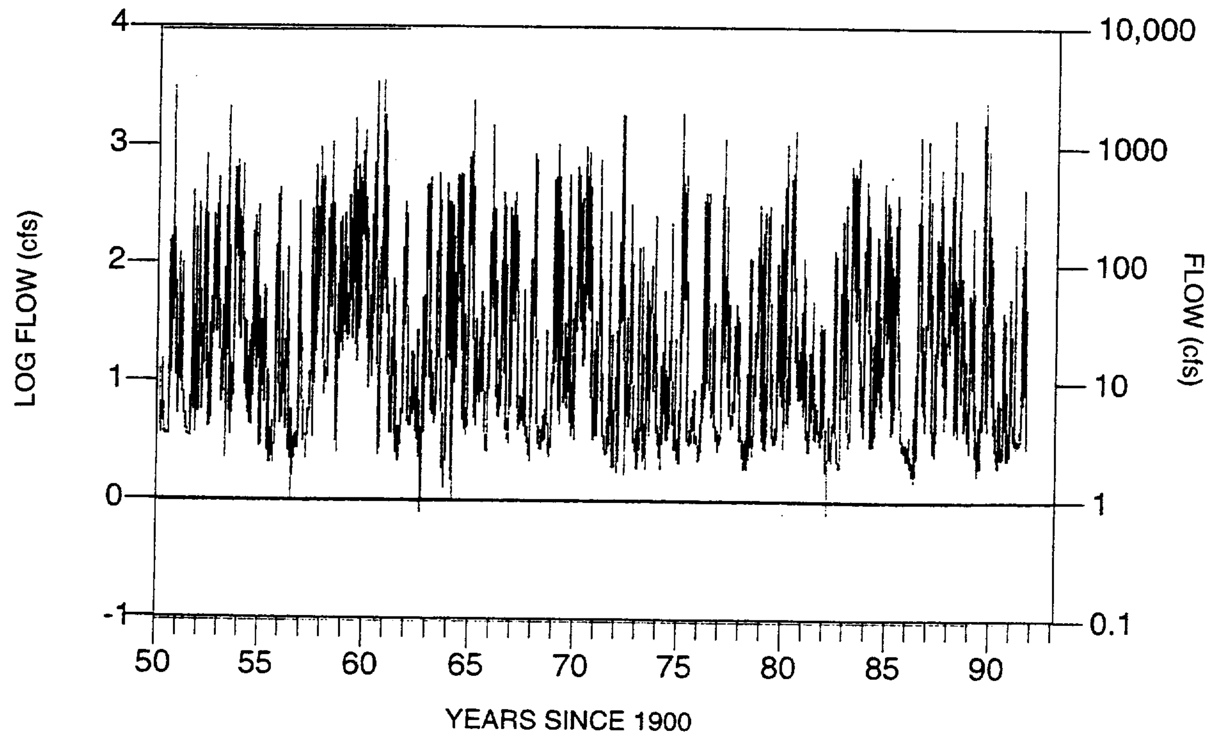


Figure 3-26. Baseflow analysis of the Anclote River near Elfers.

this gage and a discontinued gage north of Worthington Gardens at Drexel was performed by Heaney and others (1986). Although this study found no significant trend at the Worthington Gardens station, a significant downward trend was discovered at the Drexel gage beginning in 1977. No data is available for the Drexel location since 1981, but the gage location has been visually monitored since that date, with no flow found the majority of the time.

A hydrograph of annual-average runoff for Jumping Gully, located in northern Pasco County, is found in Figure 3-28. Jumping Gully is one of the few relatively well-defined channels in northern Pasco County, which is characterized by internally drained basins and low runoff. As seen in Figure 3-28, runoff has historically been low in the basin. Since the about 1987, no flow has been recorded at this station.

Flow of the Hillsborough River at the Zephyrhills and Morris Bridge stations is shown in Figures 3-29 and 3-30. The Morris Bridge station is approximately 11 miles downstream from the Zephyrhills station, and is the most downstream record of discharge not affected by the Tampa Reservoir. The period of record is much shorter at the Morris Bridge station, but discharge is actually slightly less than at the upstream station due to large wetland storage areas along the connecting reach. No trend is apparent at either station, although the flow records at the Morris Bridge station account for less than 60 percent of the Hillsborough River watershed.

Although there are several major springs in the Northern Tampa Bay WRAP area, only three springs have long periods of discharge data: Sulphur Springs, Crystal Springs, and Weeki Wachee Springs. Figures 3-31 through 3-33 present annual discharge data for each spring for the period of record. Sulphur Springs is located near the mouth of the Hillsborough River, and discharges to the river. Spring discharge appears to have decreased throughout the period of record, although high rainfall events in the beginning of the data set resulted in high spring discharge, which distorts the trend to some degree. Also, the City of Tampa has periodically used the spring as a supplemental public water supply source since 1964 (Stewart and Mills, 1984). Figure 3-31 does not include water pumped by the City of Tampa. Ground-water withdrawal data is available only since 1983; withdrawals have averaged less than two mgd, with

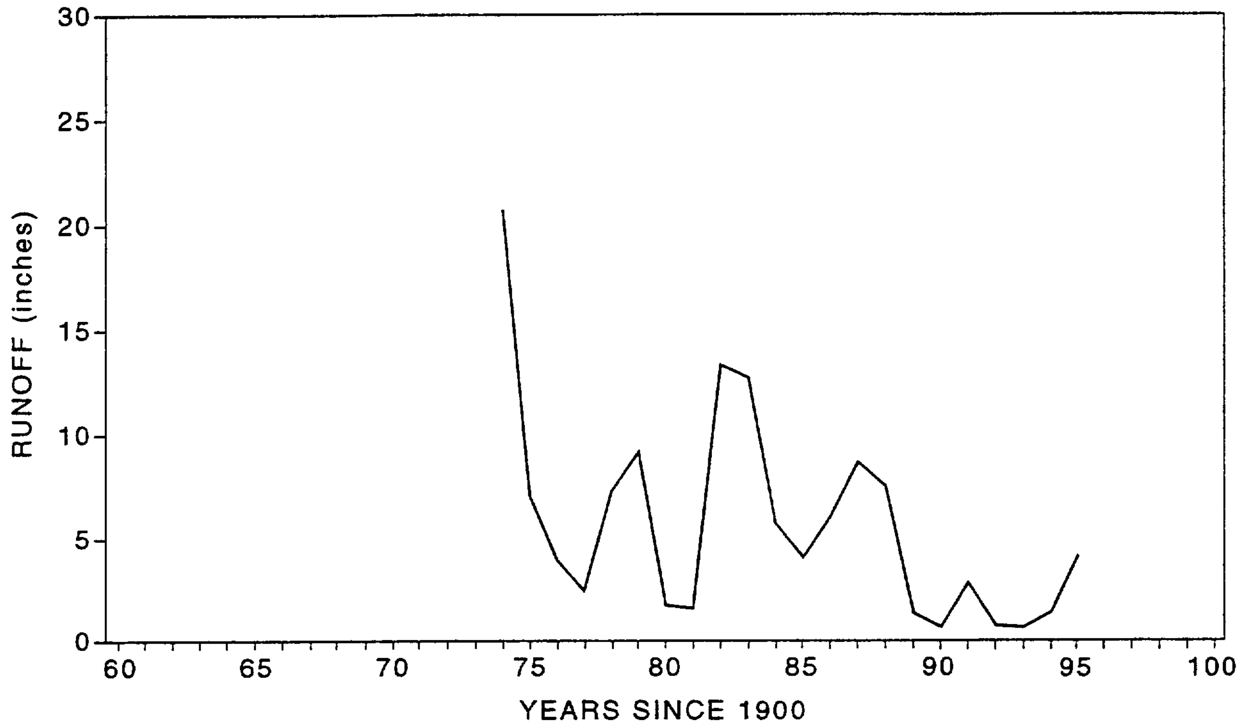


Figure 3-27. Runoff at the Cypress Creek at Worthington Gardens.

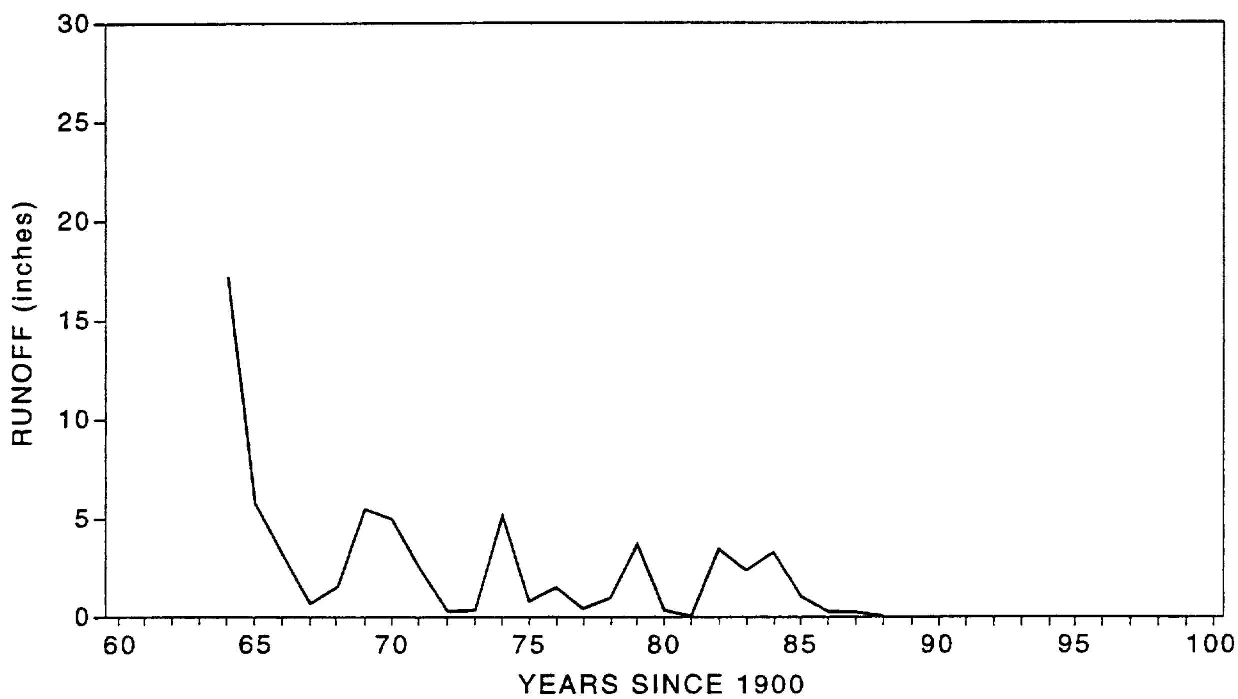


Figure 3-28. Runoff at Jumping Gully at Loyce.

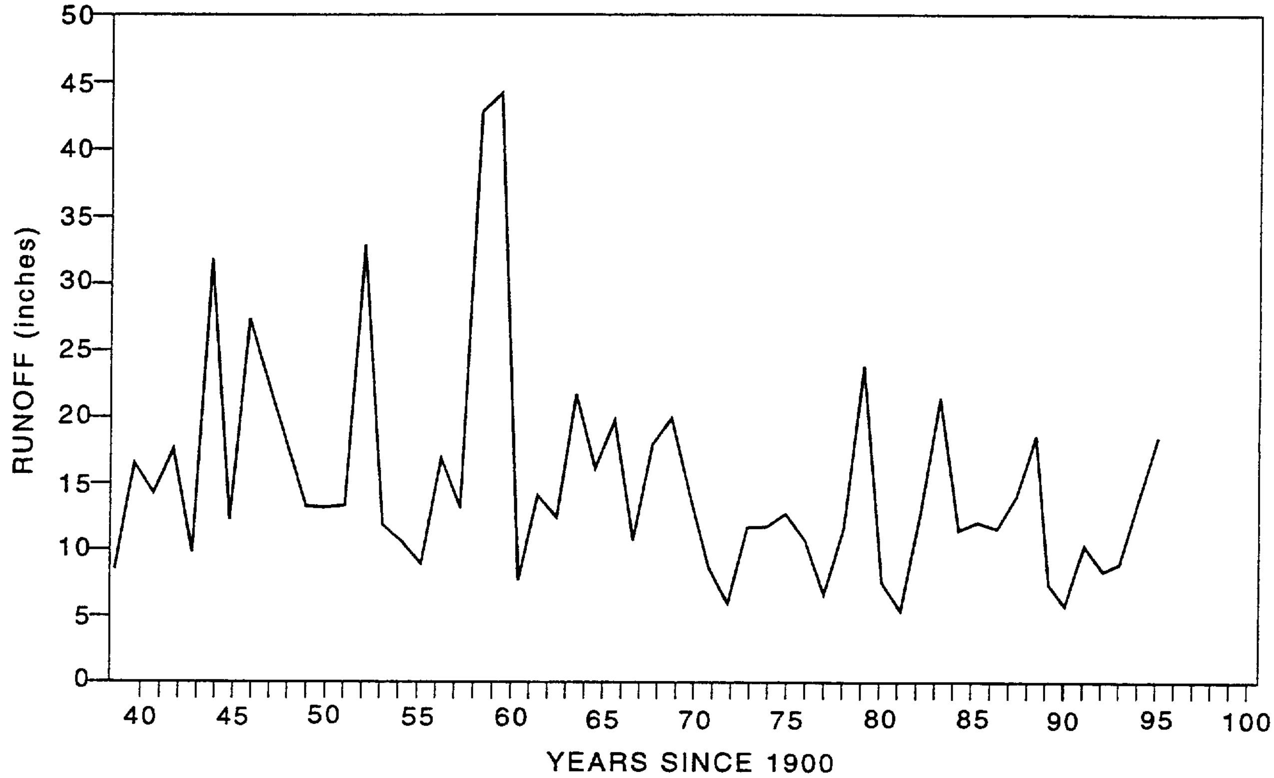


Figure 3-29. Runoff at the Hillsborough River near Zephyrhills.

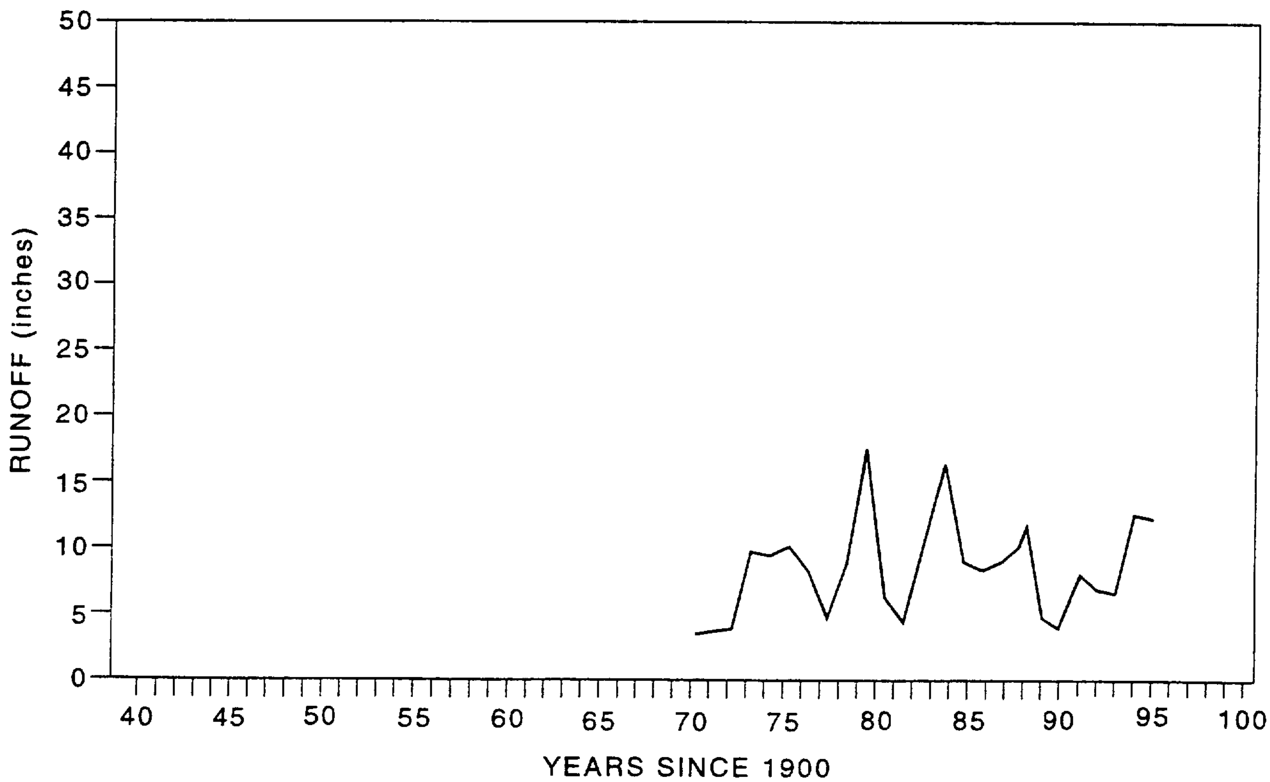


Figure 3-30. Runoff at the Hillsborough River at Morris Bridge.

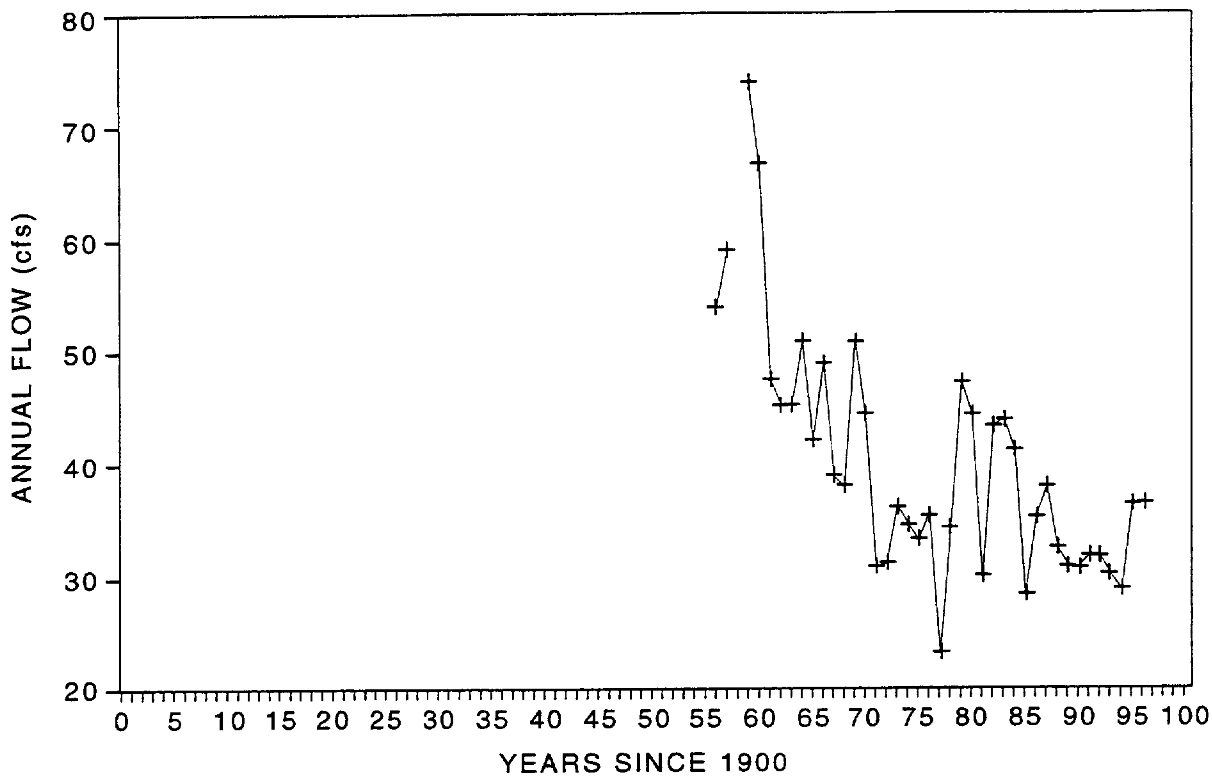


Figure 3-31. Sulphur Springs discharge.

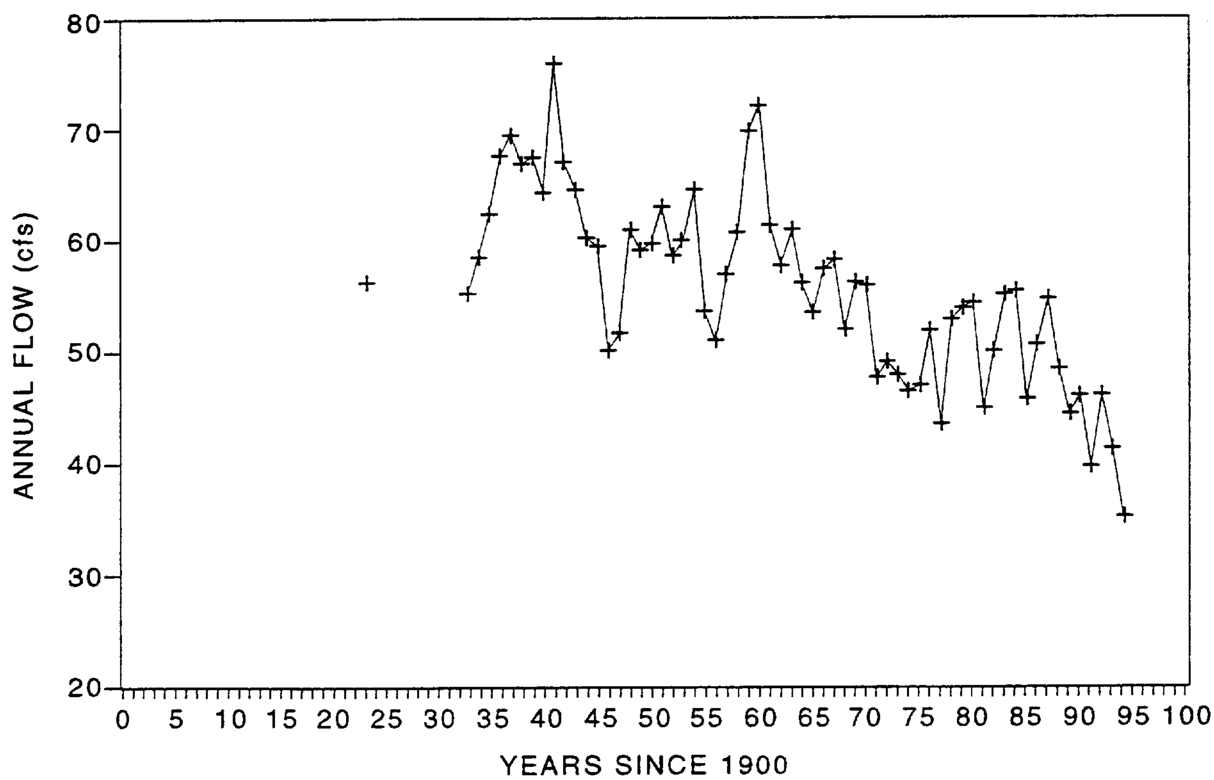


Figure 3-32. Crystal Springs discharge.

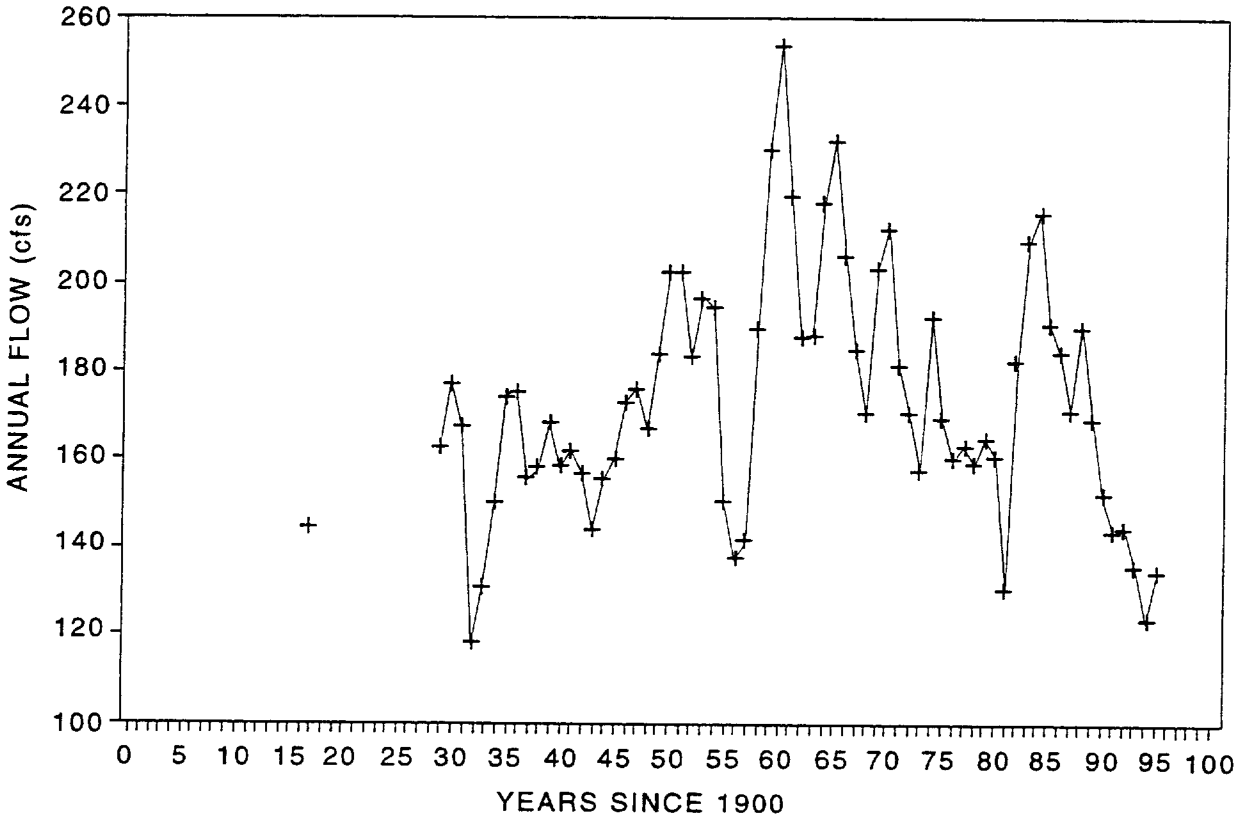


Figure 3-33. Weeki Wachee Spring discharge.

a maximum recorded withdrawal of 8.4 mgd in 1985. Crystal Springs is located in the headwaters of the Hillsborough in Pasco County, and also discharges to the river. Data for this spring are based on periodic instantaneous measurements taken on the Hillsborough River above and below the spring system. Flow is also regulated at the main springhead for recreational purposes, so interpretation of the apparent downward trend is difficult. Tibbals and others (1980) suggested that agricultural and industrial ground-water withdrawals in the Dade City and Zephyrhills area of eastern Pasco County may have had some effects on the discharge of Crystal Springs, although the relationship is not clear. Although periodic instantaneous discharge measurements have been recorded since 1917 at Weeki Wachee Springs, located in the northwest corner of the study area in Hernando County, data has become more consistent since 1966. Measurements are made about one mile downstream from the main spring. No upward or downward trend for the period of record is apparent, although the period from the mid-1960s to present appears similar to that of Sulphur Springs. Early data at Weeki Wachee Springs, however, shows that the magnitude of current spring discharges are similar to those in the 1930s to 1950s.

3.6 Water Levels

Water levels of the ground-water system in the Northern Tampa Bay WRAP area have been a major concern for over thirty years. Declining water levels in the Upper Floridan aquifer indicate lowered hydraulic potentials which cause decreased well efficiencies, intrusion of saline water, and increased recharge potential from the overlying surficial aquifer. Lowered water levels in the surficial aquifer are reflected as declining water levels in waterbodies, decreases in streamflow, and decreasing wetland health.

3.6.1 Ground Water

The annual-average potentiometric levels of the Upper Floridan aquifer have declined significantly in several sections of the Northern Tampa Bay WRAP area, and seasonal fluctuations in Upper Floridan aquifer water levels have increased. Similarly, some portions of the Northern Tampa Bay WRAP area have shown significant declines in water-table elevations.

In this section, the historical trends and seasonal fluctuations in water levels and potentiometric surfaces will be discussed.

The data used to describe these trends are records of water levels measured in wells and historical maps of the potentiometric surface or water table. The well data are presented as hydrographs that show the change with time of the water-level elevation, referenced to the National Geodetic Vertical Datum (NGVD). In this section, selected water-level records are included to illustrate representative trends. There are many other examples that could be used. A complete set of hydrographs are compiled in the Data Appendices. The hydrographs in this section were, to the extent possible, drawn with consistently scaled axes so that they can be easily compared. Because of these consistent scales, at times a scale may seem inappropriate for a particular hydrograph. However, having consistent axes allows easy comparison of water-level elevations, as well as seasonal and long-term fluctuations.

Although isolated water-level records can be found as early as the 1930s, most of the water-level records are more recent and cover periods of less than 15 years. The early data are typically from water production wells with large open-hole intervals open to multiple flow zones. Records of water levels in individual flow zones and formations are only recently available due to the construction of dedicated monitor wells by the USGS and the SWFWMD.

Upper Floridan Aquifer - In areas of heavy Upper Floridan aquifer ground-water withdrawal, there have been long-term sustained declines in the potentiometric surface. The period of this decline corresponds to the period of localized pumping. Additionally, the amplitude of seasonal fluctuations has increased in magnitude during the period of ground-water withdrawal. These trends are observed in long-term Upper Floridan aquifer monitor wells analyzed in this study.

Long-term Trends - Examples of long-term declines in the potentiometric surface of the Upper Floridan aquifer are presented in Figures 3-34 and 3-35. The location of the Upper Floridan aquifer monitor wells referenced in this section are shown in Figure 3-36. Figure 3-34 is a hydrograph of the potentiometric level at monitor well Hillsborough 13 Deep, located within the Section 21 wellfield in northwest Hillsborough County. The earliest water levels at this well are

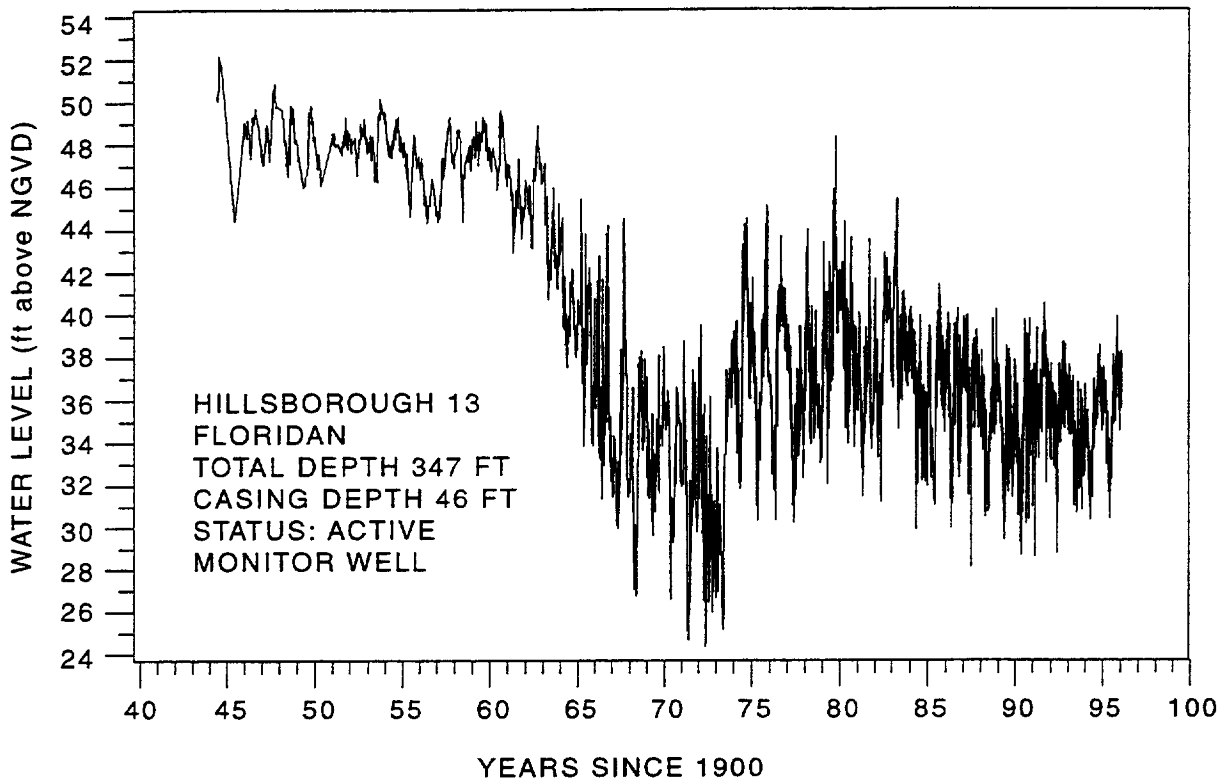


Figure 3-34. Water levels of the Hillsborough 13 Floridan aquifer well.

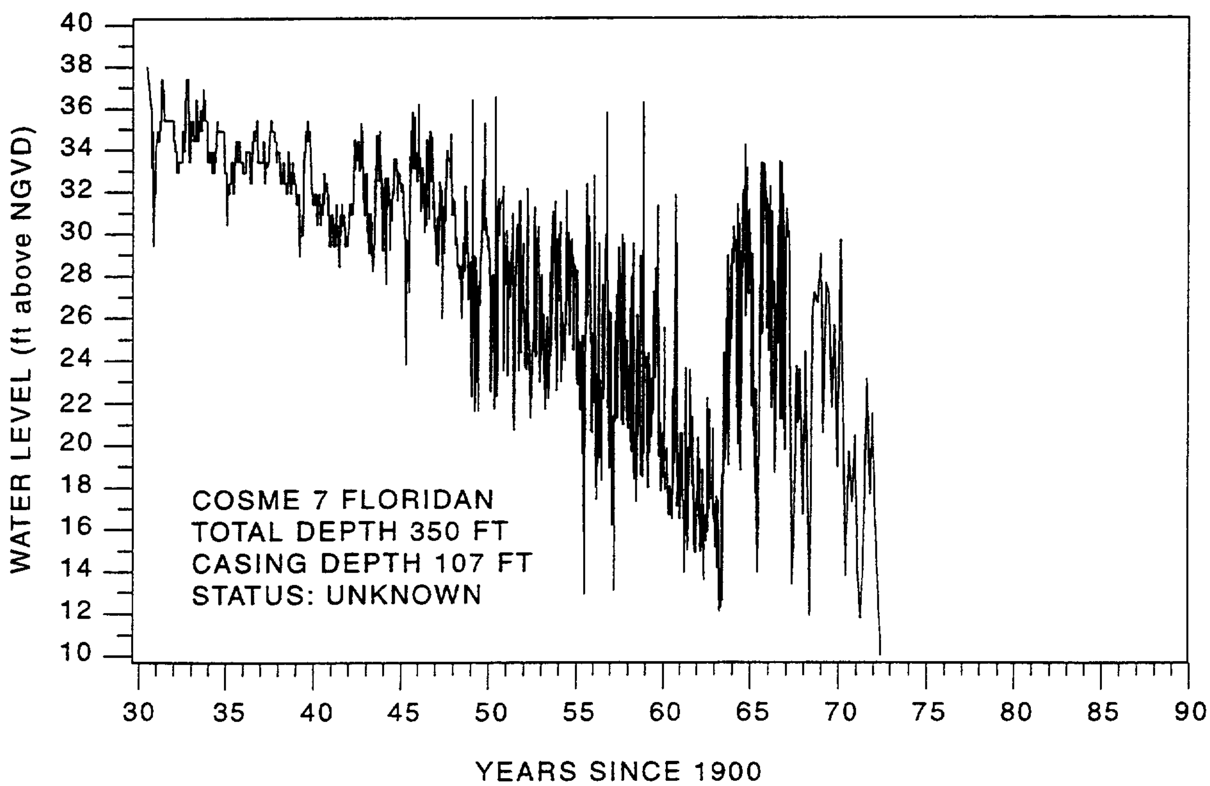


Figure 3-35. Water levels of the Cosme 7 Floridan aquifer well.

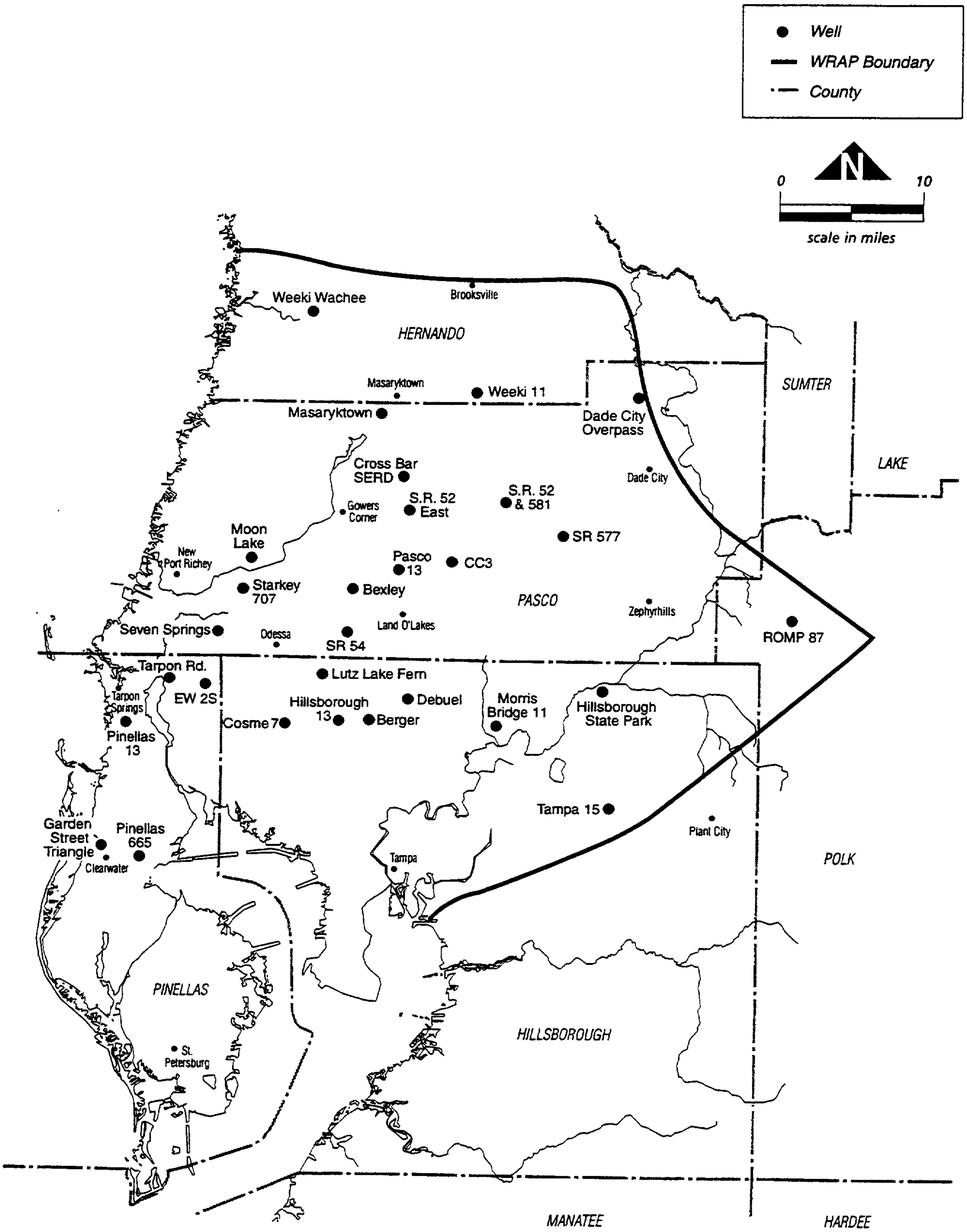


Figure 3-36. Location of Upper Floridan aquifer monitor wells referenced in Section 3.6.1.

within five to seven feet below land surface. Beginning in the early-1960s, water levels declined over 20 feet. An approximate 10 foot recovery is apparent in the 1970s, followed by another decline throughout the 1980s. Figure 3-35 is a hydrograph of the potentiometric level at monitor well Cosme-Odessa No. 7, located within the Cosme-Odessa wellfield, approximately five miles west of the Hillsborough 13 well. The earliest water levels at this well are within 10 to 15 feet below land surface. Beginning in the early portion of the hydrograph, water levels declined nearly 20 feet, with some recovery in the early-1960s. Data from this well ends in the early-1970s.

Figures 3-37 through 3-39 present Upper Floridan aquifer water levels for two wells to the east of the Hillsborough 13 well; the Berger Road and Debuel Road wells, and one well to the northwest of Hillsborough 13; the Lutz Lake Fern Road well. Data from the wells begins in the 1960s, but trends similar to the water levels of the Hillsborough 13 well are apparent. Although not as pronounced as those at the Hillsborough 13 well, similar declines and fluctuations are seen at the Berger Road well, located less than a mile from Section 21. The Debuel Road well, located about four miles from the Hillsborough 13 well, shows less change, although the long-term trends seen in the other two wells are still apparent. The Lutz Lake Fern well, located less than three miles from the Hillsborough 13 well, shows a similar pattern..

Figure 3-40 through 3-42 present hydrographs from three Upper Floridan aquifer monitor wells in eastern Hillsborough County; the Morris Bridge 11 well, the Hillsborough State Park well, and the Tampa 15 Deep well. The period of record for the Morris Bridge well only extends back to the early-1970s, but water level declines of over 10 feet have occurred during the late-1970s and early-1980s. An apparent rise in average water levels is seen in the late-1980s. The Hillsborough State Park hydrograph has a similar period of record, but shows no apparent trends. The Tampa 15 well hydrograph has data beginning in the 1950s, and shows a long-term decline throughout the period of record.

Besides the Hillsborough 13 and Cosme-Odessa No. 7 wells, only three other Upper Floridan aquifer monitor wells were found in the Northern Tampa Bay WRAP area with a period of record extending into the 1940s. The Pasco 13 well, near Drexel in Pasco County, is one of

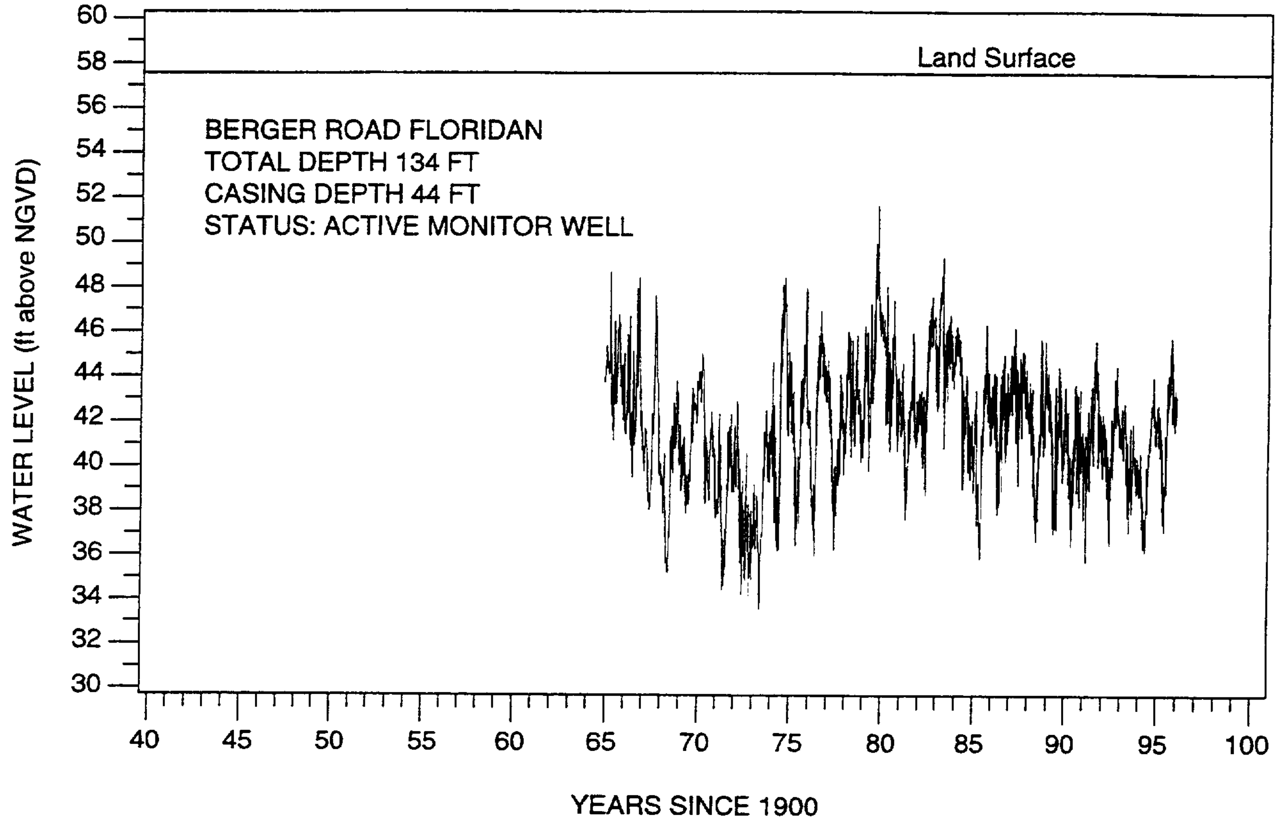


Figure 3-37. Water levels of the Berger Road Floridan aquifer well.

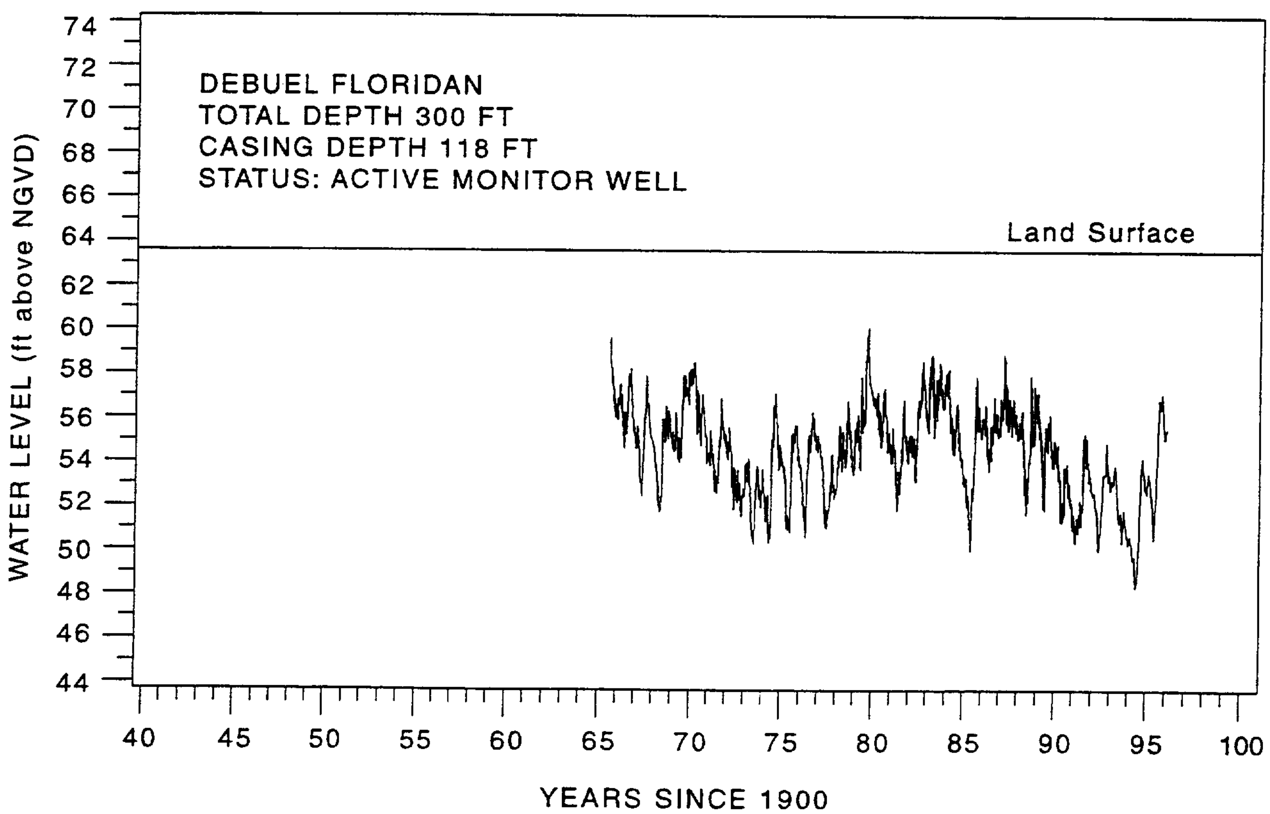


Figure 3-38. Water levels of the Debuel Floridan aquifer well.

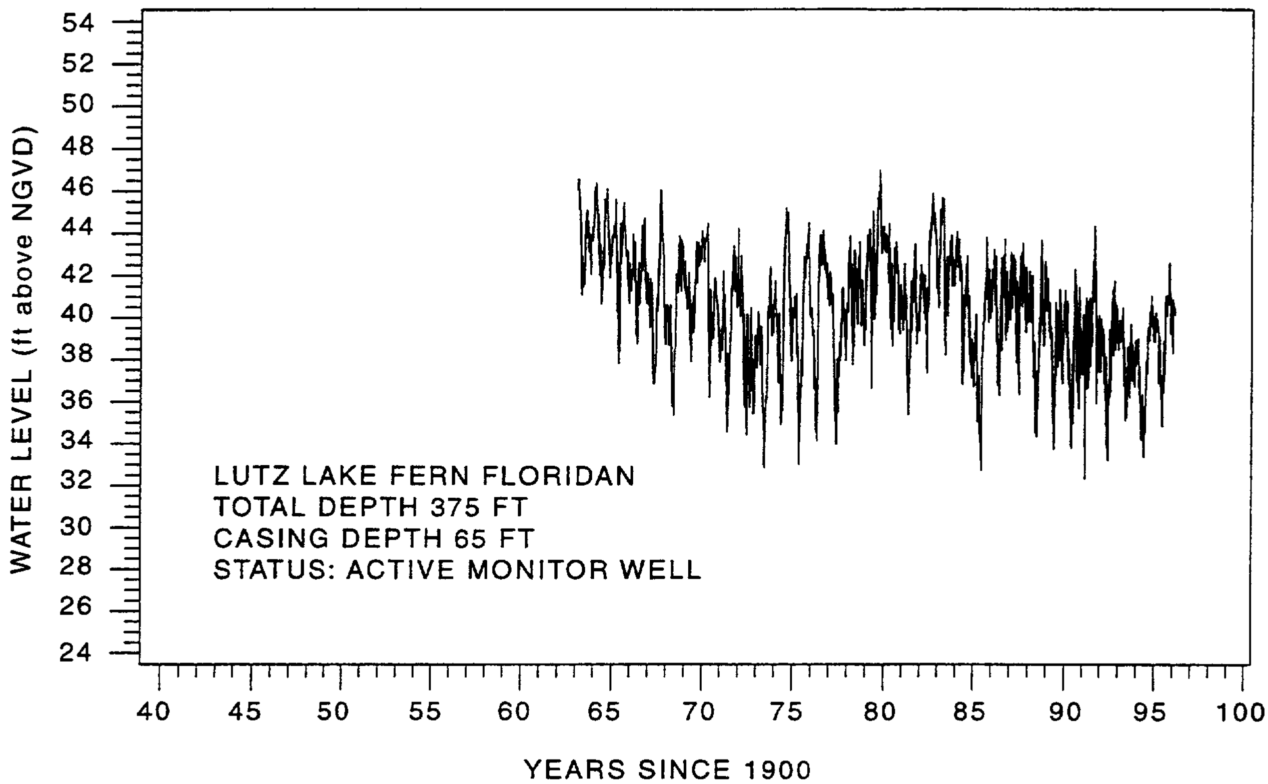


Figure 3-39. Water levels of the Lutz Lake Fern Floridan aquifer well.

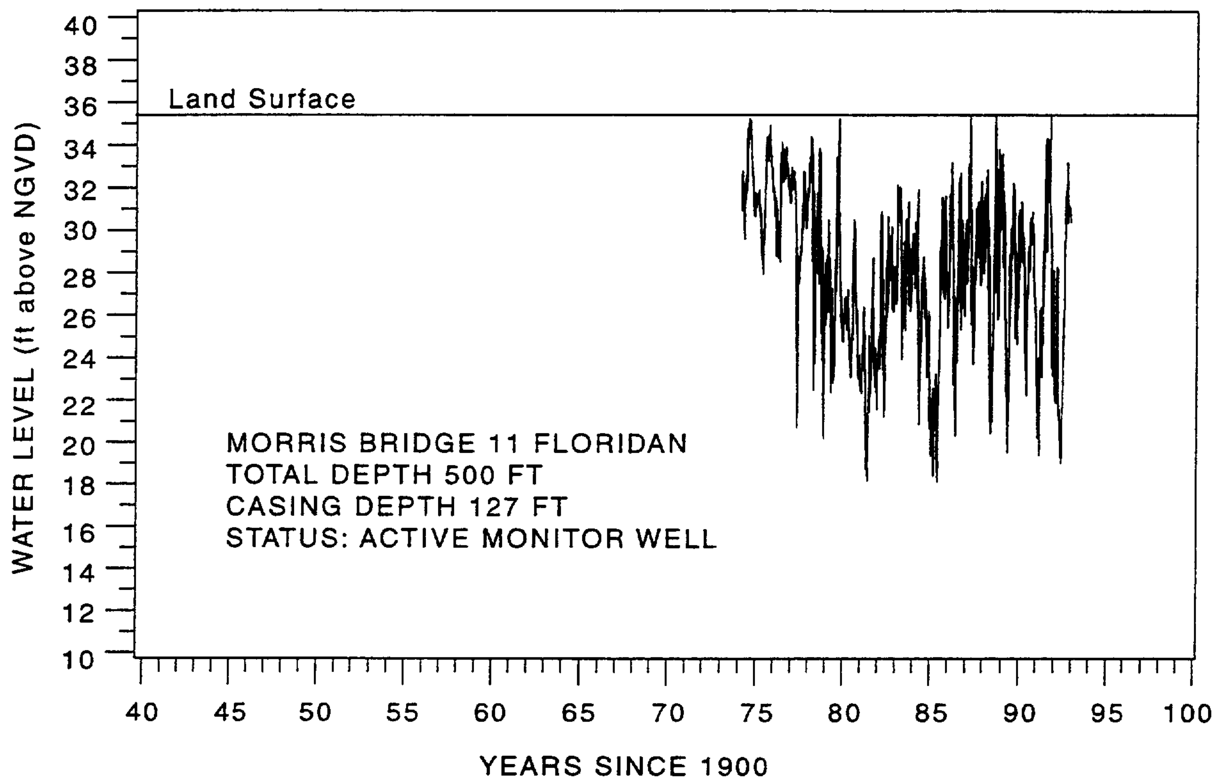


Figure 3-40. Water levels of the Morris Bridge 11 Floridan aquifer well.

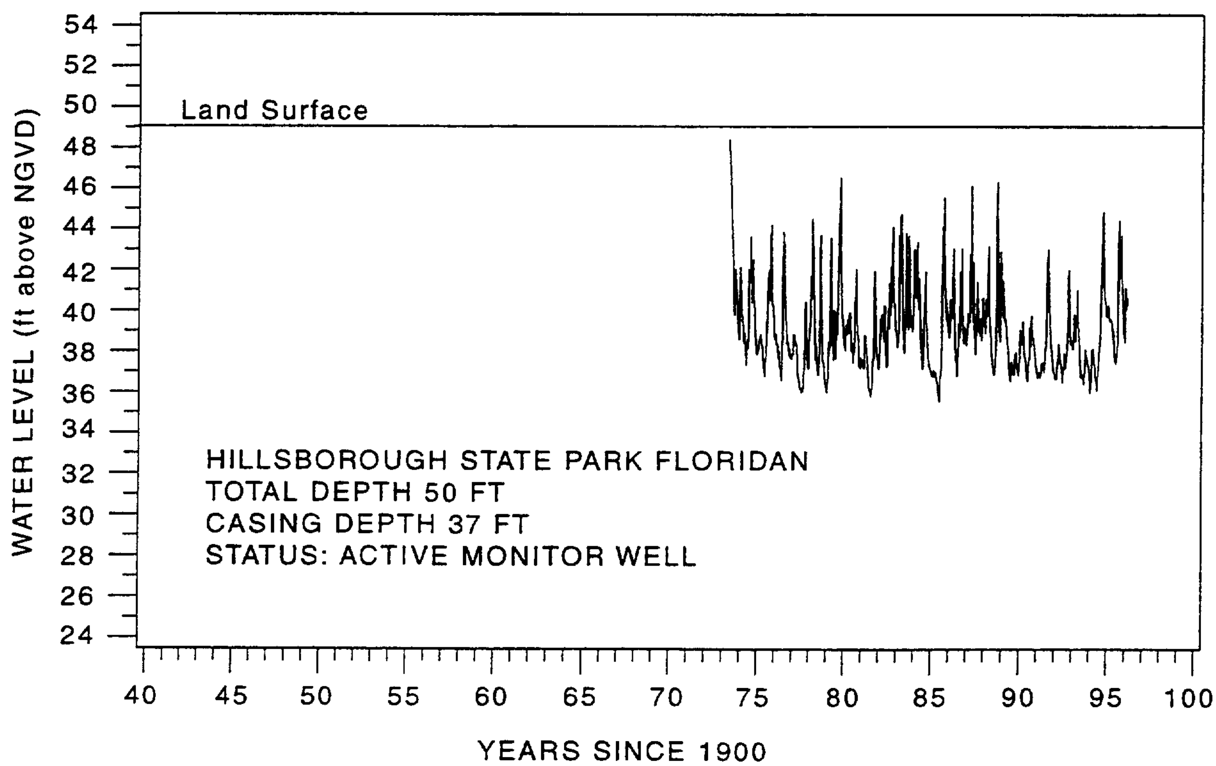


Figure 3-41. Water levels of the Hillsborough State Park Floridan aquifer well.

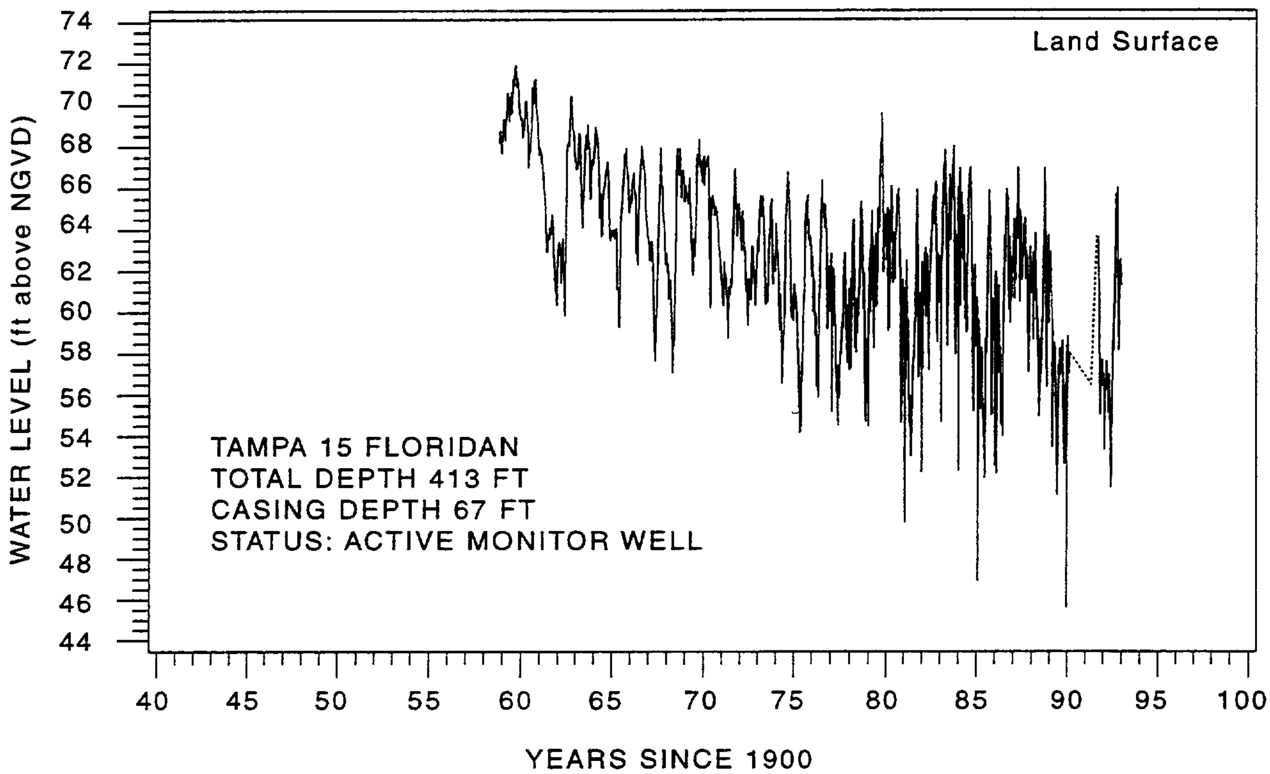


Figure 3-42. Water levels of the Tampa 15 Floridan aquifer well.

these wells (Figure 3-43). Unlike the previously discussed wells, the Pasco 13 well shows no apparent long-term water-level declines.

Figures 3-44 through 3-46 present hydrographs for the Pinellas 13, Garden Street Triangle, and Pinellas 665 wells in Pinellas County. The Pinellas 13 and Garden Street Triangle wells are the other two wells with data beginning in the 1940s, and both are affected by Gulf tides. The Pinellas 13 well is located along the coast near Tarpon Springs, while the Garden Street Triangle and Pinellas 665 wells are located near Clearwater. All three hydrographs are relatively flat, but the Pinellas 13 well shows a slight upward trend during the late-1960s and early-1970s, while the Garden Street Triangle and Pinellas 665 wells show a downward trend during this period. Data is no longer collected at the Pinellas 13 well. The downward trend at the Garden Street Triangle well appears to have leveled, while there is a clear upward trend in the Pinellas 665 well since the early-1980s.

Two Upper Floridan aquifer monitor wells located in northern Pinellas County are the Tarpon Road Deep and Eldridge-Wilde 2S Deep wells (Figures 3-47 and 3-48). Data from both wells begin in the early-1970s. The Tarpon Road well hydrograph has no obvious trend during the period of record, although the Eldridge-Wilde 2S well contains very high fluctuations and periodic trends.

Figures 3-49 through 3-51 present three Upper Floridan aquifer monitor well hydrographs from western Pasco County; the Seven Springs Deep well, the Starkey 707 Deep well, and the Moon Lake Deep well. Data from the first and third wells begins in the mid-1960s, while data from the Starkey well begins in the mid-1970s. A downward trend is apparent in the Seven Springs and Starkey 707 wells, while no trend is clear in the Moon Lake well.

Figures 3-52 through 3-56 show several hydrographs from Upper Floridan aquifer monitor wells located in central Pasco County; the Bexley Deep well, the SR 54 Deep well, the Cypress Creek 3 Deep well, the SERD well, and the SR 52 East well. The period of record of these wells is variable, with the SR54 well beginning in the mid-1960s, and the SERD well beginning in the

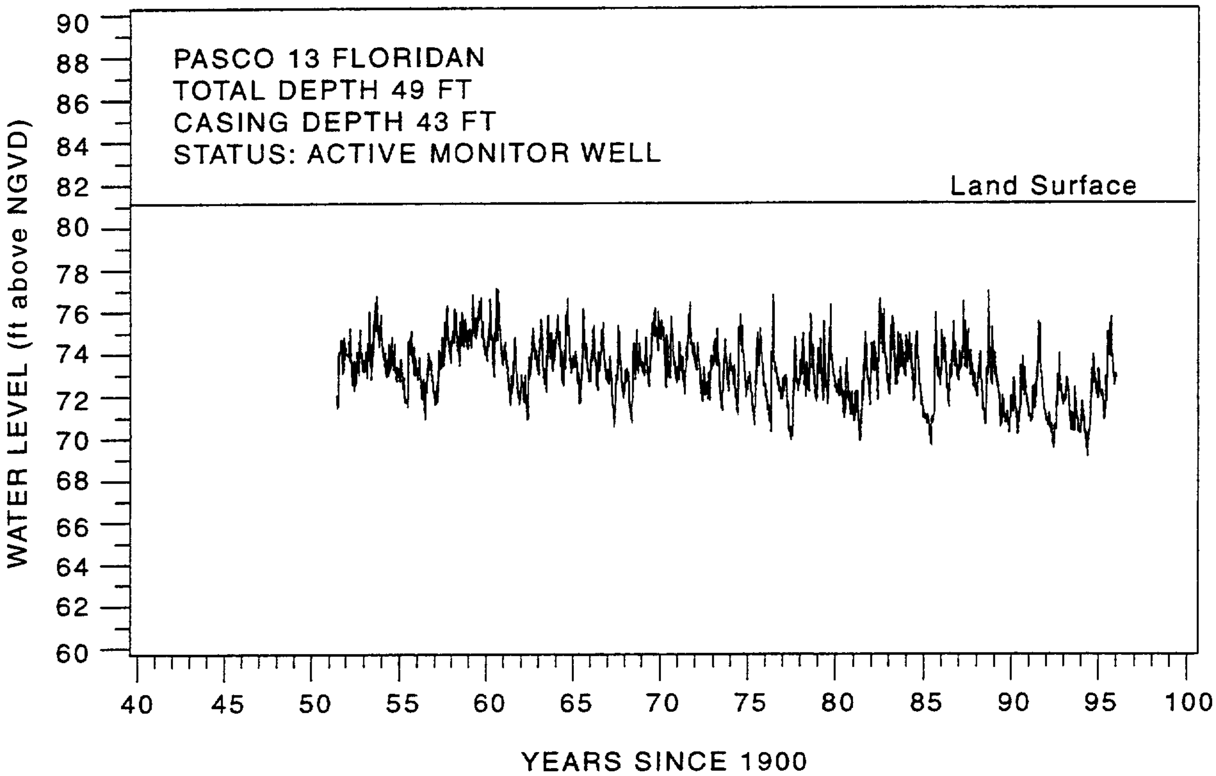


Figure 3-43. Water levels of the Pasco 13 Floridan aquifer well.

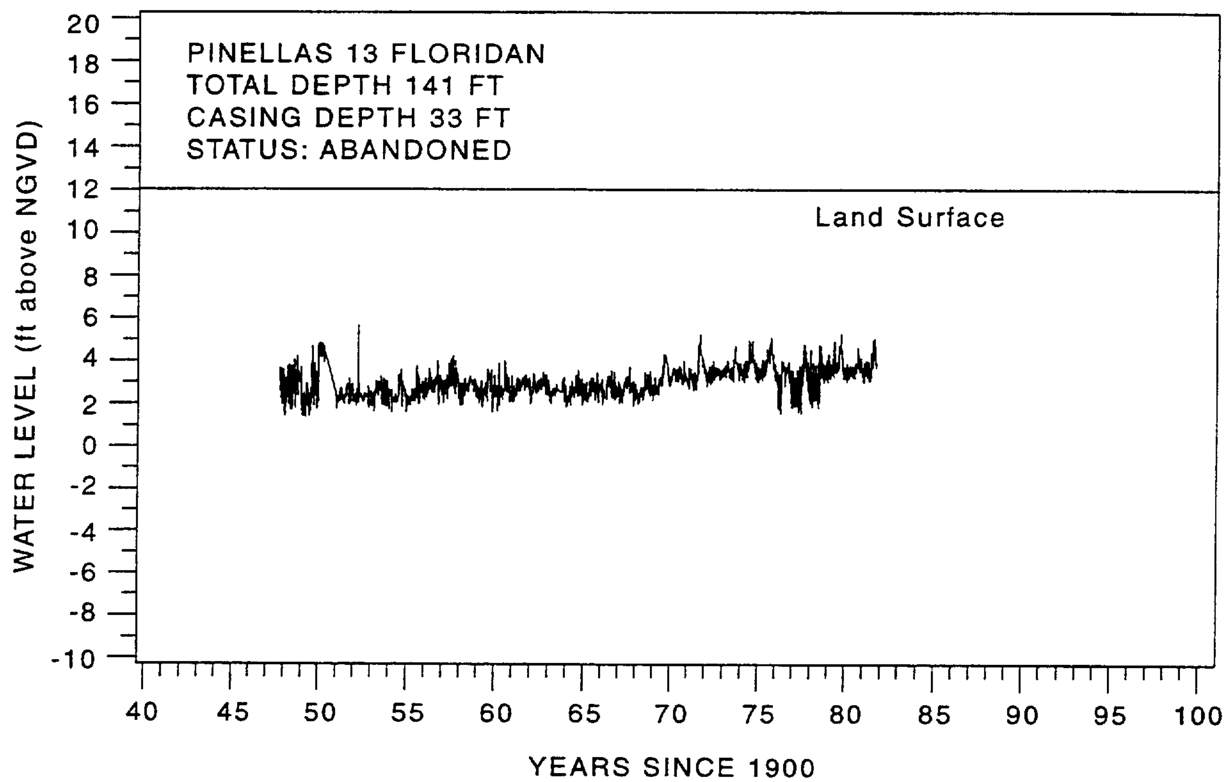


Figure 3-44. Water levels of the Pinellas 13 Floridan aquifer well.

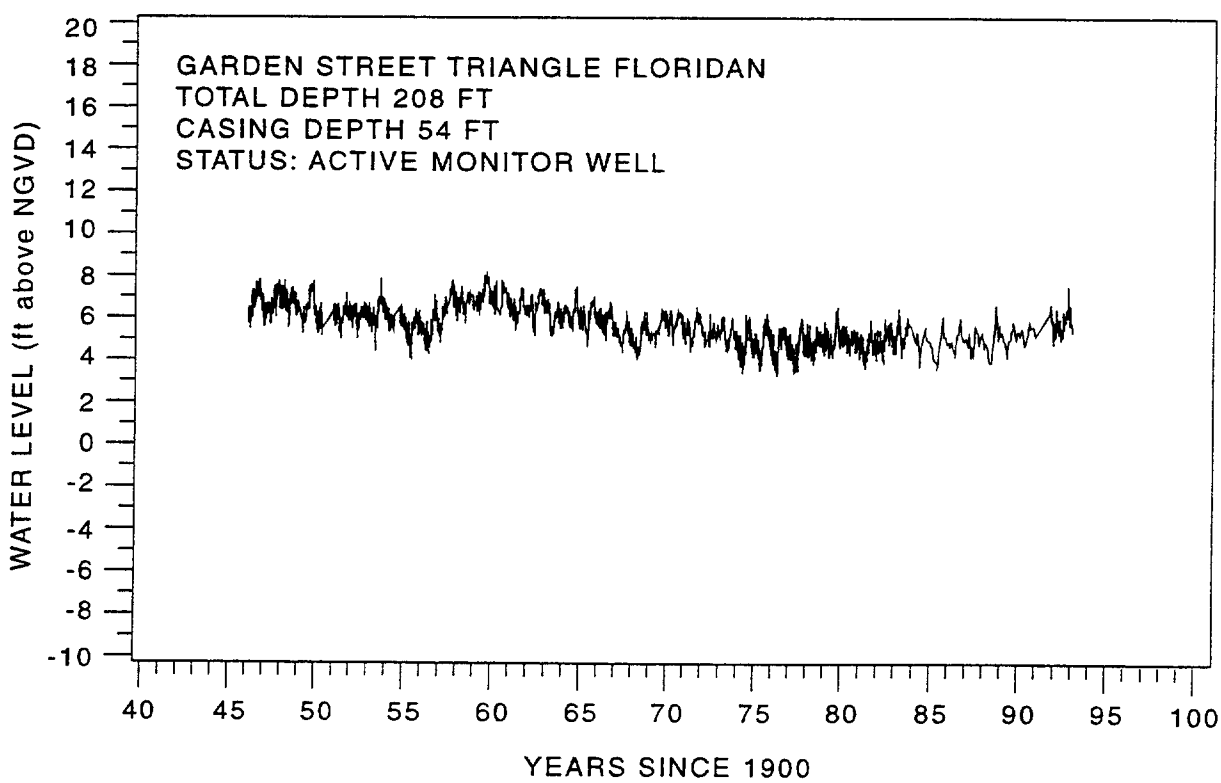


Figure 3-45. Water levels of the Garden Street Triangle Floridan aquifer well.

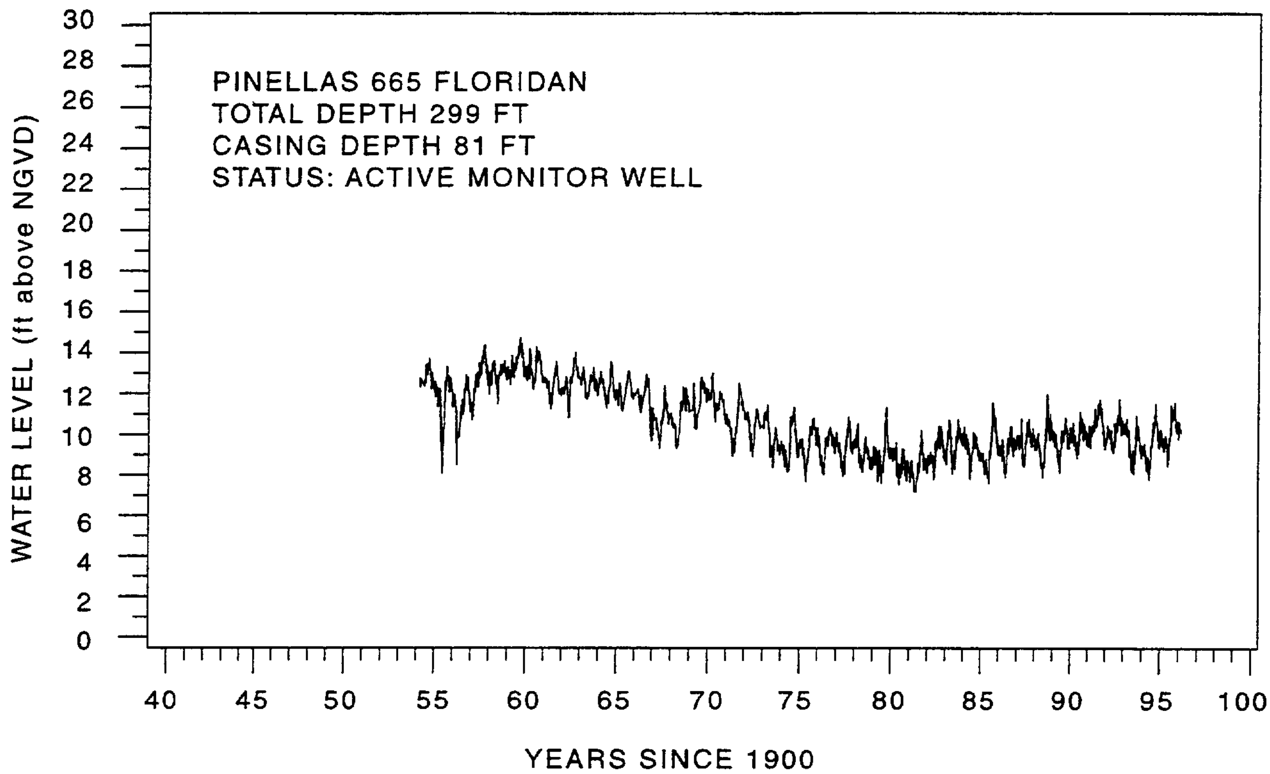


Figure 3-46. Water levels of the Pinellas 665 Floridan aquifer well.

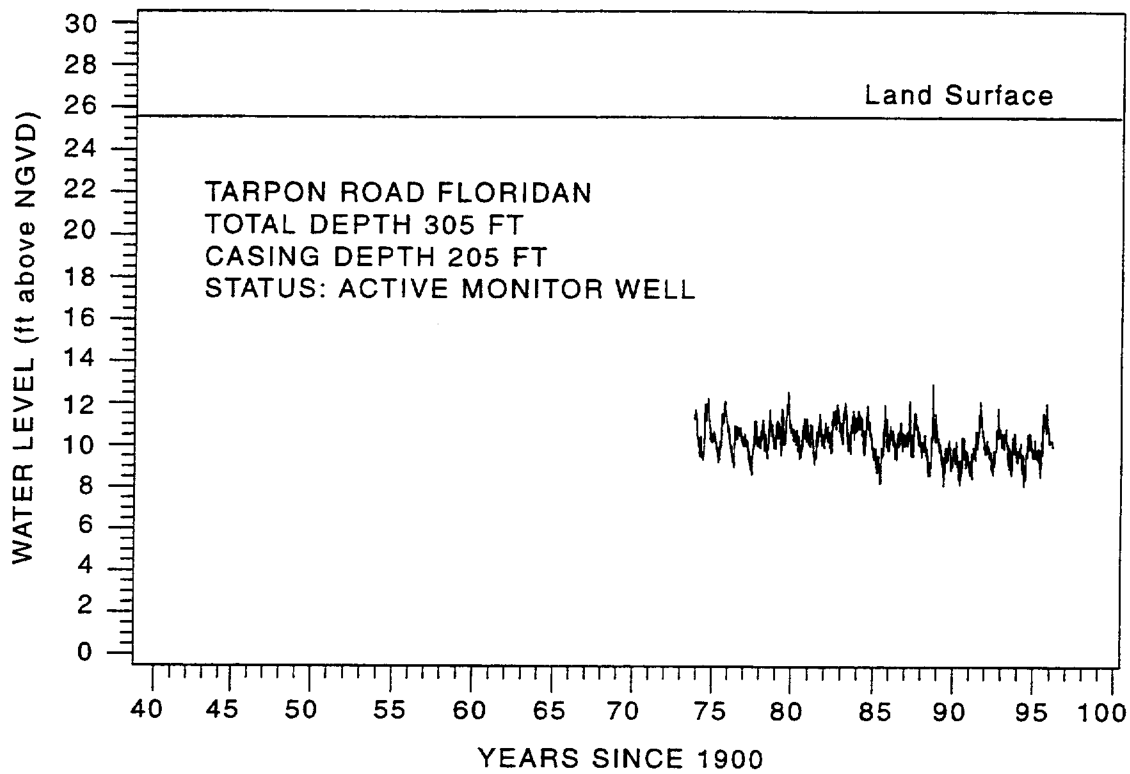


Figure 3-47. Water levels of the Tarpon Road Floridan aquifer well.

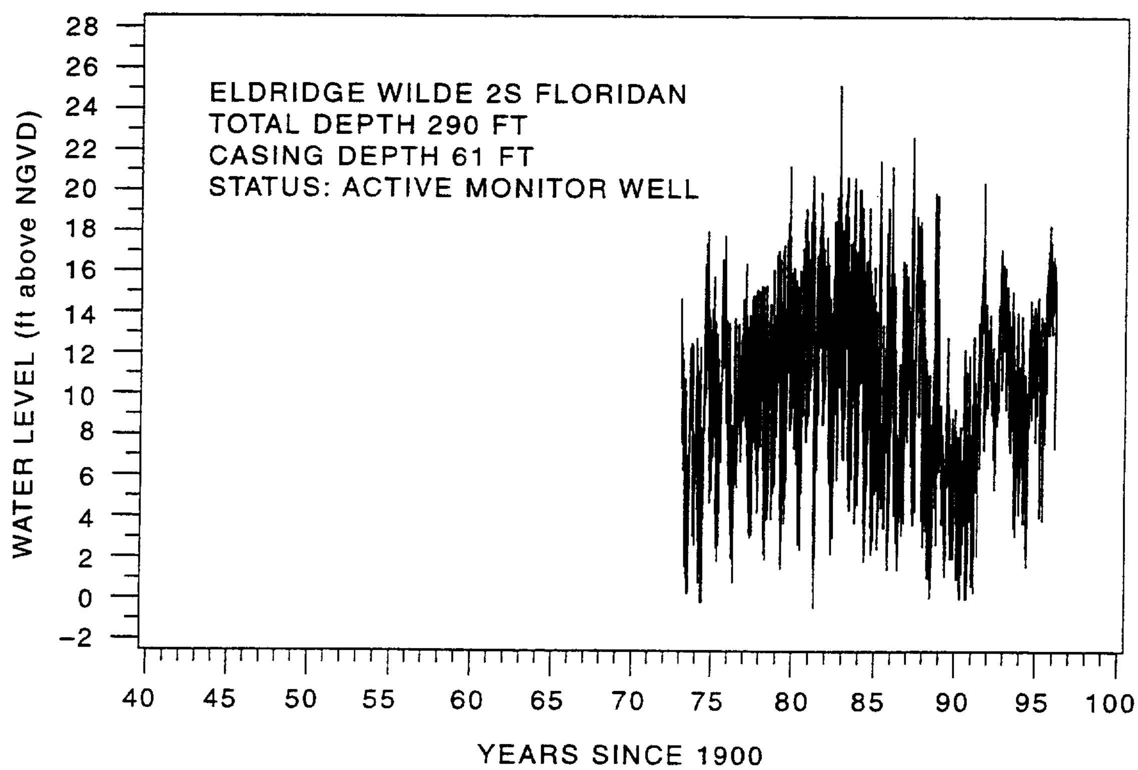


Figure 3-48. Water levels of the Eldridge Wilde 2S Floridan aquifer well.

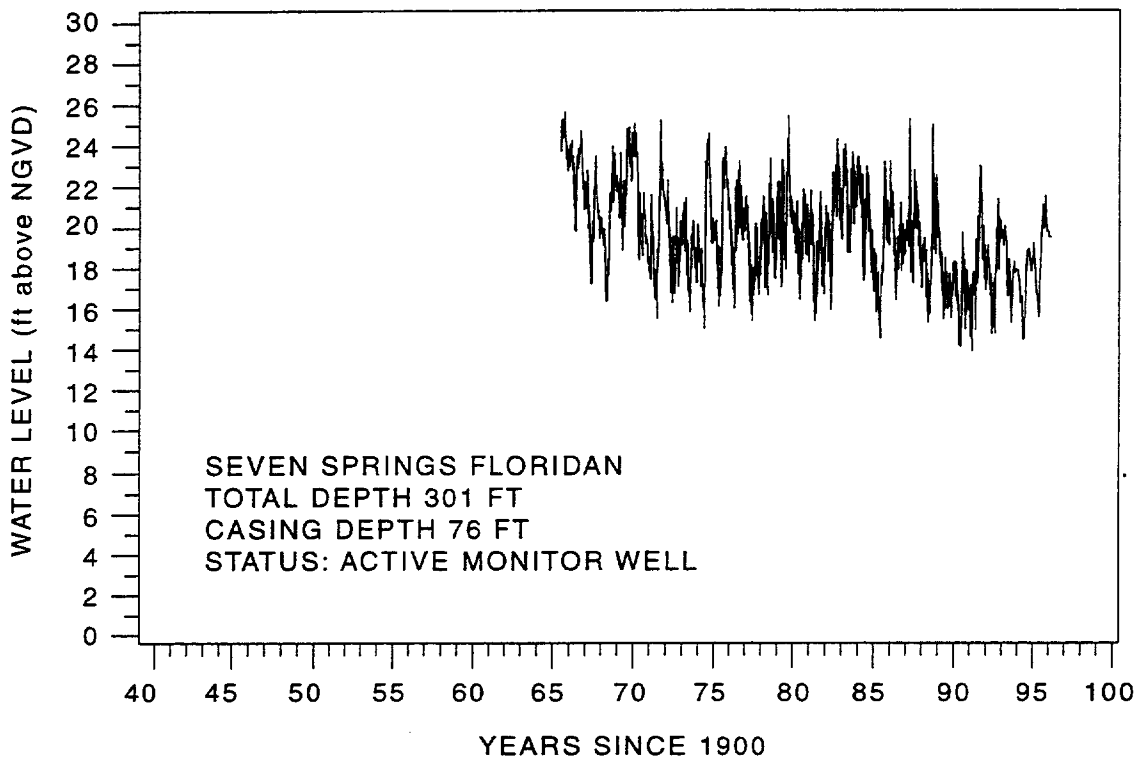


Figure 3-49. Water levels of the Seven Springs Floridan aquifer well.

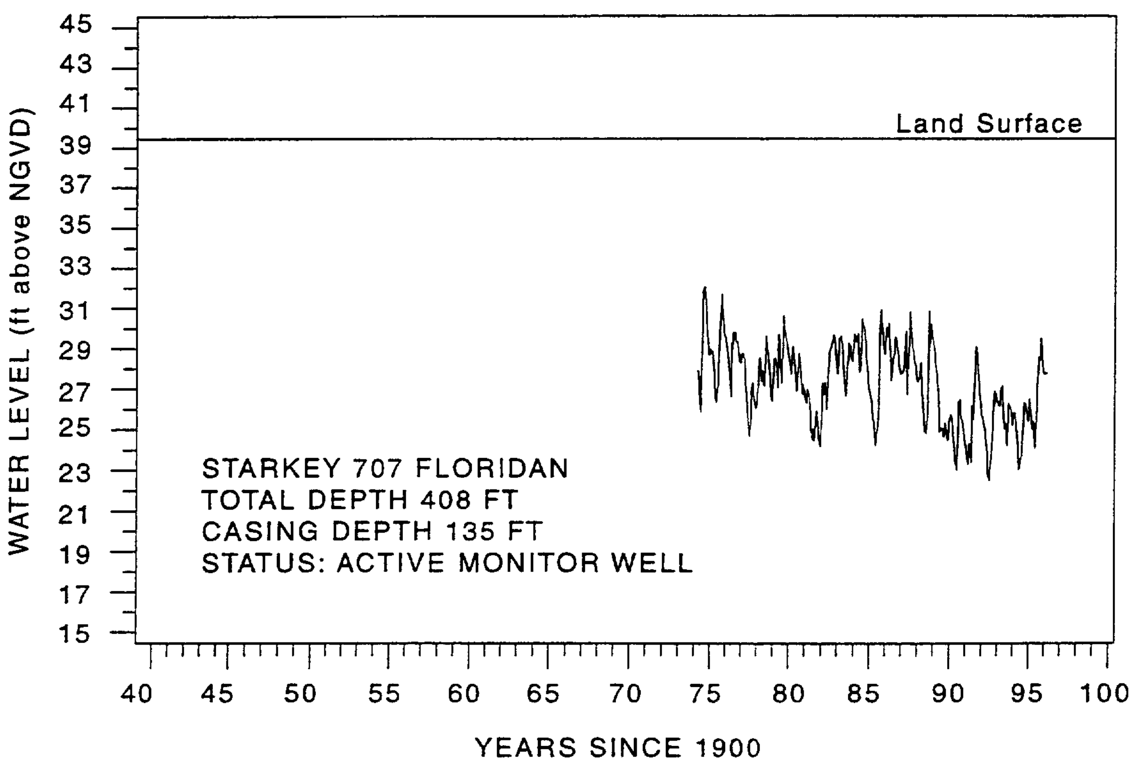


Figure 3-50. Water levels of the Starkey 707 Floridan aquifer well.

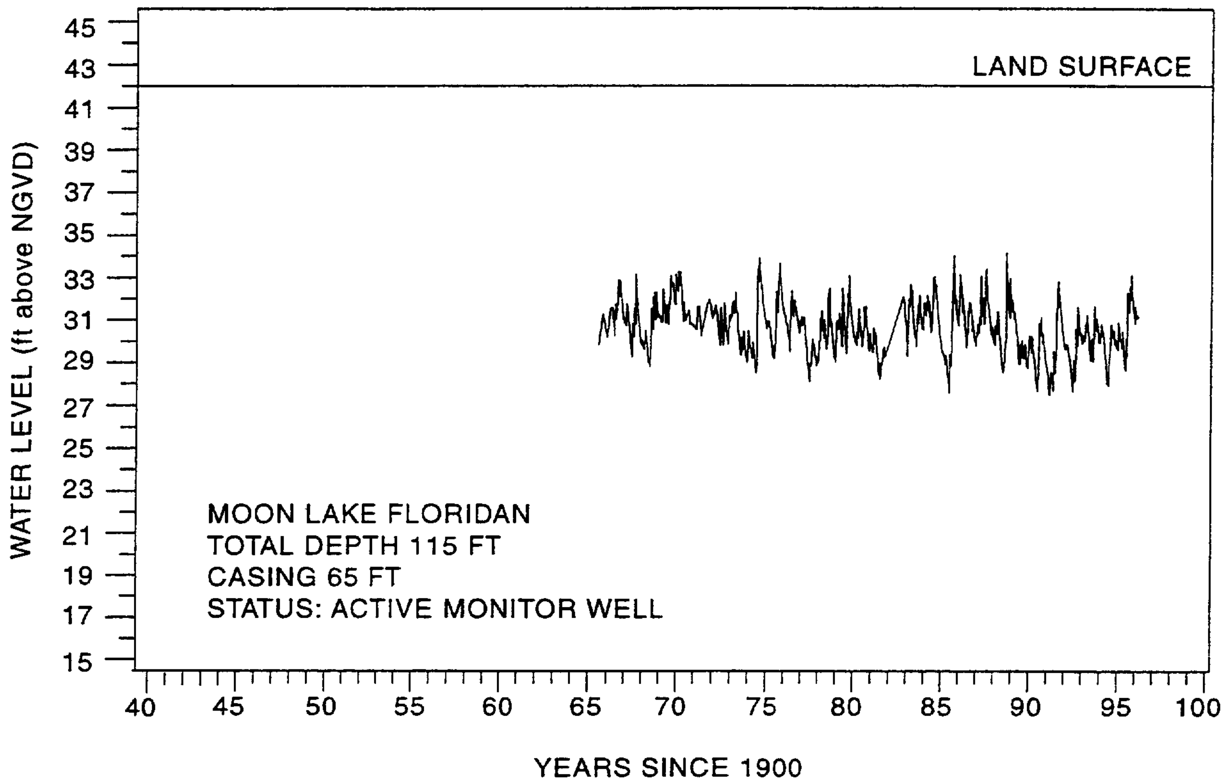


Figure 3-51. Water levels of the Moon Lake Floridan aquifer well.

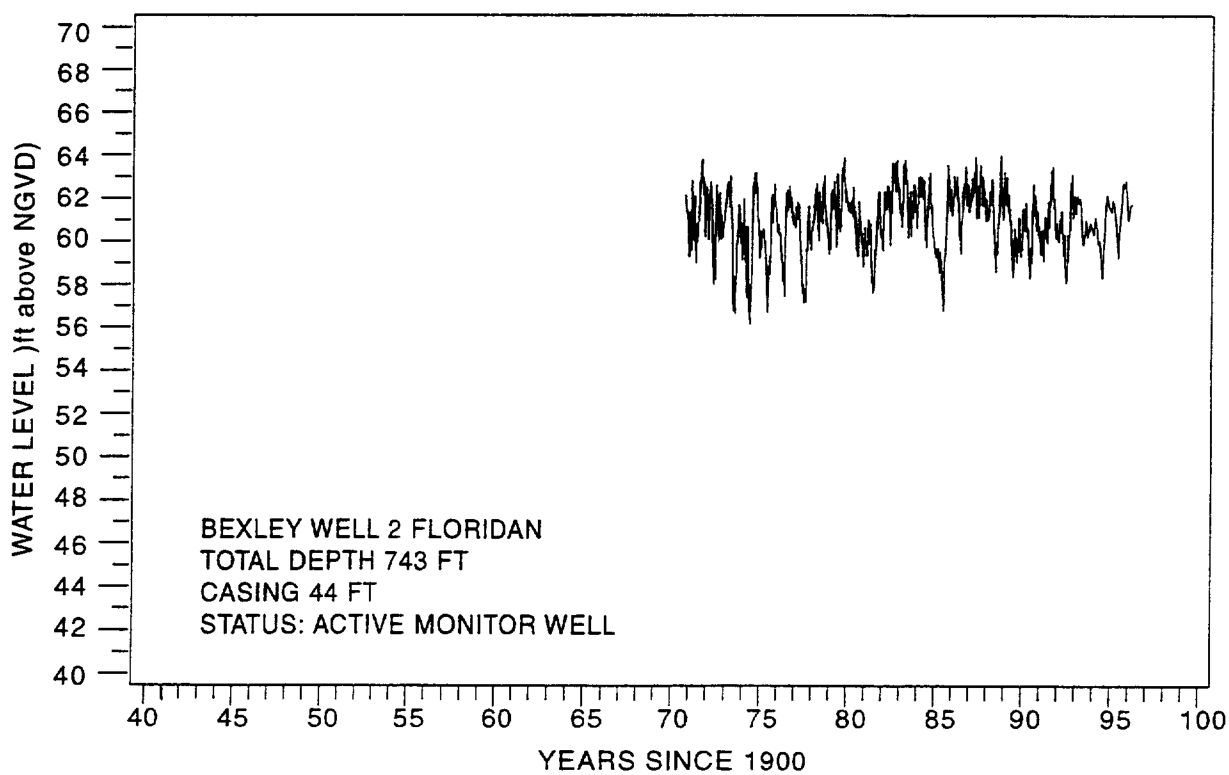


Figure 3-52. Water levels of the Bexley Floridan aquifer well.

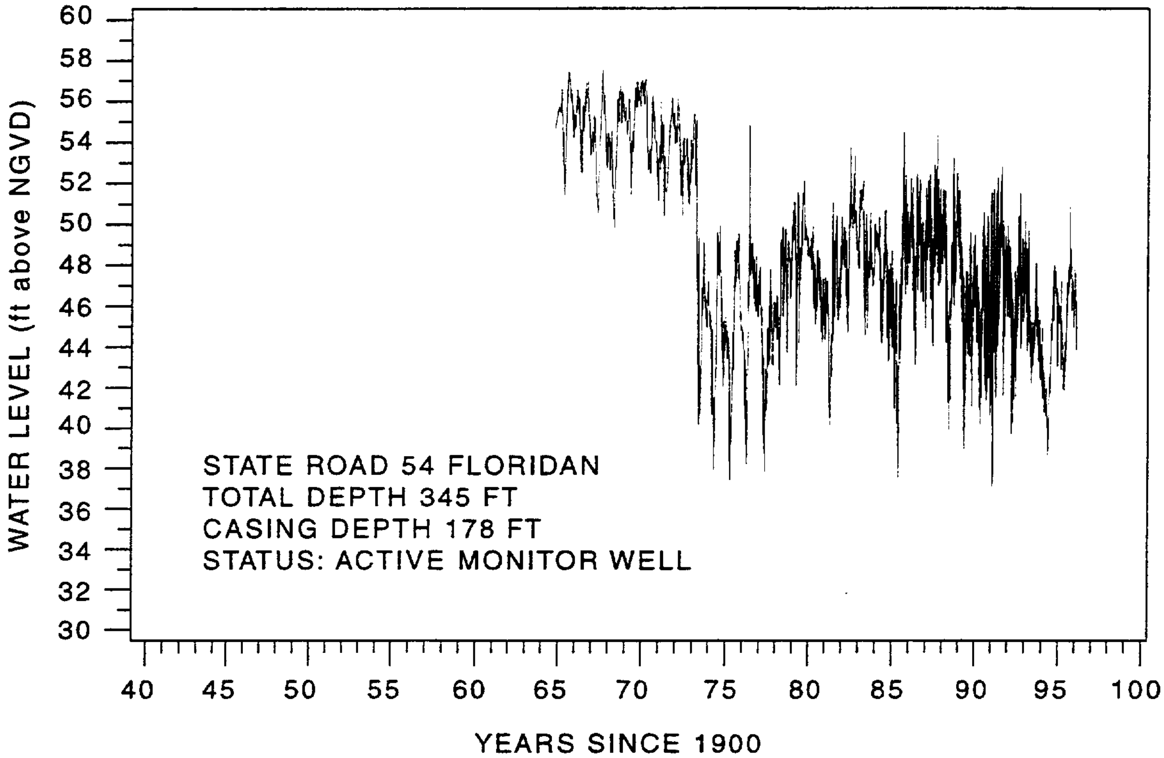


Figure 3-53. Water levels of the SR 54 Floridan aquifer well.

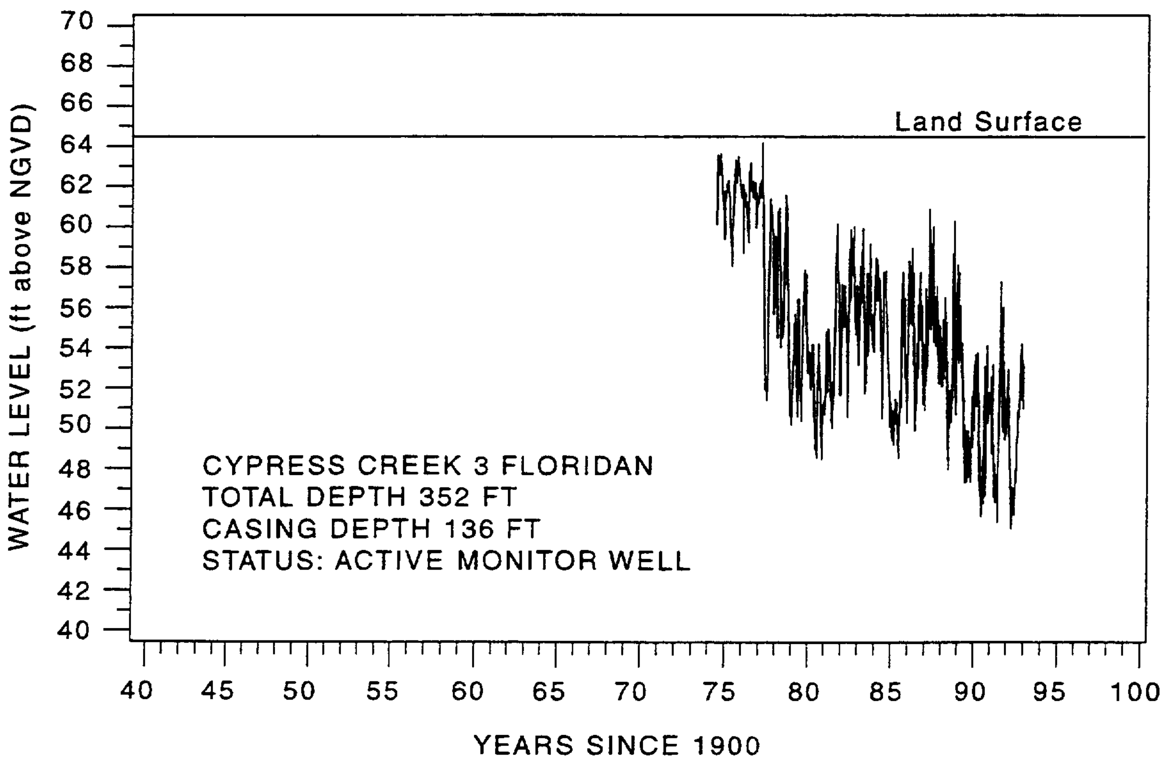


Figure 3-54. Water levels of the Cypress Creek 3 Floridan aquifer well.

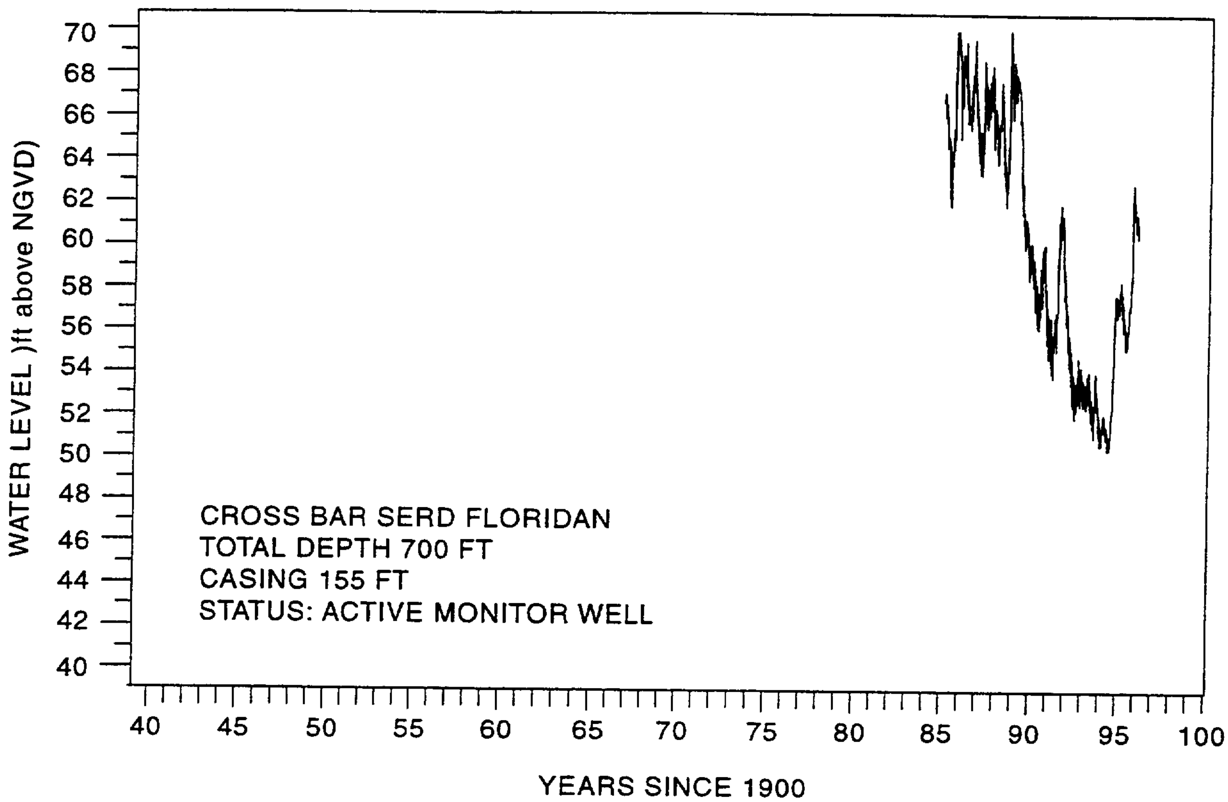


Figure 3-55. Water levels of the Cross Bar SERD Floridan well.

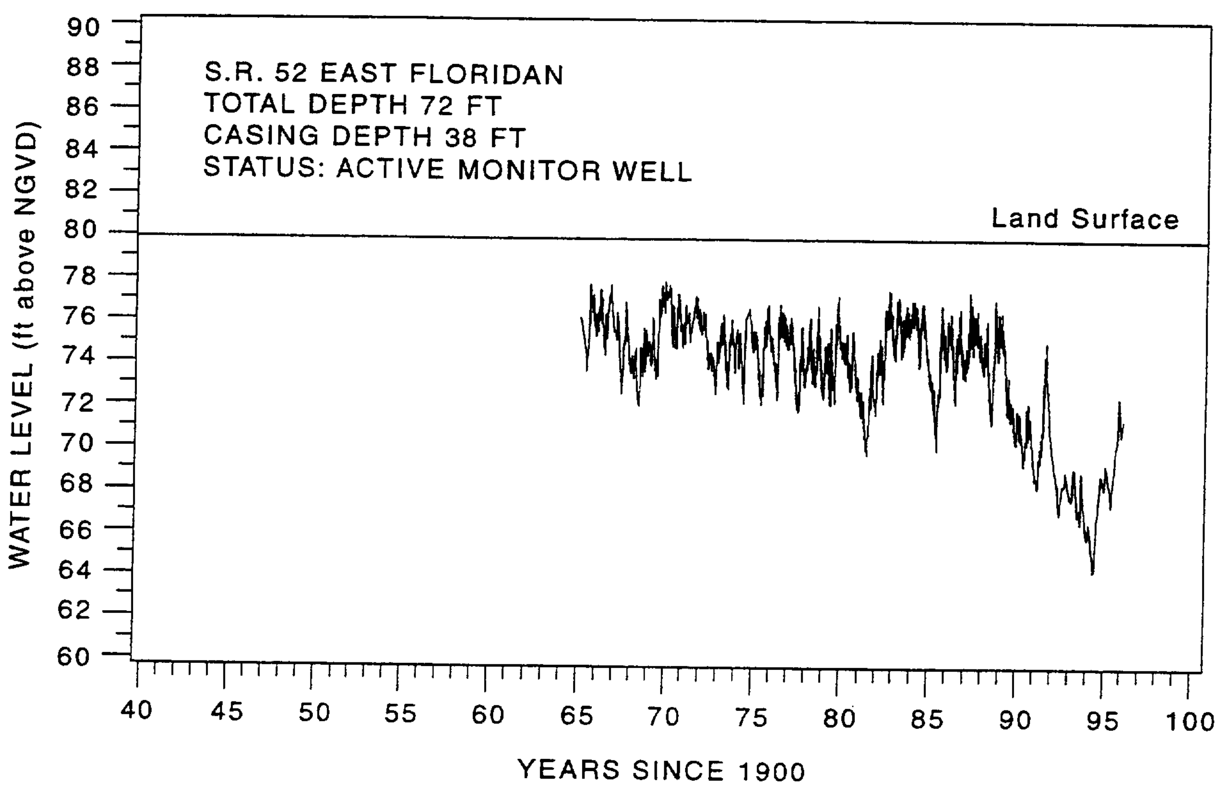


Figure 3-56. Water levels of the SR 52 East Floridan aquifer well.

early-1980s. The Pasco 13 well, discussed earlier, is also in central Pasco County, and has consistent data beginning in the early-1950s. The Bexley well and Pasco 13 well show no obvious trends. The SR 54, Cypress Creek 3, and SERD well hydrographs all show rather dramatic drops in levels, but beginning in different years. The SR 54 hydrograph drops by nearly 10 feet in the early- to mid-1970s, the Cypress Creek 3 hydrograph drops by a similar amount in the late-1970s, while the SERD hydrograph drops by over 10 feet in the late-1980s. It should be noted that the Cypress Creek 3 and SR 54 hydrographs also show an additional decline in the late-1980s, although not nearly to the degree as the SERD well. The SR 52 East well shows no apparent long-term average water-level decline, although there has been a decline in the late-1980s, similar to that of the SERD well.

Three Upper Floridan aquifer wells in eastern Pasco County are the SR 52 and 581 well, SR 577 well, and the Dade City Overpass well (Figure 3-57 through 3-59). The SR 52 and 581 well hydrograph shows a distinct decline from an average of approximately 77 feet NGVD in the 1960s and 1970s down to approximately 72 feet NGVD in the late-1980s. Since the late-1980s, the well has declined to near 60 feet and recovered to around 70 feet. The SR 577 hydrograph shows a similar decline, but with more variability. The Dade City Overpass well, located approximately 10 miles from the first two wells, does not show this trend, although the data has not been collected at this well since 1990.

Three Upper Floridan aquifer monitor wells located in the northwestern portion of the Northern Tampa Bay WRAP area are presented in Figures 3-60 through 3-62; the Masaryktown Deep well in Pasco County, and the Weeki Wachee and Weeki 11 wells in Hernando County. Despite similar names, the latter two wells are located over ten miles from one another. Although water levels of all three wells show high variability, no significant trend is apparent until the late-1980s.

Finally, a hydrograph of an Upper Floridan aquifer monitor well in the portion of Polk County within the Northern Tampa Bay WRAP area is presented in Figure 3-63 (ROMP 87). Data for this well begins in the early-1980s. Although the period of record is limited compared to most other wells presented in this section, no clear trend is observable.

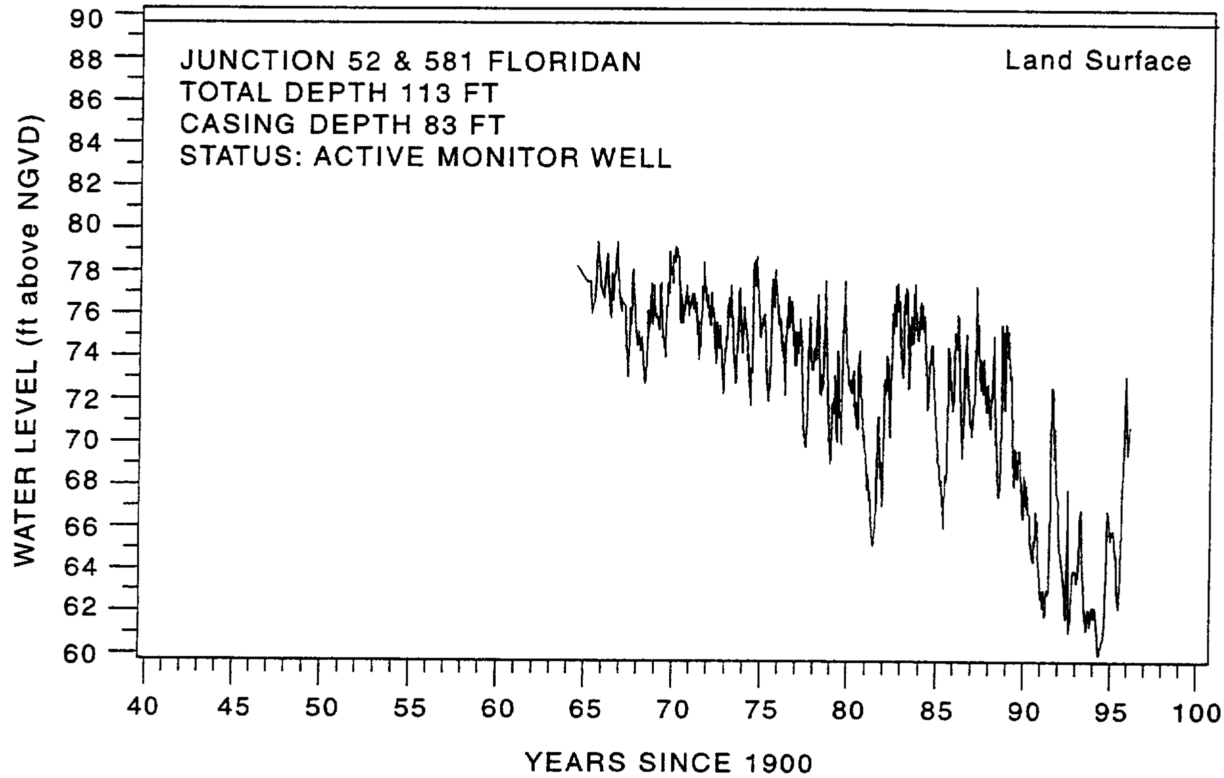


Figure 3-57. Water levels of the Junction 52 & 581 Floridan aquifer well.

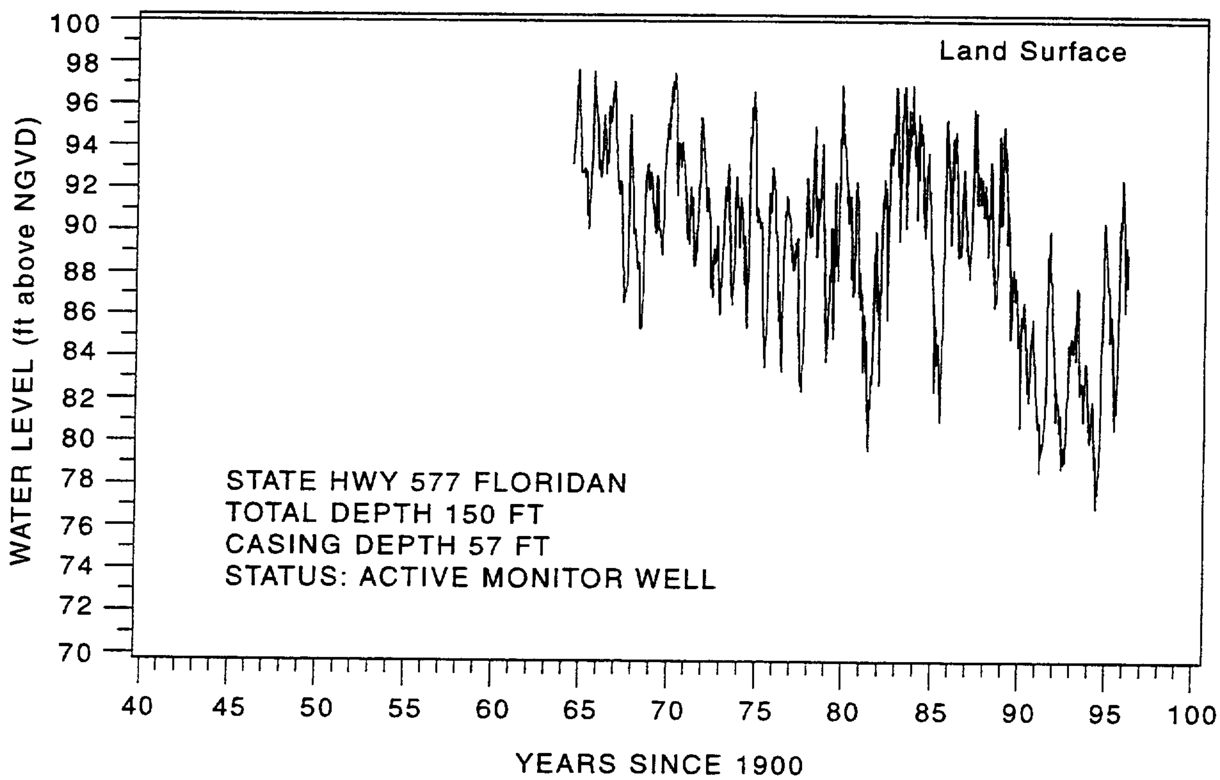


Figure 3-58. Water levels of the State Highway 577 Floridan aquifer well.

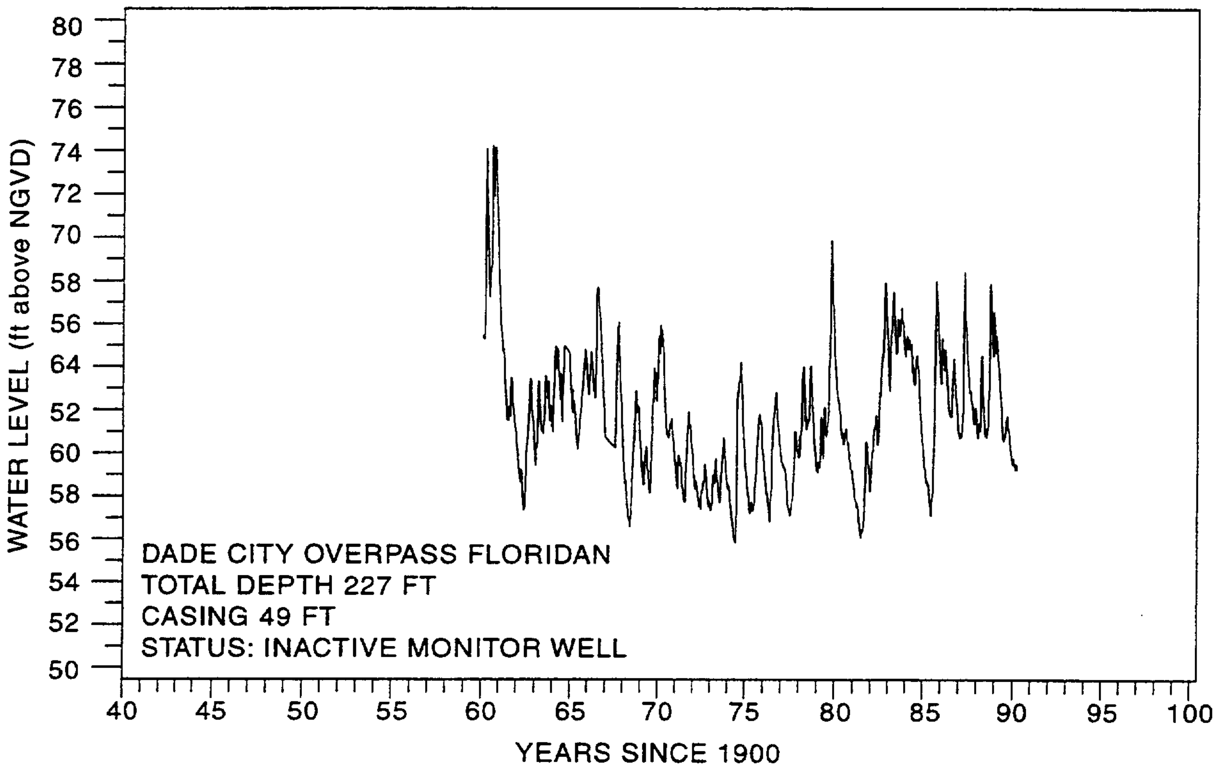


Figure 3-59. Water levels of the Dade City Overpass Floridan aquifer well.

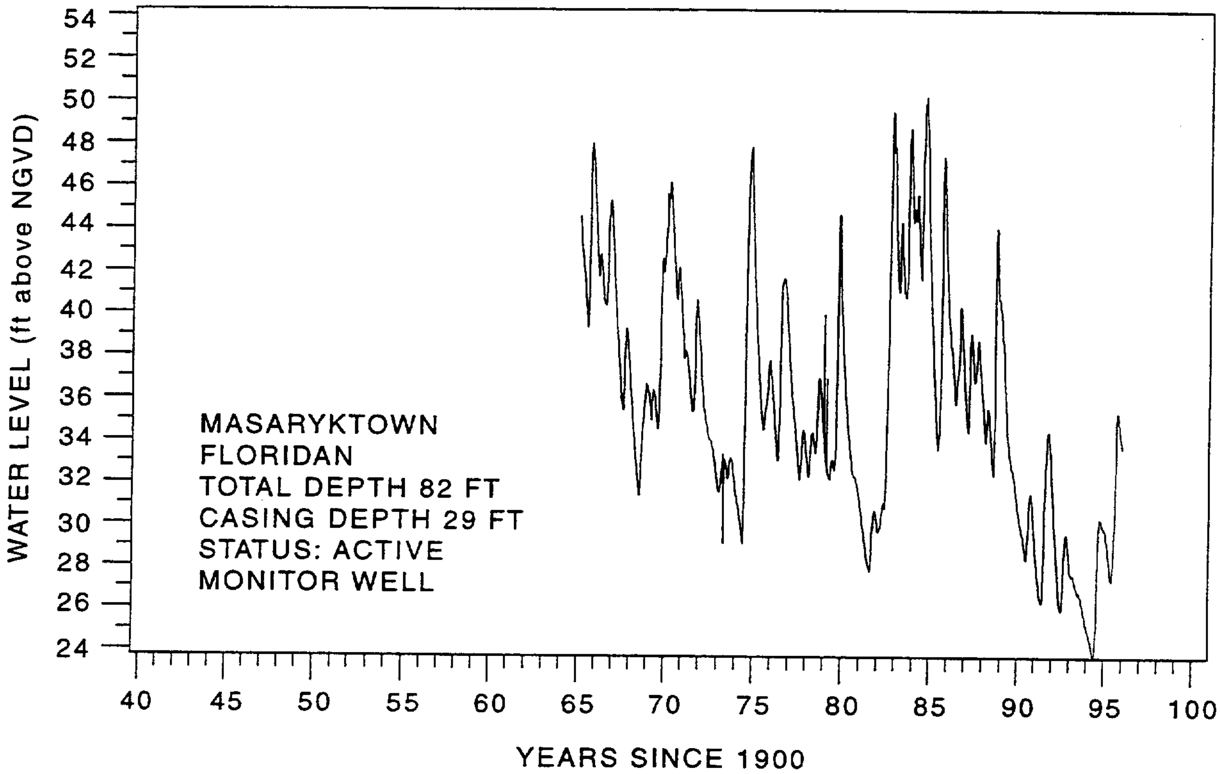


Figure 3-60. Water levels of the Masaryktown Floridan aquifer well.

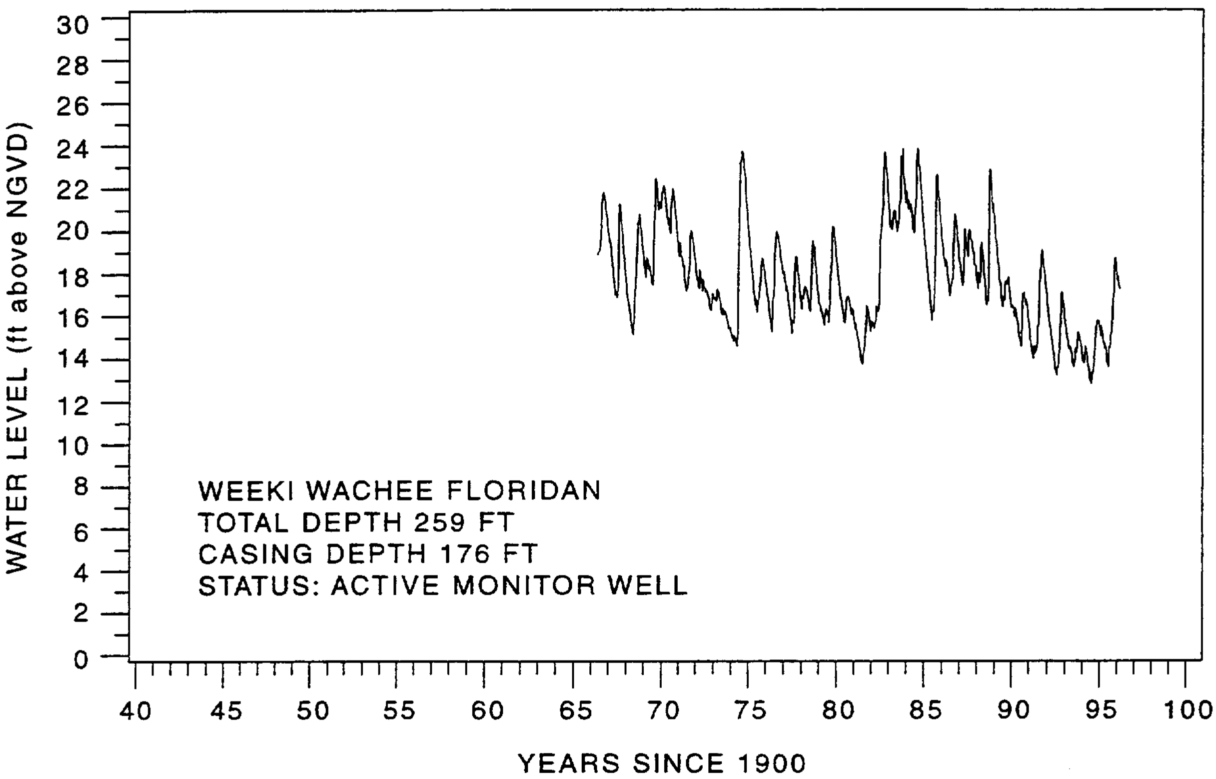


Figure 3-61. Water levels of the Weeki Wachee Floridan aquifer well.

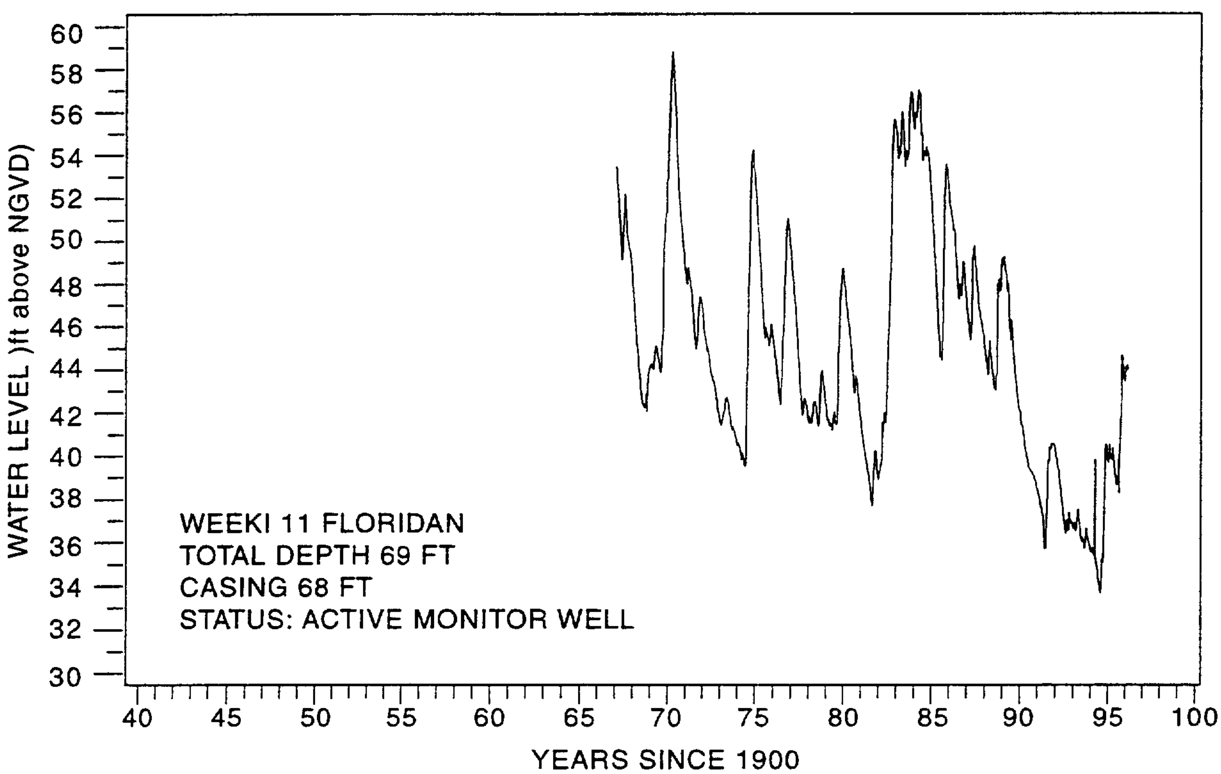


Figure 3-62. Water levels of the Weeki 11 Floridan aquifer well.

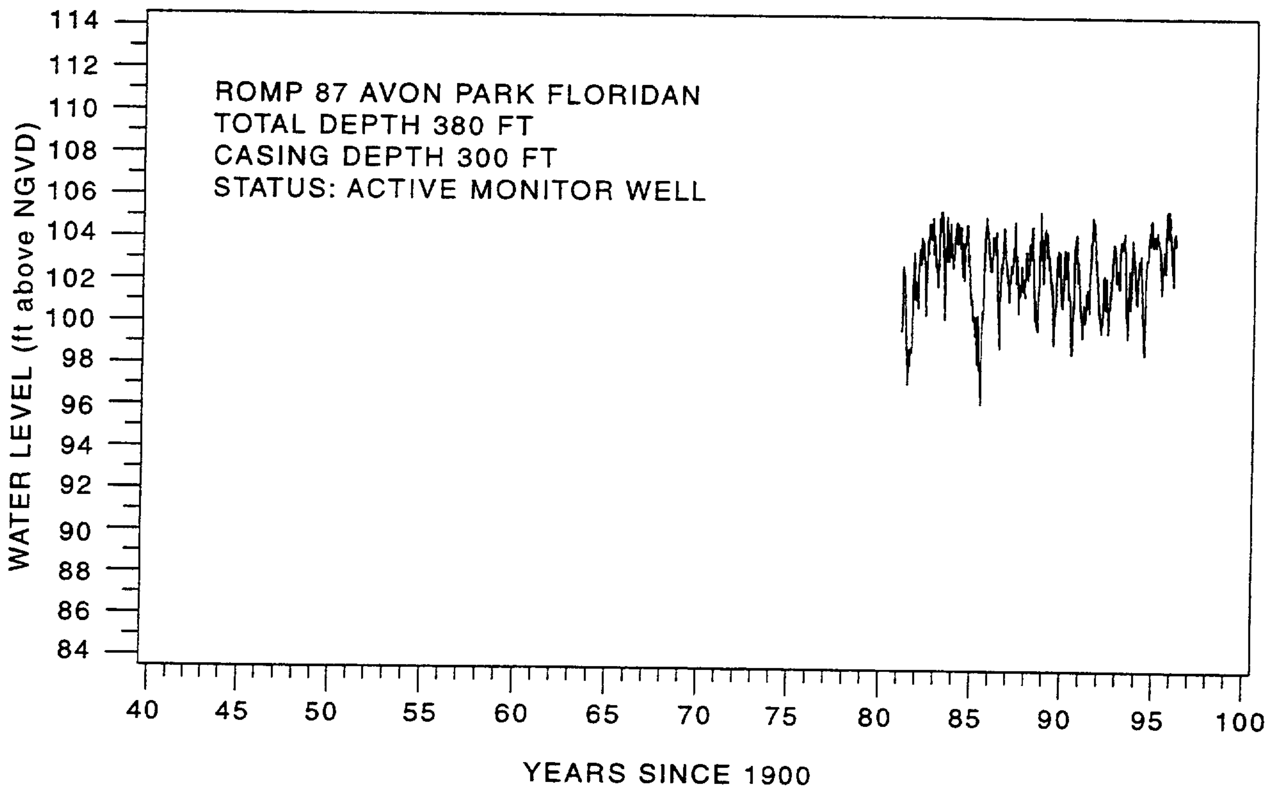


Figure 3-63. Water levels of the ROMP 87 Avon Park Floridan aquifer well.

All of the previous hydrographs, combined with those in the Data Appendices, suggest that although relatively large declines in the potentiometric surface have occurred in various areas of the Northern Tampa Bay WRAP area, the declines are not regional in areal extent. The subregional extent of the declines is difficult to assess from the data throughout the study area because few wells have a period of record longer than twenty years. Although Upper Floridan aquifer declines appear relatively localized, large areas of decline have been created by the overlapping of localized effects within the Northern Tampa Bay WRAP area.

Seasonal and Annual Fluctuation - The fluctuations in many parts of the Upper Floridan aquifer potentiometric surface in the Northern Tampa Bay WRAP area have also increased in magnitude throughout the past 30 years. In this area, the highest water level occurs in either late August or early September, at the end of the rainy season. Water levels then decline from September through November. A short recovery period may occur in November through February. In February or March, water levels in the aquifer begin to decline. The general trend after March is an oscillating decline to the lowest water levels of the year in late May. The recovery at the end of May or beginning of June is rapid and corresponds to the start of the rainy season, when lawn and agricultural irrigation decreases. The recovery extends through the rainy season of June, July and August.

Figure 3-64 shows the seasonal fluctuation at the Hillsborough 13 well for 1954 and 1985. This figure illustrates how seasonal water-level fluctuations have changed in this area, especially in the areas near ground-water withdrawal centers. In 1954, the seasonal fluctuation at the Hillsborough 13 well was approximately two to four feet. In 1985, the fluctuation was over ten feet, despite similar annual rainfall to 1954. Figure 3-34 shows how this seasonal fluctuation has changed with time: during the 1940s and 1950s, the seasonal fluctuation at the Hillsborough 13 well ranged from two to five feet, but beginning in the early-1960s, the range of fluctuation increased to as much as 20 feet. A similar change in fluctuation can be seen in the Cosme-Odessa Well No. 7 in Figure 3-35.

The increase in seasonal fluctuation is observed in many of the Upper Floridan aquifer hydrographs throughout the Northern Tampa Bay WRAP area, even in those that do not

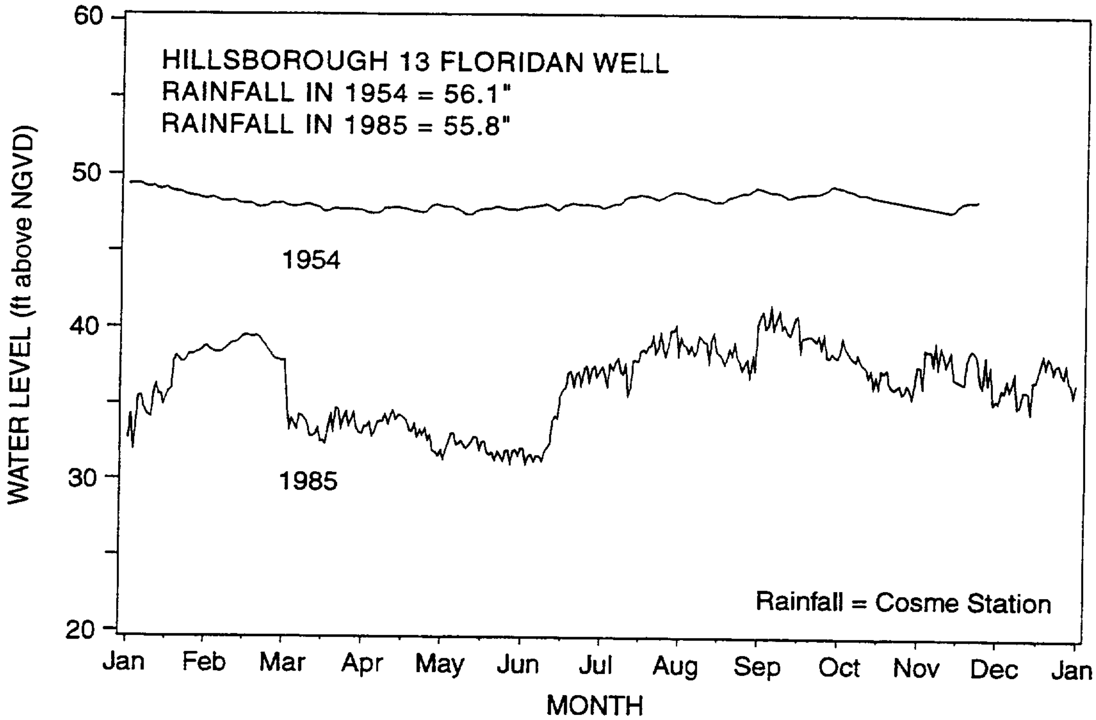


Figure 3-64. Comparison of the 1954 and 1985 Hillsborough 13 Floridan aquifer well water levels.

necessarily show a significant decline in annual-average water level. The Pasco 13 well hydrograph, presented in Figure 3-43, shows an increase in seasonal fluctuation of approximately three feet in the 1950s to about five feet currently, even though no significant downward trend in the annual-average water level is apparent. The SR 52 and 581 well hydrograph, however, shows an increase in seasonal fluctuations from about three to five feet in the 1960s to about six to nine feet in the 1980s (Figure 3-57). The Cypress Creek 3 (Figure 3-54) well shows a similar trend, with an increase in fluctuation of three to four feet in the mid-1970s to over 10 feet currently. While the SR 54 hydrographs shows a similar increase, the increase occurs in the early-1970s rather than the late-1970s. The SR 52 East well (Figure 3-56), located to the west of the SR 52 and 581 well and south of the Cypress Creek 3 well, shows only a slight increase in seasonal fluctuation, increasing from just under four feet in the late-1960s to just over five feet in the 1980s. Other wells, such as the Bexley well, show no apparent change in fluctuation.

The northern wells; Masaryktown, Weeki Wachee, and the Weeki 11 well (Figures 3-60 through 3-62), show wide variability in annual fluctuation, but a long-term change in fluctuation is not apparent. As stated before, the large fluctuation in the Masaryktown and Weeki Wachee wells make visual interpretation of the wells difficult. The Masaryktown well shows the greatest annual fluctuation and long-term variability, with an annual-average fluctuation of over eight feet, and a difference of over 19 feet from the highest to lowest water level of the period of record. The Weeki 11 well has a similar fluctuation. The Weeki Wachee well does not generally fluctuate as much of the previous two, with annual-average fluctuations of approximately three to seven feet. However, the Weeki Wachee well has a period of record range from highest to lowest level of almost nine feet.

The Pinellas County wells presented in Figures 3-44 and 3-48 show no apparent change in annual fluctuations. With the exception of the Eldridge Wilde well, the Pinellas wells presented have relatively low fluctuation, with the Pinellas 13 well averaging under two feet, while the Garden Street Triangle, Tarpon Road, and Pinellas 665 hydrographs have an annual-average fluctuation of just over two feet. The Eldridge Wilde 2S well has a much larger fluctuation, ranging from less than 10 feet to nearly 20 feet throughout the period of record.

Other wells in the area, such as the Tampa 15 Upper Floridan aquifer monitor well (Figure 3-42), also show an increased fluctuation with time, going from approximately 10 feet in the early period of the record to almost double that in current years. Conversely, wells such as the Dade City Overpass and ROMP 87 wells (Figures 3-59 and 3-63) show no apparent change. Note, however, that the period of record of the presented wells differs, so comparisons of changes in fluctuation during similar time periods are not available for all wells.

Surficial Aquifer - Similar to the Upper Floridan aquifer, water levels in the surficial aquifer have also declined in some areas. The observed declines in surficial aquifer water levels are often associated with corresponding Upper Floridan aquifer water-level declines. Increases in seasonal fluctuations are observed in some of the areas of Upper Floridan and surficial aquifer water-level declines. Refer to the Data Appendices for hydrographs of all surficial wells within the Northern Tampa Bay WRAP that were assessed as part of this study.

Long-term Trends - There are few surficial aquifer monitor wells with long-term water level data in the Northern Tampa Bay WRAP area. Therefore, evidence of long-term declines in surficial aquifer water levels are not commonly available. The locations of surficial aquifer wells referenced in this section are shown in Figure 3-65.

The water-level hydrograph for the Van Dyke surficial aquifer monitor well in northwest Hillsborough County is presented in Figure 3-66. This well has one of the two longest periods of record of surficial aquifer monitor wells within the Northern Tampa Bay WRAP area (December 1964 to present). Although several short-term trends can be seen, the Van Dyke surficial aquifer well does not appear to have a long-term water-level trend. There does appear to be a downward trend beginning in the late-1960s and 1980s, as well as a recovery during the mid- to late-1970s, but no obvious long-term trend is apparent. The Hillsborough 13 surficial aquifer monitor well (Figure 3-67) has data extending before this time, although the data are not as consistent. A decline similar to that seen in the hydrograph of the adjacent Hillsborough 13 Upper Floridan aquifer monitor well (Figure 3-34) is apparent. Both of the Hillsborough 13 wells are located within the Section 21 wellfield. Water levels in the surficial monitor well drop from an average of over 50 feet NGVD in the early-1960s to an average of about 40 feet NGVD

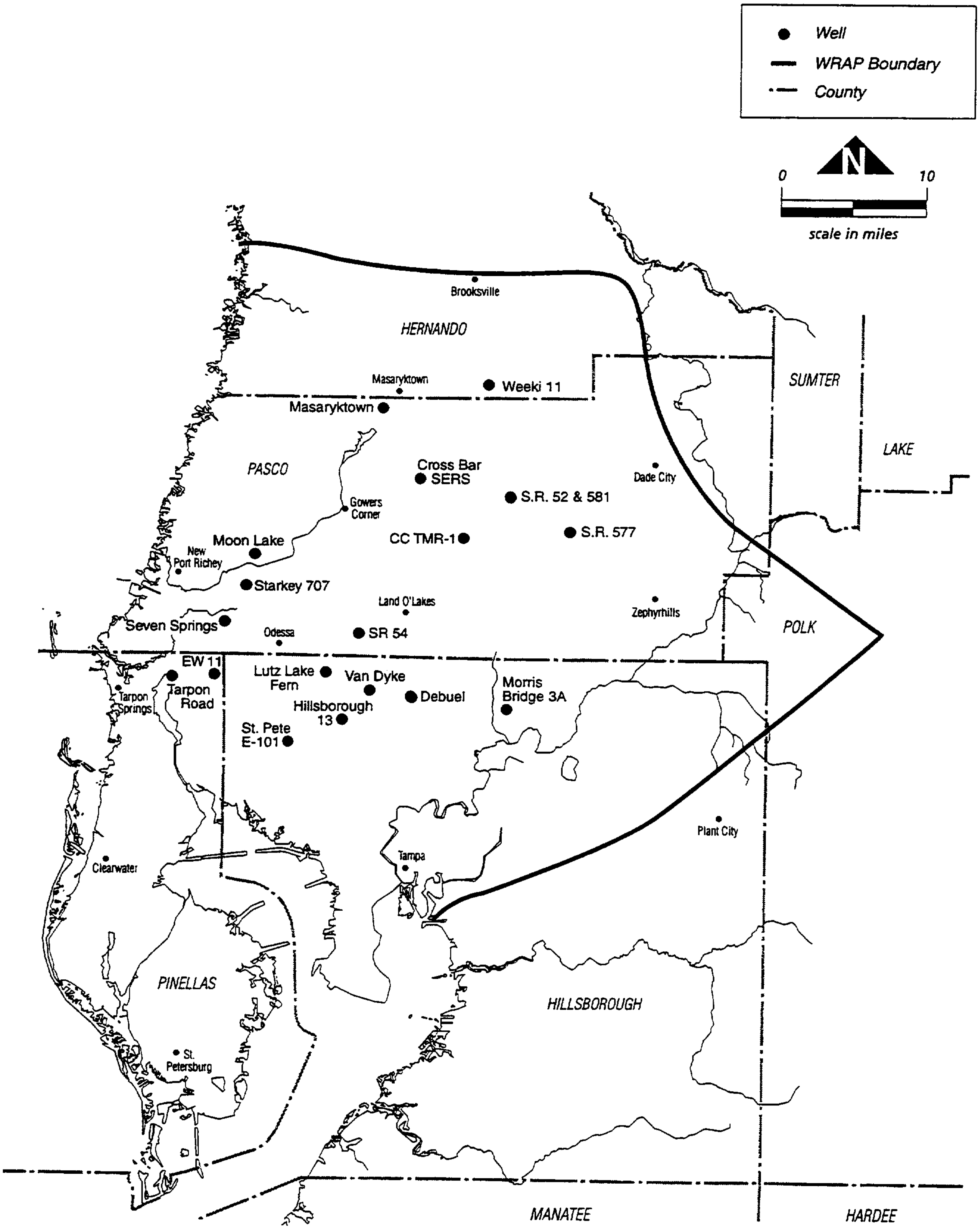


Figure 3-65. Location of surficial aquifer monitor wells referenced in Section 3.6.1.

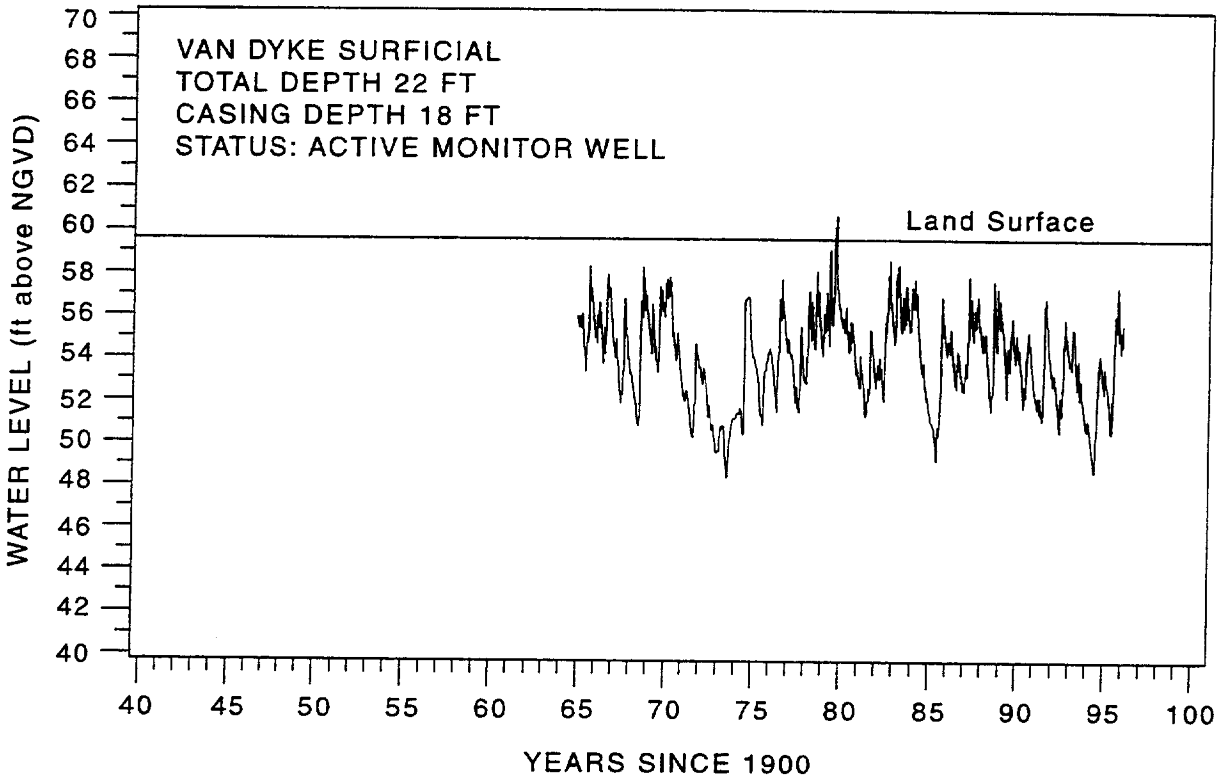


Figure 3-66. Water levels of the Van Dyke Road surficial aquifer well.

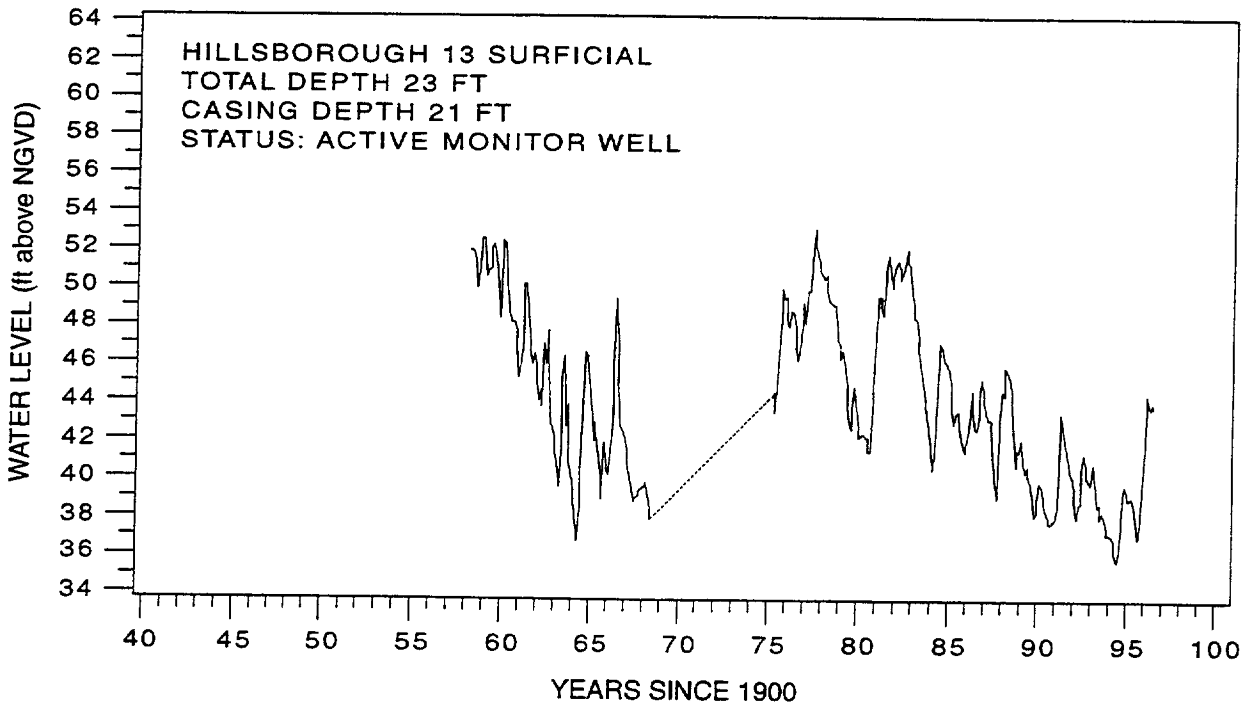


Figure 3-67. Water levels of the Hillsborough 13 surficial aquifer well.

currently. The nearby Debuel Road surficial aquifer well (Figure 3-68), follows a similar pattern, although this well does not have an extensive period of record. The apparent downward trend seen during the 1980s is more obvious in the Hillsborough 13 surficial aquifer monitor well. Similar trends are not apparent in the Lutz Lake Fern surficial aquifer well (Figure 3-69).

Figure 3-70 is a hydrograph from the E-101 surficial aquifer monitor well located to the south of the above wells. The E-101 monitor well shows no evidence of long-term trends. Figure 3-71 presents the water-level hydrograph for the Morris Bridge 3A surficial aquifer well in Northeast Hillsborough County. A downward trend is apparent until the early 1990s in this hydrograph, with an average of 34 to 35 feet NGVD in the mid-1970s, compared to an average of 31 to 32 feet NGVD in the late-1980s. Water levels have recently recovered.

Few surficial aquifer monitor wells exist within Pinellas County. Figures 3-72 and 3-73 present the hydrographs for the Tarpon Road and Eldridge Wilde 11 surficial aquifer monitor wells, located in northern Pinellas County. Periodic upward and downward trends are evident, but no long-term trends are apparent.

Figures 3-74 through 3-82 are surficial aquifer hydrographs of selected monitor wells in Pasco County, and Figure 3-83 is a surficial aquifer hydrograph of a monitor well in Hernando County. The Moon Lake surficial aquifer monitor well in western Pasco County (Figure 3-74) has the third longest period of record for the surficial aquifer within the Northern Tampa Bay WRAP area, beginning in June 1965. No long-term trends are obvious in this hydrograph. Figures 3-75 through 3-77 are hydrographs for the Starkey 707, Seven Springs, and SR 54 surficial monitor wells, respectively. The Starkey well shows evidence of decline through its period of record, while any trend in the Seven Springs surficial well is not as obvious. The SR 54 well has no clear trend, although the water level does drop below the bottom of the well periodically (as evidenced by the flat lines in the hydrograph), so any downward trend is difficult to observe.

Figures 3-78 and 3-79 present hydrographs of the SR 52 and 581 and State Highway 577 surficial aquifer monitoring wells, respectively. Both wells are located in east-central Pasco

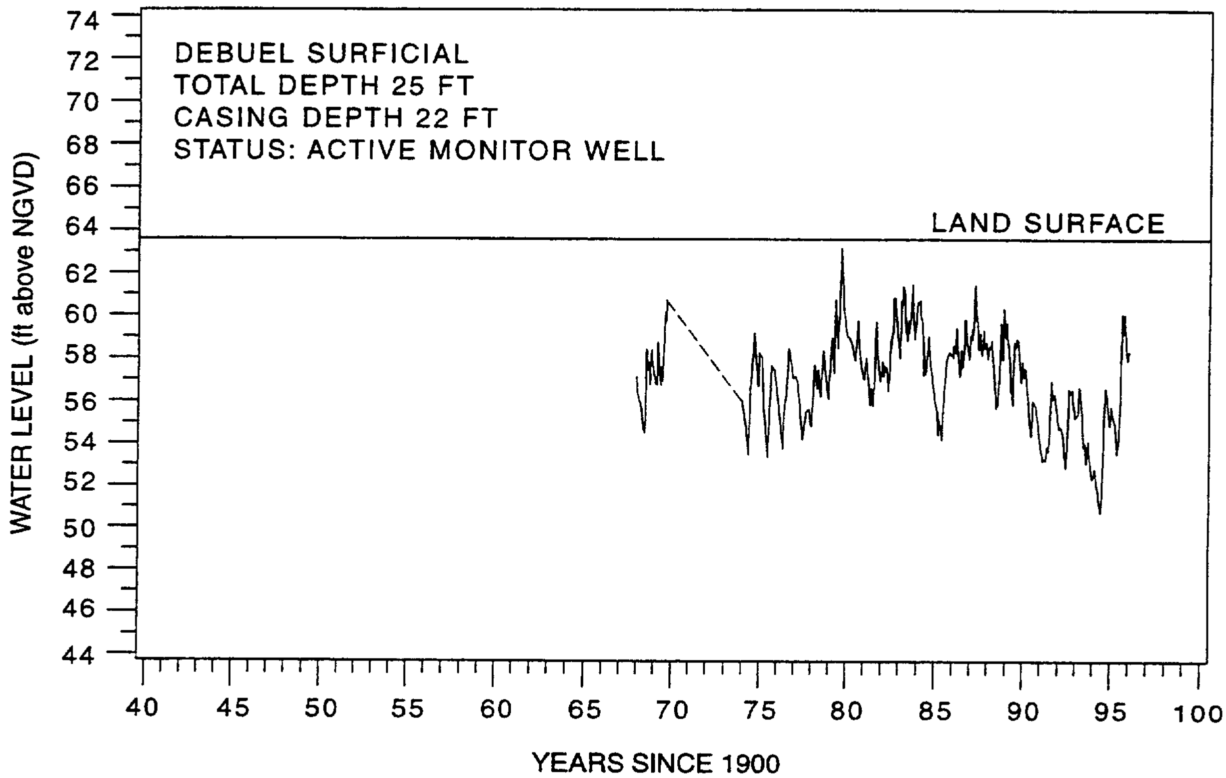


Figure 3-68. Water levels of the Debuel surficial aquifer well.

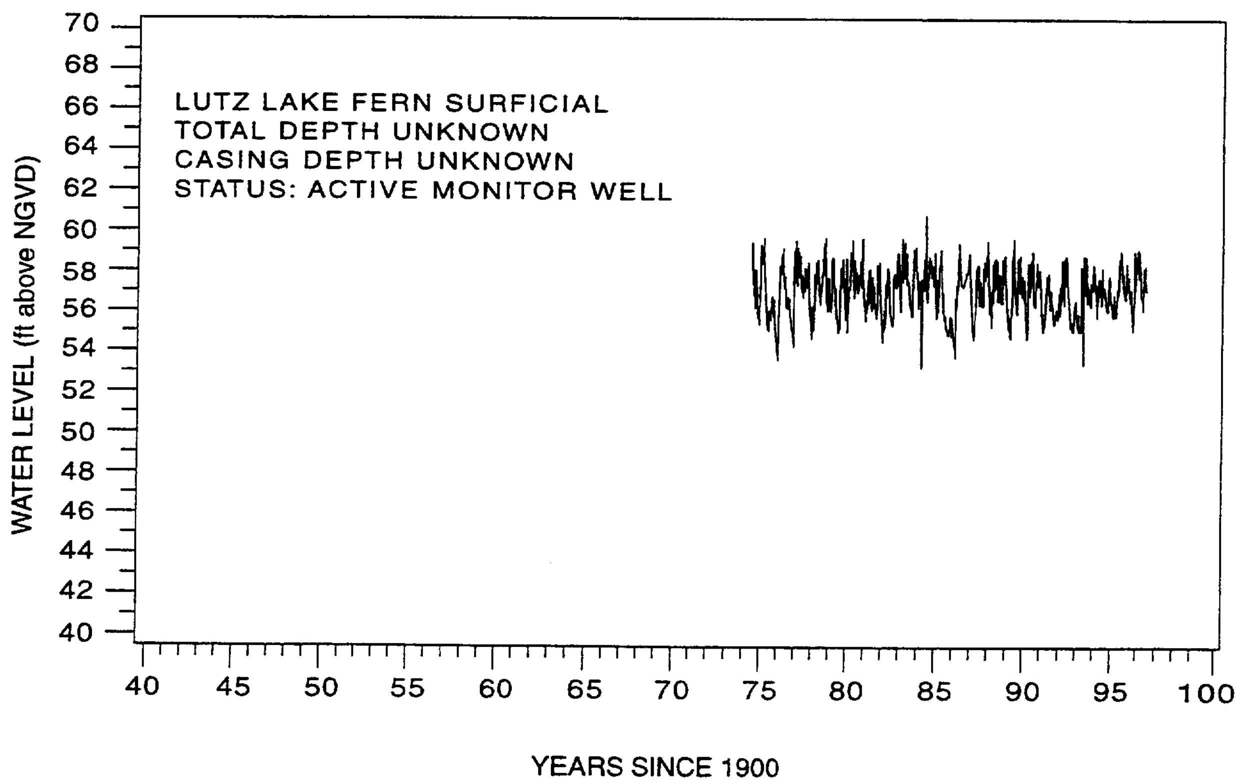


Figure 3-69. Water levels of the Lutz Lake Fern surficial aquifer well.

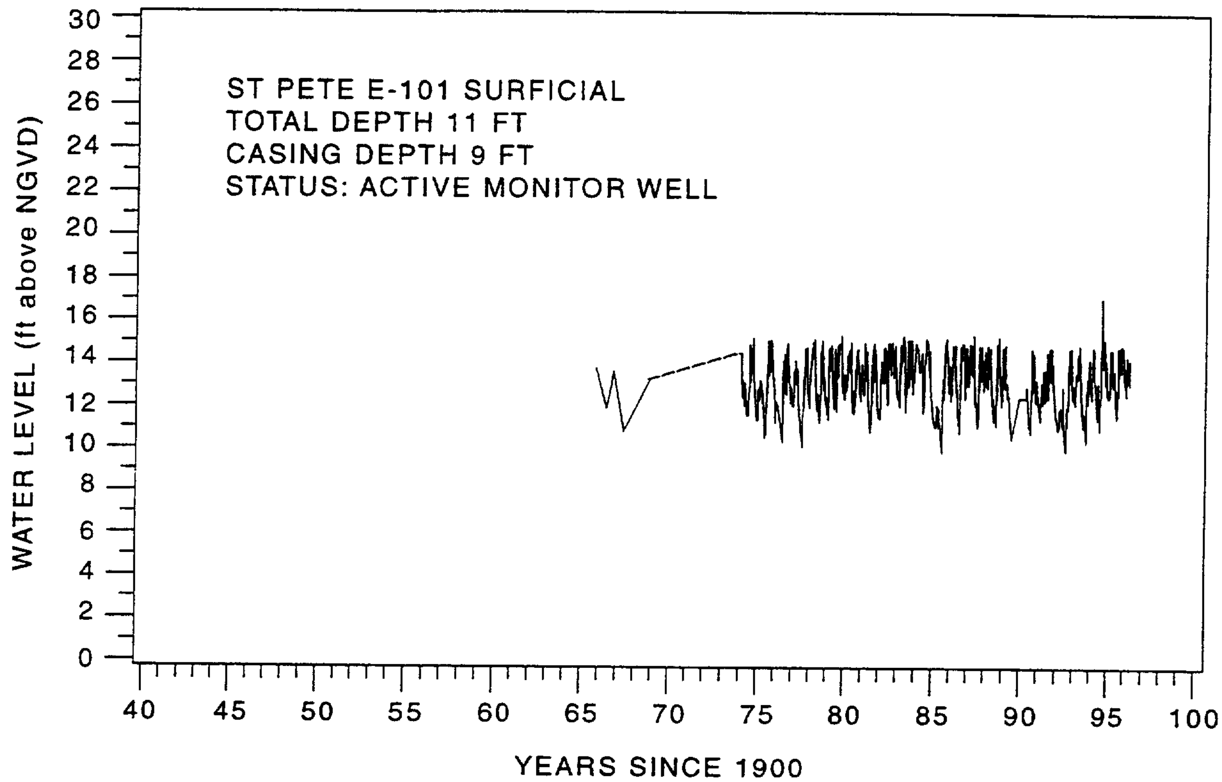


Figure 3-70. Water levels of the St. Pete. E-101 surficial aquifer well.

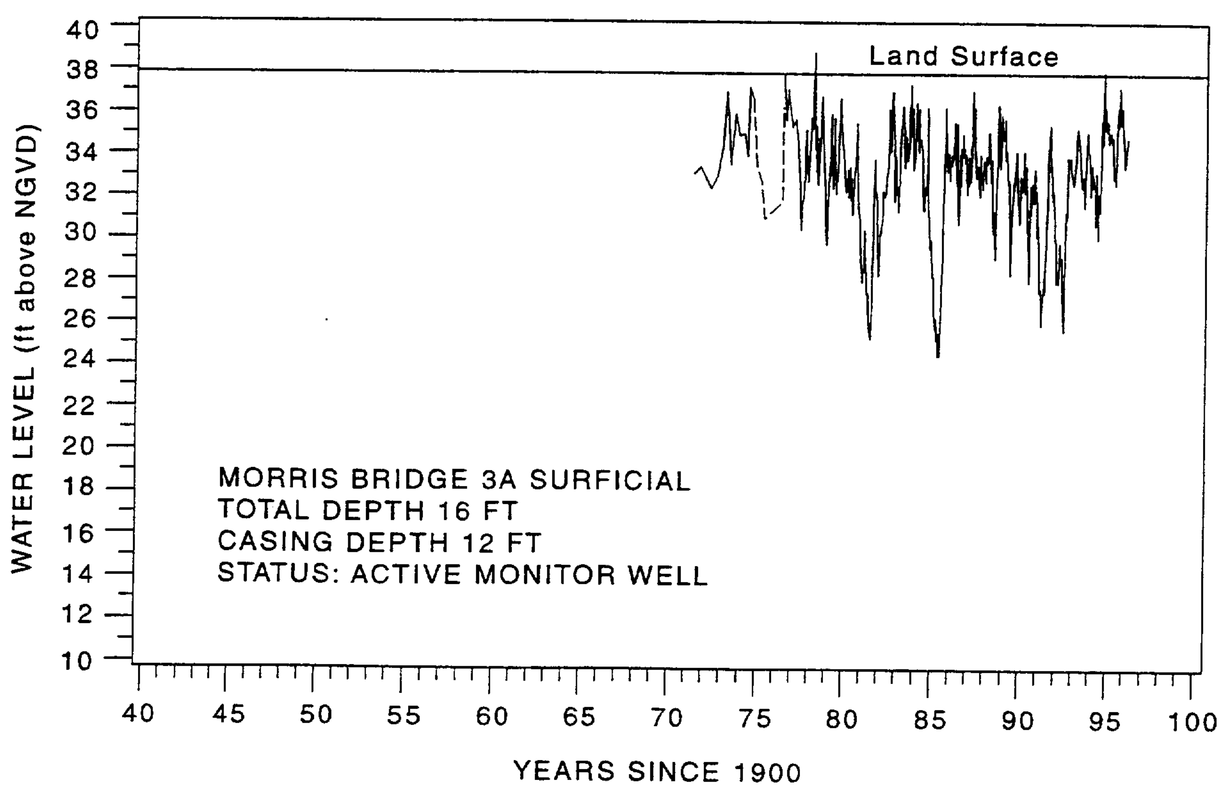


Figure 3-71. Water levels of the Morris Bridge 3A surficial aquifer well.

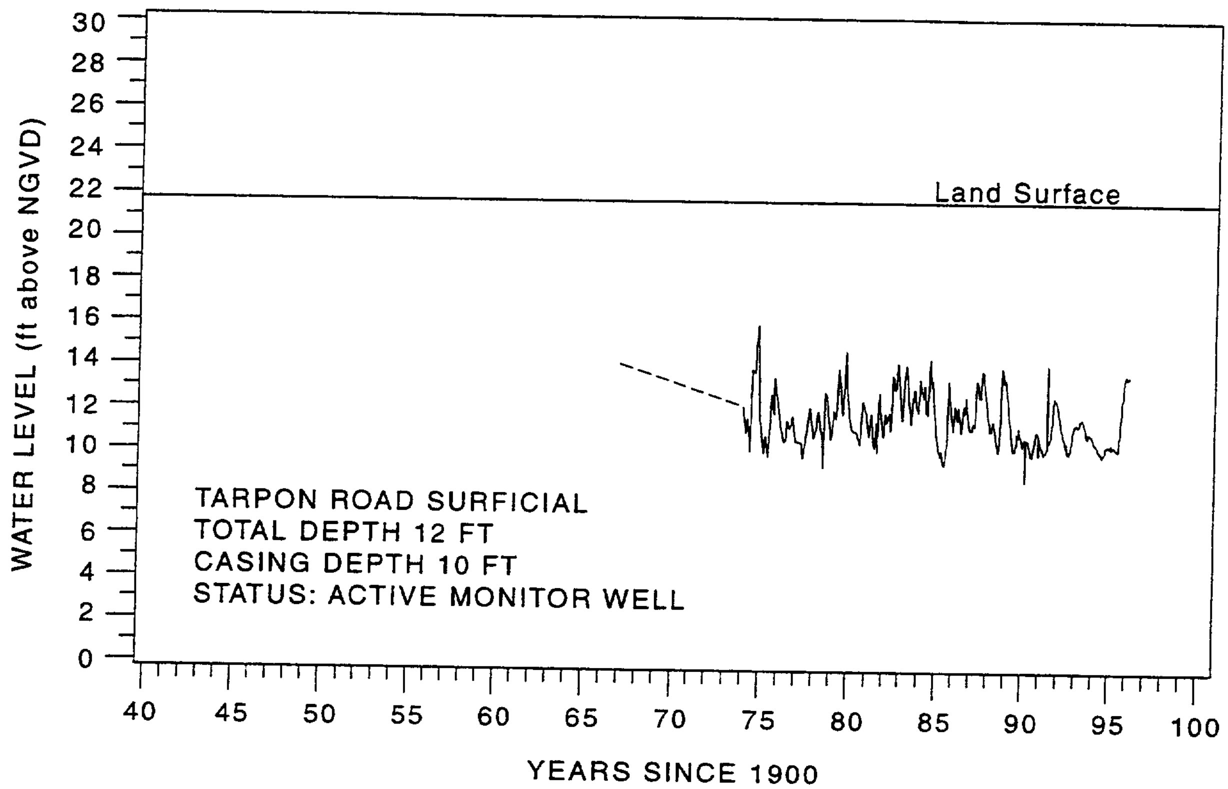


Figure 3-72. Water levels of the Tarpon Road surficial aquifer well.

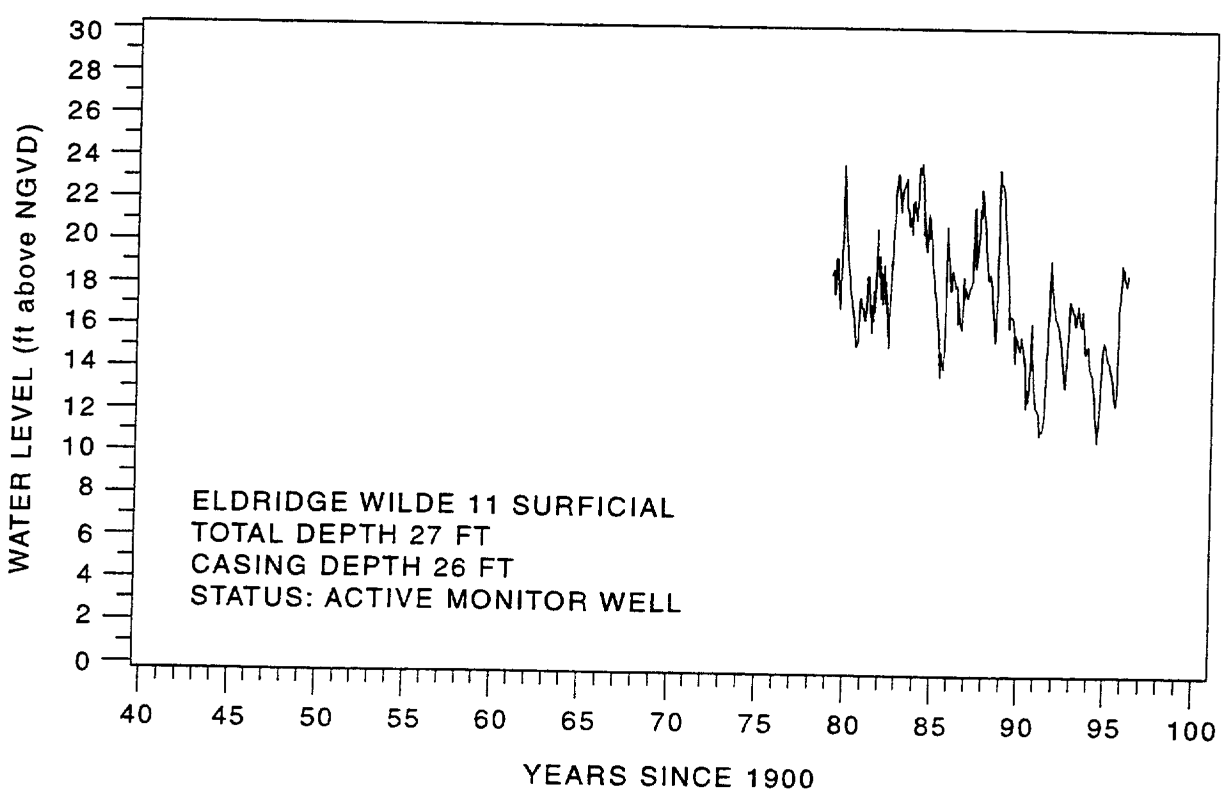


Figure 3-73. Water levels of the Eldridge Wilde 11 surficial aquifer well.

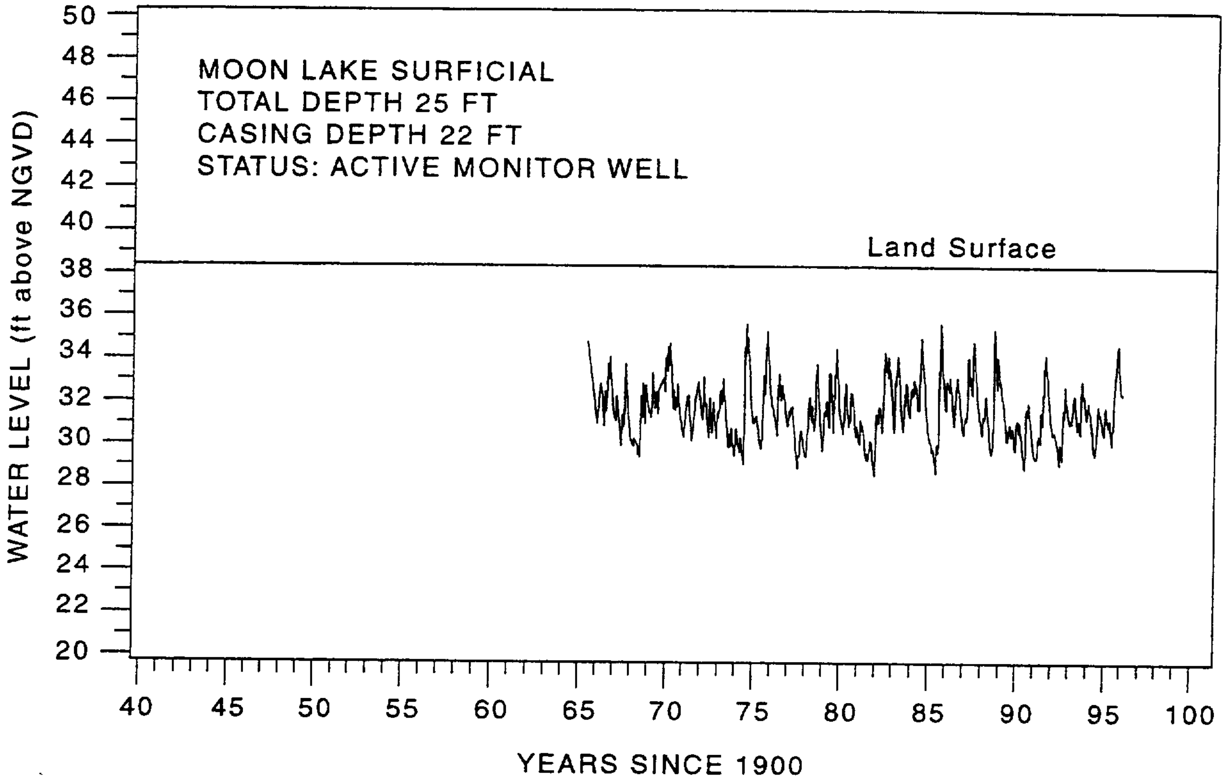


Figure 3-74. Water levels of the Moon Lake surficial aquifer well.

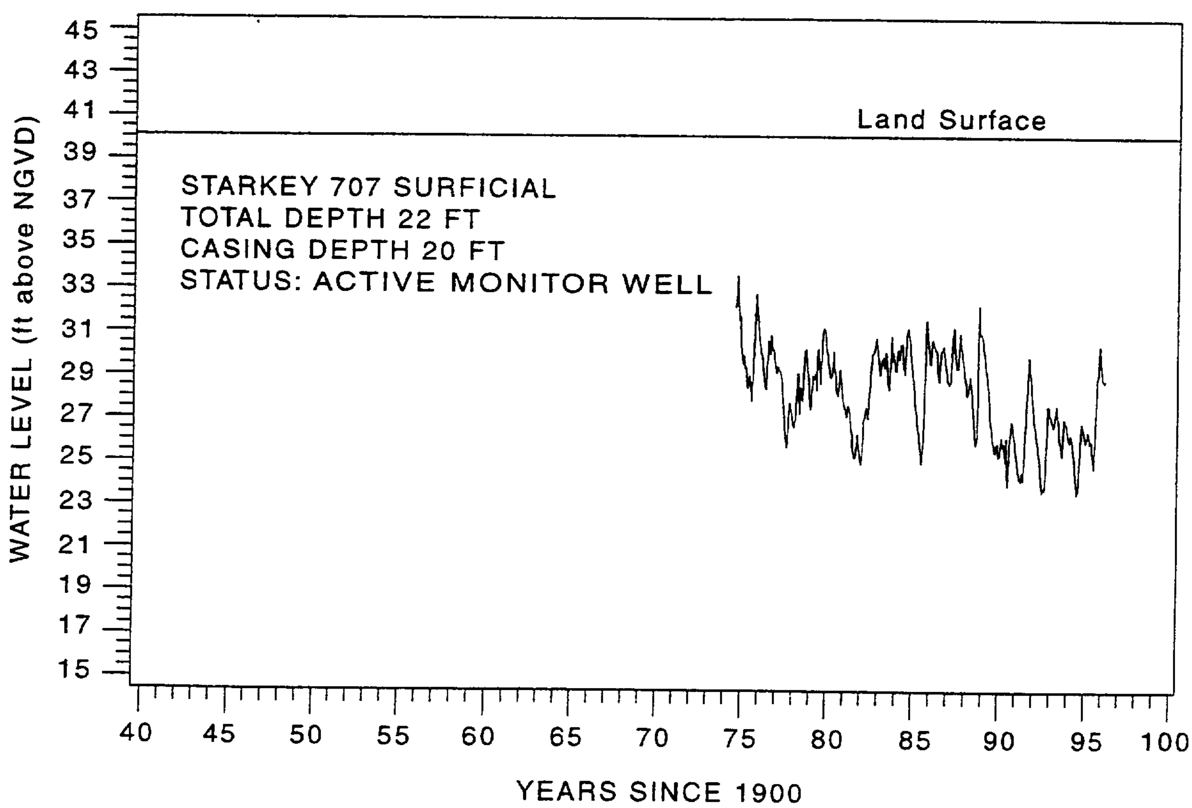


Figure 3-75. Water levels of the Starkey 707 surficial aquifer well.

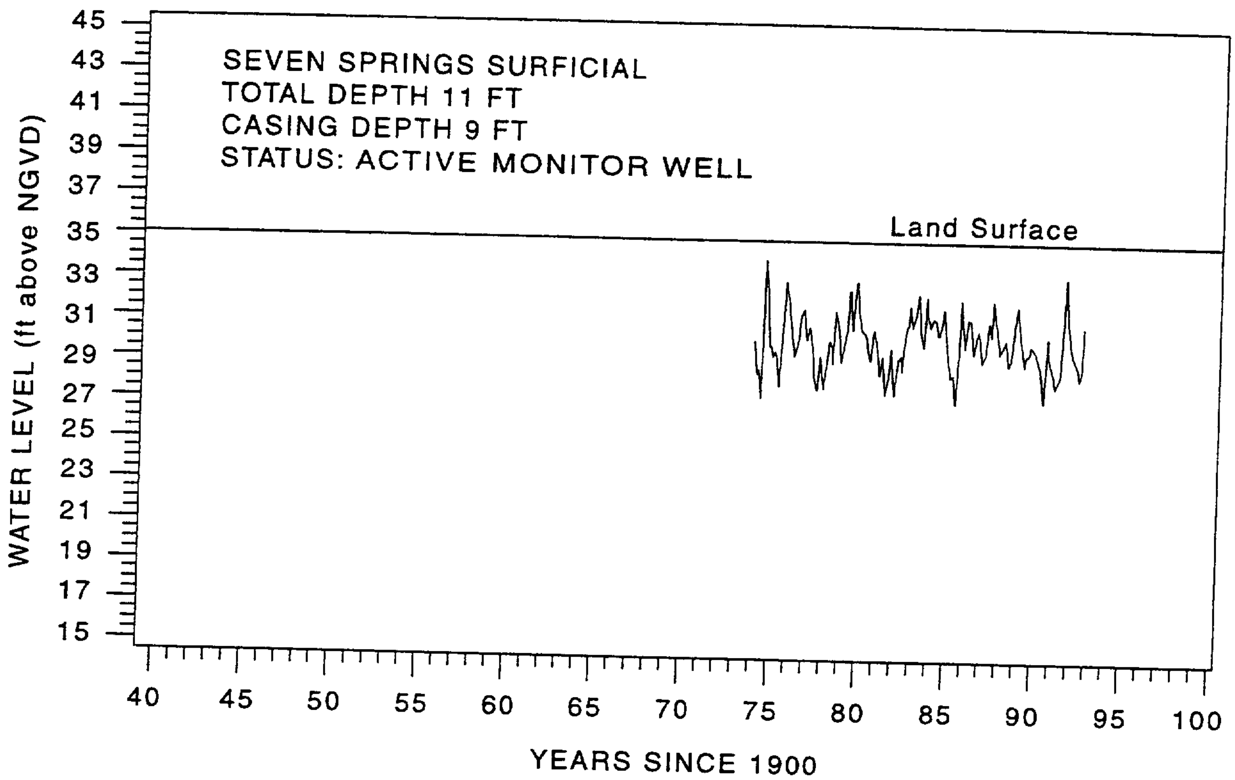


Figure 3-76. Water levels of the Seven Springs surficial aquifer well.

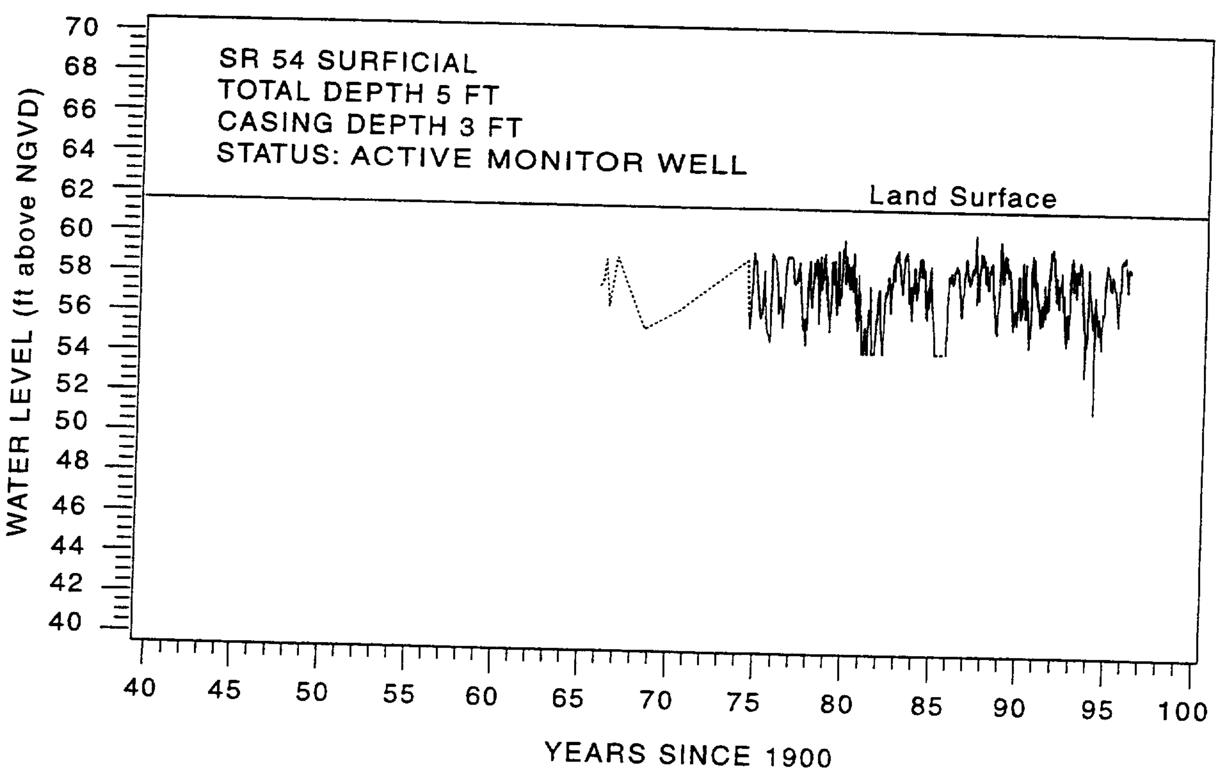


Figure 3-77. Water levels of the SR 54 surficial aquifer well.

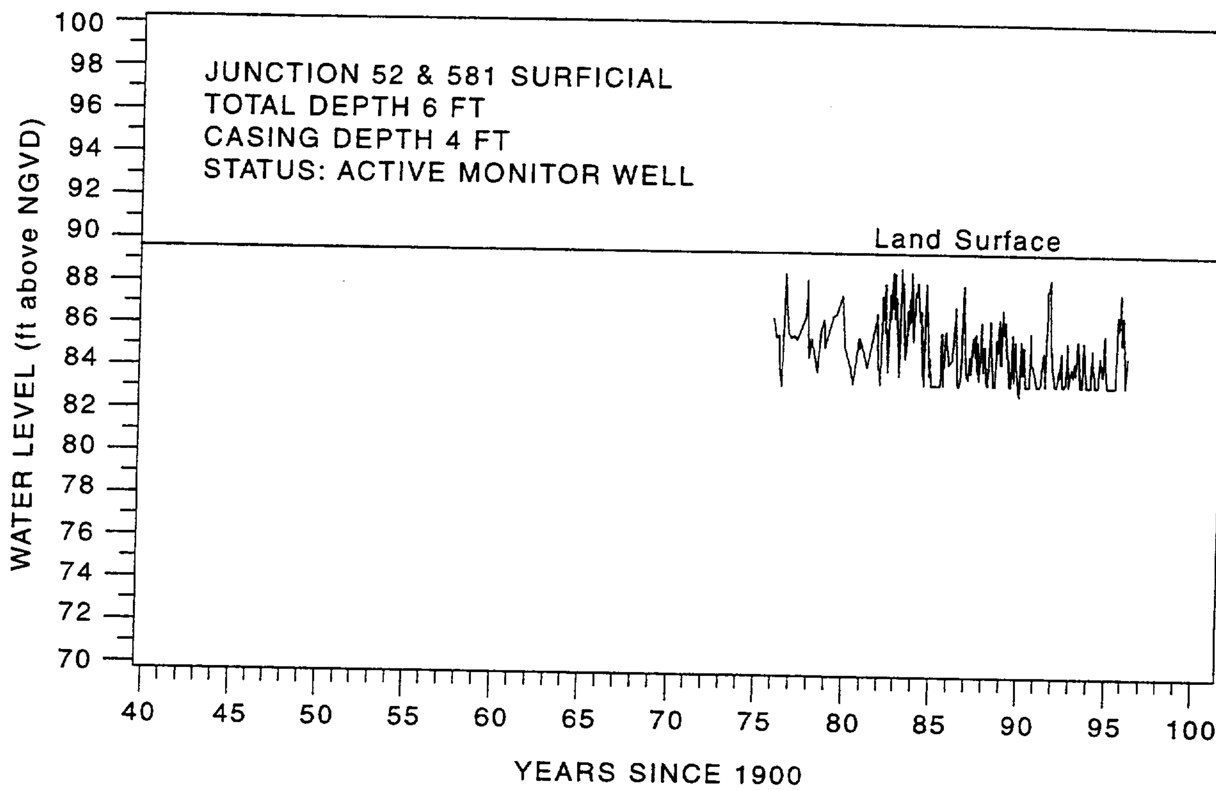


Figure 3-78 Water levels of the Junction 52 & 581 surficial aquifer well.

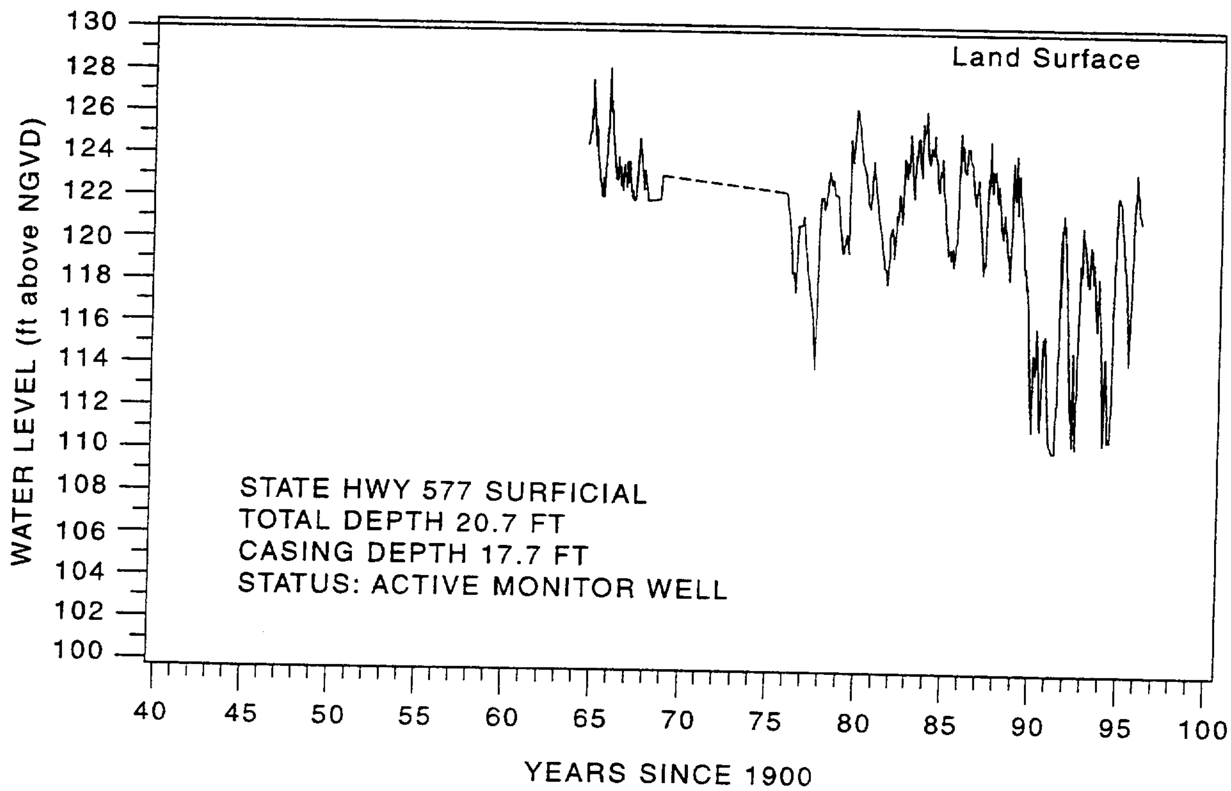


Figure 3-79. Water levels of the State Highway 577 surficial aquifer well.

County. The SR 52 and 581 well data extend only to the 1970s, and does not show a clear trend because water levels in this well have dropped below the bottom of the well, as observed in the flat portions of the hydrograph. The State Highway 577 well data extend back to the 1960s, but are missing in the early 1970s. A downward trend is apparent in the data.

Figure 3-80 and 3-81 represent hydrographs of the Cypress Creek TMR1 surficial aquifer monitor well, and the SERS surficial aquifer monitor well, respectively. The Cypress Creek well shows a declining trend throughout the period of record, but as in the SR 54 surficial monitor well presented previously, the water levels periodically drop below the bottom of the well. The SERS well has a shorter period of record, and shows a decline and partial recovery since the late-1980s.

Figures 3-82 and 3-83 present hydrographs of the Masaryktown and Weeki 11 surficial aquifer monitor wells, respectively. Because the wells periodically go dry, it is not possible to identify a trend.

Seasonal and Annual Fluctuations - Changes in fluctuations in surficial aquifer water levels are difficult to determine because; 1) long-term surficial aquifer monitor well data are generally not available, 2) most surficial aquifer monitor wells have water levels recorded on either a weekly or monthly basis, so that fluctuations are smoothed, and 3) the surficial aquifer is susceptible to rainfall and drainage alterations, so short-term rainfall events and drainage activities can cause surficial aquifer water levels to vary widely. The annual cycle of water-level fluctuation in the surficial aquifer typically correlates with local rainfall. Maximum water levels occur at the end of the summer rainy season and then gradually decline through the following spring.

The annual fluctuations seen in Figures 3-66 through 3-83 vary spatially and temporally. The Van Dyke surficial aquifer monitor well shows periods of high and low annual fluctuations; the lowest in 1973 (>three feet) and the highest in 1985 (nearly eight feet). The average throughout the period of record is approximately five feet. Analysis of Figures 3-66 through 3-83 shows that five feet is an annual-average fluctuation for most surficial aquifer monitor

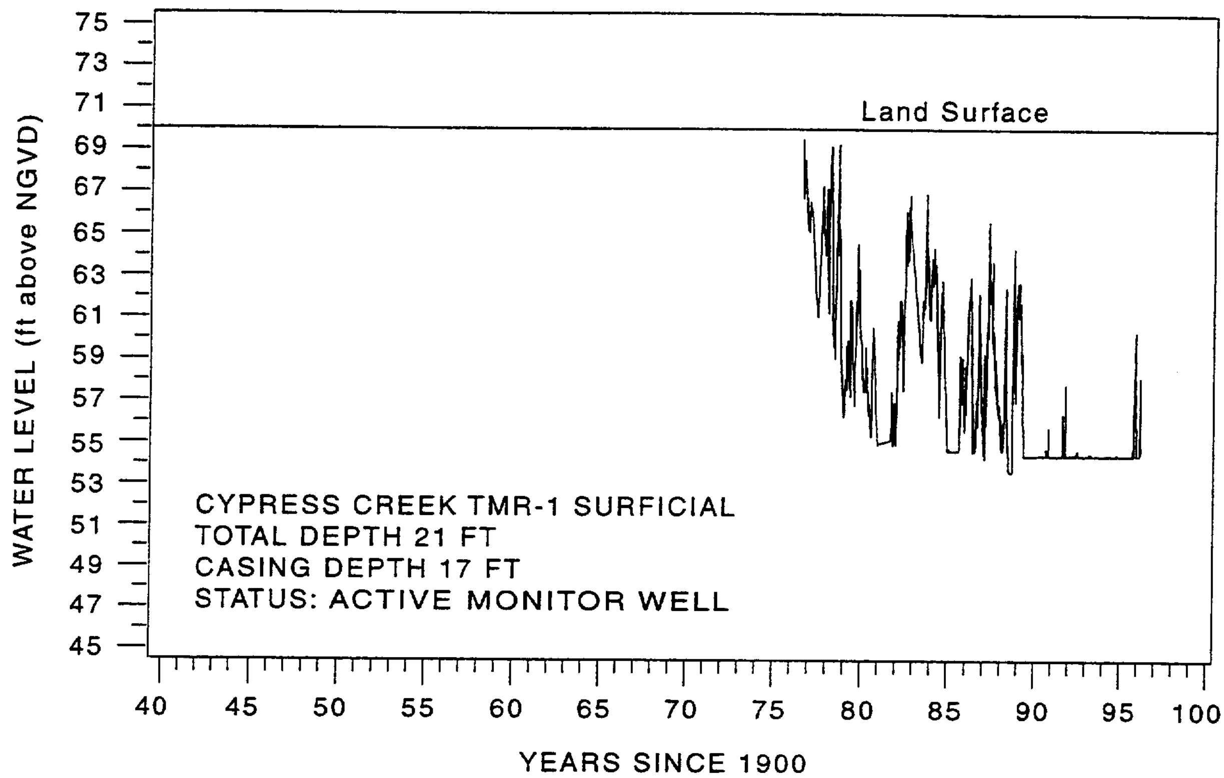


Figure 3-80 Water levels of the Cypress Creek TMR-1 surficial aquifer well.

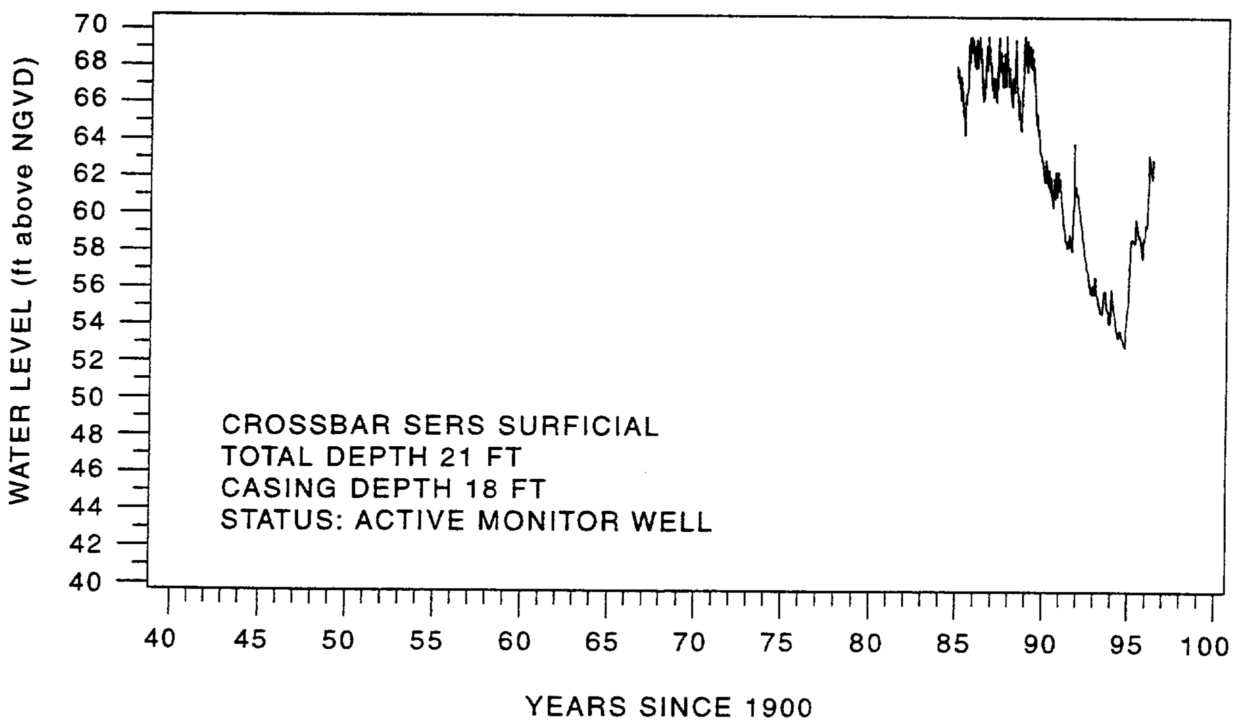


Figure 3-81. Water levels of the Crossbar SERS surficial aquifer well.

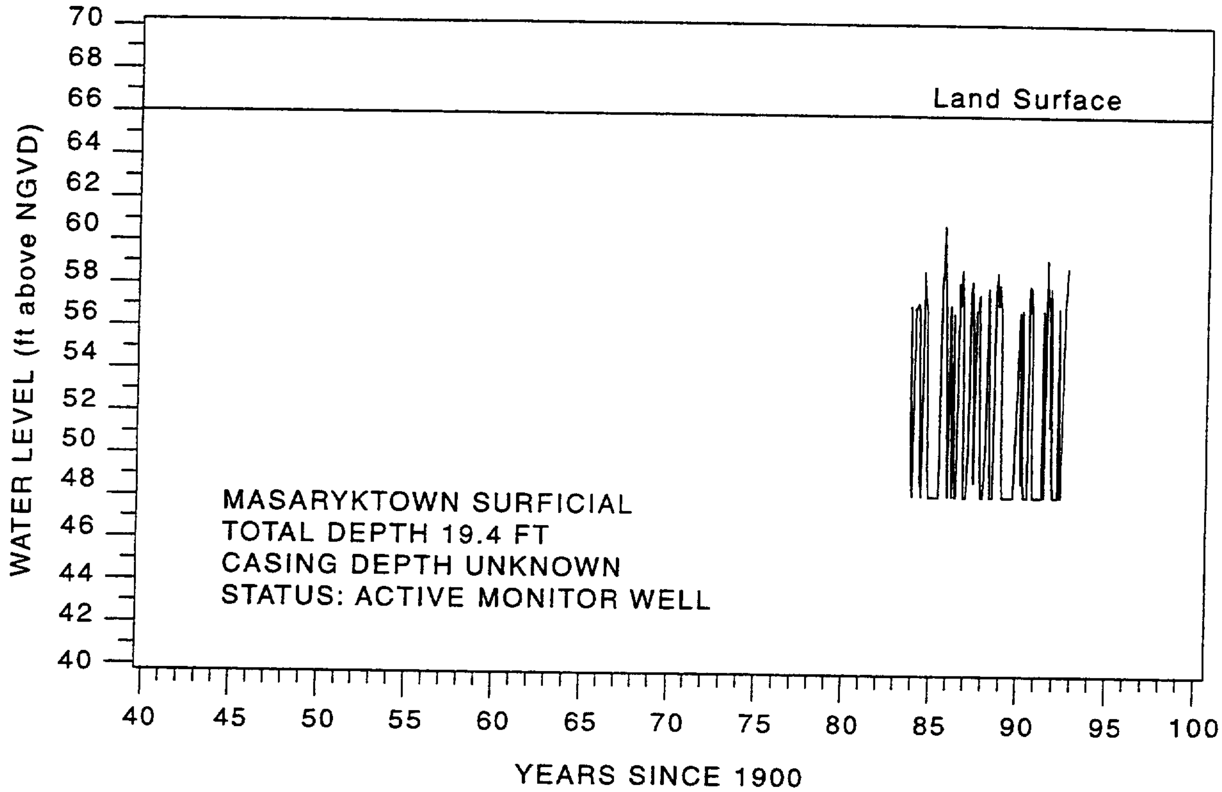


Figure 3-82. Water levels of the Masaryktown surficial aquifer well.

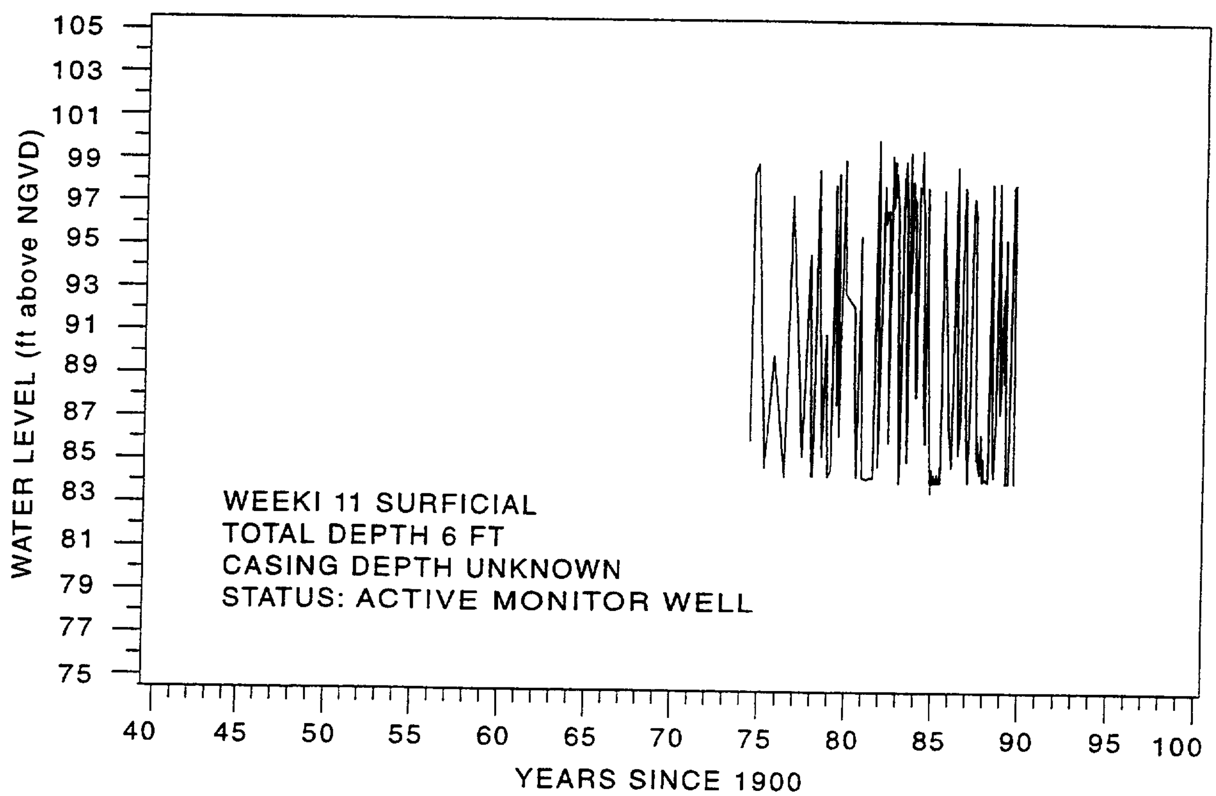


Figure 3-83. Water levels of the Weeki 11 surficial aquifer well.

wells, with a smaller water-level fluctuation near the coast. Some wells, such as the Hillsborough 13 surficial aquifer well and the Morris Bridge 3A surficial aquifer monitor well, show periods of very high annual fluctuations (10 feet or more) for periods of time, but no increasing trend in fluctuations is clear. The Masaryktown and Weeki 11 surficial aquifer monitor wells (Figures 3-82 and 3-83) show a consistently large annual fluctuation of over 10 feet. The actual fluctuation of the wells is not known since surficial aquifer water levels consistently fall below the bottom of the wells. The State Highway 577 surficial aquifer monitor well (Figure 3-79) shows evidence of an increasing trend in annual fluctuation from around five feet in the early-1960s to over 10 feet currently. There is a large gap in the data in the 1970s; therefore, interpretation of trends in this data is difficult.

3.6.2 Lakes

Lakes within the Northern Tampa Bay WRAP area are subject to many influences which alter water levels. These influences are both natural (rainfall, evaporation, sinkhole formation) and man-made (control structures, augmentation, drainage alterations, water withdrawals). All of these influences must be considered when analyzing water-level trends in lakes.

Long-term trends and fluctuations - As observed in the Upper Floridan aquifer, water levels in several lakes have declined, with an increase in seasonal fluctuation. The locations of lakes referenced in this section are shown in Figure 3-84. Figure 3-85 presents the water-level hydrograph of Starvation Lake, located within the Section 21 wellfield in northwest Hillsborough County. Starvation Lake is essentially isolated, with no natural inlet or outlet. Some flow can discharge and be received through ditches that were constructed in the early-1970s. Similar to the nearby Hillsborough 13 Upper Floridan aquifer monitor well (Figure 3-34), lake elevations have fluctuated greatly throughout the period of record. Short-term variability is also seen to change throughout the period of record. Beginning in the early-1960s, water levels dropped from an average of about 54 feet NGVD to a variable level in the low 40 foot NGVD range. Seasonal fluctuation also increased from about two to three feet in the early-1960s to about five feet in the early-1970s. The lake was periodically augmented from the late-1960s to approximately 1982 with water pumped from the Upper Floridan aquifer in response to the low

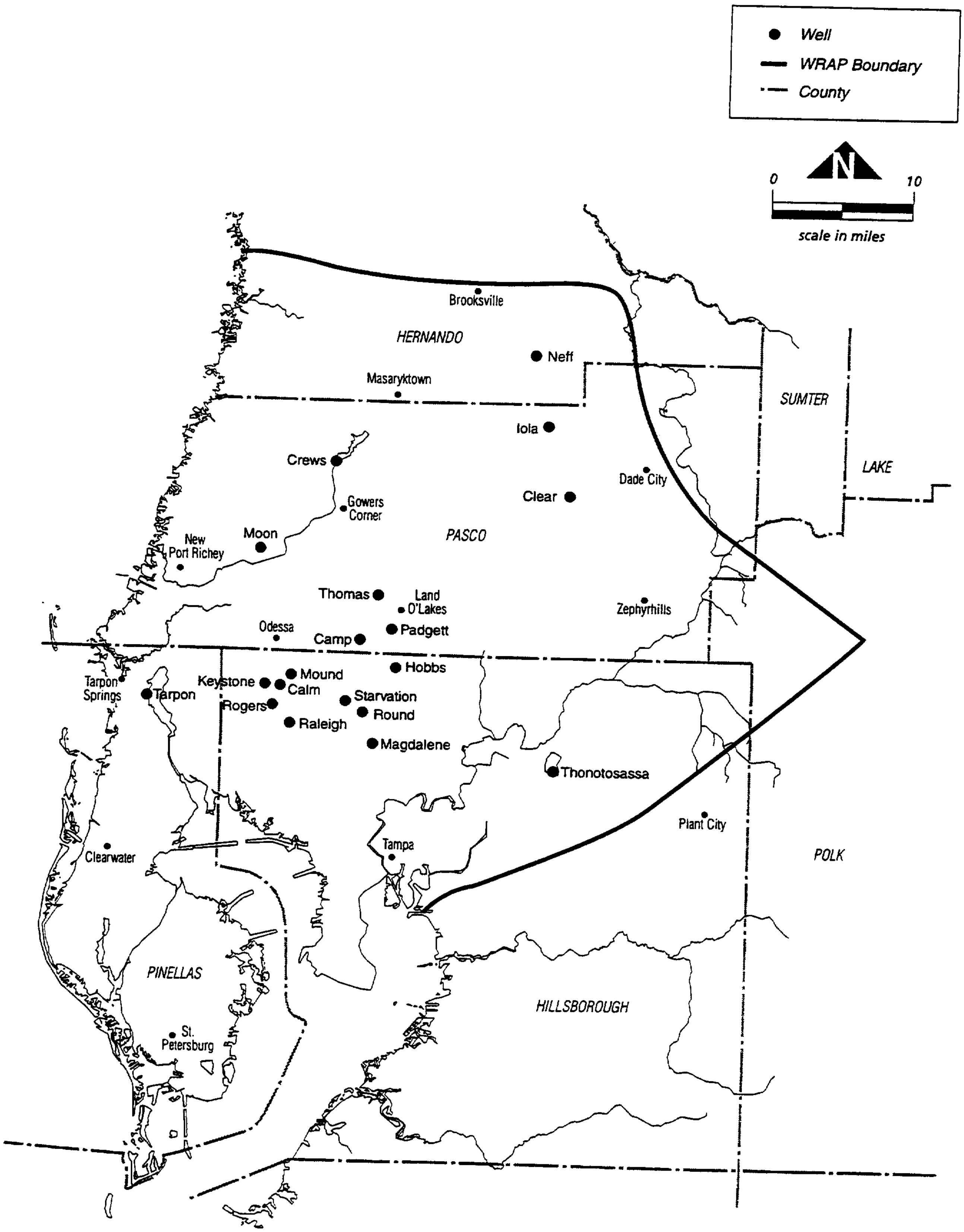


Figure 3-84. Location of lakes referenced in Section 3.6.2 .

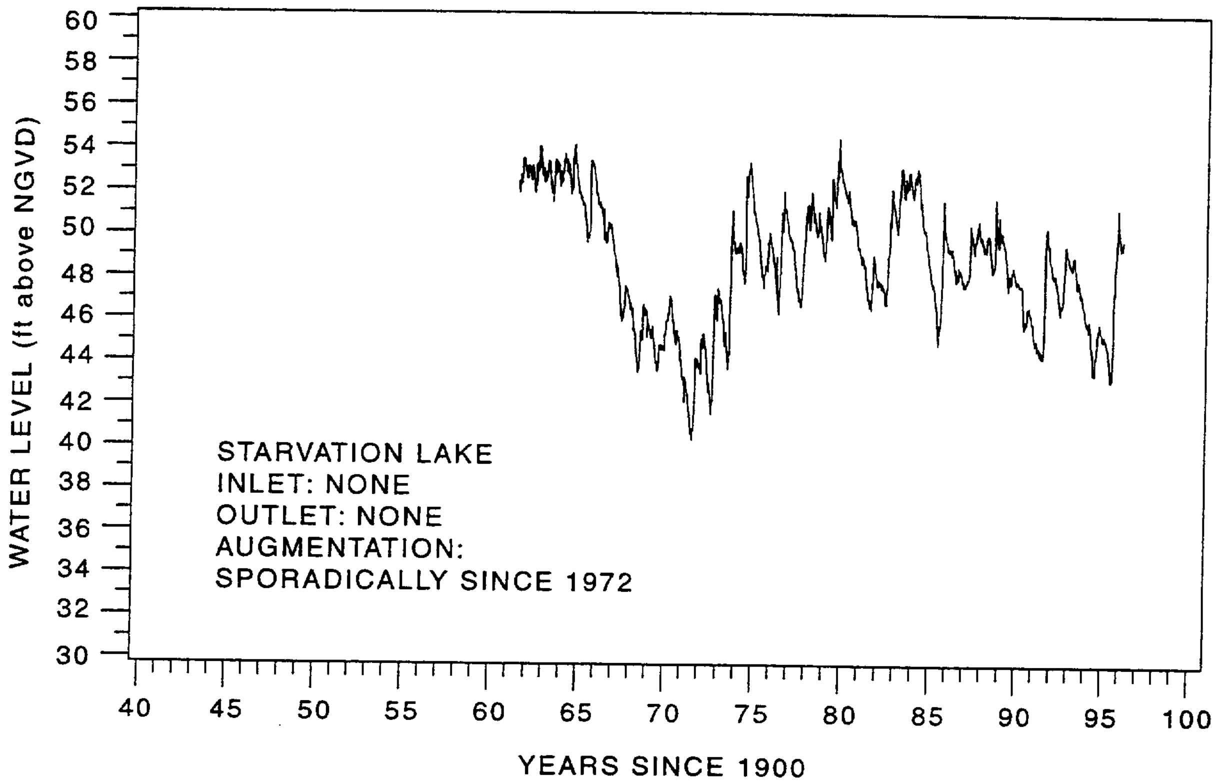


Figure 3-85. Water levels of Starvation Lake.

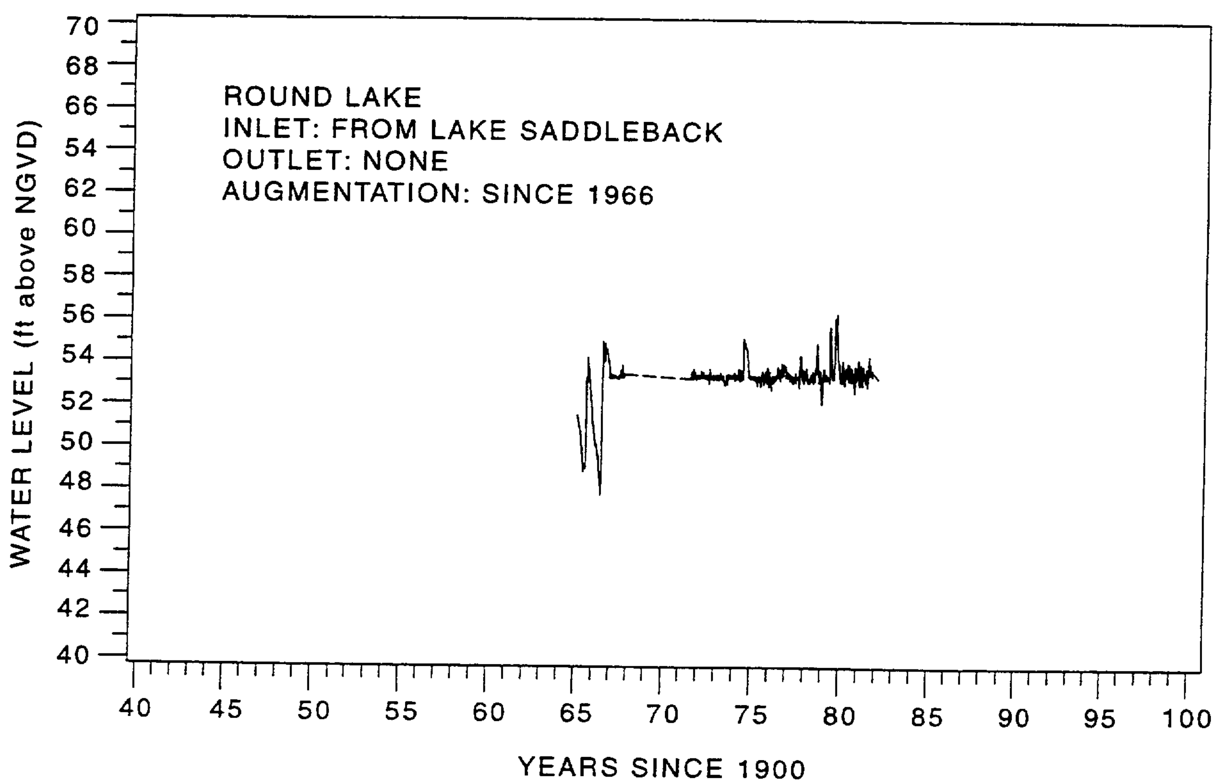


Figure 3-86. Water levels of Round Lake.

levels, but no withdrawal amounts are available. Annual-average water levels increased to approximately 50 feet NGVD in the mid-1970s, although seasonal fluctuations remained similar to those of the early-1970s. A decrease in annual-average water level is apparent in the 1980s, approaching an annual-average of 45 feet NGVD.

Round Lake (Figure 3-86) is located approximately 500 feet east of the Section 21 wellfield and Starvation Lake. Water levels in this lake show a pattern similar to those in Starvation Lake for the early data (although greater in magnitude), but level considerably in 1965. Beginning in 1965, the residents surrounding Round Lake began augmenting the lake from a Upper Floridan aquifer well. Data collection ended at this lake in the early-1980s. No accurate augmentation data exists, but it is known that the augmentation has been very regular.

Figures 3-87 and 3-88 present water-level data from two lakes located over two miles away from the Section 21 wellfield. Both lakes have a relatively long and consistent period of record. Lake Hobbs is located northeast of Starvation Lake. The water-level data shows an apparent downward trend with an increase in variability. Lake Hobbs has no inlet; however, in 1967, an outlet into Lake Cooper was created to alleviate periodic flooding, but no structure was installed. Lake Magdalene is located southeast of Starvation Lake. Although Lake Magdalene has no apparent downward trend in water levels, periodic changes in fluctuation are apparent. The lake has an inlet from Platt Lake and an operational control structure at its discharge to Bay Lake.

Since 1974, Lake Magdalene has been regularly augmented from an Upper Floridan aquifer well. The beginning of the augmentation period is obvious on the hydrograph. As a comparison, Figure 3-89 presents the hydrograph of Moon Lake in Pasco County; another lake with a relatively long period of record. Moon Lake has an inlet from an unnamed wetland, but has no outlet. The hydrograph for Moon Lake shows no long-term trends, and water levels fluctuate approximately four feet throughout the period of record.

Figures 3-90 through 3-92 show lake hydrographs from other areas of the Northern Tampa Bay WRAP area with long periods of record. Lake Rogers and Lake Raleigh are located within and

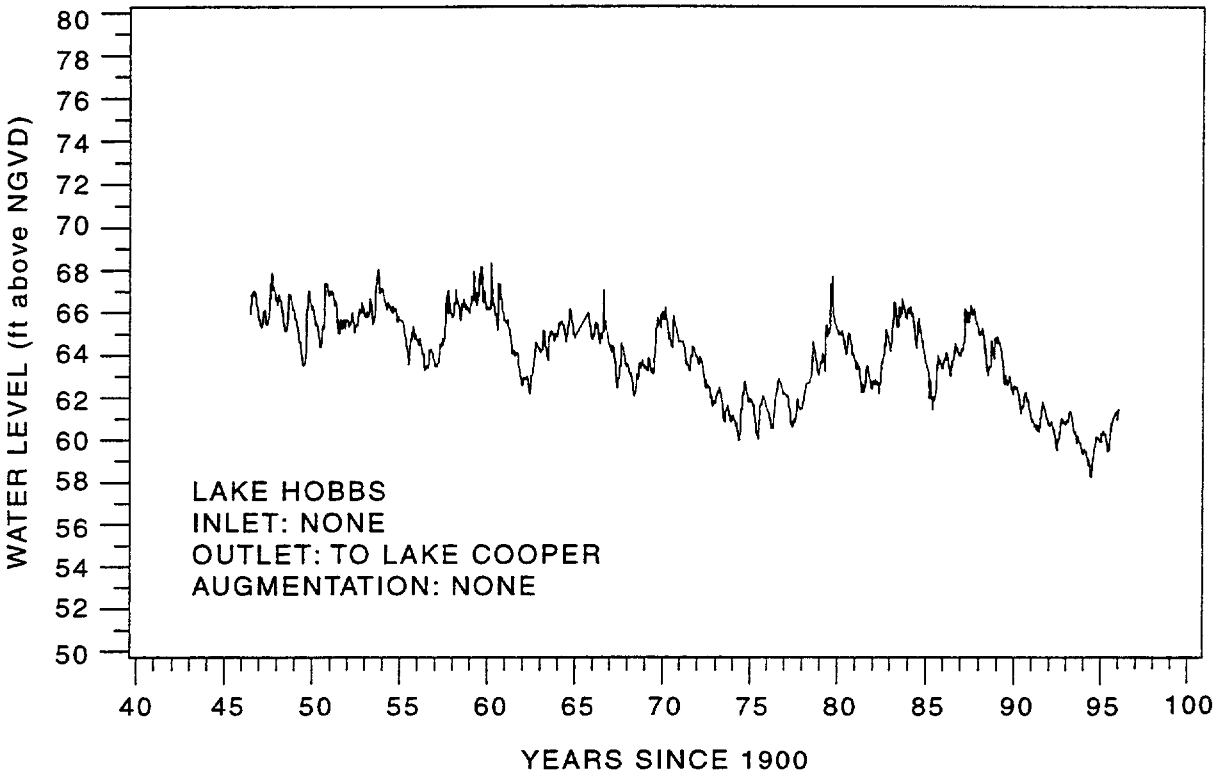


Figure 3-87. Water levels of Lake Hobbs.

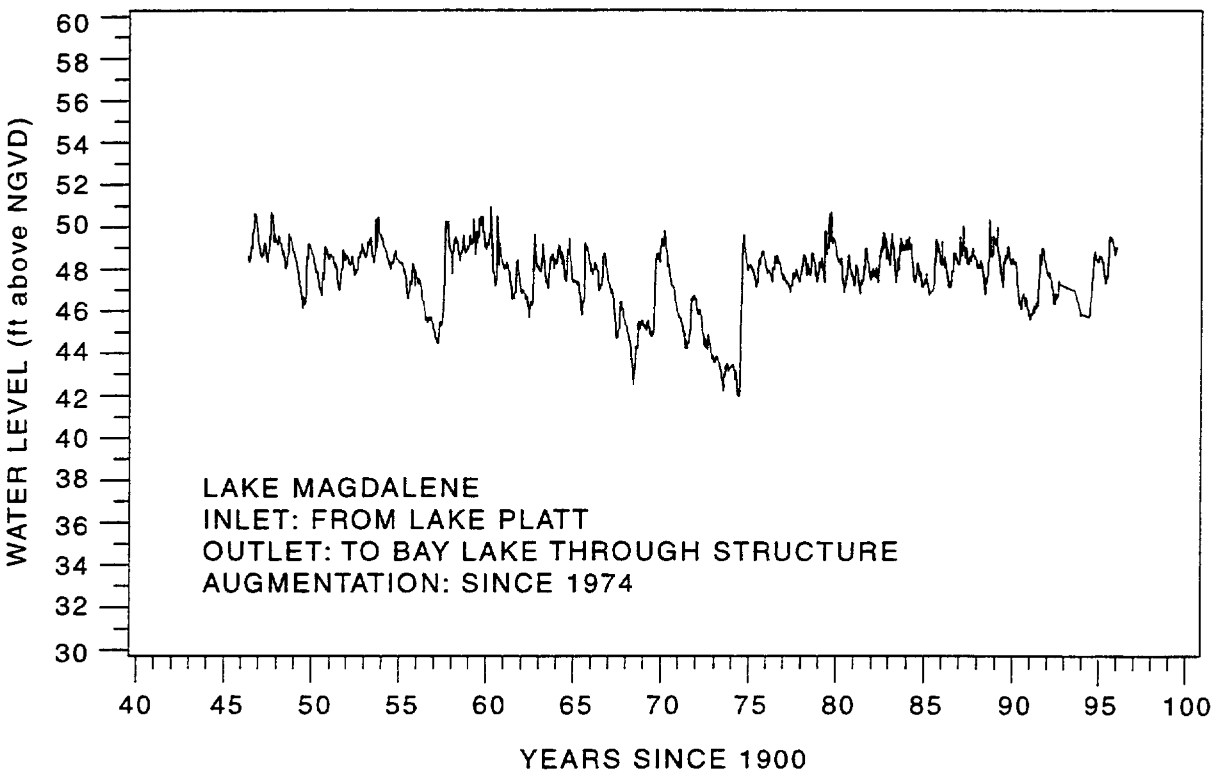


Figure 3-88. Water levels of Lake Magdalene.

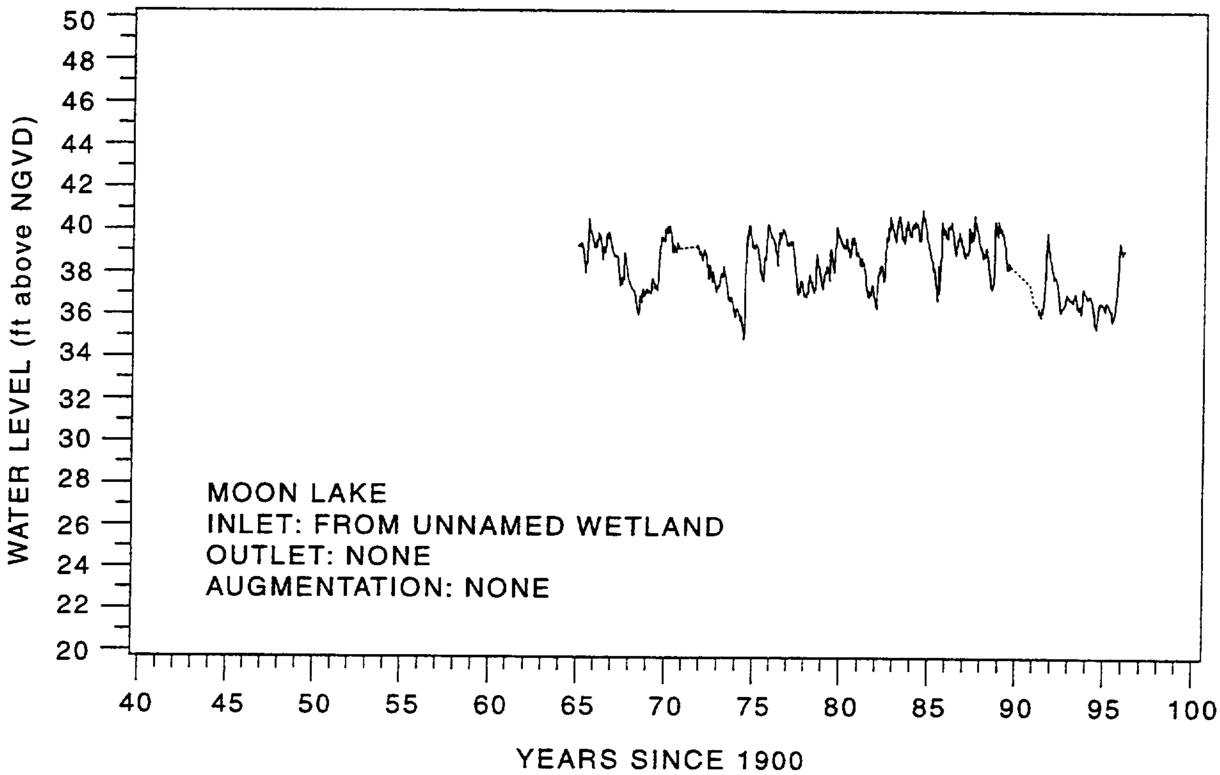


Figure 3-89. Water levels of Moon Lake.

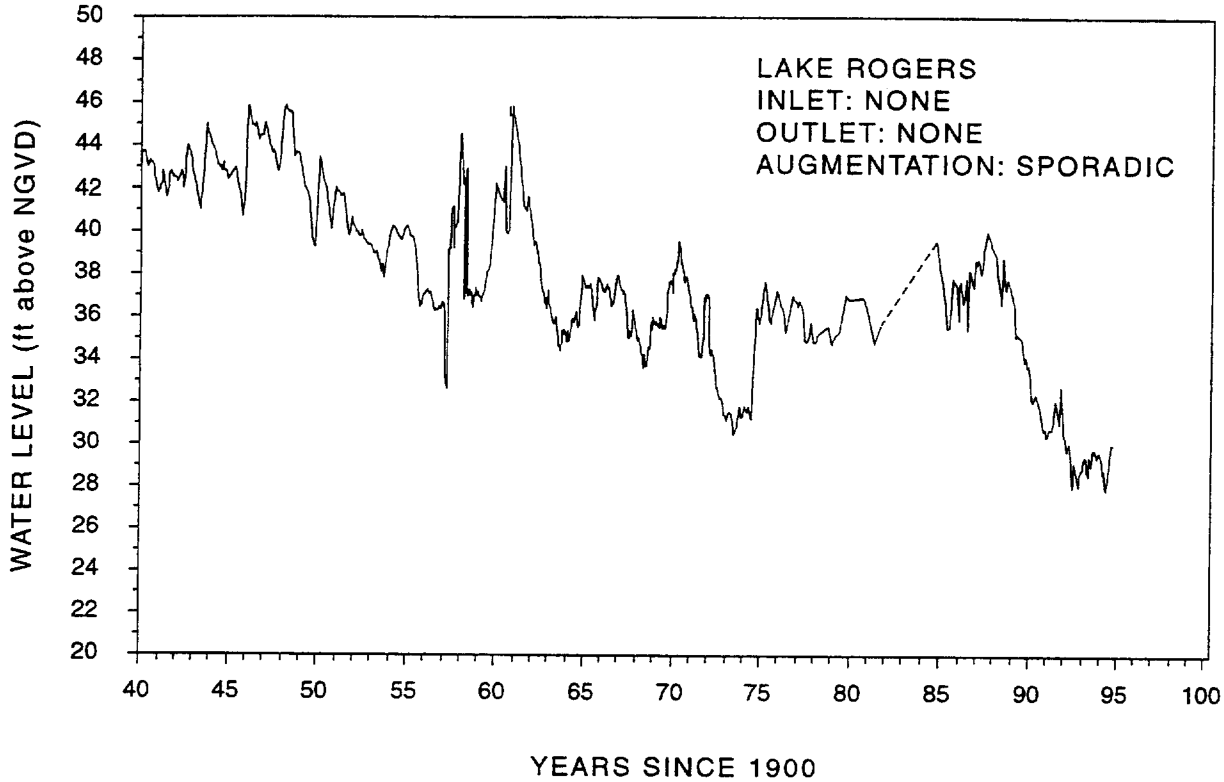


Figure 3-90. Water levels of Lake Rogers.

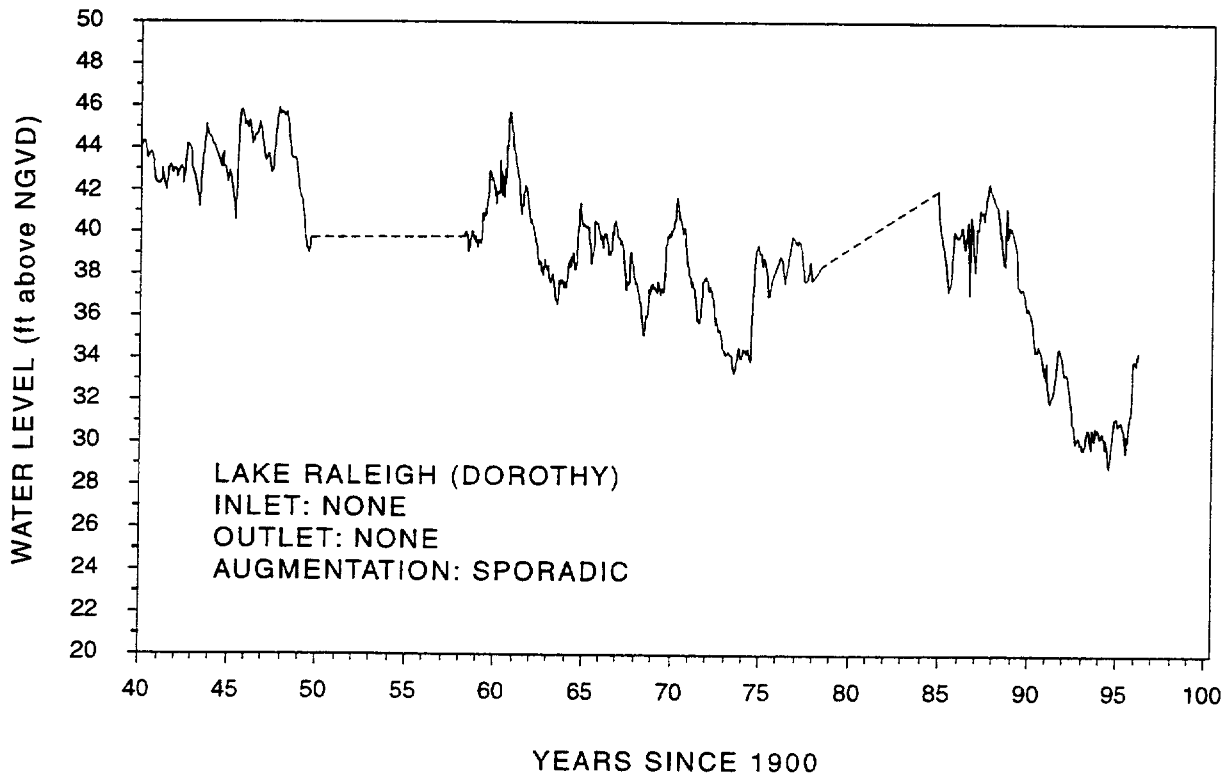


Figure 3-91. Water levels of Lake Raleigh.

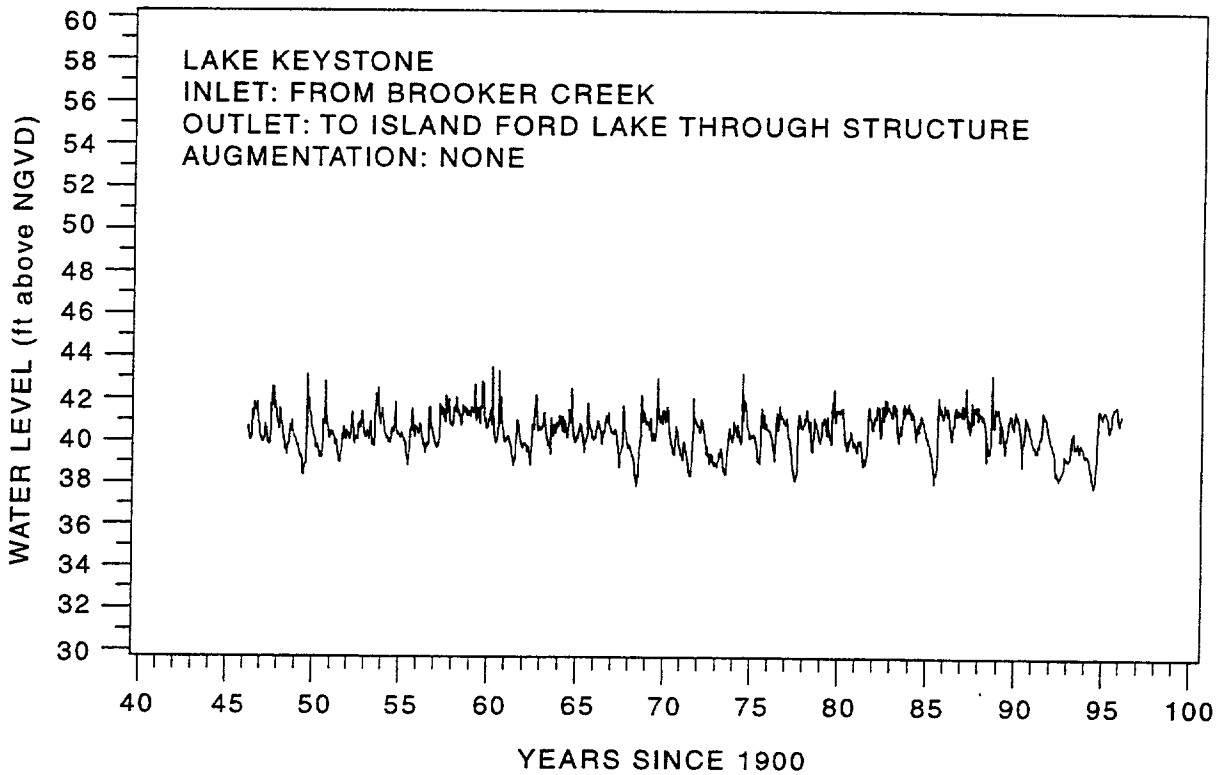


Figure 3-92. Water levels of Lake Keystone.

adjacent to the Cosme wellfield, respectively, and Lake Keystone is located to the north of the wellfield. Although the records are incomplete, both Lake Rogers and Lake Raleigh show an obvious decline in water levels from the mid-1940s to present. Both lakes are internally drained. Lake Keystone is much larger than the other two lakes, and has had an operable control structure since 1955. Lake Keystone is located along Brooker Creek, which serves as the source of lake inflow and outflow. No trends are apparent, and the lake fluctuation is regular throughout the period of record.

Figure 3-93 and 3-94 present lake hydrographs for two lakes located to the northeast of Lake Keystone: Calm Lake and Mound Lake. These two lakes are within one-quarter of a mile of each other, and are of similar size, but demonstrate significantly different fluctuations. Data for Calm Lake begin in the mid-1960s, and shows a fluctuation of three to seven feet. Data for Mound Lake begin in the early-1970s, and show a typical fluctuation of about one or two feet. The difference between the highest and lowest points of the Mound Lake data is less than five feet. Examination of the two hydrographs shows that Calm Lake clearly has a greater fluctuation of water levels than does Mound Lake, despite their proximity. Neither lake has a control structure, or a significant inlet or outlet. Therefore, the hydrographs of similar and nearby lakes can be variable throughout the study area.

Two lakes in Pasco County with relatively long periods of water-level record are Camp Lake and Crews Lake (Figures 3-95 and 3-96). Camp Lake is located adjacent to the South Pasco wellfield along SR 54, and Crews Lake is located in northern Pasco County adjacent to the Cross Bar wellfield. Although Camp Lake is isolated, Crews Lake is fed by Jumping Gully, and serves as the source of the Pithlachascotee River. Camp Lake shows an increase in water-level fluctuation and decreasing trend, while Crews Lake shows a slight downward trend in water levels throughout the late-1980s and early-1990s.

Figures 3-97 and 3-98 present hydrographs for Lake Padgett and Lake Thomas, both in central Pasco County. Data for Lake Padgett begins in 1965, while Lake Thomas data begins in 1968. Lake Padgett has both an inflow and outflow from and to other lakes through culverts, but does

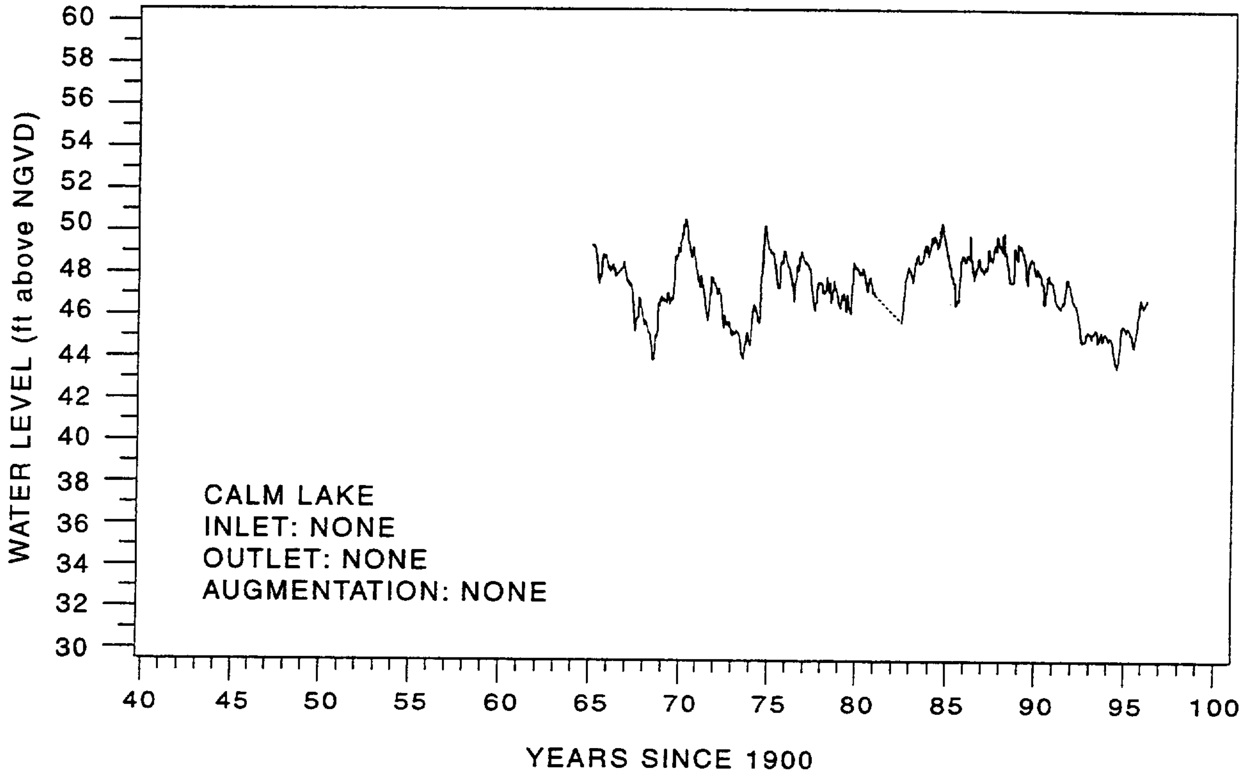


Figure 3-93. Water levels of Calm Lake.

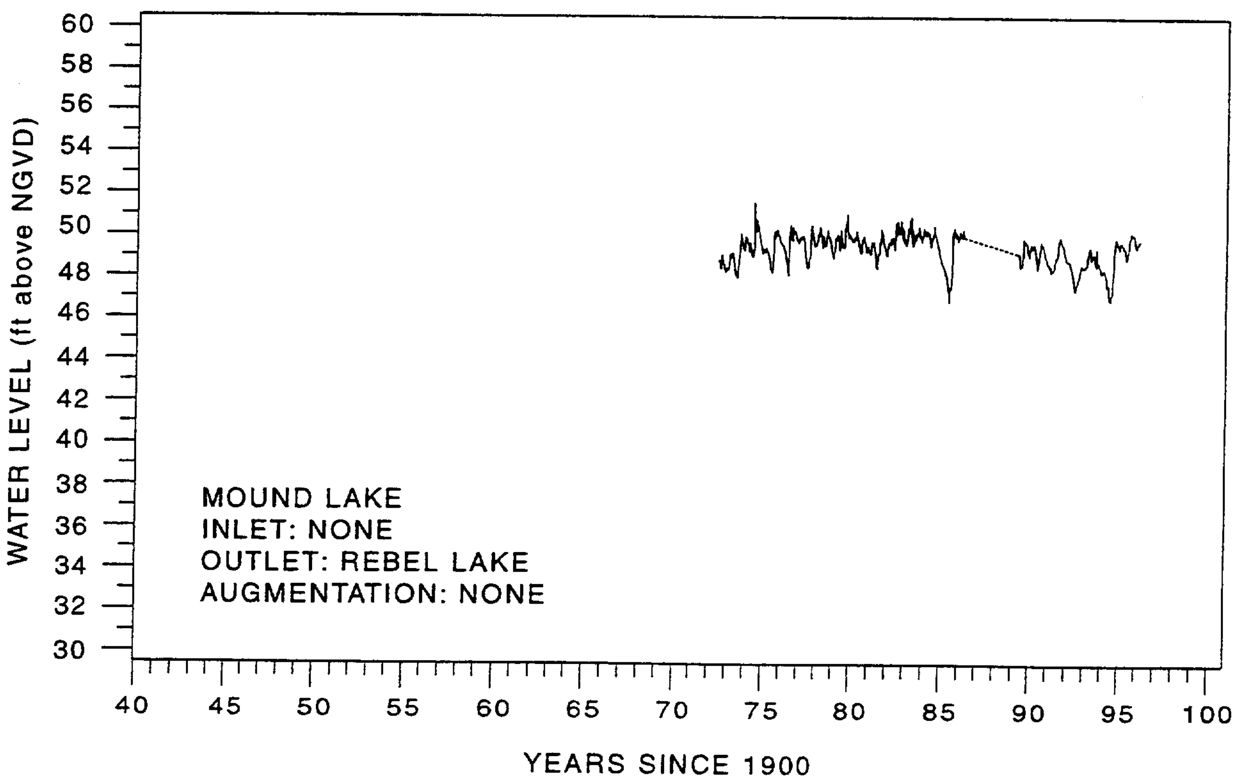


Figure 3-94. Water levels of Mound Lake.

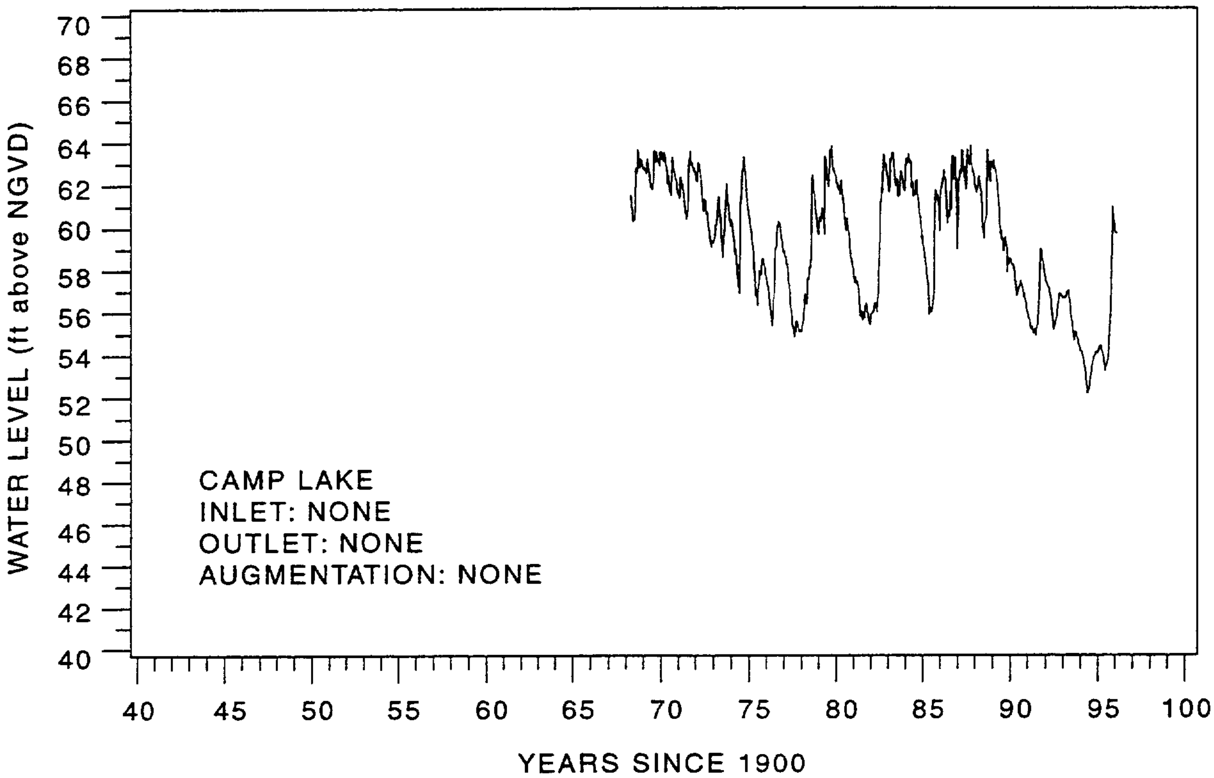


Figure 3-95. Water levels of Camp Lake.

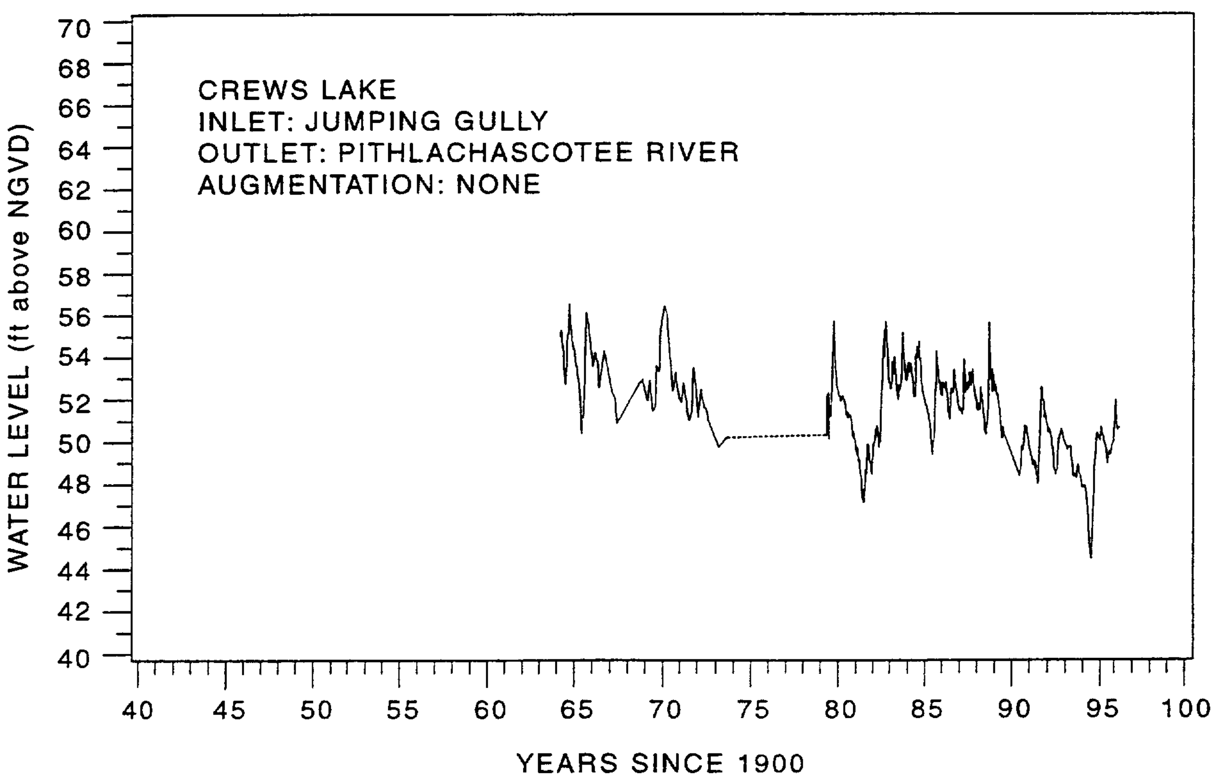


Figure 3-96. Water levels of Crews Lake.

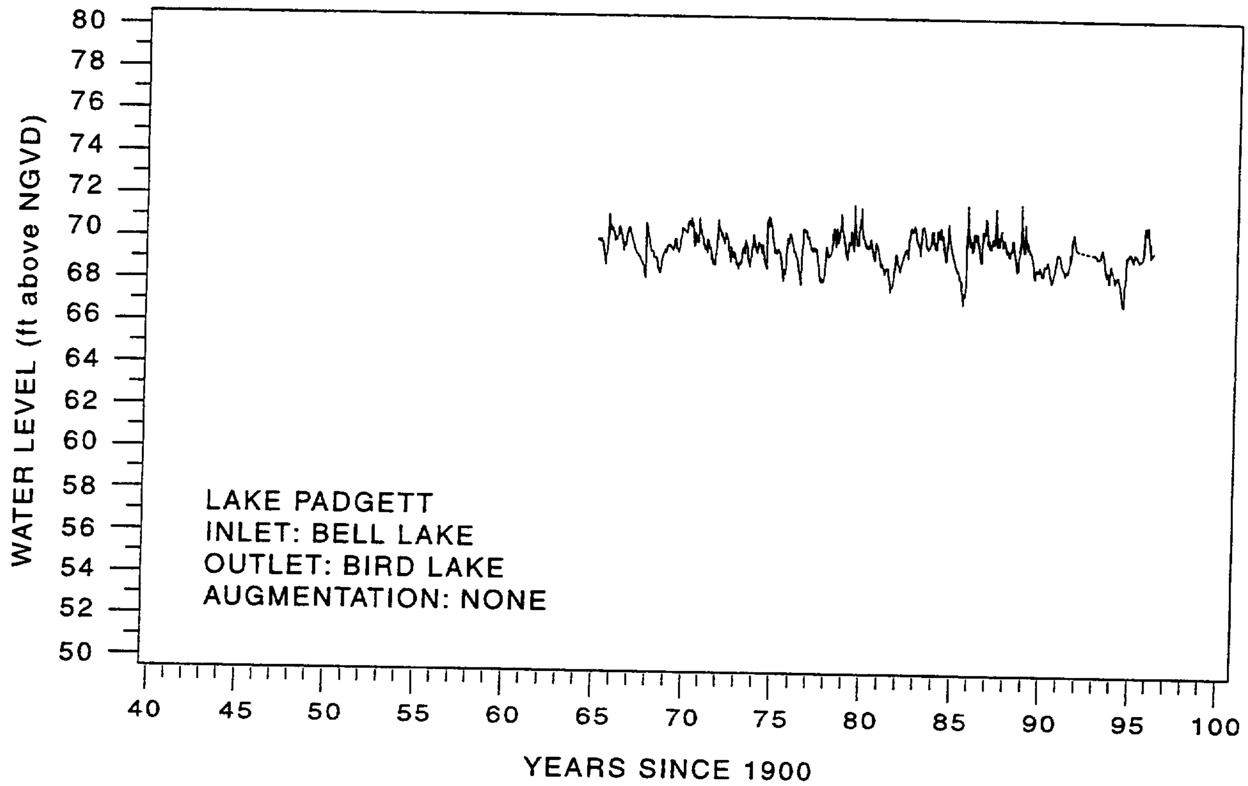


Figure 3-97. Water levels of Lake Padgett.

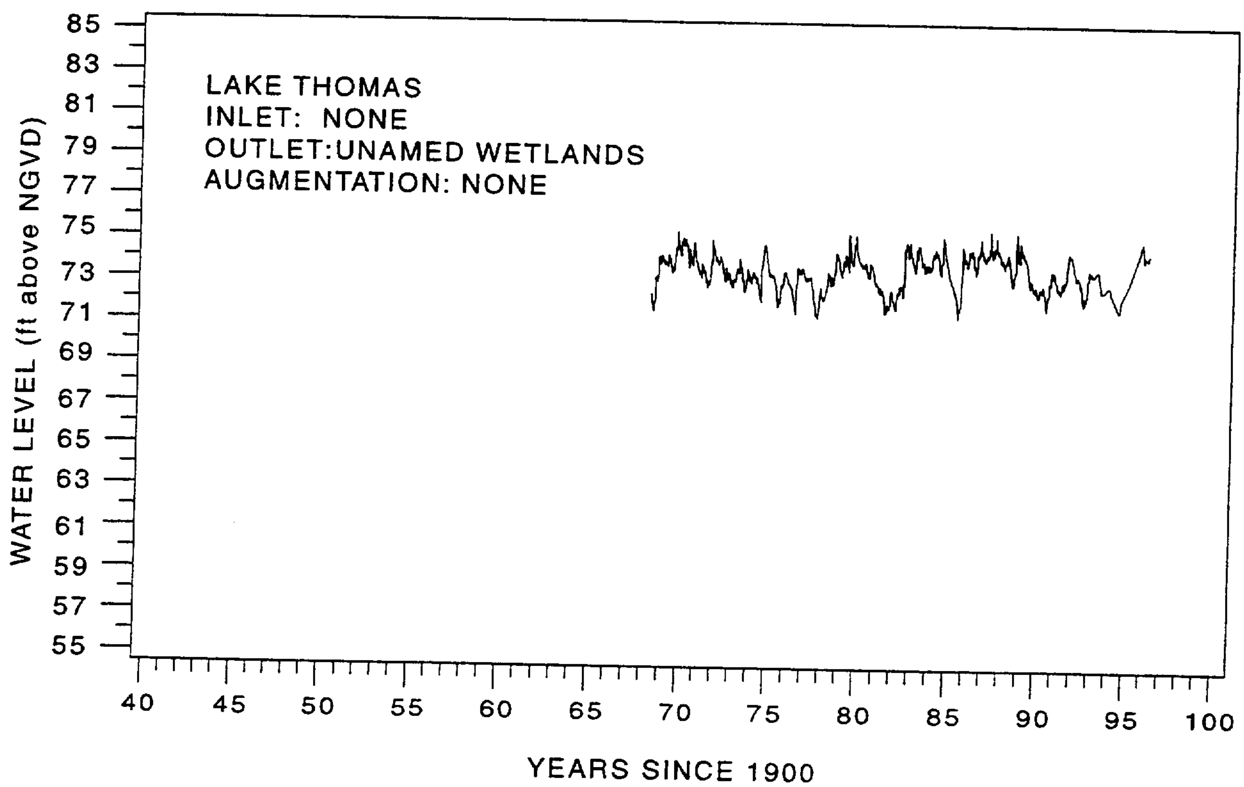


Figure 3-98. Water levels of Lake Thomas.

not have a fixed control structure on the lake. Lake Thomas has an outlet through a culvert, but no significant inlet. Neither lake shows any apparent trends, and have maximum fluctuations of two to four feet.

Figures 3-99 through 3-101 present the water-level hydrograph for Lake Iola, Neff Lake, and Clear Lake, located along the Brooksville Ridge in the northeastern portion of the Northern Tampa Bay WRAP area. Both Lake Iola and Lake Neff display a relatively high variability in water levels throughout the period of record. These lakes, and others nearby, are controlled by active sinkhole features located within the lake bottoms, whose connection to the Upper Floridan aquifer varies depending on levels of siltation. Lakes in this area are not representative of most lakes within the Northern Tampa Bay WRAP area, since they are perched high above the local water table and potentiometric surface. Because of the high head differential, these lakes drain rather quickly through open sinkhole features. Clear Lake may also be perched, but shows a much lower fluctuation, more similar to Lake Padgett and Lake Thomas.

Several lakes located in northern Pasco County have gone dry or near dry in recent years, including Big Fish Lake, Loyce Lake, and Lake Pasco. These lakes, like many of the aquifer hydrographs in the northern section of the Northern Tampa Bay WRAP area, have historically had high fluctuations, and some have had evidence of having become dry in the past. Many of the north Pasco County lakes have been dry or near dry for the last six or more years. Other shallow lakes located in eastern Pasco County, within the Starkey wellfield, have also been reported to be dry or near dry for a similar period.

Finally, Figures 3-102 and 3-103 present water-level hydrographs of Lake Tarpon in northern Pinellas County and Lake Thonotosassa in eastern Hillsborough County. These are the two largest lakes within the Northern Tampa Bay WRAP area. The water levels in both lakes are controlled by operable structures. Lake Tarpon is fed by Brooker Creek, and discharges to Safety Harbor via the Lake Tarpon Outfall Canal. Lake Tarpon naturally discharged through a sinkhole located along the western shore, which was diked from the remainder of the lake in August 1971. Lake Thonotosassa is fed by Baker Creek, and discharges to the Hillsborough

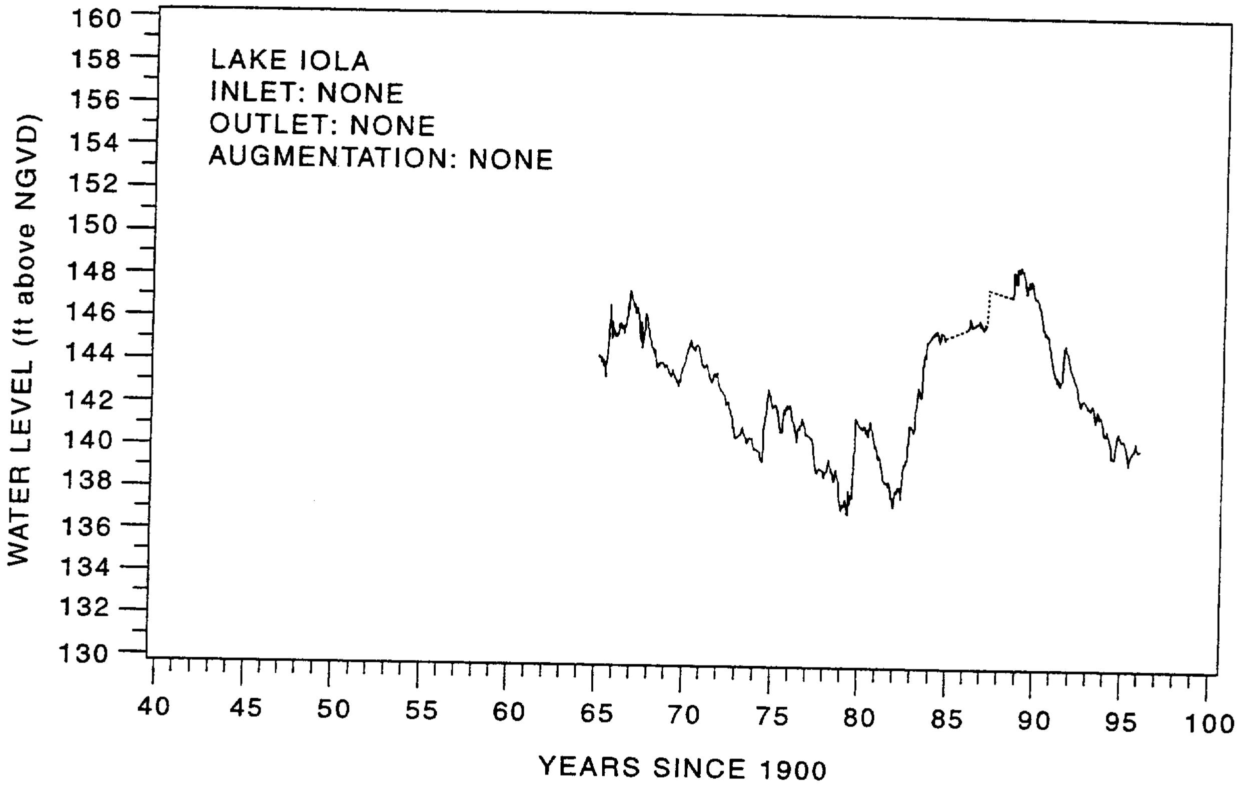


Figure 3-99. Water levels of Lake Iola.

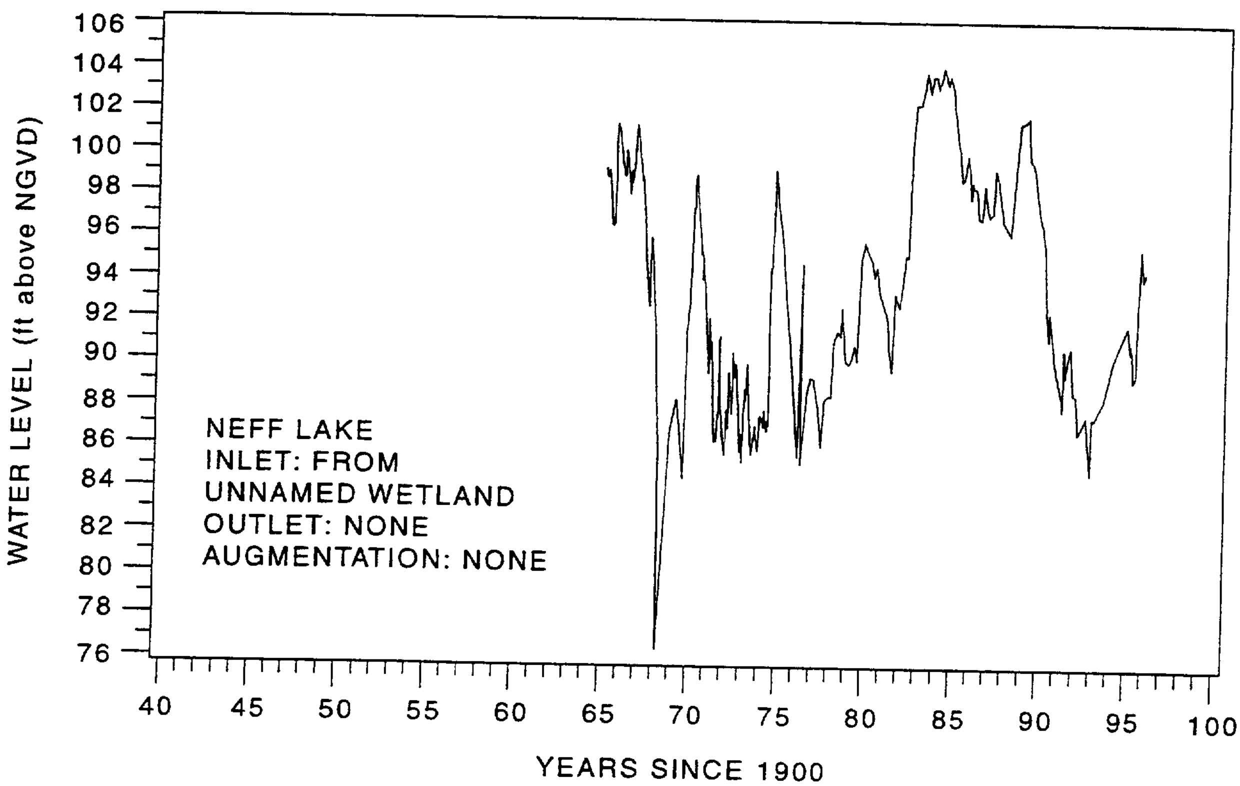


Figure 3-100. Water levels of Neff Lake.

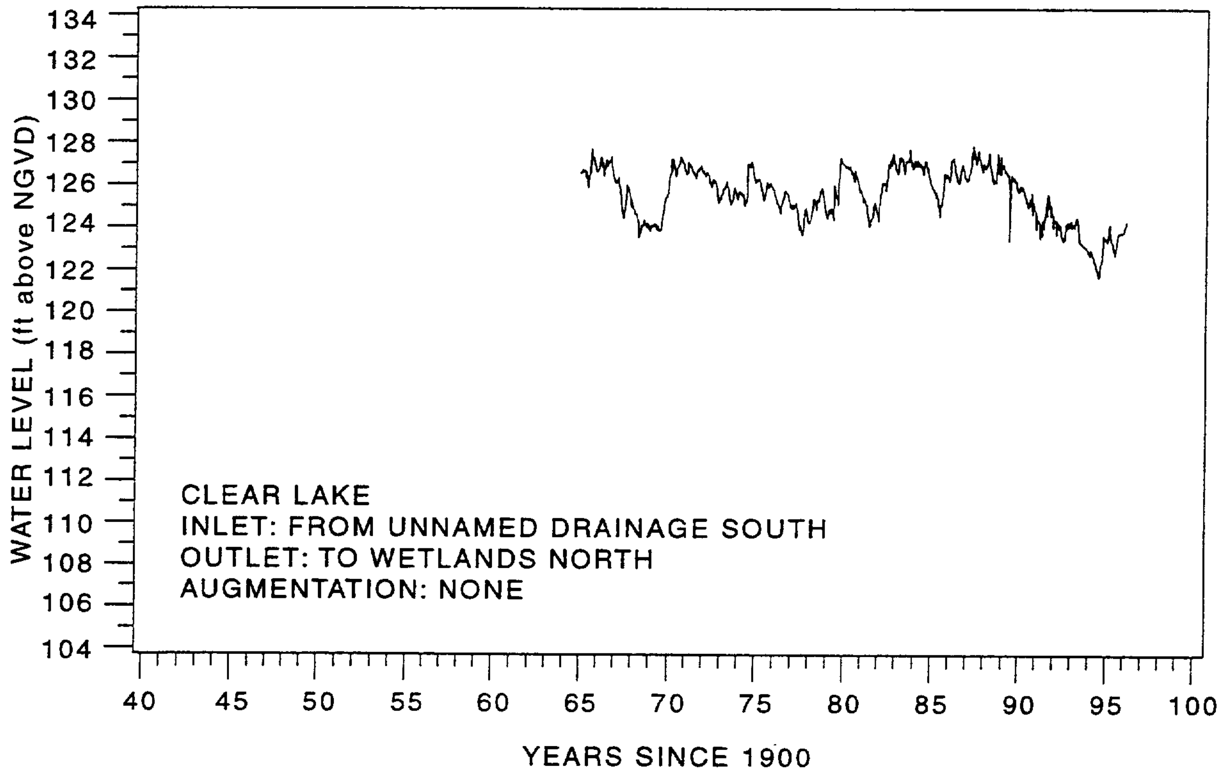


Figure 3-101. Water levels of Clear Lake.

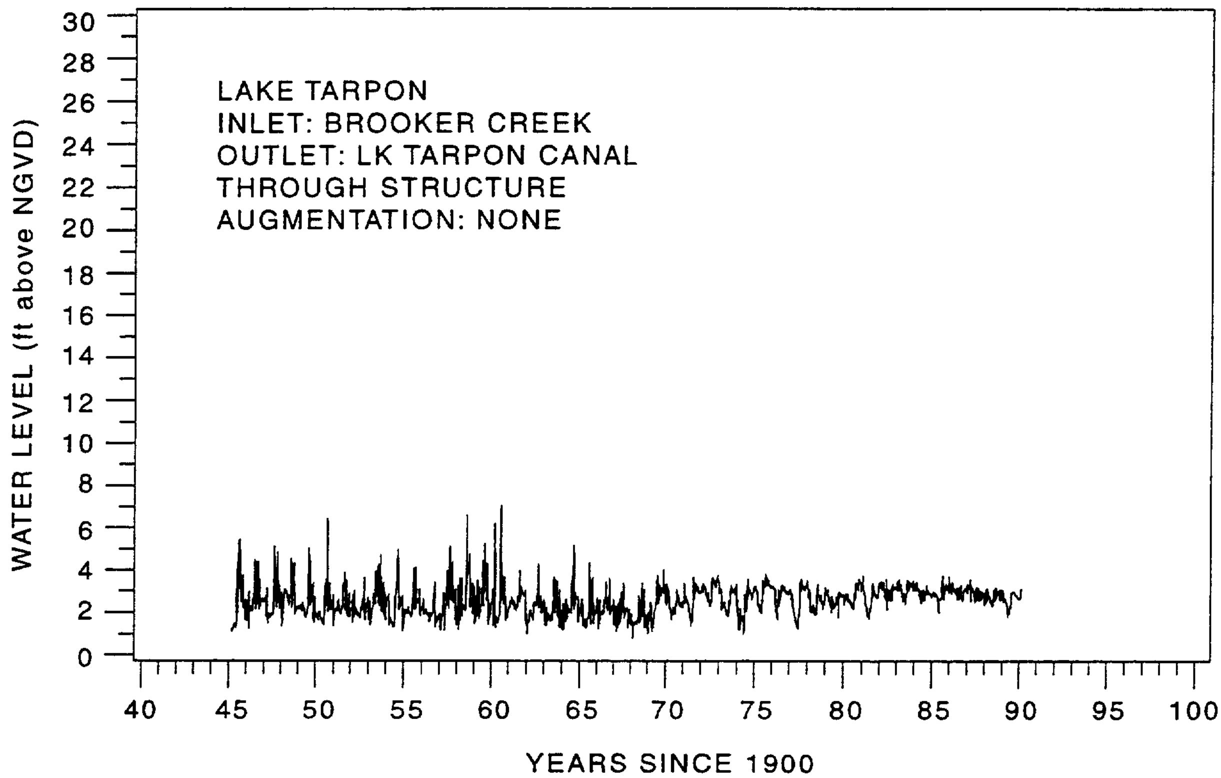


Figure 3-102. Water levels of Lake Tarpon.

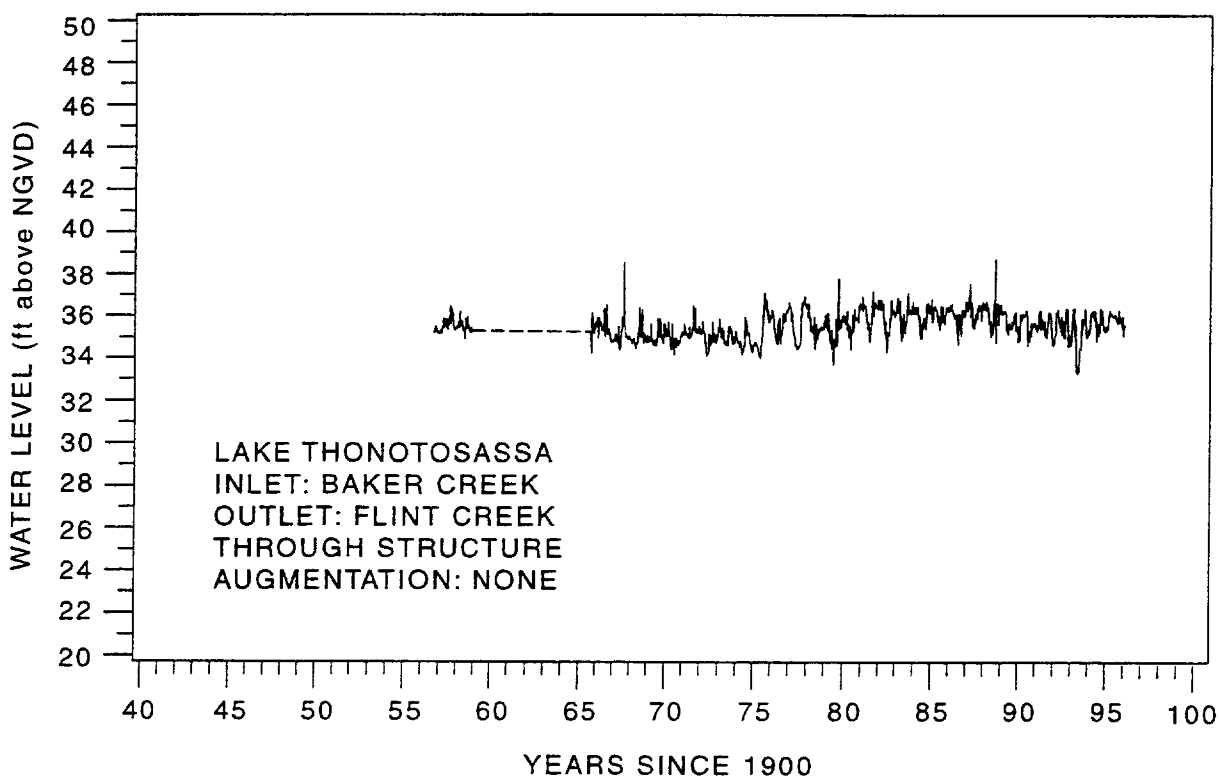


Figure 3-103. Water levels of Lake Thonotosassa.

River via Flint Creek. The current control structure was installed in 1975. The water levels of both lakes are very stable due to the control structures.

Regional analysis - Due to the many influences on individual lakes through time, it is difficult to visualize a regional perspective on lake water-level trends by reviewing individual lake level hydrographs. However, through the use of adopted lake management levels, some analysis can be performed to assess regional lake-level trends. Initial work on establishing an acceptable range of lake levels started in 1971 with Lake Tarpon (Gant, 1988). The SWFWMD Governing Board established adopted levels in June 1972 for Lake Tarpon. Subsequently, a survey of lakes in northwest Hillsborough County was completed in October 1973. That survey served as the basis for later investigations and the setting of lake management levels in the Northwest Hillsborough Basin. Eventually, lake management levels were adopted for lakes in other basins.

The Lake Levels Program that developed from this early work has the objectives of:

1. providing guidelines for development bordering lakes.
2. conserving the water storage and recharge capabilities of lakes.
3. providing levels for operation of lake control structures.
4. providing information for District water use permitting (WUP) activities.

The levels established by the Lake Levels Program are reviewed in public workshops and hearings and are adopted by the District's Governing Board. The four management levels are explained in detail in Gant (1990) and are listed below and illustrated in Figure 3-104:

1. **The Ten-year flood warning level** - an advisory level provided as a discretionary guideline for lakeshore development that approximates the ten-year recurring flood level.

2. **The Minimum flood level** - the highest level a lake is allowed to fluctuate without interference, except as approved by the Board (for lakes with control structures). Often regarded as a typical annual high.

3. **The Minimum level-low management level** - the normal annual low and is used to regulate lake augmentation and to provide information to regulate ground-water and lake withdrawals affecting the lake level.

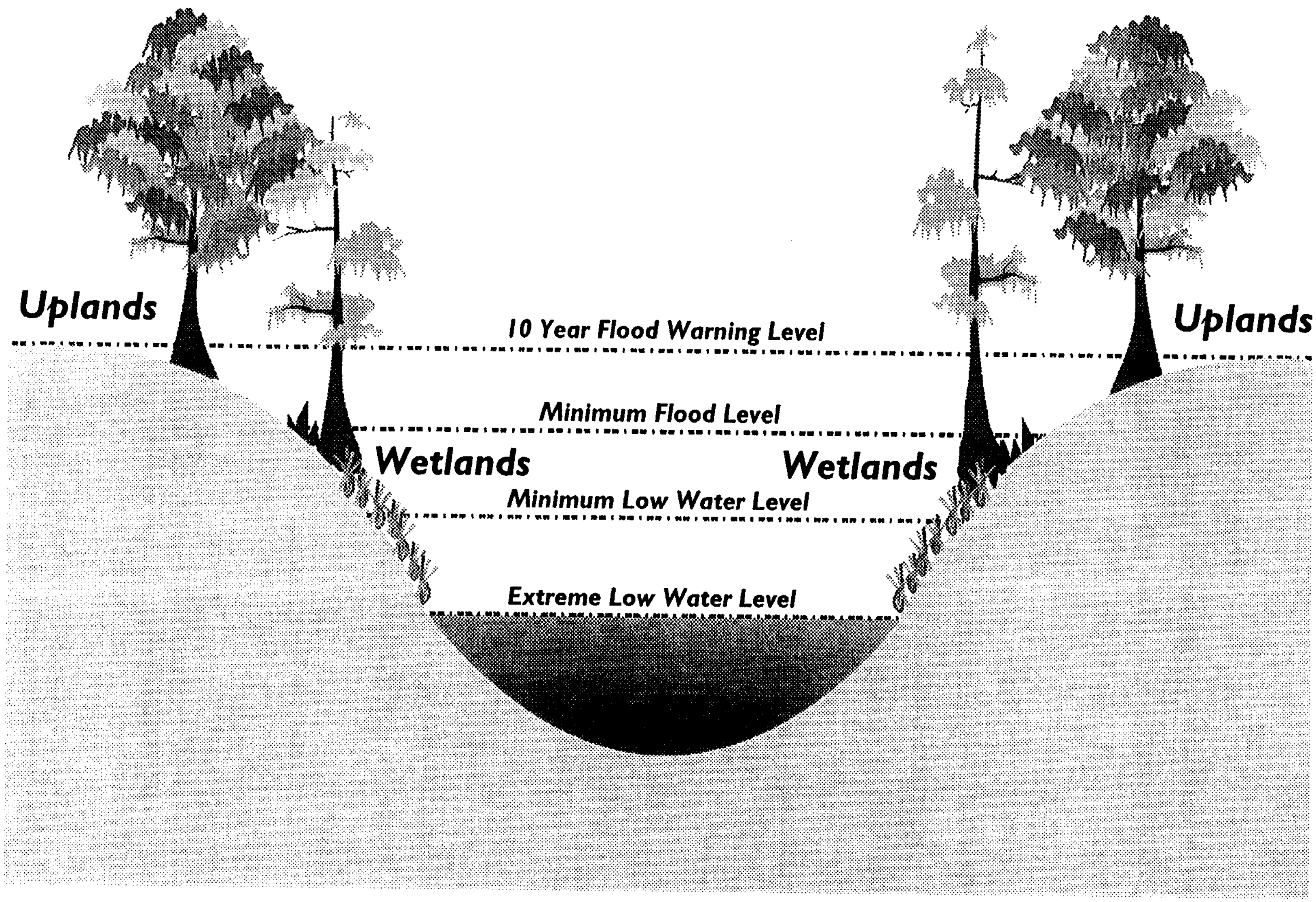


Figure 3-104. SWFWMD lake management levels.

4. **The Minimum level-extreme low management level** - a normal cyclic level the lake should reach only periodically for the biological health of the lake. This level is also used to operate control structures during very low rainfall years.

If a lake fluctuates below a level that is not within a normal range determined by long-term indicators, the lake is considered stressed. More specifically, a lake at or below the seasonal-low water level or low management level for two-thirds of the most recent five-year period is considered to be fluctuating significantly lower than normal and is given a "stressed lake" designation. In this determination, District staff uses a record of monthly mean values. Lakes without adopted management levels can also be classified as stressed by on-site observations using indicators of historic water level fluctuations, such as vegetation and man-made structures. Flannery (1990) recommends that the stressed lake classification be used in the regulatory process for restricting withdrawals from lakes and for identifying lakes which could possibly be impacted by large, nearby ground-water withdrawals.

To provide a broad view of lake water-level trends, a scaling system was devised using 153 lakes throughout the Northern Tampa Bay WRAP area. Management levels have been adopted on many lakes throughout the Northern Tampa Bay WRAP area, based upon biological and other indicators observed in the field. Most of these lakes have adopted lake levels, and have a record of water level for varying lengths of time. Unadopted lakes have been observed for sometime during this and other related studies. The lakes are tabulated in Appendix A.

The three categories used in this assessment are as follows:

1. **Stressed**- adopted lakes already defined as stressed by the SWFWMD lake level program, or unadopted lakes that are defined as stressed by this study using the same criteria used by the lake level program (Flannery, 1990).

2. **Did not meet minimum flood two or more times during the period of stress analysis** - lakes which do not meet the stressed threshold, but have not met minimum flood levels more than twice within the period of stress analysis.

3. **Did meet minimum flood two or more times within the period of stress analysis** - as defined.

This rating system was devised to give a rough estimate of the recent spatial variation in lake water levels throughout the Northern Tampa Bay WRAP area. Category 1 lakes are those that are no longer functioning as healthy lakes. Some have been completely dry for many years, and some have lost most lake benefits. Category 2 lakes are experiencing chronic low water-levels and alterations to their expected fluctuations. Category 3 lakes meet normal fluctuations during at least some period of time.

Figures 3-105 through 3-108 represent the results of this analysis for 1991 through 1994. Note that these years followed two relatively low rainfall years in 1989 and 1990 (40 to 45 inches). Most stations in the Northern Tampa Bay area received average to higher than average rainfall for 1991 (52 to 59 inches), and received higher than average rainfall in the spring of 1993 when the analysis was performed for these years. Overall, however, 1992 and 1993 were dry years.

In all four years, most of the lakes are in either category 1 or 2. In 1991, 82 percent of the lakes were either category 1 or 2, with approximately 17 percent of the lakes classified as category 1 (stressed). In 1992 and 1993, although the percent of category 1 and 2 lakes increased only to 84 percent and 88 percent, respectively, the percentage of category 1 lakes increased to 36 percent and 43 percent, respectively. In 1994, category 1 and 2 lakes increased to 96 percent, while the percentage of category 1 lakes increased to 53 percent. While some lakes with the same rating are clustered, lakes of all three categories are seen in localized areas. Most of the lakes that have shown a decrease in category between the three time periods are located near wellfields, but there are exceptions in the northeast. These lakes, located along the Brooksville Ridge, are controlled by distinct sink features within the lakes. These sink features have periodically become plugged and unclogged with sediments, so drastic fluctuations in water levels are common. Examples are Lake Iola and Lake Neff, whose hydrographs were presented earlier in Figures 3-99 and 3-100.

Rainfall is an important parameter in lake water-level fluctuations, and is reflected in the lake-level status of the lakes in all three figures. However, Figures 3-105 through 3-108 demonstrate two other concepts; 1) because the fluctuation of lake water levels is dependent on many parameters; including rainfall, lake bottom geology, existence of control structures, periods of

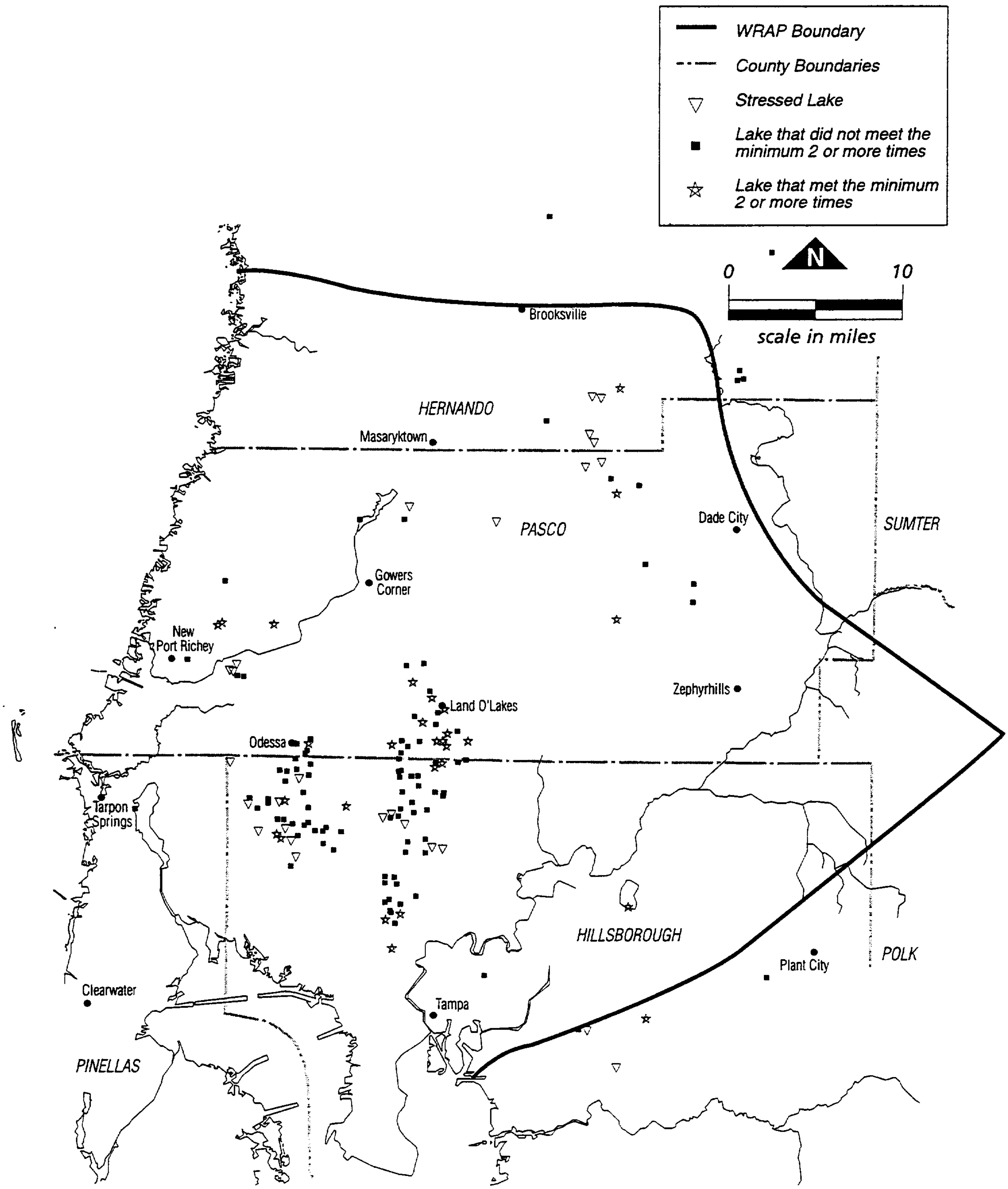


Figure 3-105. Lake rating in the Northern Tampa Bay WRAP area for the 1991 analysis period.

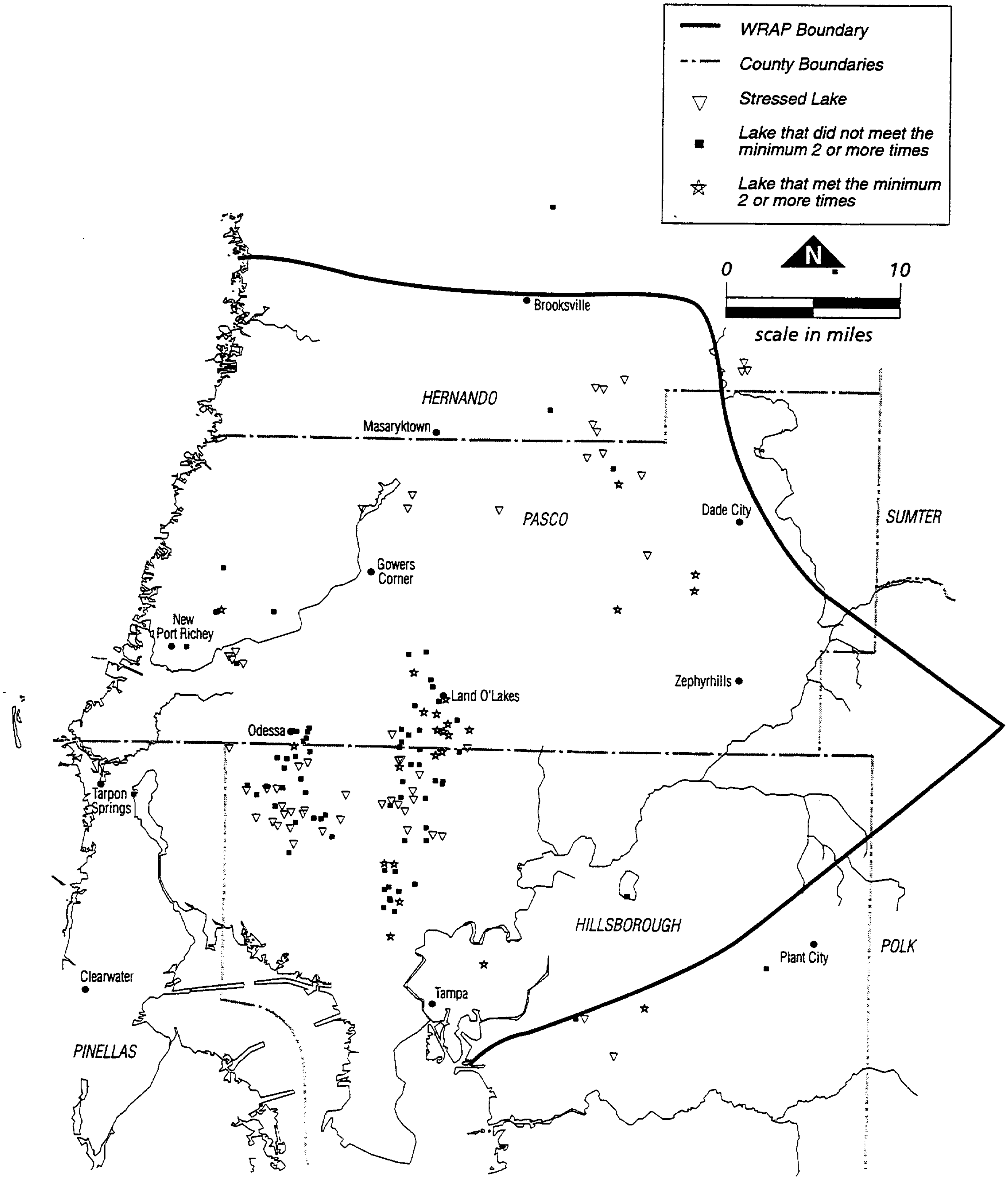


Figure 3-106. Lake rating in the Northern Tampa Bay WRAP area for the 1992 analysis period.

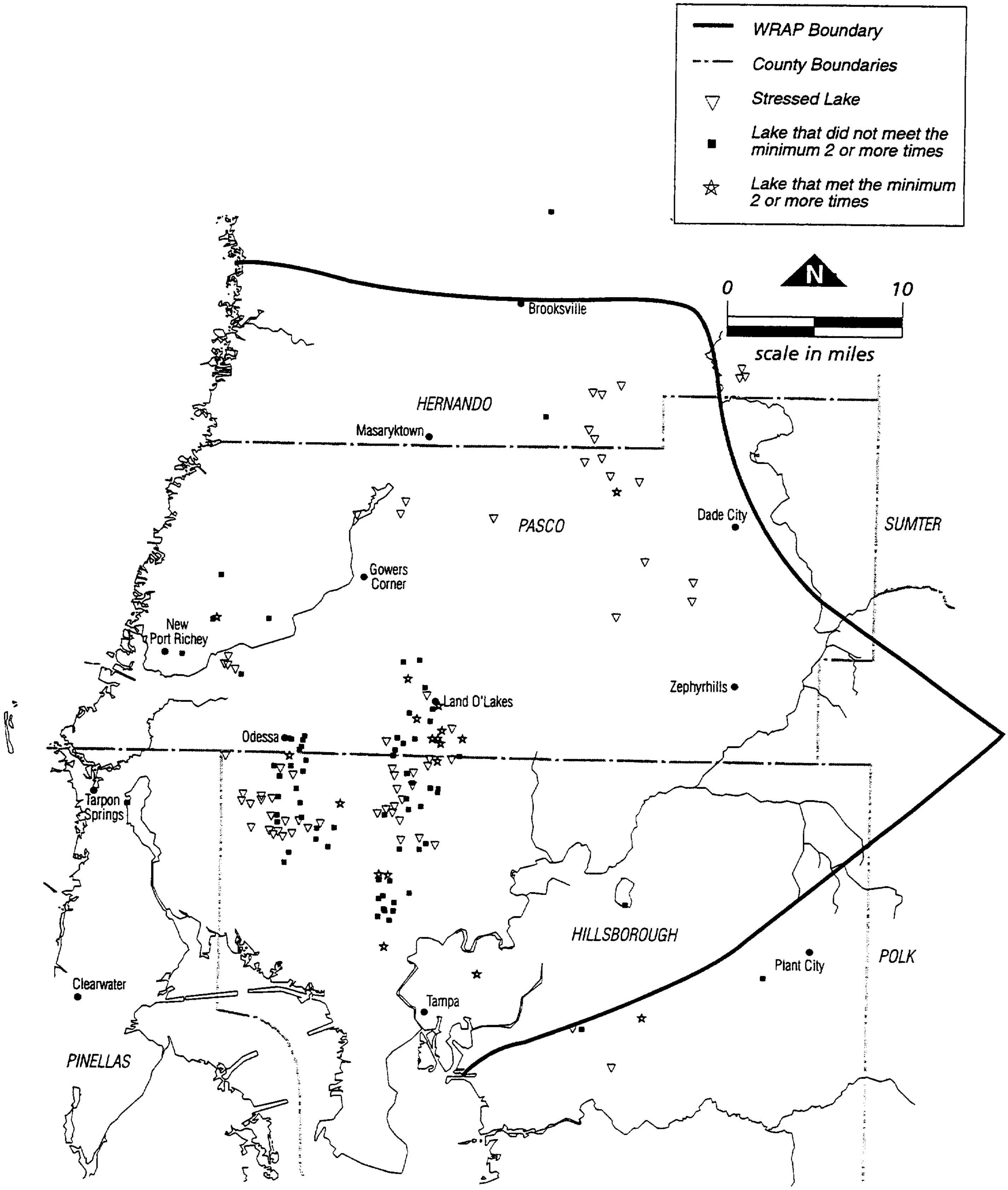


Figure 3-107. Lake rating in the Northern Tampa Bay WRAP area for the 1993 analysis period.

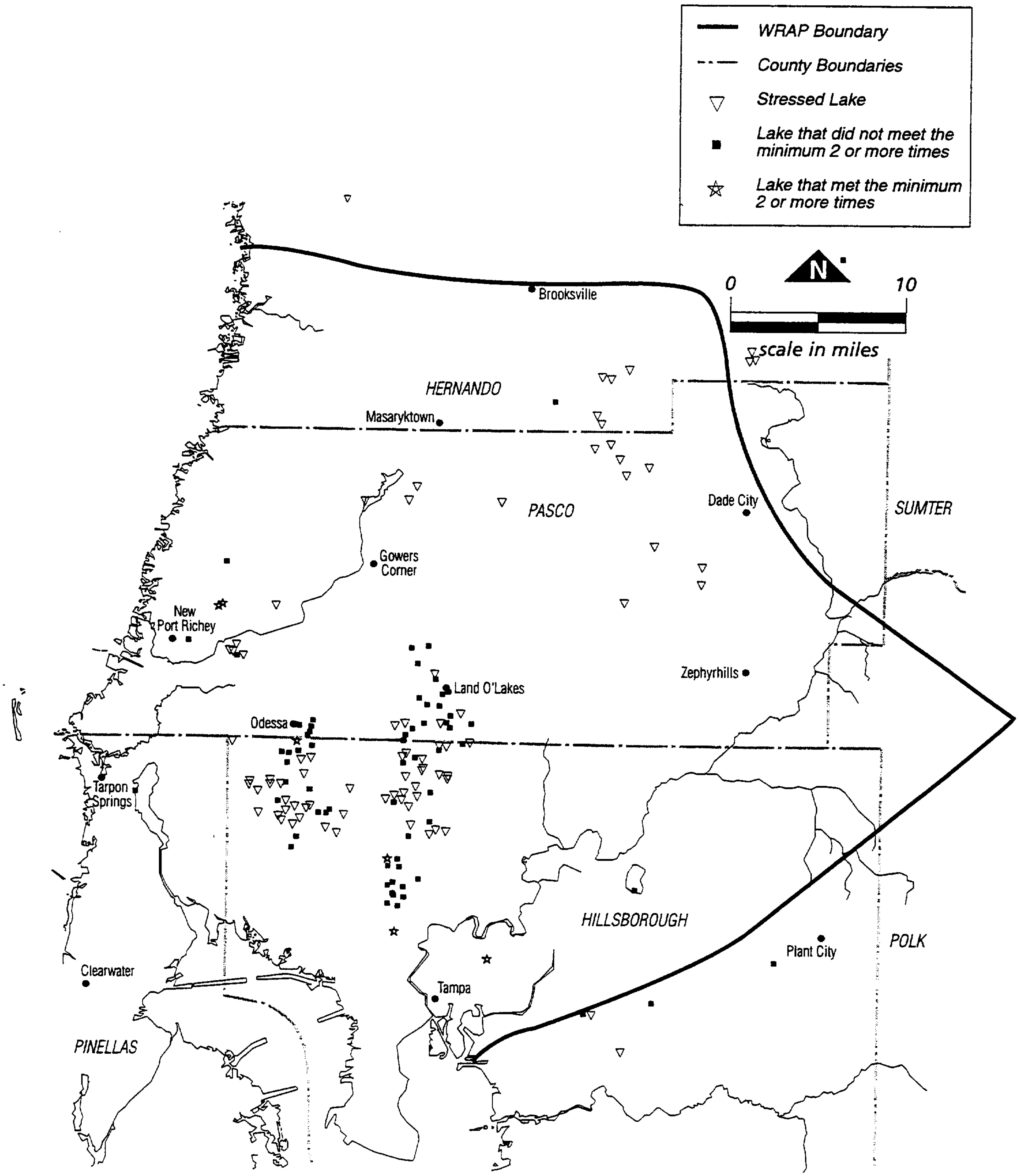


Figure 3-108. Lake rating in the Northern Tampa Bay WRAP area for the 1994 analysis period.

augmentation, inlets and outlets, surrounding land use, and regional ground-water withdrawals, the condition of lakes at any given time in any local area can be highly variable, and 2) with the exception of the lakes along the Brooksville Ridge, the lakes that have shown the greatest decrease in water-level category over the four-year period are located near wellfields. However, most of the lakes within the Northern Tampa Bay WRAP area, regardless of water-level status, are near wellfields. Therefore very few control sites are available. This analysis will be taken one step further in Chapter 4.

3.6.3 Wetlands

The SWFWMD has been studying wetland water levels in the Northern Tampa Bay WRAP area and nearby Green Swamp area of Florida since the 1970s. Wetlands in the Northern Tampa Bay area consist of both forested and non-forested areas, typified by cypress domes and marshes. Presently, more than sixty wetlands in the project area have surface-water records of at least five years. Many wetlands with long-term records are in the Starkey, Cypress Creek, and Morris Bridge wellfields. Water level gages were installed for control purposes in wetlands in the Green Swamp and the Hillsborough River State Park. A lengthy record of control wetland water levels, extending back to the late-1970s and early-1980s, facilitates detection of water-level trends that may be occurring in wetlands throughout the project area.

The network of long-term wetland hydrographs is not uniformly distributed within the Northern Tampa Bay WRAP area. When the present project was begun, it became evident that the existing network of wetland water-level gages did not cover certain parts of the project area to the extent desired. For this reason, additional staff gages were located in wetlands of agricultural and urbanized parts of Hillsborough, Pinellas and southern Pasco counties. Others were placed in the South Pasco and Eldridge-Wilde wellfields. The following discussion focuses on trends that have been noted in wetland water levels. The locations of wetland monitor sites referenced in this section are shown in Figure 3-109. Note that land surface is implied along the flat portion of each hydrograph, where the wetland was dry. Because of slight updates in survey data, the elevation of land surface in these hydrographs does change. Land surface is

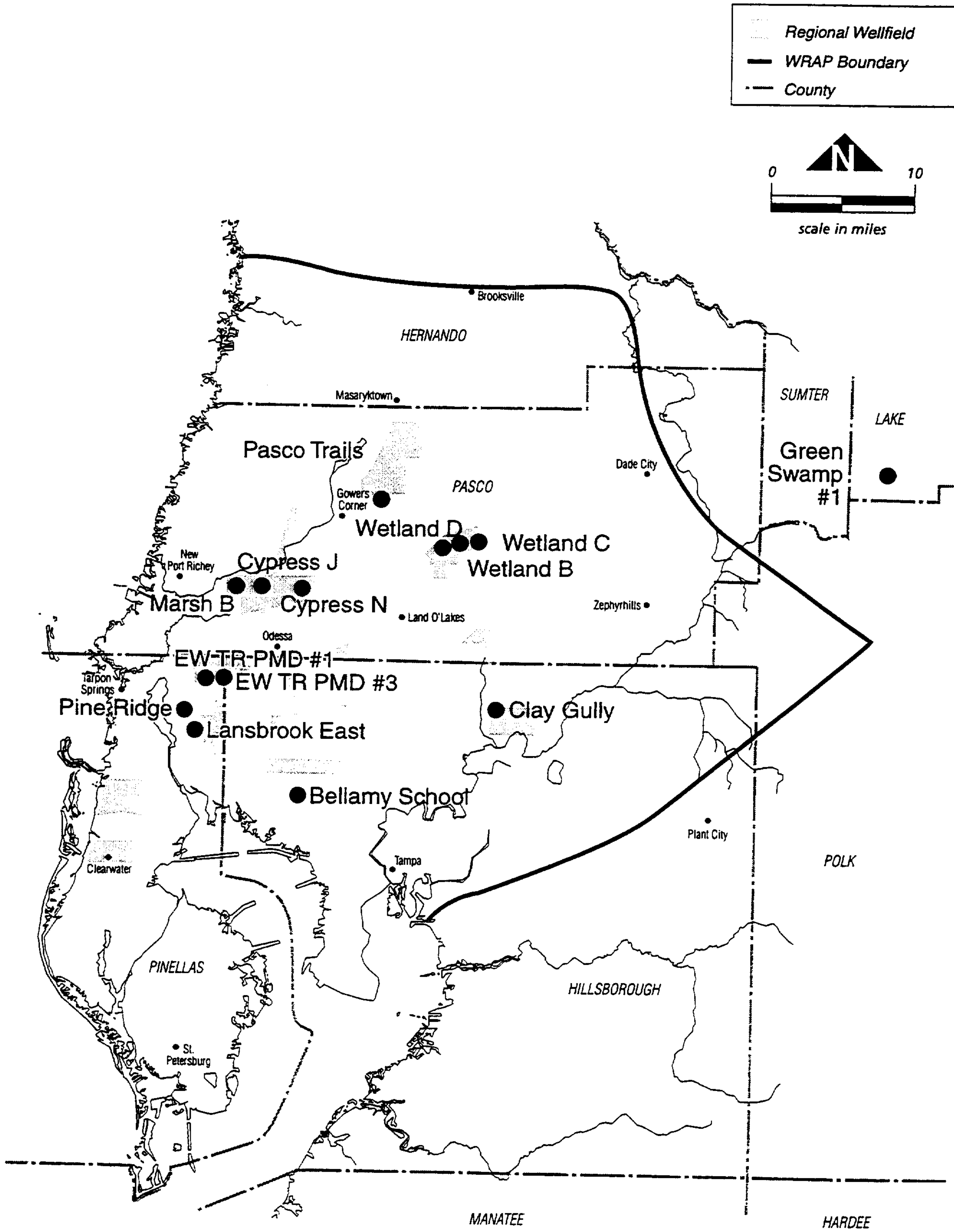


Figure 3-109. Location of wetland sites referenced in Section 3.6.3 .

shown in Figures 3-110 (Green Swamp #1) because an adjacent surficial aquifer monitor well measures water level below the bottom of the wetland.

Figure 3-110 shows a pattern of normal surface-water response in a Green Swamp cypress dome located in a natural flatwoods setting several miles from urban development and ground-water withdrawals. Surface water is present most of the year in this wetland although annual rainfall is variable. Further, maximum water levels are a common occurrence during the rainy season. When peak water levels are present, the entire wetland is flooded. Figure 3-111 shows an abnormal pattern of surface-water behavior in a dome at the Starkey wellfield. Since 1983, the surface-water hydroperiod has become considerably more abbreviated and maximum annual water levels have declined. When maximum annual surface-water levels decline, much of the wetland is dry.

Figures 3-112 through 3-114 represent water-level hydrographs of three wetlands within the Cypress Creek wellfield. The wetlands are part of a network of monitor sites within the wellfield that have been observed and analyzed by the SWFWMD for many years (Rochow, 1985). The first two hydrographs, sites B and D, are located in the central part of the wellfield. Site D was originally a deep marsh, but has been completely dry since 1977. Site B is a shallow, somewhat perched cypress dome, and although it has been wet for short periods of time, the decline of water levels within the wetland is evident on the hydrograph.

The Cypress Creek wellfield has several wetlands that have been augmented using water pumped from the Upper Floridan aquifer. The third wetland hydrograph (Figure 3-114), Wetland C, represents the water levels of an augmented wetland. This site is a cypress dome located in the northeastern section of the wellfield. As the hydrograph shows, the wetland was dry for several years subsequent to 1977. Upland plant species began increasing throughout the wetland, and fire caused severe damage in 1979. In 1981, the WCRWSA began augmenting the wetland, and the wetland began to recover. Wetland plant species replaced the invading upland species, and water levels consistently remained elevated.

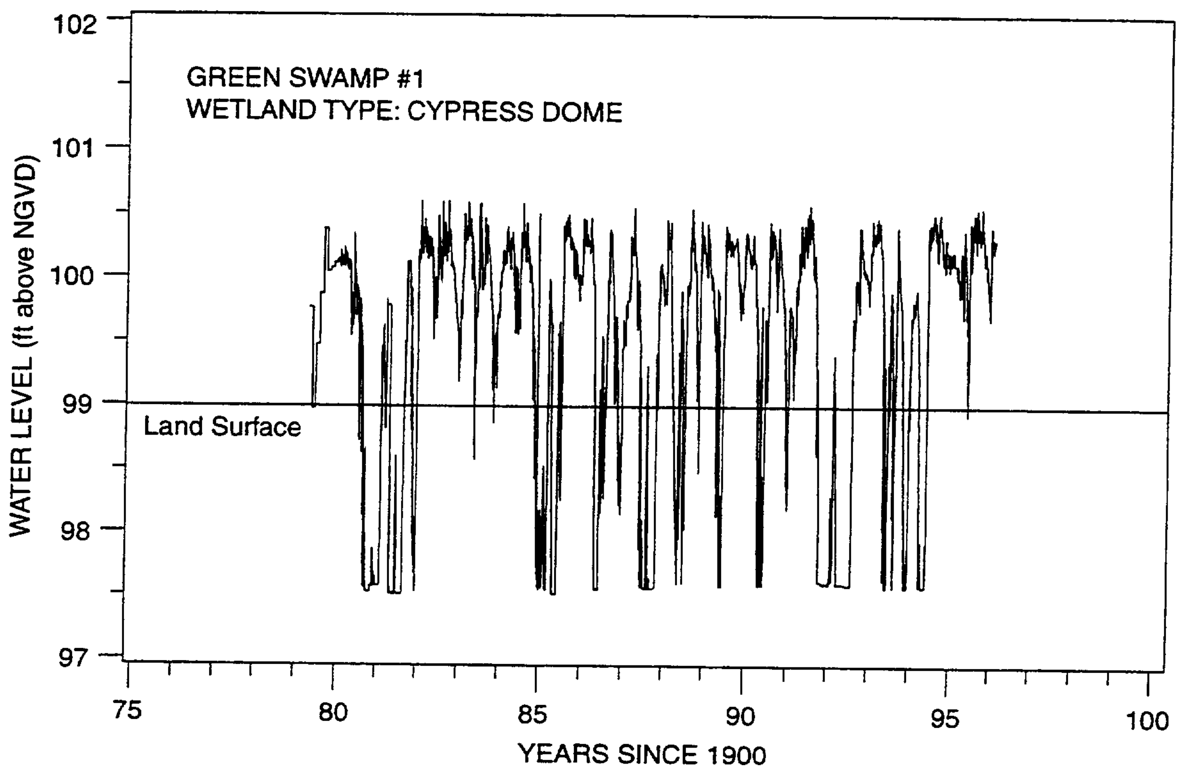


Figure 3-110. Water levels of the Green Swamp #1 cypress dome.

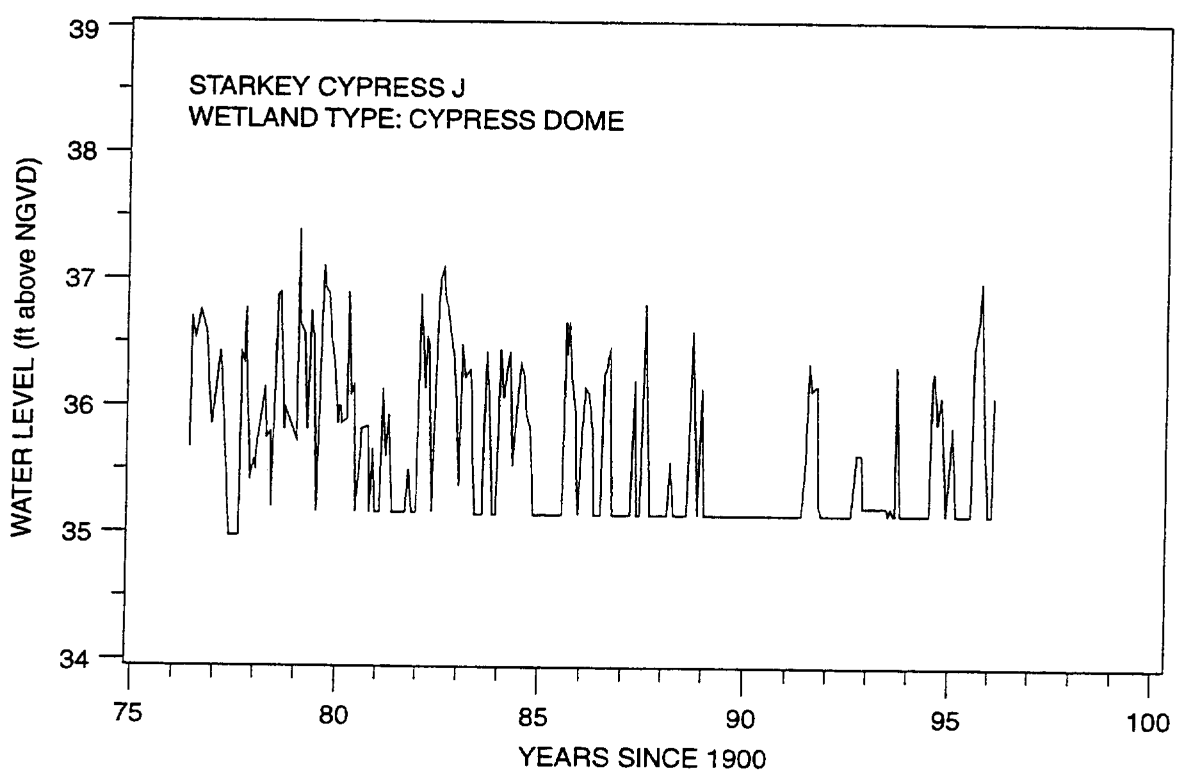


Figure 3-111. Water levels of the Starkey Cypress J cypress dome.

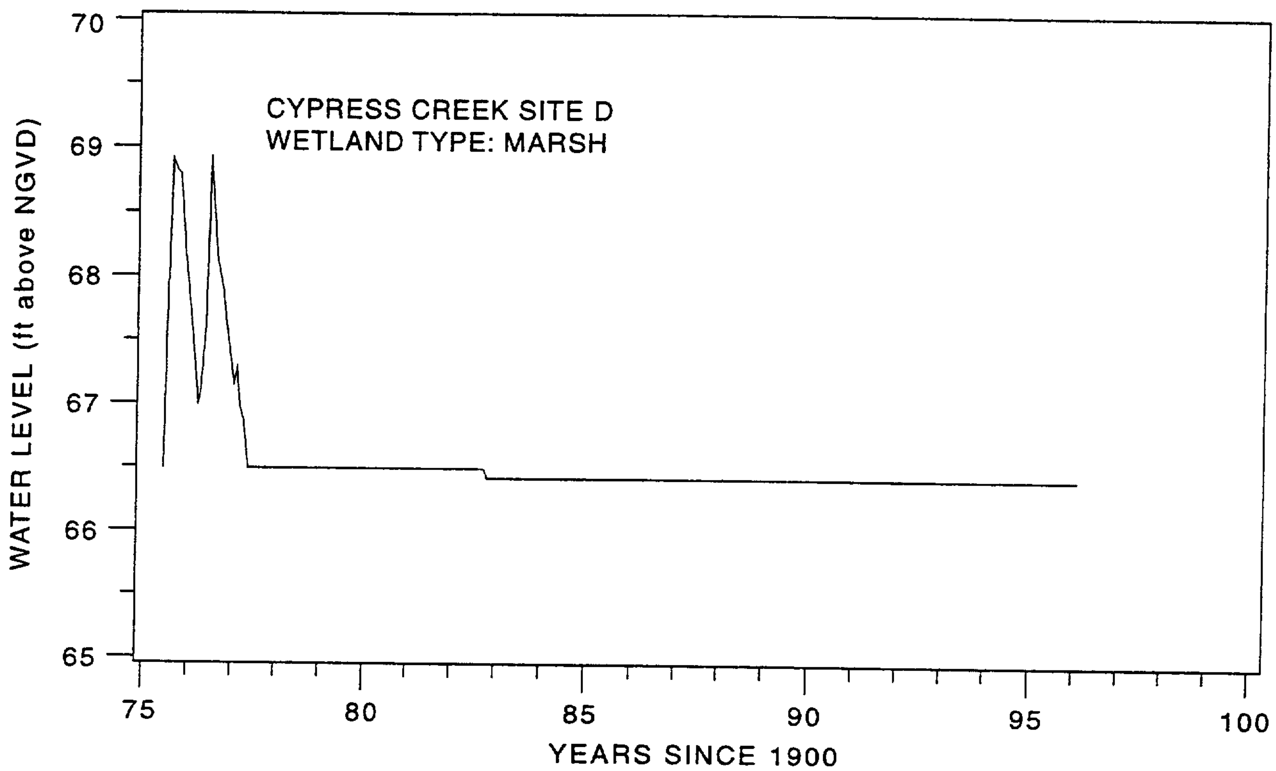


Figure 3-112. Water levels of the Cypress Creek Site D marsh.

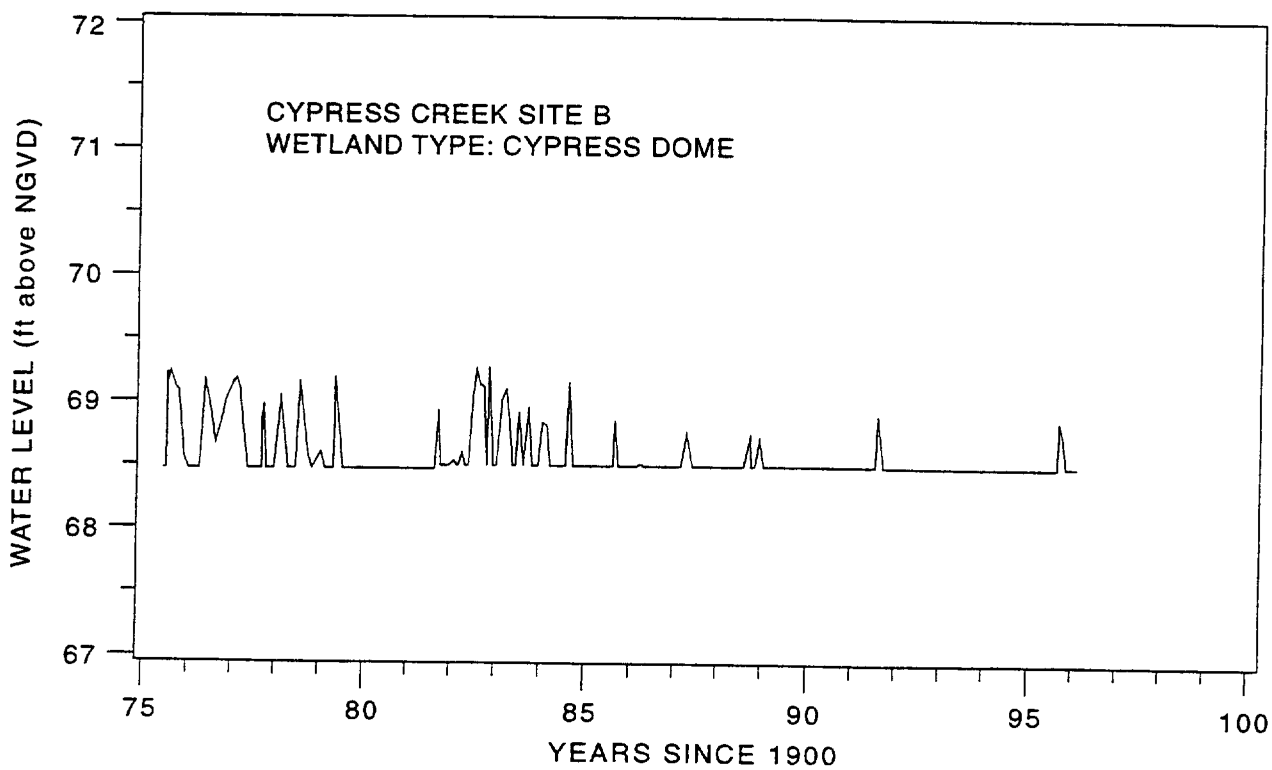


Figure 3-113. Water levels of the Cypress Creek Site B cypress dome.

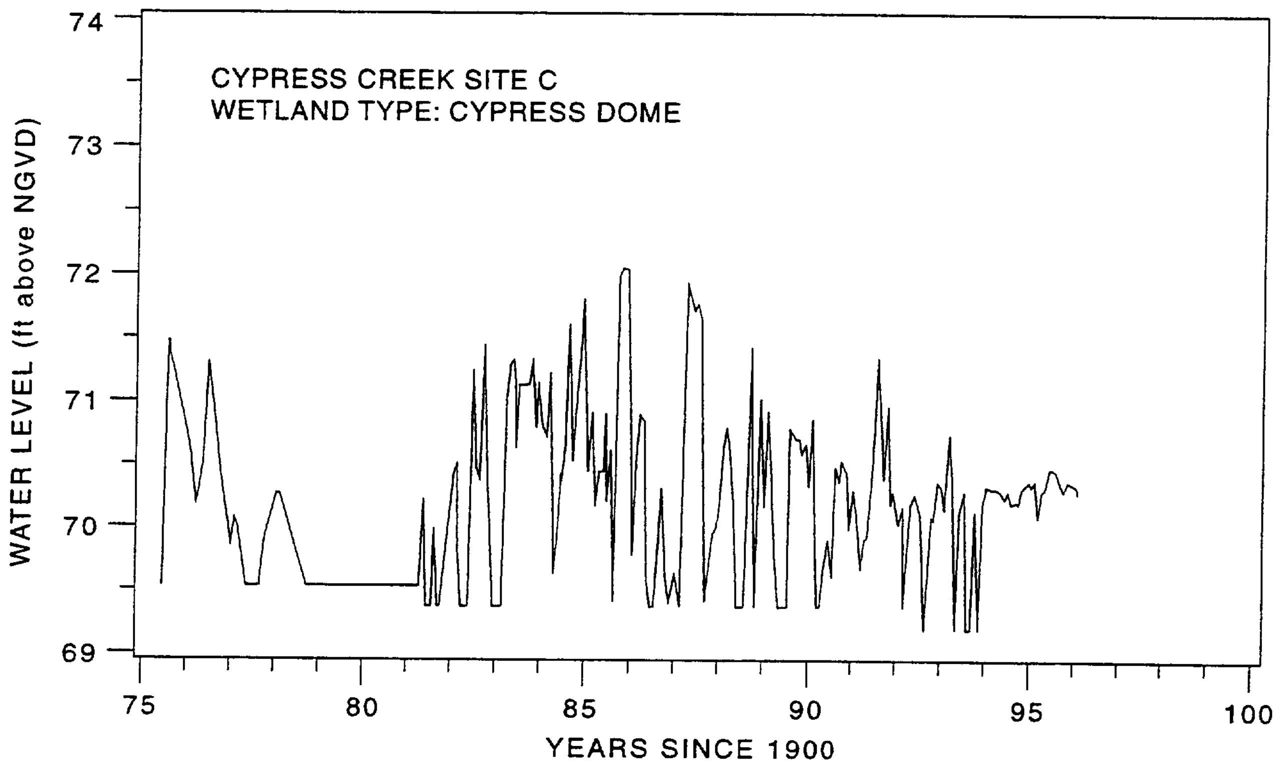


Figure 3-114. Water levels of the Cypress Creek Site C cypress dome.

Along with Figure 3-111, Figures 3-115 and 3-116 show water-level hydrographs from three wetlands in the Starkey wellfield. Figure 3-115 presents water-level data for Marsh B, which is a large grass prairie marsh located near the western edge of the wellfield (Figure 3-109). As the hydrograph of Marsh B shows, the marsh was often dry during the late-1970s and early-1980s, but recovered quickly in the mid-1980s. The marsh has been mostly dry for the last several years.

Figure 3-111, presented earlier, represents the water-level hydrograph of Cypress J, located in the center of the wellfield. This hydrograph is one of the few central wellfield wetlands that has a water-level record beginning in the mid-1970s. The hydrograph shows that in recent years the wetland has experienced long periods of dryness that were uncommon prior to 1984. Recent visual inspection of Cypress J confirms that water-levels have been rapidly declining. Other wetlands in this area, as documented by Watson and others (1990), have shown similar or more extensive impacts, depending on the hydrologic connection to the Upper Floridan aquifer. At least one wetland in this area has collapsed entirely, and has experienced several feet of land subsidence over the last few years.

As a comparison, Figures 3-116 and 3-117 present water-level data from Cypress N, located approximately 2.5 miles from the center of the Starkey wellfield along the eastern property boundary, and the Pasco Trails Cypress, located northwest of the Cypress Creek wellfield. When compared to Cypress J, Cypress N and the Pasco Trails Cypress show very little change in water-level fluctuation, although the Pasco Trail Cypress has been dry for long periods since 1993. The Green Swamp #1 cypress dome (Figure 3-110) is located over 35 miles to the east of the Starkey wellfield (Figure 3-109). The Green Swamp wetland hydrograph looks similar to that of Cypress N.

Hillsborough County has very few wetlands with long-term water-level data. Figure 3-118 presents water-level data for Clay Gully Cypress, located within the Morris Bridge wellfield (Figure 3-109). Wetland water levels at this site have been depressed, and long-term periods of dryness have been apparent since the early-1980s. Figure 3-119 shows short-term data from the Bellamy School Cypress in western Hillsborough County. This wetland is located within a

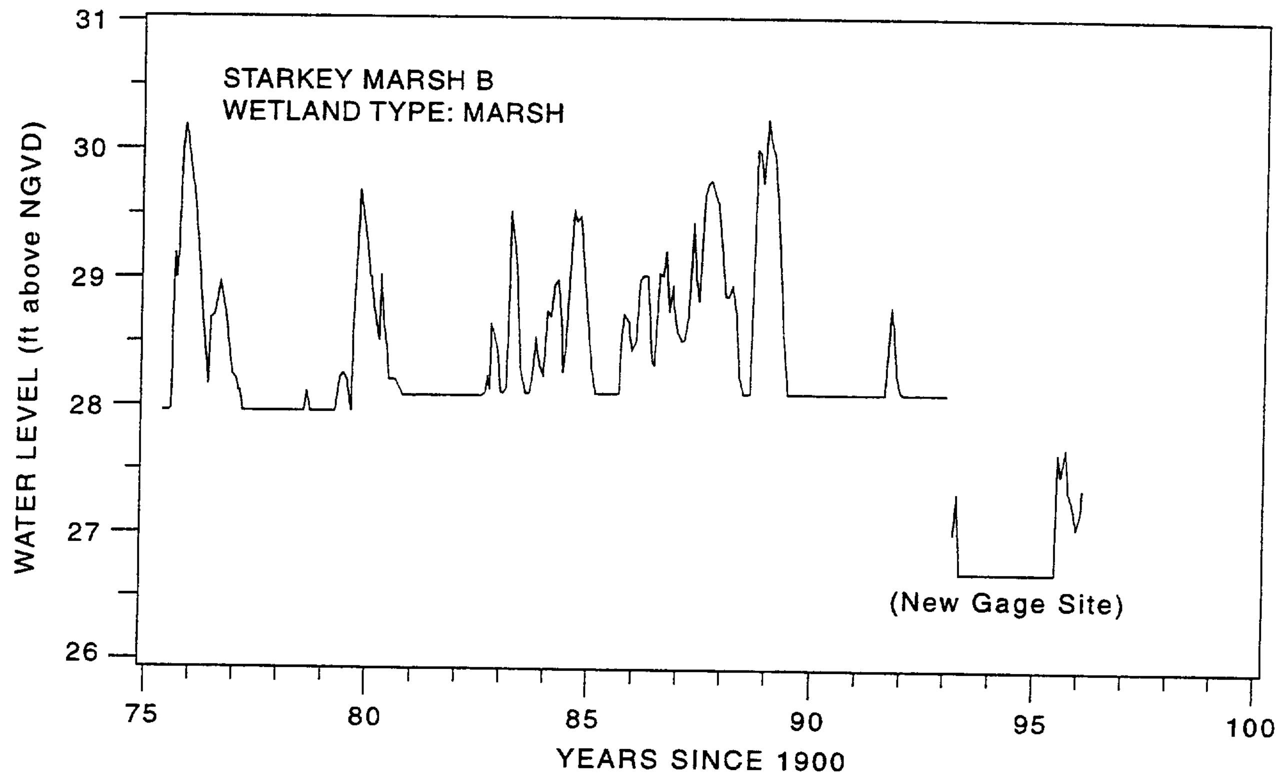


Figure 3-115. Water levels of the Starkey marsh B.

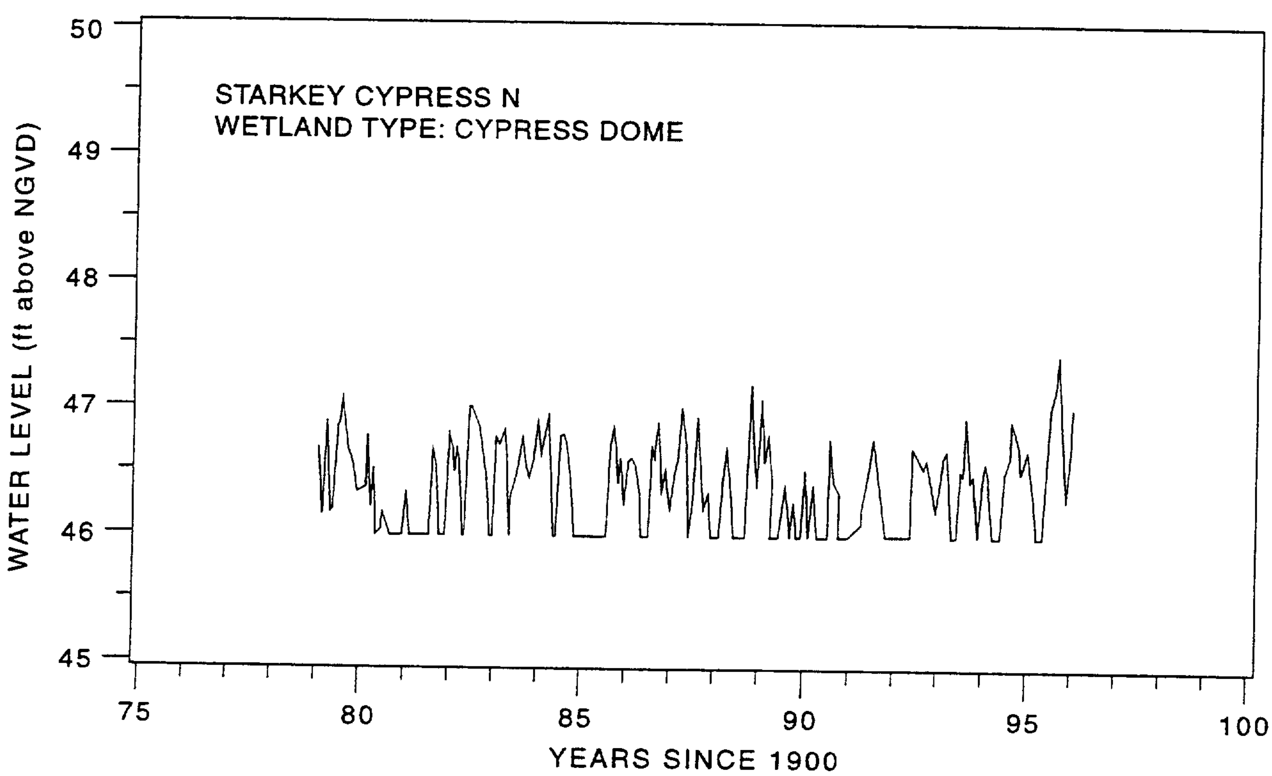


Figure 3-116. Water levels of the Starkey cypress N cypress dome.

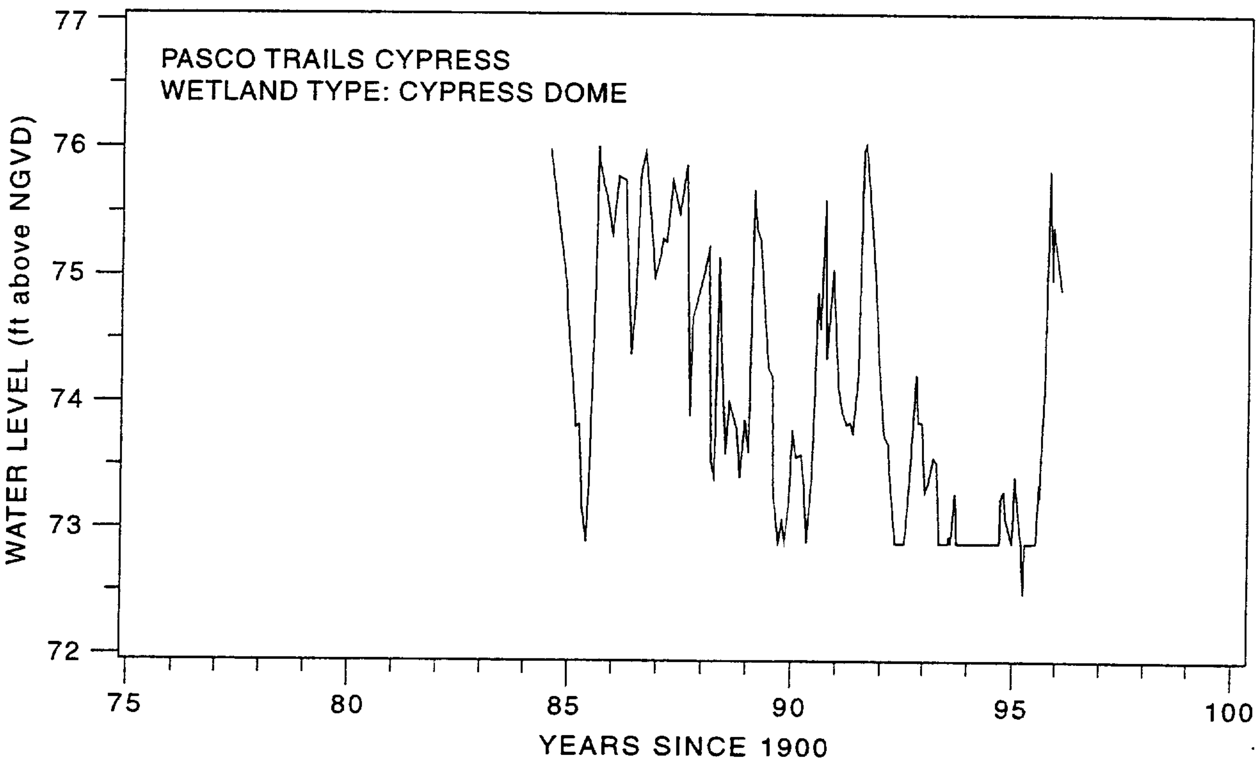


Figure 3-117. Water levels of the Pasco Trails cypress dome.

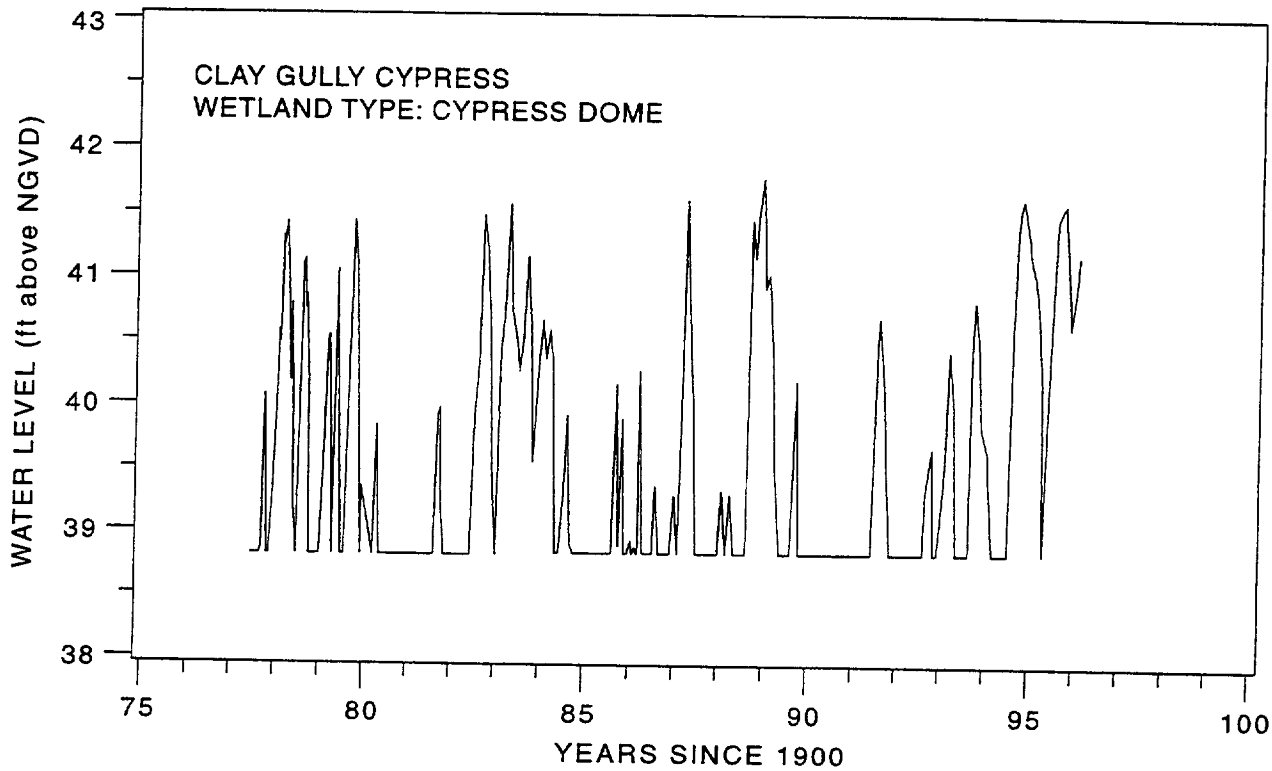


Figure 3-118. Water levels of the Clay Gully cypress dome.

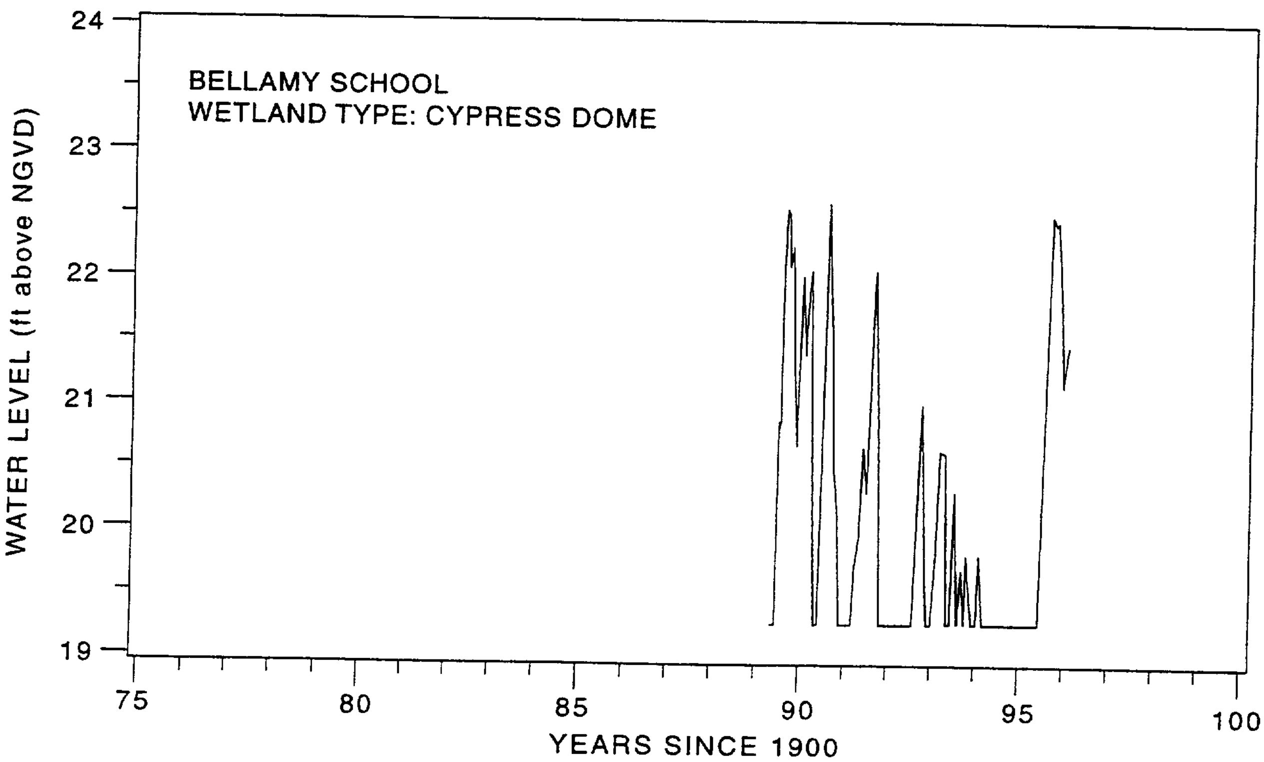


Figure 3-119. Water levels of the Bellamy School cypress dome.

highly urbanized area, but has shown relatively stable water levels until about 1994. The wetland may receive runoff from a nearby ditch and road.

Most wetland data in Pinellas County is on the east side of Lake Tarpon near the East Lake and Eldridge-Wilde wellfield. Generally, wetlands in the Eldridge-Wilde wellfield area are highly impacted, with many wetlands having no hydroperiod at all. Figure 3-120 presents water-level data from the EW TRPMD #1 Cypress. Although data only begins in 1989, this wetland has rarely had any standing water until very recently. The EW TRPMD #3 Cypress, located to the east (Figure 3-109), has had no standing water for the same period of record. The Pine Ridge Cypress (Figure 3-121), located to the southwest of the Eldridge-Wilde wellfield, has a relatively normal hydroperiod for the same time period. The Lansbrook East Cypress (Figure 3-122), located to the south within the East Lake wellfield, shows somewhat depressed water levels and a shortened hydroperiod. Water-level declines are not as severe at this site as compared to the Eldridge-Wilde wellfield.

3.7 Wetland Health

The regional health of wetlands in the Northern Tampa Bay WRAP area was not well known at the beginning of the project. Although it was recognized that wetlands in heavily developed parts of the project area have been destroyed by filling and draining, little was known about the overall health of the remaining wetlands throughout the study area. An exception can be made for wellfield areas of the Northern Tampa Bay area where extensive studies of wetlands have continued for many years. These studies have been conducted by the SWFWMD and others to supply information required by the SWFWMD as a condition on the issuance of water withdrawal permits.

The most significant efforts at monitoring the hydrology and biologic condition of wetlands in ground-water withdrawal areas within the Northern Tampa Bay WRAP area have taken place at the South Pasco wellfield (Bradbury and Courser, 1982, Water and Air Research, Inc., 1994a), Northwest Hillsborough Regional wellfield (Water and Air Research, 1992; HSW Environmental Consultants, Inc. and Water and Air Research, Inc., 1995), Eldridge-Wilde

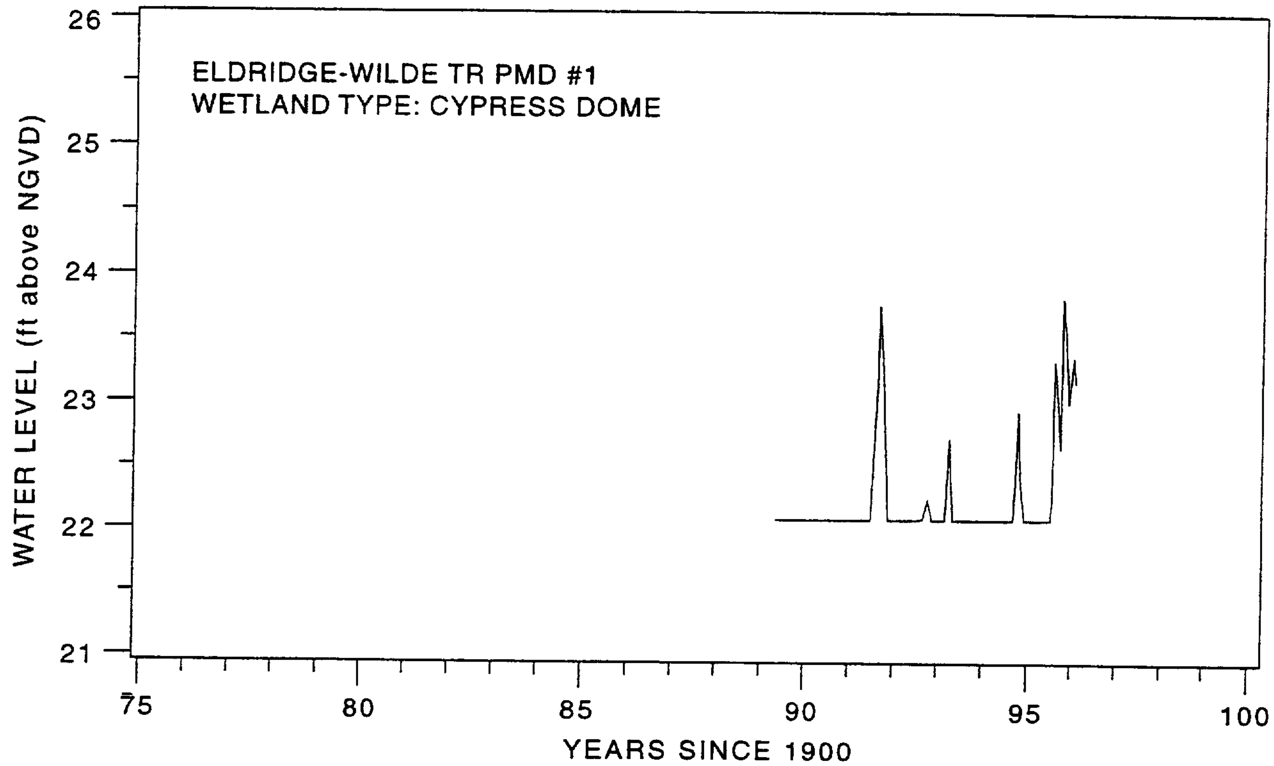


Figure 3-120. Water levels of the Eldridge-Wilde TR PMD #1 cypress dome.

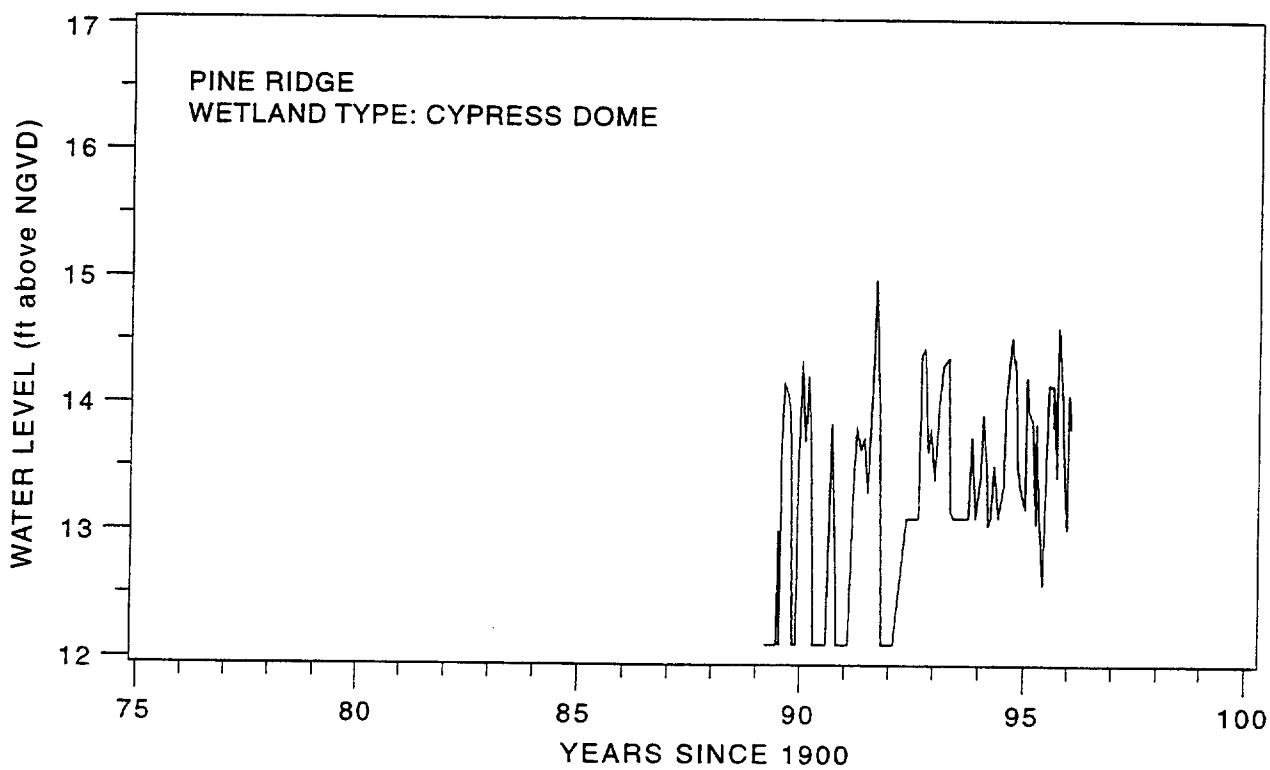


Figure 3-121. Water levels of the Pine Ridge cypress dome.

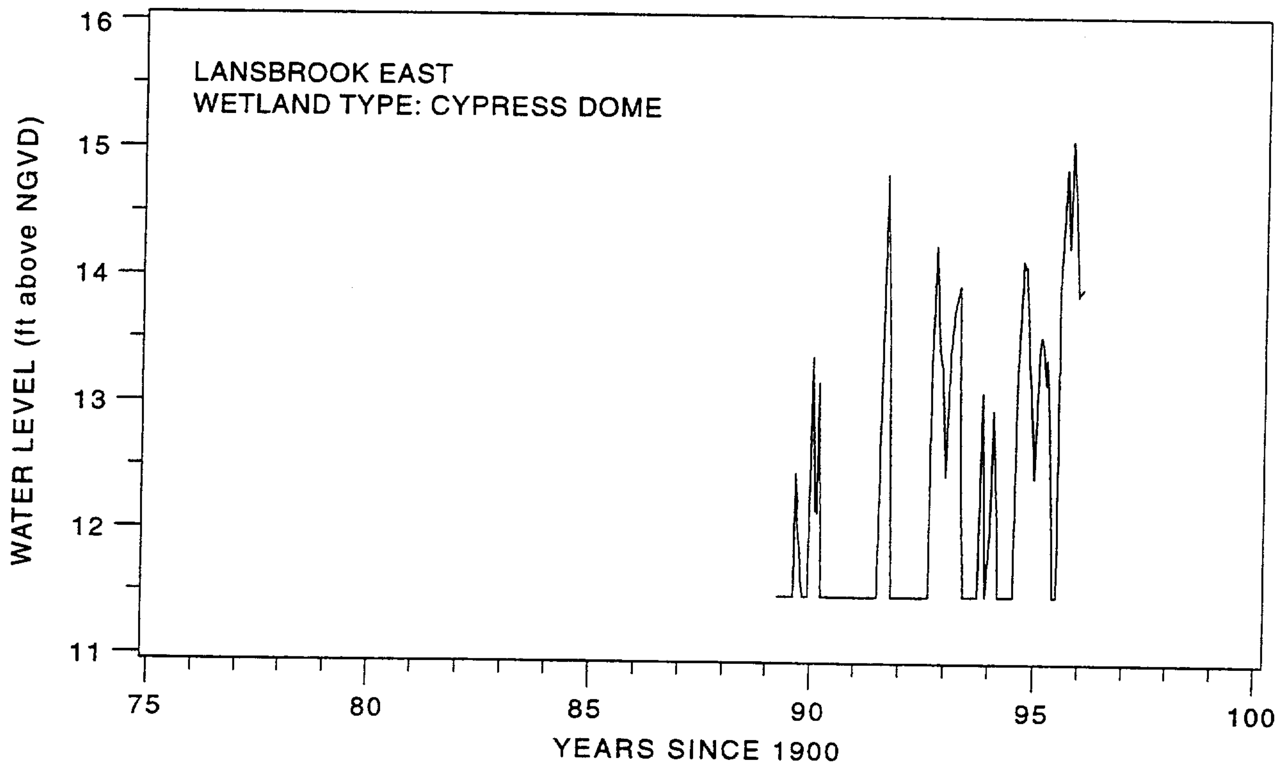


Figure 3-122. Water levels of the Lansbrook East cypress dome.

wellfield (Courser, 1973; SWFWMD, 1982a,b; FDER, 1988; Rochow, 1988; Rochow and Rhinesmith, 1991), Morris Bridge wellfield (Lopez, 1983; Biological Research Associates, Inc., 1992a; Biological Research Associates, Inc., 1994), Starkey wellfield (Rochow, 1985a; CH2M Hill, 1991; Rochow and Rhinesmith, 1991; Environmental Science and Engineering, Inc. 1993a; Environmental Science and Engineering, 1995), Cross Bar wellfield (Biological Research Associates, Inc., 1992b; CCI Environmental Services, Inc. and Terra Environmental Services, Inc., 1995) and Cypress Creek wellfield (Rochow, 1985b; Environmental Science and Engineering, Inc., 1993b; Environmental Science and Engineering, Inc. and HSW Environmental, Inc., 1995). These studies have described wetland impacts ranging from moderate to severe. Much of this work is summarized in Rochow, 1994.

Within two wellfield areas of the Northern Tampa Bay WRAP area, two studies have been performed in which the trend in wetland health has been measured through the use of historic aerial photography. The SWFWMD (1982a,b) observed 17 wetlands within the Eldridge Wilde wellfield through aerial photography over the period of 1948 to 1981. The study concluded that decreases in cypress density and increases in terrestrial vegetation encroachment were apparent. Rochow and Rhinesmith (1991) analyzed aerial photography for three wetlands within the Starkey wellfield and two wetlands within the Eldridge Wilde wellfield. The wetlands assessed were the same assessed hydrogeologically by Watson and others (1990), which are discussed in Chapter 4. The photography spanned from 1941 to 1990. Wetland quality was observed to deteriorate in three of the five sites. The proposed explanation for two of the sites remaining healthy is discussed in Chapter 4.

Because most information on the health of wetlands was limited to areas in the vicinity of ground-water withdrawals, an intensive study was begun in the Northern Tampa Bay area to acquire more on-ground information on the health of representative wetlands throughout the study area, including in urban and agricultural areas. Wetland sites were also assessed in wellfield areas that did not previously have long-term monitoring sites, such as the Section 21 wellfield. To utilize project resources most effectively, attention was focused on the health of isolated cypress wetlands, although several marsh systems were also assessed. Additionally, the wetland sites finally selected for environmental assessment were strongly influenced by

availability of suitable site access, since obtaining permission and access to conduct studies was sometimes difficult.

Wetland health was assessed based upon water levels, soil condition, canopy condition, fire effects, plant and animal life, and human effects. The detailed methodology for the wetland health assessment is presented in Appendix C. Based on this methodology, wetland sites were ranked on a scale from 1 (poor) to 5 (good). Certain characteristics generally apply to sites ranked at different points on the qualitative ranking scale. These are described as follows:

> **Sites ranked 5**: Water levels, soil conditions, and canopy appearance generally are all normal. No excessive fire effects are observed. Plants and animals are all, or nearly all, associated with a wetland environment.
>
> **Sites ranked 4 - 4.5**: Water levels are usually lower-than-expected. Weeds and upland plants are found in greater abundance than under natural conditions. Wetland wildlife usage is likely not as high as under natural conditions.
>
> **Sites ranked 3 - 3.5**: Water levels are much lower than expected and the sites may be dry in below-normal rainfall years. Fire effects may be greater than expected. Weeds and upland plants begin to dominate the understory. Wetland wildlife usage is poor.
>
> **Sites ranked 2 - 2.5**: Surface water is absent except when rainfall is considerably above normal. Fire effects may include some peat burning. The tree canopy is thinner than previously. Weeds and upland plants dominate the understory. Wetland wildlife usage is virtually non-existent.
>
> **Sites ranked 1 - 1.5**: Surface water is almost never observed. Fire effects, when present, often include severe peat burns. Tree canopy is much thinner than previously and leaning and fallen trees are usually apparent.

Nearly 350 wetlands were assessed as part of this analysis. Most wetlands assessed were cypress wetlands, although marshes were included for project areas where these systems were prominent features of the landscape. The environmental assessments for all wetlands are shown in Appendix C. The location of the wetlands, along with an indication of their relative health, is depicted in Figure 3-123. The figure also depicts the property boundaries of the regional wellfields in the area (see Figure 2-34 for wellfield identification). The Cone Ranch property, a proposed regional wellfield, is also shown on the figure since extensive wetland monitoring on that property has also been performed. For purposes of this figure, wetlands are grouped

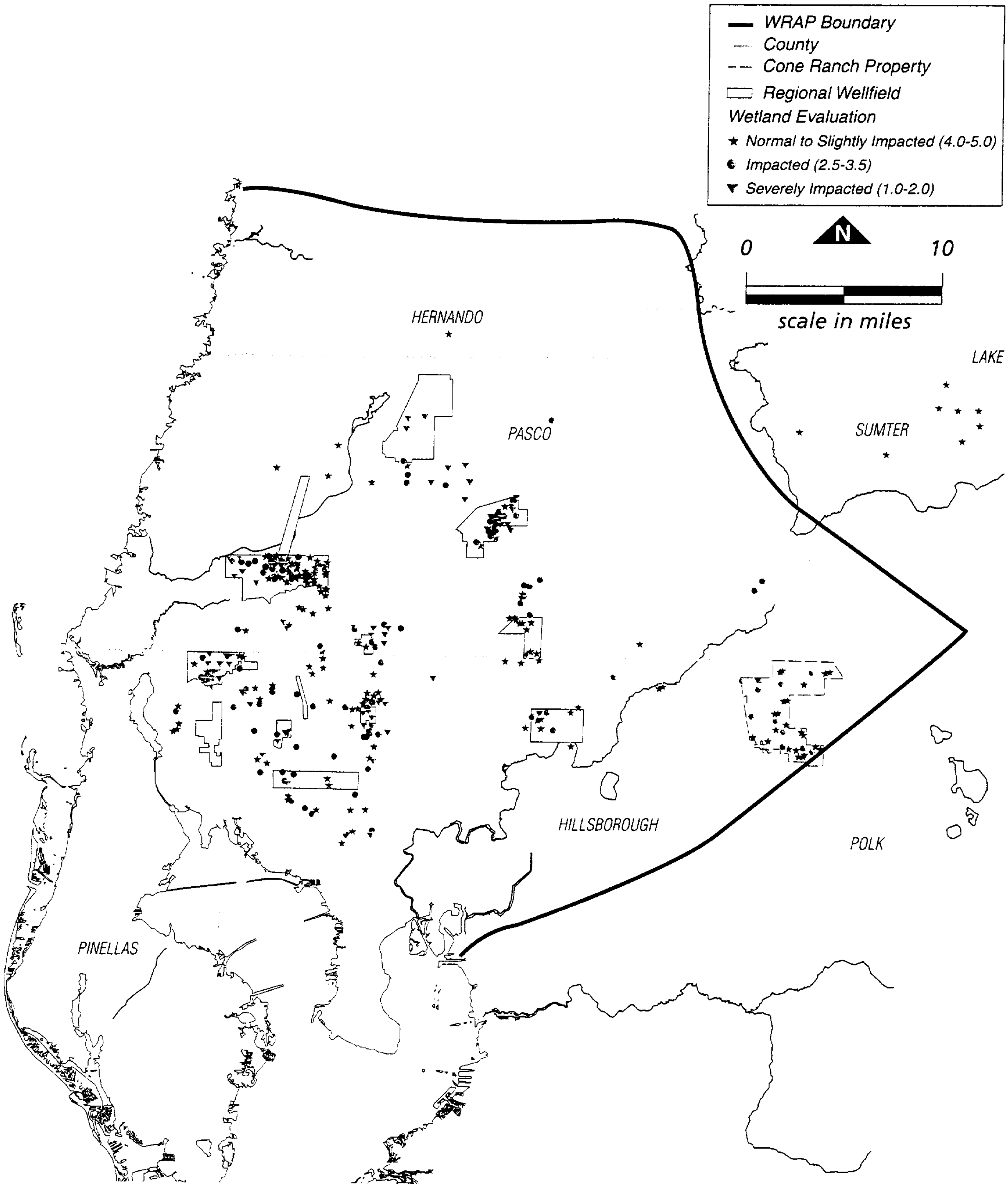


Figure 3-123. Wetland ranking of 343 SWFWMD long-term monitoring sites within the Northern Tampa Bay WRAP area.

into three categories by site ranking: "**normal to slightly impacted**" are wetlands rated 4.0 to 5.0; "**impacted**" are wetlands rated 2.5 to 3.5, and; "**severely impacted**" are wetlands rated 1.0 to 2.0.

The figure shows that many of the assessed wetlands are located in wellfields. As previously stated, this distribution is the result of several of SWFWMD's previous wetland monitoring programs that were designed to provide information on and near major ground-water withdrawal areas. In making the assessments of wetland health, environmental conditions were judged through the use of several techniques and references, including 1) the use of regional controls, such as wetland controls in the Green Swamp area of Sumter and Lake counties, as well as the Hillsborough River State Park in northeastern Hillsborough County, 2) comparisons of environmental conditions between wetlands located throughout the Northern Tampa Bay region, including those near sources of ground-water withdrawal or development and those in more natural surroundings, and 3) literature reports on natural conditions that would normally be expected in the type of wetlands being assessed.

In addition to SWFWMD's assessment of over three hundred wetlands, wetlands are also being assessed independently by others to provide environmental information required by SWFWMD as a condition on the issuance of water use permits (WUPs). For this reason, as with SWFWMD's wetland monitoring program, long-term monitoring sites cluster around major ground-water withdrawal areas. As part of the Northern Tampa Bay WRAP, the information reported for nearly two hundred and fifty WUP wetland monitoring sites was reviewed. Making use of criteria similar to those used to rank SWFWMD's sites, the WUP wetlands were divided into two categories: "**normal to slightly impacted**" and "**moderately to severely impacted**". For reference, "normal to slightly impacted' wetlands were considered to be within the 4.0 to 5.0 ranking category previously discussed. "Moderately to severely impacted wetlands" were considered to be within the 1.0 to 3.5 category. The WUP wetland monitoring stations reviewed are discussed in the following reports: CCI Environmental Services, Inc. and Terra Environmental Services, Inc. 1995; Environmental Science & Engineering, Inc. and HSW Environmental, Inc. 1995; Environmental Science & Engineering, Inc. 1994; Reynolds, Smith & Hills, Inc. and Terra Environmental Services, Inc. 1995; Water and Air Research, Inc.

1994; Biological Research Associates, Inc. 1994; HSW Environmental Consultants, Inc. and Water and Air Research, 1995.

Figure 3-124 depicts the results of SWFWMD's evaluation of wetland conditions reported for WUP monitored wetlands. Regional wellfields, as well as the Cone Ranch property, are also presented. There is some overlap in monitoring between Figures 3-123 and 3-124, whereby the same wetland is monitored by both programs and appears on both maps. Nevertheless, a close inspection of the maps indicates that a great number of wetlands have not been subject to duplicative monitoring. It should be added that many wetlands in and immediately around the Cypress Bridge wellfield and within the Cone Ranch property are included in Figure 3-123 rather than Figure 3-124 because they based upon on-site SWFWMD evaluations, even though the wetlands are part of long-term WUP monitoring programs (USF Institute for Environmental Studies & Terra Environmental Services, Inc. 1995; Henigar & Ray, Inc. and Center For Wetlands, 1993).

An examination of Figures 3-123 and 3-124 shows a considerable number of "impacted", "severely impacted", and "moderately to severely impacted" wetlands. In Pasco County, many such wetlands are found in and between the Cross Bar Ranch and Cypress Creek wellfields, in and around western and central Starkey wellfield, to the east of the North Pasco wellfield, and around the South Pasco wellfield. "Impacted" wetlands generally are found in the same areas as "severely impacted" wetlands but are also found in the Saddlebrook development just north of the Cypress Bridge wellfield. "Normal to slightly impacted" wetlands are apparent in eastern Starkey wellfield, northwestern Pasco County, areas to the east of the North Pasco wellfield, and in the area of the Cypress Bridge wellfield. Control wetlands in the Green Swamp area of Sumter and Lake counties as well as in the Hillsborough River State Park in northeastern Hillsborough County are indicated by the map to be mostly rated as "normal to slightly impacted".

In Hillsborough and Pinellas counties, a considerable number of "severely impacted" wetlands are found in or around the Eldridge-Wilde, Cosme, and Section 21 wellfields, although a

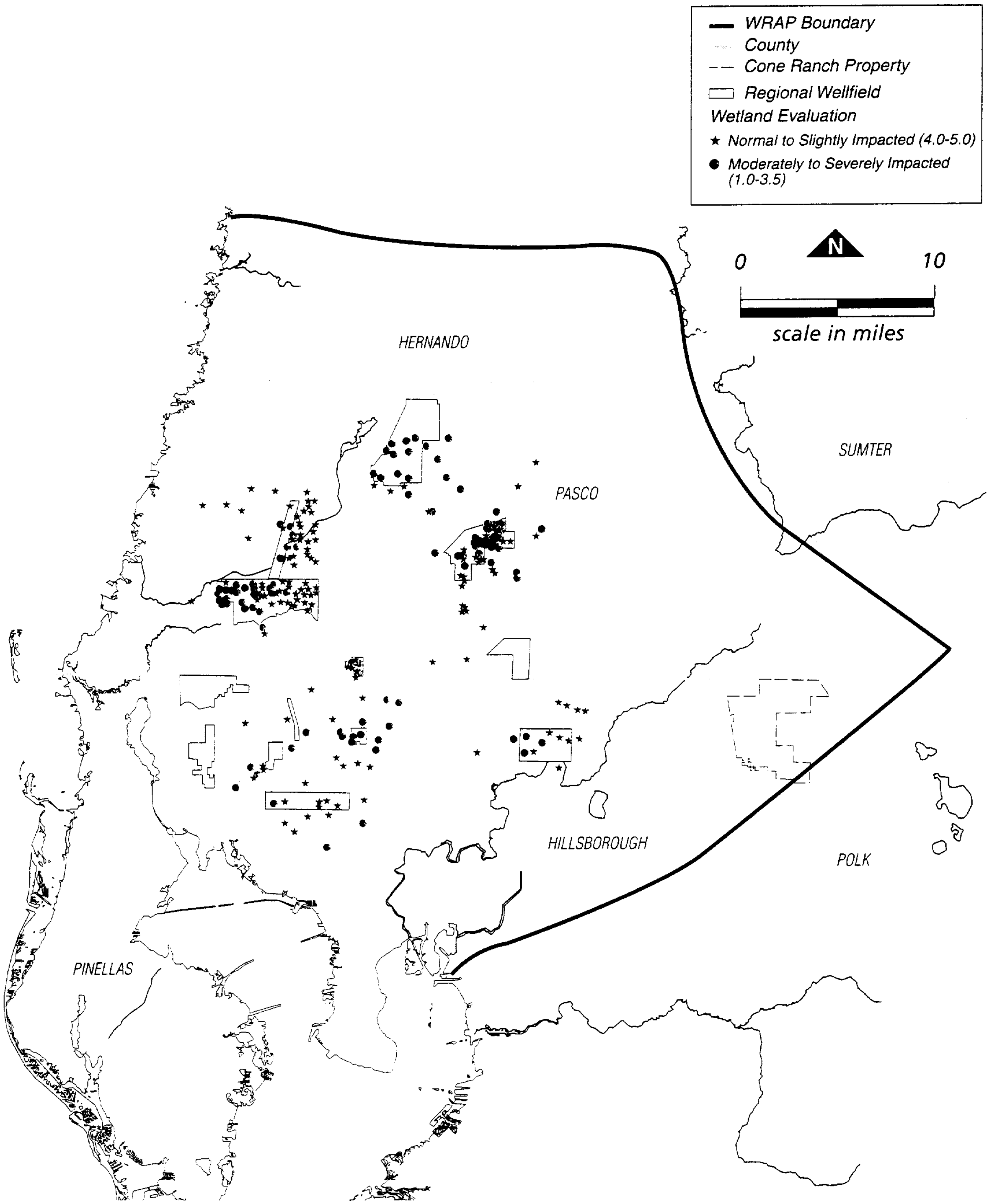


Figure 3-124. Wetland ranking of 245 WUP long-term monitoring sites within the Northern Tampa Bay WRAP area.

scattering of "severely impacted" wetlands occurs at various locations in Hillsborough County. "Impacted" wetlands as depicted in Figure 3-123 are common throughout northwestern Hillsborough County and in the Cone Ranch property in far northeastern Hillsborough County. "Normal to slightly impacted" wetlands are common to the north and west of the Section 21 wellfield and on the Cone Ranch property. Additionally, there is a scattering of "normal to slightly impacted" wetlands in inter-wellfield areas with occasional representation on Eldridge-Wilde, Northwest Hillsborough Regional and Morris Bridge wellfield land.

Figures 3-123 and 3-124 show strong similarities in the spatial pattern of wetland health in the Northern Tampa Bay WRAP area although the information on the wetlands comes from independent monitoring programs. It is significant that SWFWMD's monitoring program has been in existence since the 1970s and the various WUP monitoring programs since the late-1970s or 1980s. Consequently, there is a long site-by-site history of wetland conditions over time for each of the several hundred wetlands depicted on the maps. Because of this long-term monitoring record, a site-by-site examination of the hydrology and biology of these wetlands can provide insights into changes in wetland health that have occurred through time. For example, virtually all wetlands within the Starkey, Cypress Creek, South Pasco, Eldridge-Wilde, and Morris Bridge wellfields and in the Green Swamp area of Sumter and Lake counties have ten-to-twenty year monitoring histories. In the case of the Starkey Wellfield, virtually every wetland in the central portion of the wellfield was originally in good health, but it is evident from Figures 3-123 and 3-124 that many have experienced declining wetland health to the degree that they are presently "impacted or severely impacted". Degradation in wetland health during the period of monitoring has also been documented in and around the Cypress Creek, South Pasco, Eldridge-Wilde, and Morris Bridge wellfields. Wetland controls in the Green Swamp and Hillsborough River State Park have monitoring histories dating back to the late-1970s. The hydrology and biology of these wetlands has been regularly monitored over the entire period. Although the health of these control wetlands has fluctuated to a degree over time, there has not been the prolonged downward trend that has been seen for many wetlands in SWFWMD's long-term monitoring studies at wellfields (see Figures 3-110 to 3-122, as well as the Data Appendices). Additionally, approximately a dozen Technical Reports over the years have documented vegetational data on a site-by-site basis for about forty wetlands that are monitored

quantitatively. Data for other wetland monitoring sites is retained and updated periodically. A recent discussion of SWFWMD's wetland monitoring programs appears in two Technical Reports (Dooris and others, 1990; Rochow, 1994). Site-by-site discussions of effects on wetlands health are included in Chapter 4.

3.8 Summary

Ground-water withdrawals throughout the Northern Tampa Bay WRAP area have been increasing since the 1930s. The increasing trend is projected to continue. The increase is largely the result of increased demands by public supply use. Significant declines in the potentiometric surface of the Upper Floridan aquifer, and in many cases the surficial aquifer and surficial features, have been observed in several large sections of the Northern Tampa Bay WRAP area. The decline of water levels in the surficial aquifer and surface waters, and the decline of wetland health, are associated with declines in water-levels of the potentiometric surface. The declines originate as localized areas within the Northern Tampa Bay WRAP area, but, due to the large number of localized declines, have become subregional in nature. Additionally, impacts to surface-water features have been observed to be increasing throughout the study area.

The following chapter will discuss the relationships between the various hydrologic, biologic, and man-made stresses, and identify the specific causes for the various trends presented above.

CHAPTER 4 - CAUSE-AND-EFFECT RELATIONSHIPS

Several water resource concerns have been identified within the Northern Tampa Bay WRAP area: 1) the lowering of average water levels and increased fluctuations in lakes and wetlands; 2) reduced streamflow in some river systems; 3) declining ecological health, and 4) the threat of seawater intrusion, resulting in deteriorating water quality. Water-level declines and increased seasonal fluctuation in the potentiometric surface, water table, lakes, and wetlands have been discussed in Chapter 3. Upper Floridan aquifer water levels in the Northern Tampa Bay WRAP area have been declining in some areas since the 1940s, while seasonal fluctuations in the water levels have increased as much as 20 feet. Additionally, water levels in many observed wetlands and lakes, as well as some water-table observation points, have declined by varying degrees. These lowered water levels have resulted in declines in the biological health of many lakes and wetlands.

Because the hydrologic system of the Northern Tampa Bay WRAP area contains several highly interrelated components, these trends could be caused, directly or indirectly, by variations in any one component. Possible causes of water-level decline include changes in rainfall, evapotranspiration, runoff (either as overland flow, streamflow, or unsaturated flow), ground-water inflows and outflows, or man-induced causes, such as drainage systems and ground-water withdrawals. Water-level declines in an aquifer, no matter what the cause, can in turn cause reductions in spring discharge and streamflow, lowering of water levels and biological health in surficial features, reductions in freshwater discharge to the Gulf of Mexico, and induced seawater intrusion.

This chapter discusses the relationship between water-levels of the Upper Floridan and surficial aquifers and surface-water features. First, the possible adverse effects of lowered ground-water levels are discussed, including decreases in spring discharges, decreases in streamflow, water-table lowering, and biological degradation. Secondly, possible causes of lowered ground-water levels are assessed, including changes in rainfall, surface-water flow, ground-water inflow, and man-induced stresses. Finally, both regional and local analyses which demonstrate the cause-and-effect relationships are presented. Analyses performed in this study and by others have

shown that ground-water withdrawals are the primary cause of subregional increases in annual water-level fluctuations and long-term water-level declines.

Volume Two of this report will discuss the relationship between aquifer water levels and seawater intrusion. The possible adverse effects of lowered ground-water levels on water quality and seawater intrusion are also discussed.

4.1 Effects of Ground-Water Level Declines on Surficial Features

Declines in ground-water levels can affect lake and wetland levels, spring and stream flow, and vertical flow between aquifers, depending on the degree of hydraulic connection between aquifers. The potential for these relationships is clear by the description of the regional hydrogeology in Chapter 2. Water-level declines can also provide an indication of changes in flow through the aquifer, which in turn can control seawater intrusion.

4.1.1 Spring Discharge and Streamflow Reduction

Due to the highly variable nature of the confining layer throughout the Northern Tampa Bay WRAP area, the effect of lowered Upper Floridan aquifer water levels on streamflow and springs has been a concern for many years. Spring discharge and streamflow are closely related in the major rivers of the Northern Tampa Bay WRAP area. Much of the baseflow of the Hillsborough and Withlacoochee Rivers is derived from spring discharges. The smaller coastal streams, including the Pithlachascotee River, Anclote River, Brooker Creek, and Rocky Creek systems, obtain most of their baseflow from discharges from the unconfined surficial aquifer.

Because flow in streams fed by the surficial aquifer within the Northern Tampa Bay WRAP area is highly dependant on rainfall and antecedent conditions, and therefore highly variable, correlation analysis between streamflow and potentiometric water levels is difficult. Regardless of the effects of the potentiometric surface on streamflow, rainfall will always be a significant parameter affecting flow in these coastal stream systems. Flow in the coastal streams of the Northern Tampa Bay WRAP area is highly dependent on rainfall intensity, antecedent conditions, and water-table elevations. Because rainfall intensity is often much higher than soil

infiltration rates, and surficial aquifer discharge to streams is generally more rapid than downward leakage to the Upper Floridan aquifer, some streamflow can be expected to occur during high rainfall events regardless of the effect of the potentiometric surface on the water table.

A more appropriate correlation test would be between the water table and the potentiometric surface, since baseflow is derived from ground water. As discussed in Chapters 2 and 3, the coastal streams within the Northern Tampa Bay WRAP area have very little baseflow, and many segments are intermittent. However, flow in river segments within areas of potentiometric surface lowering, where water-table lowering will most likely be the greatest, can be expected to decrease. A review of the data and previous studies show significant changes for reaches of Brooker Creek, Cypress Creek, and Jumping Gully (see Section 3.5). Other coastal river systems, such as Rocky Creek, may also be subject to the effects of intensive urban development, which may explain the apparent increase in Rocky Creek flows in recent years. Water-table fed river systems in relatively undeveloped areas, however, will most likely be affected by lowering of the water-table, which in turn may be related to a decline in the Upper Floridan aquifer water levels. Because of this, it may be more appropriate to assess the relationship between water table and potentiometric surface elevations to determine effects on these coastal streams. This relationship is discussed in the next section.

River systems with substantial baseflow contributions from the Upper Floridan aquifer may be expected to show more direct effects from water-level changes in the aquifer. However, both of the river systems within the Northern Tampa Bay WRAP area with such baseflows, the Hillsborough and Withlacoochee Rivers, are distant from the major Upper Floridan aquifer drawdowns, and no declines in baseflows have been identified in past studies. To better define the interconnection between the Hillsborough River and the aquifer, Wolansky and Thompson (1987) performed seismic-reflection profiles along the river. Several solution features or fractures were identified, confirming the existence of intermittent discharge and recharge reaches along the Hillsborough River. Therefore, because of the interconnection between the Hillsborough River and the Upper Floridan aquifer, significant changes in potentiometric levels in the vicinity of the Hillsborough River could be expected to affect streamflow.

One major tributary to the Hillsborough River, Cypress Creek, receives substantial contributions from the Upper Floridan aquifer in some reaches. Its flow has been found to be affected by Upper Floridan aquifer drawdowns (Heaney and others, 1986). Although much of the Cypress Creek Basin has been previously identified as a discharge area (Aucott, 1988), parts of the basin have become a recharge area in the last 15 years in the vicinity of the Cypress Creek wellfield, due to lowering of the Upper Floridan aquifer levels (see Section 4.1.3). Like the coastal streams, however, river systems receiving Upper Floridan aquifer discharge also receive flow contributions from the surficial aquifer and overland flow, which can mask any effects from Upper Floridan aquifer drawdowns. If the potentiometric surface is lowered near such river systems in the future, effects to streamflow may become more evident.

The majority of springs in the Northern Tampa Bay WRAP area either discharge directly to the Gulf of Mexico or the Hillsborough River. The one exception is Weeki Wachee Springs, which has a 7.5 mile river run before discharging to the Gulf of Mexico. Springflow is related to the gradient of the potentiometric surface in all three of these major springs. Correlation studies have shown that the flow in Weeki Wachee Springs increases or decreases by approximately 12.5 cubic feet per second for every foot of water-level increase or decrease in the Upper Floridan aquifer, respectively (Yobbi, 1992). Therefore, springflow could be affected by significant changes in the potentiometric surface of the Upper Floridan aquifer near each location.

Discharge measurements are available for only one spring along the coast within the Northern Tampa Bay WRAP area (Weeki Wachee Springs). However, springs without measured flow are expected to have similar relationships with the potentiometric gradient as do the larger inland springs. These springs would be similarly affected by changes in Upper Floridan aquifer water levels, although tidal influences would also be a factor. Many small coastal springs are near areas of large potentiometric surface drawdown (northwest Hillsborough, western Pasco, and northern Pinellas counties), and have the potential to be affected by lowered Upper Floridan aquifer water levels.

4.1.2 Lowering of the Water Table

The major concern within the Northern Tampa Bay WRAP area is the water-level decline of surface-water features and the surficial aquifer. To understand these declines, it is necessary to understand the relationship between surface-water features, the surficial aquifer, and the Upper Floridan aquifer. The variation in confinement between these three components throughout the study area defines the relationship between the water table and the potentiometric surface. Although surface-water bodies and the surficial aquifer system are usually related, the nature of water-level fluctuations in the two features often behave quite differently due to storage differences and the level of connection between the two systems. Because of this, the two features are discussed separately in this section. When the two are discussed simultaneously, the general term "water table" is used.

Aquifer Relationships - Recharge and confinement

To understand the relationship between water levels in the Upper Floridan aquifer and the surficial aquifer, we must re-examine the regional hydrogeology of the Northern Tampa Bay WRAP area. As discussed in Chapter 2, the regional flow of ground water in the study area begins in either the Green Swamp or the Pasco High area, and flows south and west (Figure 2-26). These potentiometric highs create the regional pressure head for flow throughout the study area, but because the Upper Floridan aquifer is semi-confined, recharge occurs throughout the study area (except in coastal areas, were the Upper Floridan aquifer discharges to the surficial aquifer). Recharge is dependent on both the hydraulic gradients caused by vertical hydraulic head differences between the surficial and Upper Floridan aquifers, and the leakance coefficient of the confining layer. Spatial variations in either of these two parameters cause variations in local recharge.

Spatial variations in head differences between the aquifers are a result of natural and man-made causes. Variations in hydrogeologic parameters between the unconfined aquifer, confining layer, and semi-confined aquifer cause natural differences in aquifer heads. Because the pressure differentials between the aquifers is dependent on each of these parameters, differences in head result. In areas of withdrawals from the Upper Floridan aquifer, potentiometric levels are

lowered, increasing the head difference over natural conditions between the surficial and Upper Floridan aquifers, and thus increasing recharge. This increase over natural recharge is known as **induced recharge**. Although induced recharge results in greater water availability in the Upper Floridan aquifer, it also can result in a decrease of storage in the surficial aquifer.

The leakance coefficient is a measure of the ability of water to pass through the semi-confining layer. Variations in leakance coefficients are caused by the variations in the thickness and vertical hydraulic conductivity of the semi-confining layer. In general, the thickness of the semi-confining layer between the surficial aquifer and the Upper Floridan aquifer thins from south to north, although confinement thickens somewhat beneath the Brooksville Ridge. However, vertical hydraulic conductivity of the semi-confining layer in the Northern Tampa Bay area is controlled by secondary porosity features, such as fractures and/or openings that occur due to subsidence or collapse of the carbonate formations below (sinkholes). All solution features in karst terrains are not reflected on the surface (Parker, 1992). Solution features are widespread throughout the underlying limestone in the Northern Tampa Bay area, and can become evident on the surface as sinkhole features during prolonged periods of low rainfall or man-induced stress. Similar to the function of lakes and wetlands, however, the solution features can serve as conduits of preferential flow for recharge from the surficial to the Upper Floridan aquifer (Sinclair, 1974). Because such features are highly localized (albeit widespread), the corresponding effect on recharge can vary considerably.

One measure of the level of confinement is the head difference and relationship between the surficial aquifer and the Upper Floridan aquifer. Water-table and Upper Floridan aquifer hydrographs which display little to no head difference and similar patterns of fluctuation are evidence of little to no confinement. Water-table and Upper Floridan aquifer hydrographs that display a head difference but consistently mimic each other show evidence of a leaky confining layer. Figure 4-1 presents hydrographs (using monthly data) for five nested wells (well sites with both surficial and Upper Floridan aquifer monitor wells) in the Northern Tampa Bay WRAP area, plus the Romp 50 nested well located in southern Hillsborough County (within the Eastern Tampa Bay WRAP area). Figure 4-2 presents the location of these sites. The south to north trend of decreasing confinement is observed in the water level data from these wells. As seen in Figure 2-14, a very consistent confining unit exists in the southern portion of the

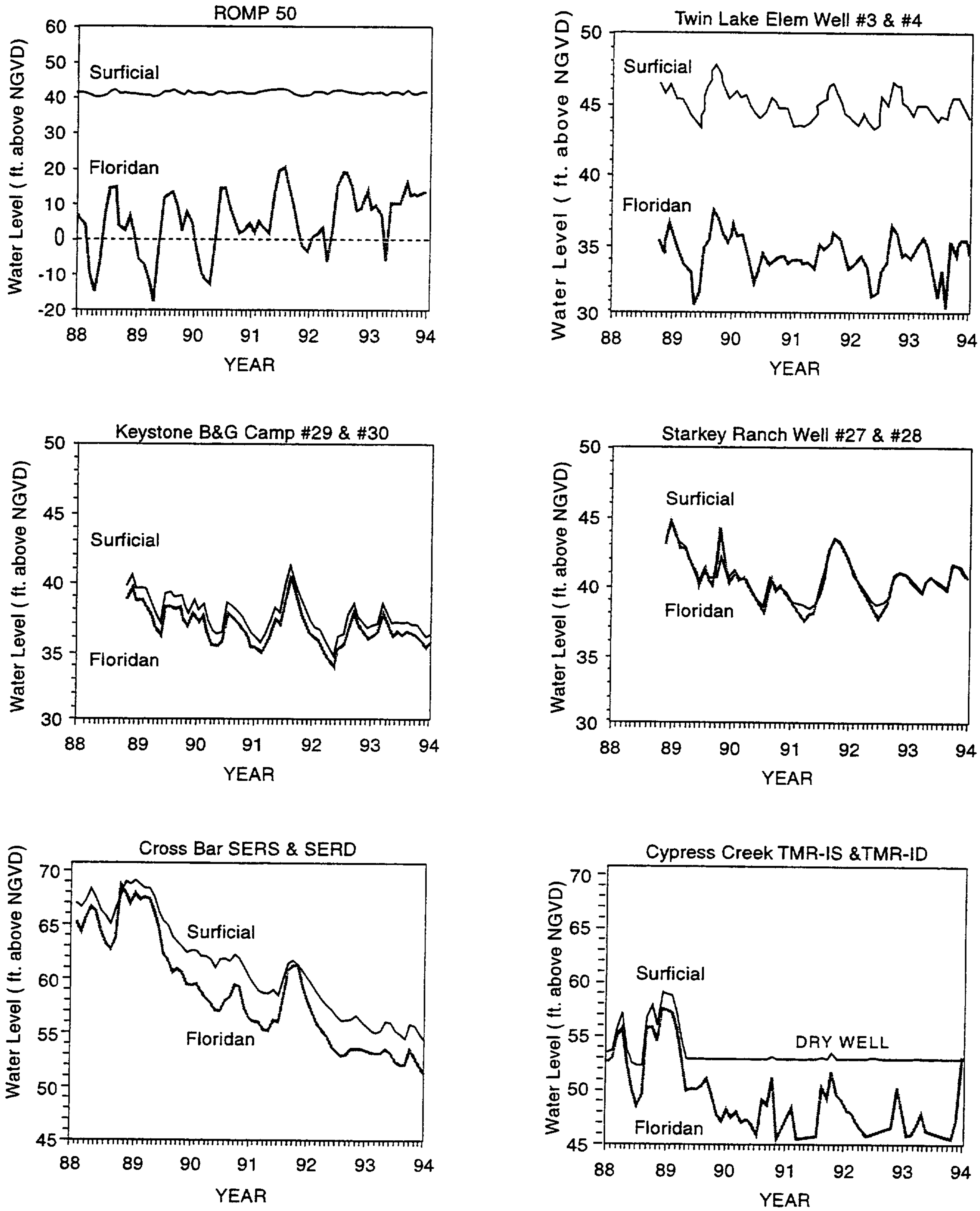


Figure 4-1. Hydrographs of six nested wells within the Northern Tampa Bay WRAP area.

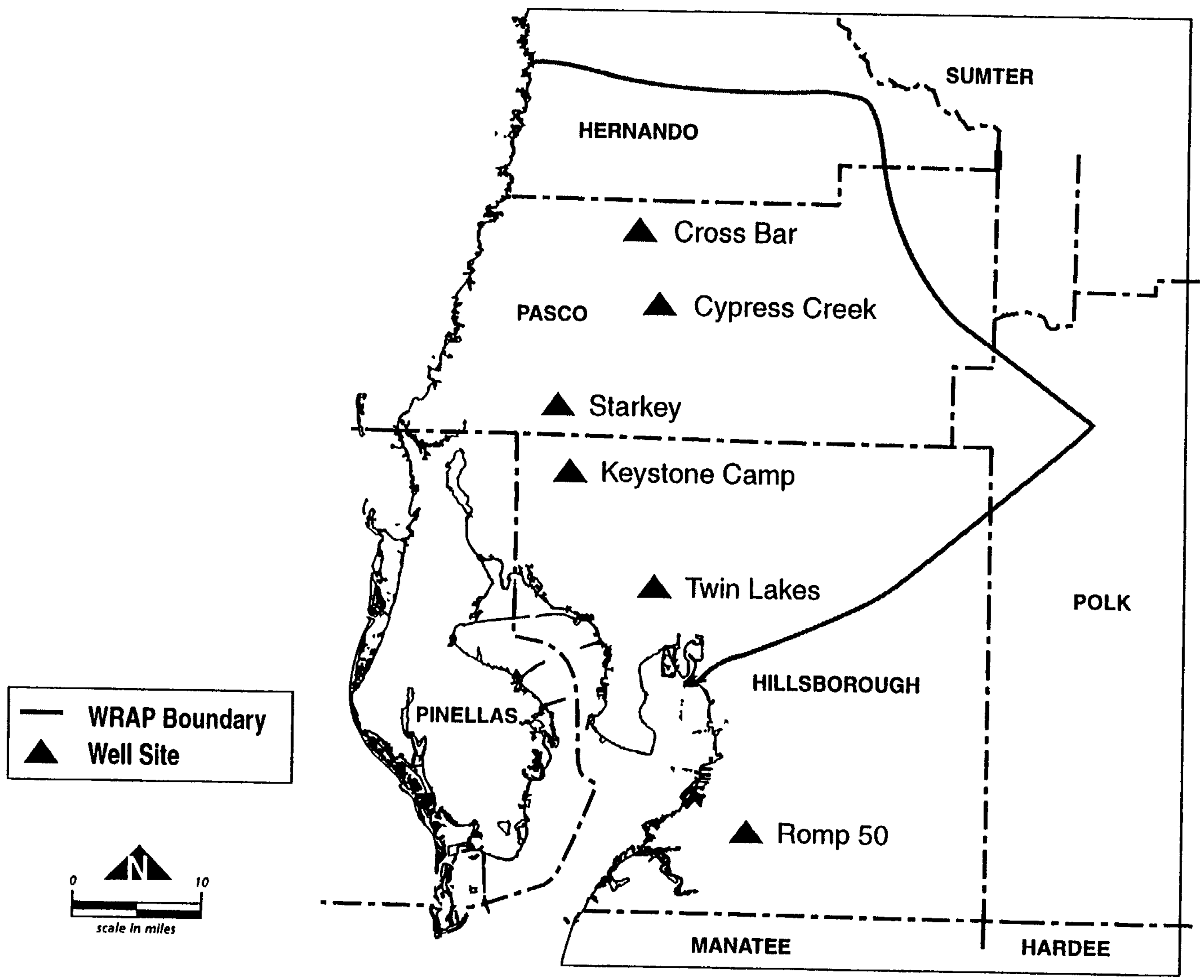


Figure 4-2. Location of well nests referenced in Figure 4-1.

SWFWMD. Accordingly, the water levels seen in the Romp 50 well nest are dissimilar. In this well nest, the Floridan aquifer fluctuations are very different than those in the surficial aquifer, and there is about a 30-foot head difference between the two water levels. The two hydrographs in the Twin Lake Elementary School well nest are separated by approximately 10 feet, and the fluctuations are similar, indicating some confinement, but a higher leakance coefficient than at the Romp 50 site. The hydrographs in Figure 4-1 for the four well nests to the north display hydrographs that have little to no separation, with nearly identical fluctuations. This situation indicates little to no confinement in these areas.

Although the hydrographs shown in Figure 4-1 follow the general south-to-north trend of thinning confinement and increasing leakance coefficients, the system can be highly variable. Monthly hydrographs are presented in Appendix E from 99 nested well sites (one surficial well and one Upper Floridan well per site) throughout the Northern Tampa Bay WRAP area, 36 of which were constructed as part of the Northern Tampa Bay WRAP. A location map of all wells is presented in Figure 4-3 and keyed to Table 4-1. In general, a review of the hydrographs shows that the surficial and Upper Floridan aquifer hydrographs track each other consistently in most cases. At many sites, especially the more northerly sites, the water table and Upper Floridan aquifer hydrographs are nearly identical. However, the relationship is variable, and some areas of relatively good confinement are evident, such as in the Dunn and Oldsmar Elementary School monitor wells in Pinellas County.

The variability of the relationship between the Upper Floridan and surficial aquifers is demonstrated in another way in Figure 4-4 and Table 4-1 using these same well nests. The figure presents the spatial distribution of coefficients of determination (R-square) resulting from a correlation analysis of monthly data from nested surficial and Upper Floridan aquifer wells throughout the Northern Tampa Bay WRAP area. For simplicity, each coefficient is rounded to the nearest tenth. With the exception of the Dunn and Canal Park monitor wells, all of the data for the wells constructed for the WRAP are based on water-level readings taken once each month. Both the Dunn and Canal Park monitor well coefficients are based on monthly averages of daily data. The data for all other wells range from daily to monthly, but each were converted to monthly values. All relationships were shown to be statistically significant. The figure and

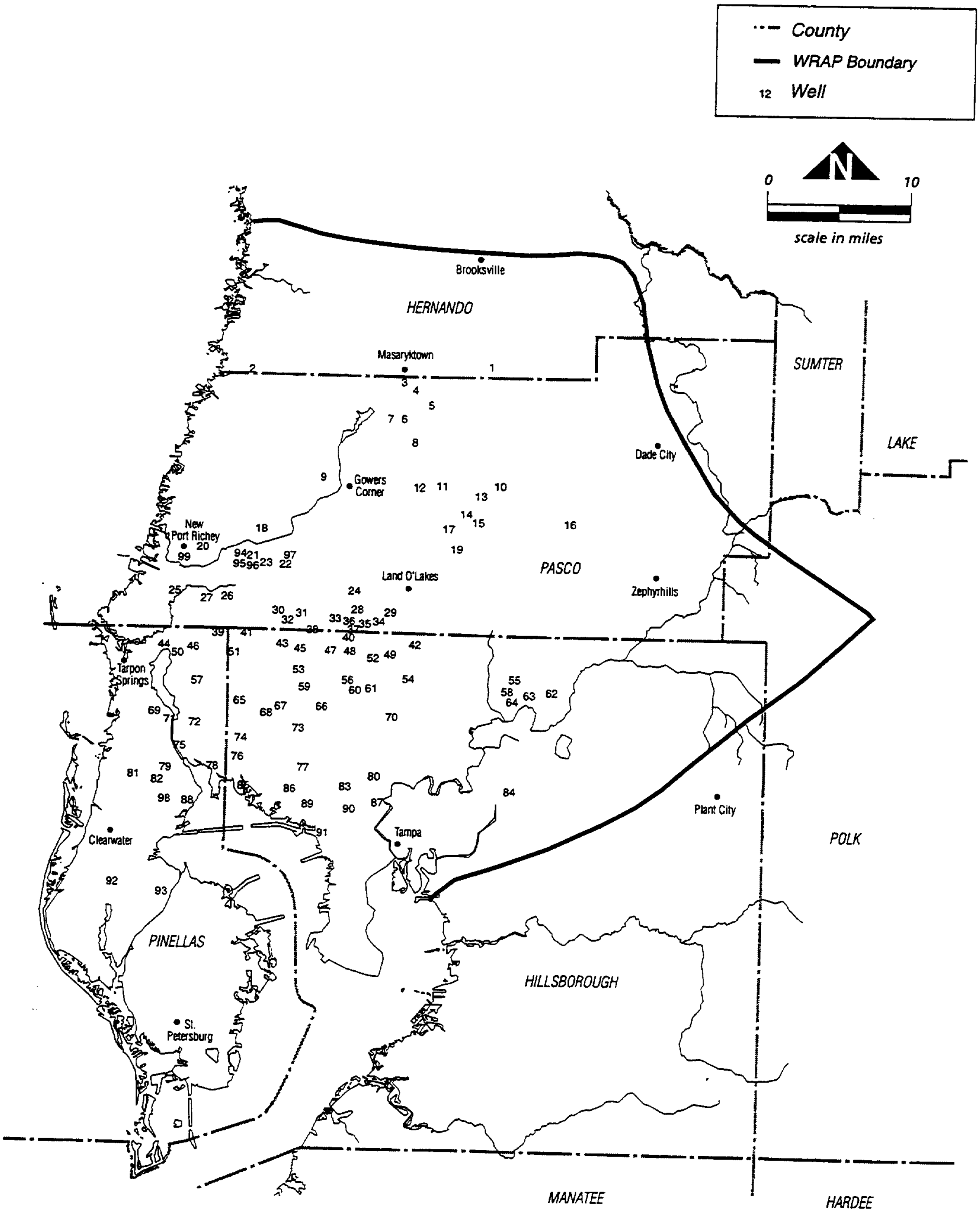


Figure 4-3. Location of nested wells within the Northern Tampa Bay WRAP.

Table 4-1. Coefficients of determination of Northern Tampa Bay WRAP area nested wells[1].

Map ID #	Well Nest	R-Square	Map ID #	Well Nest	R-Square
1	WEEKI 11	0	51	E-W 11	0.4
2	TR18-3	0.7	52	PASCO 210	0.5
3	MASARYKTOWN	0	53	***KEYSTONE PARK***	1
4	CROSS BAR NRW	0.4	54	DEBUEL RD	0.9
5	CROSS BAR NERW	1	55	MORRIS BRDG 537	0.8
6	CROSS BAR WRW	1	56	JACKSON 26A	0.5
7	CROSS BAR SRW	0.9	57	***DUNN***	0.5
8	CROSS BAR SERW	1	58	MORRIS BRIDGE 153	0.4
9	SR 52 W - FIVAY RD	0.8	59	JAMES 11/10S	0.5
10	SR 52-581	0.1	60	HILLS 13	0.4
11	ROMP 93	0.7	61	BERGER	0.5
12	SR 52 E	0.9	62	MORRIS BRIDGE 13	0.4
13	CYPRESS CREEK TMR-2	0.9	63	MORRIS BRIDGE 166	0.1
14	CYPRESS CREEK TMR-3	0.7	64	MORRIS BRIDGE 6	0.5
15	CYPRESS CREEK TMR-1	0.9	65	***EAGLES GC***	0.6
16	SR 577	0.8	66	***HUTCHINSON***	0.4
17	CYPRESS CREEK TMR-4	0.9	67	E-100/IC-6	0.4
18	MOON LAKE	0.9	68	***DIOCESE***	0.4
19	CYPRESS CREEK TMR-5	0.7	69	***ALDERMAN U.S. 19***	0.2
20	N PRT RICHEY	0.2	70	***BUCHANAN SCHOOL***	0.7
21	STARKEY 707	0.8	71	***HIGHLANDS LK GC***	0.8
22	STARKEY 1B CENTRAL	0.9	72	***E. LK WOODLAND***	0.6
23	STARKEY 730	0.8	73	***CITRUS PARK ELEM.***	0.9
24	***LEDANTEC***	0.7	74	ROMP TR13-3	0.5
25	***ANCLOTE***	0.8	75	***CANAL PK***	0.6
26	SEVEN SPRINGS	0.7	76	***TAMPA BAY DOWNS***	0.6
27	***SEVEN SPRNGS***	0.8	77	***BELLAMY ELEM.***	0.6
28	SR 54	0.4	78	***OLDSMAR EL. SCHL***	0.5
29	***WILSON***	0.9	79	***COUNTRYSIDE GC***	0.4
30	***STARKEY RNCH***	1	80	***TWIN LAKE ELEM.***	0.7
31	***BENKE***	0.8	81	TR 14 -2	0.1
32	***HOLIDAY LK***	1	82	TR 14-3	0.2
33	S PASCO WEST	0.7	83	***CRESTWOOD ELEM.***	1
34	H. MATTS	0.8	84	EUREKA SPGS LNDFL	0.3
35	SP 45	0.6	85	***UPPER TAMPA BAY PK***	0.2
36	E-105	0.7	86	SHELDON ROAD	0.7
37	SP 42	0.6	87	***OAK GROVE SCHOOL***	0.9
38	PASCO 305	0.9	88	TR 14-1	0.8
39	E-W 5	0.8	89	***TWN / CNTRY ELEM***	0.2
40	PASCO 204	0.2	90	***ALEXANDER ELEM.***	0.8
41	E-W 142	0.2	91	TR 12-1	0.4
42	***NEWBERGER***	0.7	92	TR 13-1X	0.1
43	***KEYSTONE B & G***	1	93	TR 13-2X	0.2
44	***JOHNSON***	0.9	94	STARKEY 710	0.4
45	***MCDONALD ROGERS***	0.7	95	STARKEY 728	0.7
46	***BISHOP***	0.7	96	STARKEY 729	0.8
47	LUTZ LAKE FERN	0.5	97	STARKEY SM-2	0.6
48	PASCO 205/206S	0.3	98	***BOY SCOUT***	0.4
49	***LUTZ PARK***	0.7	99	***GULF MIDDLE SCHOOL***	N/A
50	TARPON RD	0.6			

[1] Names in bold are Northern Tampa Bay WRAP wells.

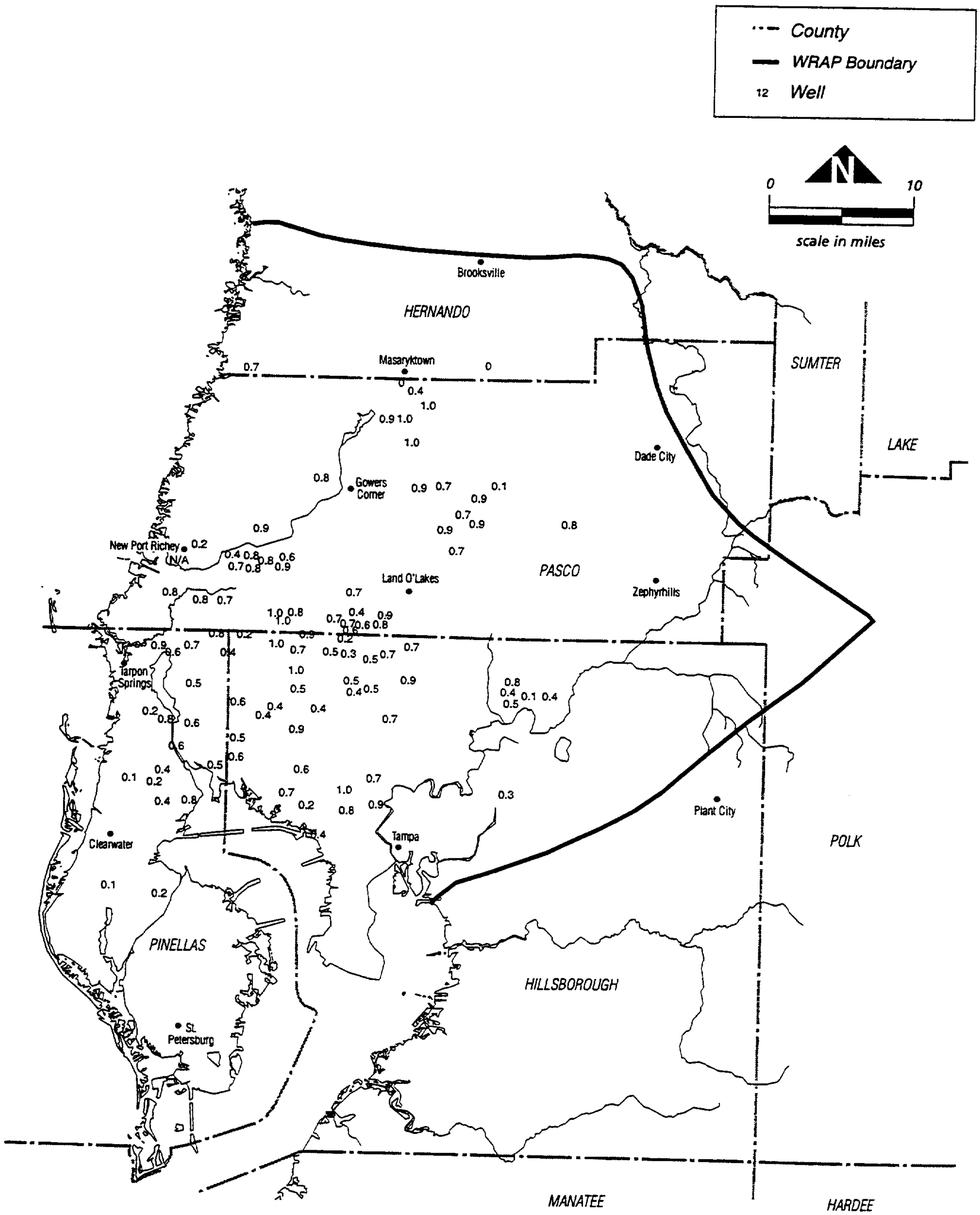


Figure 4-4. Coefficients of determination (R^2) for nested well pairs as presented in Figure 4-3.

table demonstrate that although surficial and Upper Floridan aquifer water levels are highly correlated throughout much of the tri-county area, especially in the northern areas, there are still differences in this relationship. Despite regional trends, there are examples of highly correlated water levels in the southern part of the area, as well as relatively uncorrelated water levels toward the north.

Visual inspection of the hydrographs in Appendix E shows that many of the sites with lower coefficients of determination appear to have a strong visual correlation despite the low R-square coefficient. This can be explained in large part not only by the lag time between the surficial and Upper Floridan aquifers' response to atmospheric conditions and man-made features, but the lag time between the Upper Floridan and surficial aquifers' response to stress on the Upper Floridan aquifer. Aquifer characteristics such as specific yield and hydraulic conductivity of the surficial aquifer can moderate water-level responses to some short-term perturbations, such as tides, barometric pressure, and seismic activity. The greater storage capacity and lower hydraulic conductivity of the surficial aquifer can dampen these changes fairly quickly compared to the Upper Floridan aquifer. This relationship is demonstrated in the Hutchinson monitor well, which appears well correlated, but has a low R-square coefficient (Figure 4-4). The low coefficient appears to be the result of large, short-term water-level fluctuations in the Upper Floridan aquifer.

Due to the variability of the confining unit, recharge from the surficial aquifer to the Upper Floridan aquifer is also variable. Because of these localized recharge conditions within the Northern Tampa Bay WRAP area, drawdown in the potentiometric surface of the Upper Floridan aquifer is largely attenuated and more localized than in the southern half of the SWFWMD, where the Upper Floridan aquifer is more confined. The degree of drawdown, as well as the response time of the water-table to Upper Floridan aquifer withdrawals, is highly dependent on rainfall conditions, withdrawal amounts, and most importantly, local geologic conditions. Sinclair (1977) explained the variability of the water table's response to drawdowns of the potentiometric surface around the Section 21 wellfield. Sinclair observed that although the water table response was greater in the immediate vicinity of the greatest drawdown in the potentiometric surface, thin or absent clay conditions to the east of the largest drawdowns caused water tables there to be similarly lowered. In areas near solution features, lowering of the water

levels in the surficial aquifer caused by Upper Floridan aquifer drawdowns may be greater due to the more direct connection between the aquifers. Therefore, the water table drawdown will not necessarily coincide symmetrically with the largest potentiometric drawdowns.

A recent study of the surficial aquifer and confining unit in the Northern Tampa Bay area has demonstrated that the potential for leakage through the confining unit to the Upper Floridan aquifer is variable, depending not only on the vertical hydraulic gradient but also on the elevation or stage of the water table in the surficial aquifer (Parker and Stewart, 1990; Parker, 1992; Stewart and Parker, 1992). The mechanism which causes the potential for leakage to the Upper Floridan aquifer to vary with the stage of the water table is called "stage-dependent effective leakance". Karst processes have caused the upper surface of the sandy-clay leaky confining unit to be undulating and dimpled, and the unit is perforated by numerous relict sinkholes. Sandy sediments of the overlying surficial aquifer have raveled and subsided into most of the many perforations, creating sand columns which extend through the confining unit and into the limestone of the Upper Floridan aquifer. The sand columns have vertical hydraulic conductivities which are several orders of magnitude greater than the sandy-clays of the confining unit. Recharging ground water moves laterally in the surficial aquifer to sand columns and then vertically downward to the limestone of the Upper Floridan aquifer. The numerous sand columns underlie only a small percentage of the total land area (one to two percent), but they are the avenues through which most of the recharge to the underlying Upper Floridan aquifer occurs. It is also observed that the sandy sediments of the surficial aquifer decrease in horizontal hydraulic conductivity with depth. This characteristic causes the horizontal flow of water to the sand columns to be impeded as the water table declines into the less-permeable sediments, so that the contribution of recharge through the sand columns is dependent not only on the hydraulic gradients between the surficial and Upper Floridan aquifers, but also on the elevation of the water table.

Stage-dependent effective leakance is caused by the patterns of localized variability which exist in the limestone-covering sediments of the Northern Tampa Bay area, and in theory can influence the behavior of the hydrogeologic system on a subregional scale. As the stage of the water table declines during a low rainfall period, flow paths by which recharge water moves may become increasingly tortuous, and water could be less readily released from storage to recharge the Upper Floridan aquifer. According to Parker (1992), the shape and volume of a cone of depression induced

by a well or wells withdrawing from the Upper Floridan aquifer will change with the fluctuation of the surficial aquifer stage. As the effective leakance decreases during the water-table decline of a dry season or a protracted low rainfall period, the cone of depression in the pumped Upper Floridan aquifer will expand and deepen until balanced by the capture of leakage from a larger area. Near centers of concentrated ground-water withdrawals, where induced leakage from the surficial aquifer exceeds available recharge, this can contribute to accelerated water-table declines during dry seasons and low rainfall years. Likewise, as the water table is refilled to a high stage during a period of high rainfall, the cone of depression in the pumped Upper Floridan aquifer will decrease in volume because recharging waters move more readily to the localized points of recharge to the Upper Floridan aquifer. In this way, the area of influence of major withdrawals from the Upper Floridan aquifer will vary with the prevailing hydrologic conditions.

Although the solution features are highly variable throughout the Northern Tampa Bay WRAP area, some generalizations can be made about hydrogeology and levels of connection between the Floridan aquifer and overlying surficial aquifer and surface-water features. Figure 4-5 shows four regions of similar hydrogeology, which are to a large degree reflective of the physiographic provinces of the area (Figure 2-3). Note that the boundaries of these regions are only general in nature, and should not be interpreted as concise.

Southern Pinellas County forms one of these regions. Unlike much of the Northern Tampa Bay area, this region has a relatively thick and consistent confining layer separating the surficial and Upper Floridan aquifers. However, being separated on three sides by the Gulf of Mexico or Tampa Bay, this region is similar to an island, and is to a large degree separated from the rest of the Northern Tampa Bay area. Additionally, the water quality of the Upper Floridan aquifer is poor due to high chlorides. Therefore, this region is of very limited interest for future Upper Floridan aquifer water supply.

The majority of the study area lies within a region covering almost all of northern Hillsborough County, northern Pinellas County, and much of Pasco County. This is generally the transition area from the southern section of the SWFWMD where confinement is thick and consistent, to the northern section of the SWFWMD where confinement is thinner and sometimes absent. This

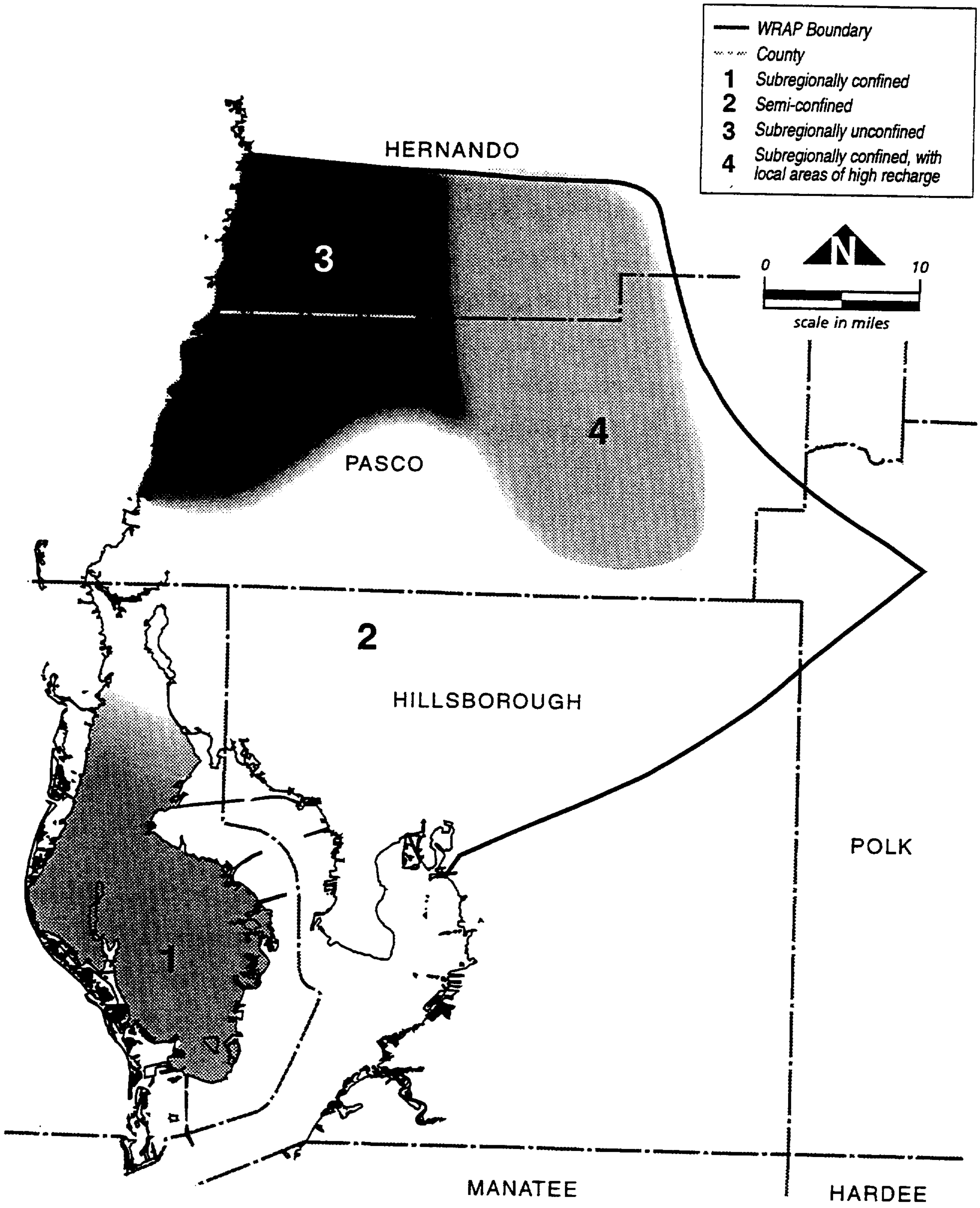


Figure 4-5. Zones of similar subregional hydrogeology within the Northern Tampa Bay WRAP (modified from Ryder, 1985 and Parker, 1992).

transitional region is characterized by variable confinement, which is partially reflected in the clay thickness data presented previously in Figures 2-18 and 2-19.

A third region is located in northwest Pasco and western Hernando Counties. Within this region, the regional semi-confining layer between the surficial and Upper Floridan aquifers is thin, very leaky, and sometimes completely absent. This is demonstrated by the hydrographs of wells such as the Masaryktown and Weeki Wachee wells presented in Chapter 3 (Figures 3-60, 3-61 and 3-82). It has been observed by the SWFWMD (Perry, 1992) that the water levels of the Masaryktown Upper Floridan aquifer monitor well respond as an unconfined aquifer, and react very quickly to rainfall. The high transmissivity of the Upper Floridan aquifer in this area (100,000 to 1,000,000 ft^2/day) creates a relatively high ground-water flow rate toward the coast. This in turn creates the 10 to 20 foot fluctuations in the hydrographs of monitor wells in this area. Because of this unconfined response, and based upon statistical analysis performed by Perry, it is hypothesized that steady-state conditions may be difficult to achieve within short time periods, and the cones of depression within the Upper Floridan aquifer may expand over a long time period to reach equilibrium with recharge from the surficial aquifer. Parker (1992) indicated that this relationship can change seasonally due to stage-dependent effective leakance described earlier, and would be especially noticeable during periods of low rainfall. However, because of the short period of record available for most surficial aquifer monitor wells, as well as the relatively short period of ground-water withdrawal in the northern portions of the Northern Tampa Bay WRAP area, it is difficult to assess this idea with historic data.

Finally, the fourth region consists of the Brooksville Ridge, a highly karst, sand ridge system with relatively thick confinement. Although the clay layer in this region is thick, it is riddled by solution features, and contains many perched lakes and water tables. Because of the perched nature of this system, as well as the relatively large head difference between the perched systems and the underlying Upper Floridan aquifer (as compared to the rest of the Northern Tampa Bay area), lake, wetland, and water table systems in this area are subject to abrupt water level changes when infill material of solution features collapses. Much of the regional recharge of the Northern Tampa Bay area is believed to occur along the slopes of the Brooksville Ridge (Fretwell, 1988; Swancar and Hutchinson, 1992). Because of the hydrogeologic differences

between these four regions, one must be careful to keep these differences in mind when comparing water resource systems located in two different regions.

Surficial Aquifer Flow

The surficial aquifer within the Northern Tampa Bay WRAP area is not a true regional flow system, although it is often depicted as such for regional mapping purposes. Although the undifferentiated sands, silts, and clays that comprise the surficial aquifer exist throughout the study area, the low permeability of these surficial materials, and the karst nature of the system, cause flow in the surficial aquifer to be more localized. As water flows through these sands, it is usually intercepted by breaches in the confining layer or stream and wetland systems within short distances, and quickly either enters the Upper Floridan aquifer, discharges as runoff, or is lost through evapotranspiration.

Evidence of the spatial variability can be observed in the monitor wells throughout the study area. Different surficial aquifer monitor wells located within a small area can show relatively large variations in water level. In one case, two surficial aquifer monitor wells within the Starkey wellfield, located within 100 feet of each other, have shown four to five feet of difference in water levels, despite equal ground elevations and simultaneous readings. This variation is common in karst areas such as the Northern Tampa Bay WRAP area, and is caused by the presence of localized confinement or vertical conduits connecting the surficial aquifer with the Upper Floridan aquifer.

As was presented in Chapter 3, few long-term trends are seen in the water levels of the surficial aquifer throughout the Northern Tampa Bay WRAP area. Much of this is due to the lack of a long-term surficial aquifer monitor well network. However, it is to be expected that water-table decline due to Upper Floridan aquifer declines should be greatest in areas of numerous solution features, regardless of whether these features are apparent on the surface. With no easy way to identify subsurface solution features, it is difficult to plan a water-table monitoring program that can differentiate between water-table effects near these features from areas having more consistent confinement.

The features described in this and the previous section result in a somewhat discontinuous semi-confining layer and water table, which cause variability in water-table drawdown due to ground-water withdrawals in the Upper Floridan aquifer. These variations explain why parts of the surficial aquifer above areas of large Upper Floridan aquifer drawdown exhibit small resulting drawdowns. In contrast, some areas more distant from large Upper Floridan aquifer drawdowns show greater hydraulic connection between the overlying surficial aquifer and the Upper Floridan aquifer. The variations also explain why these relationships can change with time, and how the effects caused by Upper Floridan aquifer drawdowns can expand during low rainfall periods. This highly variable and localized relationship between surface-water features, the surficial aquifer, and the Upper Floridan aquifer is the major factor influencing this study.

As discussed in Chapter 3, rainfall conditions are vary both temporally and spatially. On a short-term basis, the water table will rise and fall as rainfall increases and decreases. During periods of steady rainfall, the water table will continually rise. During times of extended low rainfall, the water table will continually fall. Water-table elevations are naturally variable, due to the sporadic nature of rainfall. However, in the absence of other stresses, only a long-term increase or decrease in rainfall will cause a long-term increase or decrease in water-table elevations. Neither of these rainfall trends were identified in Chapter 3.

Lakes and Wetlands

The impact of localized geology is most evident in the case of lakes and wetlands. Many of the lakes and wetlands throughout the Northern Tampa Bay area have been similarly formed. Cherry and others (1970) state that these features are formed by either; 1) shallow depressions in the surficial deposits or, 2) depressions caused by the collapse of solution features in the underlying limestone aquifer. The difference between lakes and wetlands in the Northern Tampa Bay area is usually determined by vegetation and depth; hydrologically they function similarly.

The connection between the water within a lake or wetland and the surficial and Upper Floridan aquifers is determined by the level of confinement within or below the waterbody. If a lake or wetland contains a consistent clay or organic layer covering its bottom, the waterbody may be completely perched, and have little or no relationship with the underlying aquifers. Within the

Northern Tampa Bay WRAP area, this local confining layer may allow almost no connection between the waterbody and the Upper Floridan aquifer, and may limit interaction with the surficial aquifer.

If there is a collapsed solution feature below the wetland, a direct connection to the Upper Floridan aquifer may exist. The characteristic of the connection will then be determined by the condition of the sediments that have infilled the solution feature over the years. Silts or clays may inhibit this connection, while sands may do little to impede flow. With variable levels of stress, either natural or man-made, this level of impedance can change. As sediments settle to the bottom of the lake, the connection may be blocked. With increased stress, or if a lake is dredged, as is the case in some lakes within the study area, this blockage can be removed.

Some evidence of the influence of geologic setting on wetland water levels can be seen by the visual inspection of cypress domes throughout the Northern Tampa Bay area. Most domes are characterized by shallow depths along the edges with a deep-water area in the center, and are usually located within shallow sinkholes (Sinclair, 1982). Some wetlands have a deeper sinkhole feature or series of features in the center, and result in small cypress rimmed lakes. Lakes such as Crews Lake in Pasco County and Lake Hancock in Hernando County are known to have sinkholes along their bottoms which act as drains. Several lakes along the Brooksville Ridge in Hernando and Pasco Counties have lake bottom sinkhole features that are periodically clogged and unclogged, which subsequently cause the lakes to fill or drain, depending on the sedimentation within the sink.

Usually, however, the geology is not evident at the surface. Subsurface evidence of the relationship between surface-water features, the surficial aquifer, and the Upper Floridan aquifer is demonstrated more accurately by both bathymetric and geophysical evidence. Lopez and Fretwell (1992) used bathymetry to define the bottom contours of several lakes within the Northern Tampa Bay area. The work revealed several deep depressions within the lake bottoms. The depressions near the shoreline are attributed to dredge areas, but those distributed in the center of the lake are most likely related to solution features.

Stronger evidence of lake bottom geology is attained through the use of geophysics and well drilling. Watson and others (1990) used ground-penetrating radar and well drilling to identify the geologic setting of five cypress domes within the Northern Tampa Bay area. Figure 4-6 shows what has been visualized in the past as a profile of a typical cypress dome, showing a peat layer with underlying sand, clay, and limestone. However, Watson and others (1990) identified three types of geologic settings: shallow depressions, shallow depressions with solution features, and relict sinkhole systems (Figure 4-7). The shallow depression type of setting is characterized by a relatively consistent confining layer beneath the wetland, and is similar to Figure 4-6. This type of wetland is formed by a shallow depression in the surficial deposits, and is not associated with solution features and subsidence in the underlying limestone. The underlying confinement can be either part of the regional upper confining layer, or may be a more localized form of confinement. The more localized confinement can be a localized clay lens, organic layer, or some other restrictive material. This type is sometimes referred to as a "perched" system, and may not function as a part of the regional or subregional water table. The result of either type of confinement is little or no relationship between the wetland water levels and the underlying potentiometric surface. The example used by Watson and others (1990), presented as the first cross-section in Figure 4-6, was a cypress dome located within an area of large potentiometric drawdowns. The wetland, however, showed no adverse impact, even though most other wetlands in the area were consistently dry.

The second and third types of cypress dome geologic settings are characterized by the existence of sinkhole features beneath the wetland bottom. The difference between the two is determined by the integrity of the localized confining layer (Figure 4-6). The second cross-section in Figure 4-7 displays the geologic cross-section of a cypress dome located within an area of relatively large Upper Floridan aquifer water-level drawdowns. Although a sinkhole feature is present below the dome, a clay and/or organic confining layer separates the surficial and Upper Floridan aquifers. This confinement can vary, and may function to only slow the reaction of the water level in the cypress dome to Upper Floridan aquifer drawdowns. In the case of the second cross-section in Figure 4-7, cypress dome water elevations had shown no reaction to lowered Upper Floridan aquifer levels initially, but have recently begun to experience lower water levels than was historically measured. The third cross-section in Figure 4-7 represents a cypress dome that experienced an immediate and drastic lowering of water levels when the underlying

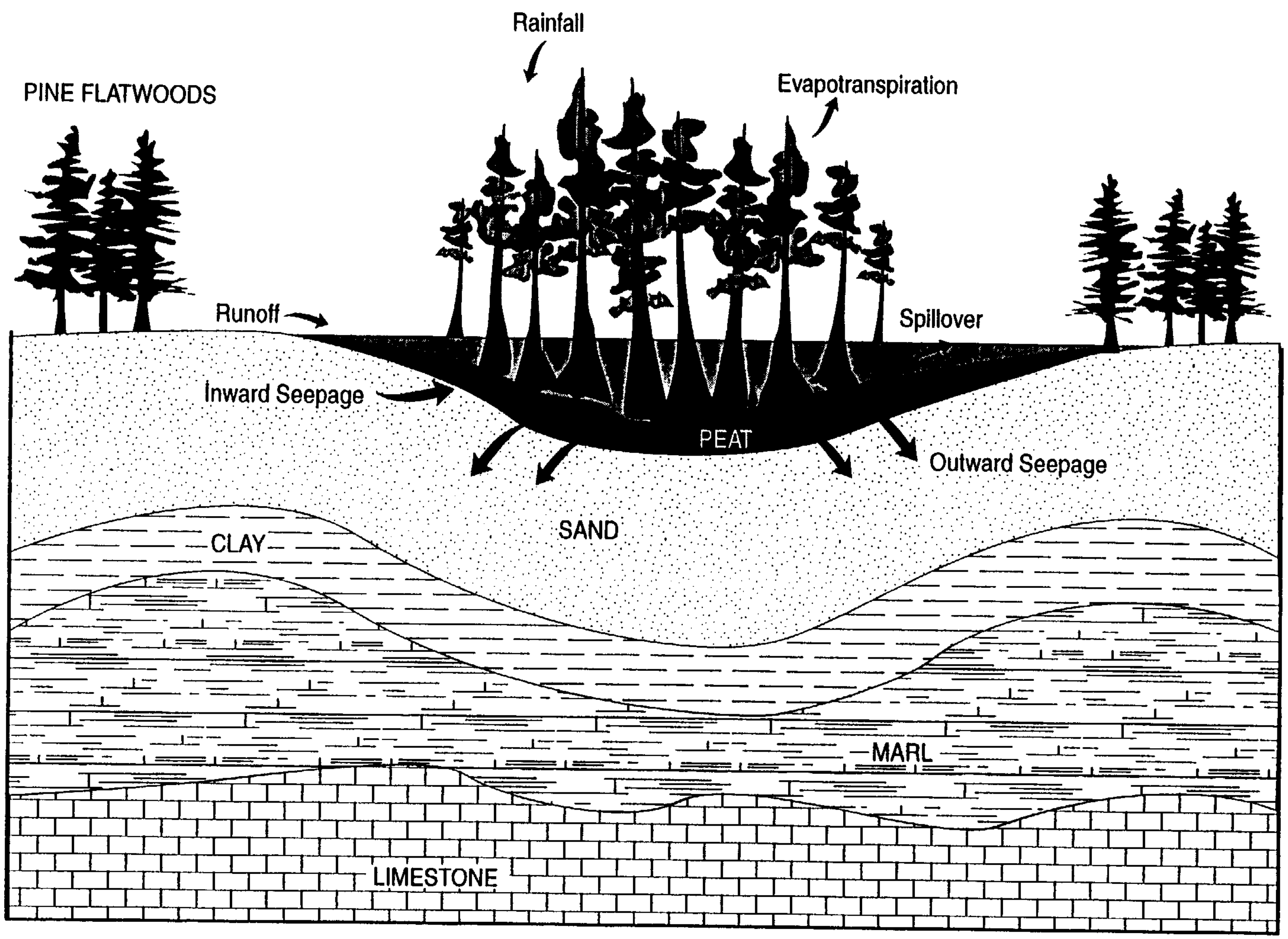


Figure 4-6. Typical cypress dome profile.

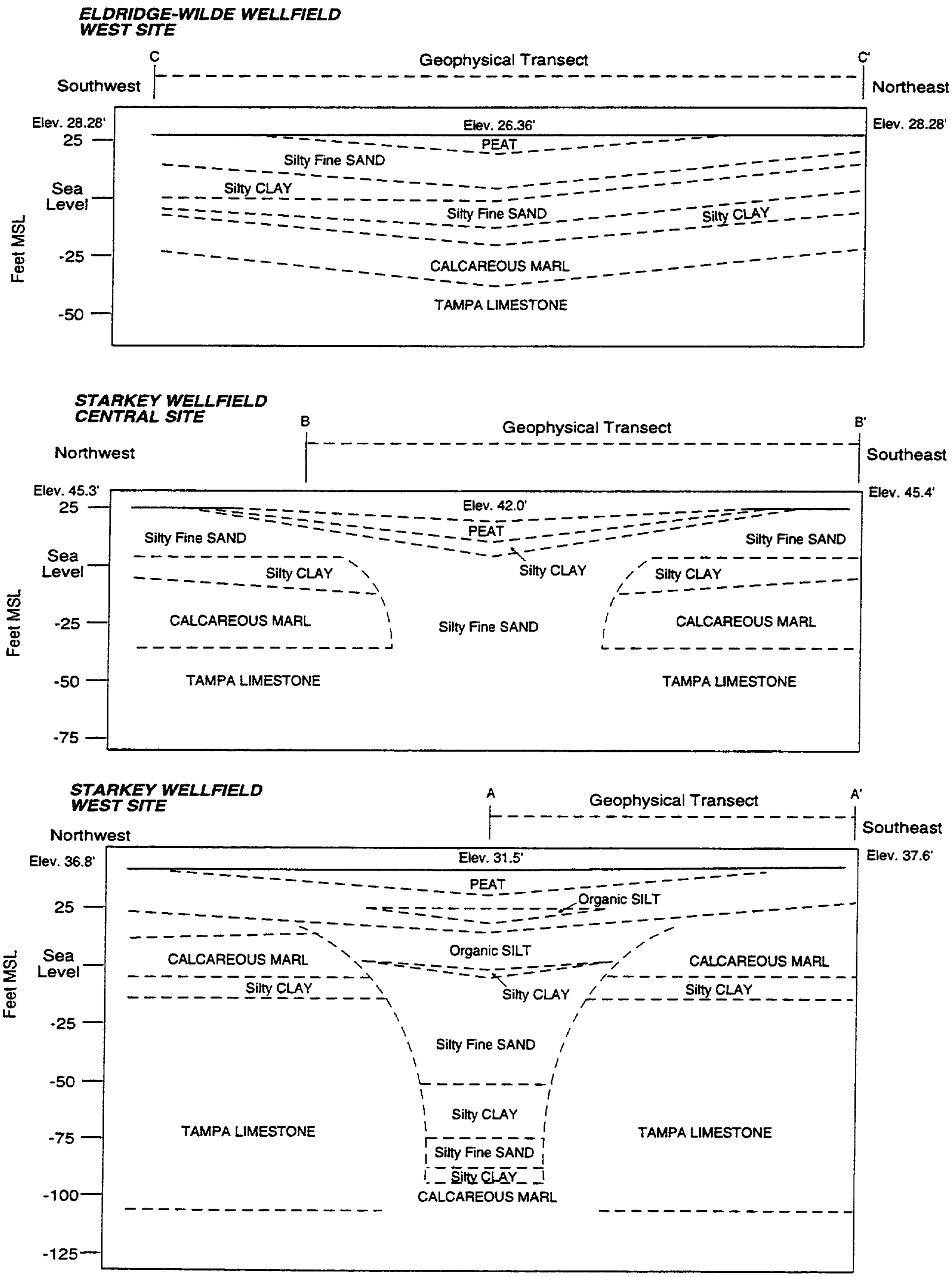


Figure 4-7. Cross sections of three representative geologic settings (modified from Watson and others, 1990).

potentiometric surface was lowered. A well-defined sinkhole feature in the cross-section is evident. The solution feature beneath the cypress dome is so well-defined in this example that dramatic land subsidence has occurred over a period of two years, due to the collapsing overburden with lowered water levels.

Thus, the relationship between declines in the potentiometric surface and water levels in surface-water features is highly dependent on the subsurface geology. As was shown by Ryan (1989), the absence of sinkhole features beneath surface-water systems does not prevent interaction between surface-water and the Upper Floridan aquifer, since leakage can still occur with appropriate head differences. However, sink features certainly can provide a more direct connection between the two water levels.

Marine seismic and ground-penetrating radar methodologies have been used within or near the SWFWMD to show similar relationships in lakes (Ryan, 1989; Synder and others, 1989; Lee and others, 1990, Subsurface Detection Investigations Incorporated, 1995). Most lakes are found to have multiple solution features, any or all of which can control the level of connection between the lake level and water levels in the underlying aquifers (Figure 4-8). In addition to sink features, many lakes within the Northern Tampa Bay WRAP area have been subject to dredging activities (Reichenbaugh, 1977; Jones, 1978, Henderson, 1986; Lopez and Fretwell, 1992), which can breach or alter the confining layer of a lake. Dredging was performed along the shores of several lakes to provide additional lakefront property on adjacent wetland areas, to provide fill for lakefront homes, and to deepen lakes in the area of docks. Once the confinement is removed, the dredged area can function similarly to a sink, and render the lake more susceptible drawdowns in the Upper Floridan aquifer. This phenomenon not only pertains to surface-water elevations, but also to surficial aquifer water elevations. Unfortunately, few records exist on the dredging activities of individual lakes, so it is difficult to inventory this activity. Bathymetric studies (Henderson and others, 1985; Lopez and Fretwell, 1992) can usually identify small-scale depressions, but because both sinkholes and dredged areas are common in Northern Tampa Bay lakes, it is often difficult to distinguish between the two features. Subsurface Detection Investigations Incorporated (1995) was able to distinguish between dredged areas and sinkholes through the use of ground-penetrating radar techniques.

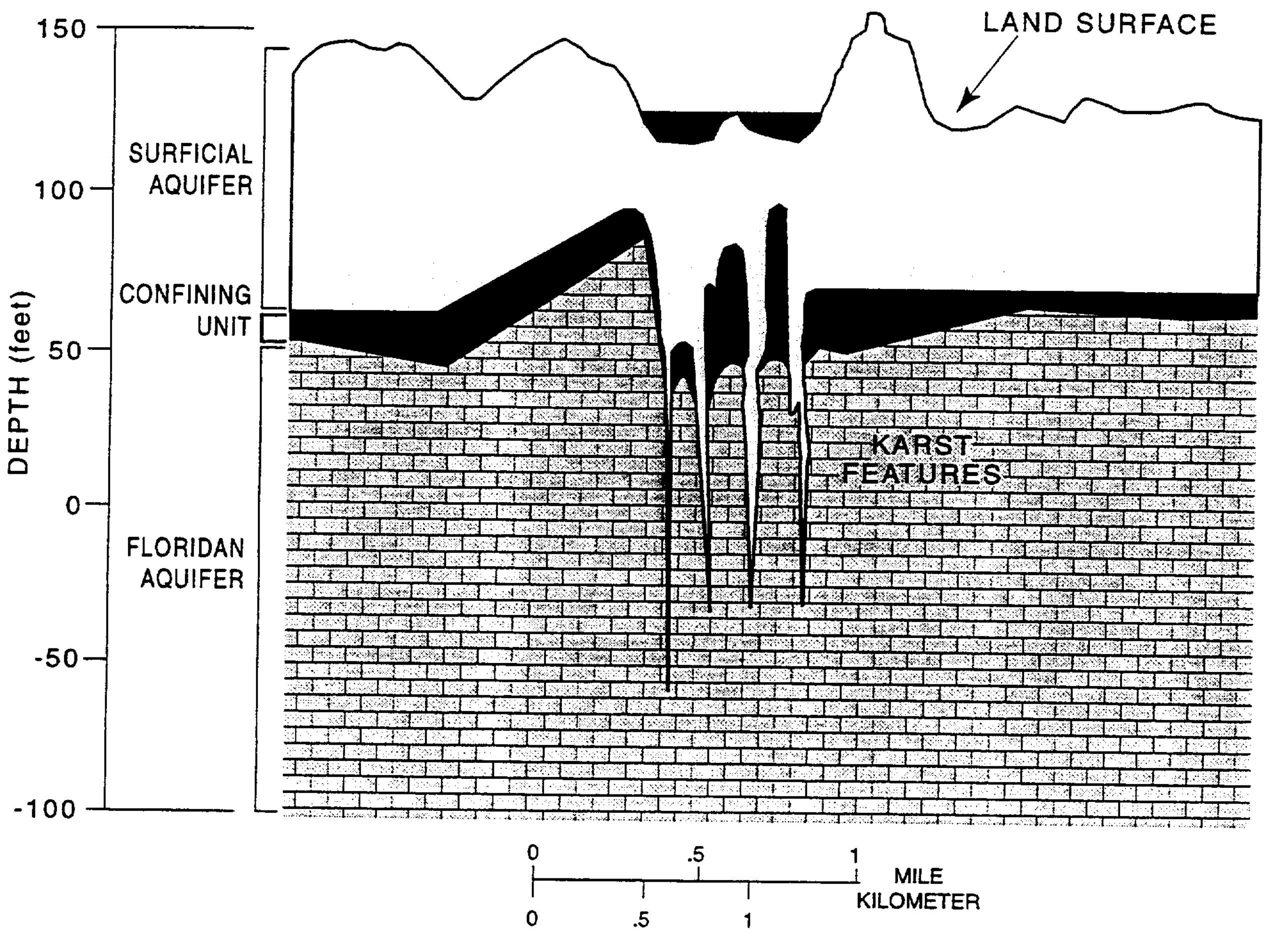


Figure 4-8. Hydrogeologic cross-section of Lake Lucerne, Polk County, showing karst features (modified from Lee and others, 1990).

Lakes, wetlands, and to some degree, the surficial aquifer within the Northern Tampa Bay WRAP area all have very similar hydrogeologic characteristics. All are situated in a covered-karst geology, with a variable confining unit, and therefore are regionally susceptible to effects from variations in Floridan aquifer levels. Because of the spatial and temporal variability, however, the degree of effect will also be variable throughout the Northern Tampa Bay area.

4.1.3 Biological Health

A significant concern within the Northern Tampa Bay WRAP area is the documented decline in wetland health. Urban development has directly impacted wetland health in areas of dredging and filling of wetlands. Declines in water quality, caused by the influx of pesticides, fertilizers, septic tank discharges, and atmospheric precipitants have also been noted in some wetlands and lakes, which in turn can cause wetland health deterioration. However, dramatic declines in wetland health have been observed for some time in wetland areas throughout the Northern Tampa Bay WRAP area that are not readily susceptible to these elements. This decline in wetland health is caused to a large extent by the reduction in average water levels and hydroperiods (periods when water is above land surface) of isolated wetlands throughout the Northern Tampa Bay WRAP area. These declines were discussed previously in Chapter 3.

Biologists have no general standard for determining the state of a wetland's health. However, they have expressed some viewpoints on the matter. Karr and others (1986), for example, considered a wetland healthy when its inherent potential is realized, its condition is stable, its capacity for self-repair when disturbed is preserved, and minimal external support for management is needed. More recently, healthy wetlands have been mentioned as exhibiting a persistence of physical, chemical, and biological conditions which sustain the long-term processes and structure of the regional wetland resource (Brown and others, 1989).

Viewing wetland health from the opposite perspective, namely what constitutes unhealthy conditions, can also be informative. Schaeffer and others (1988) included:

- relative declines in the numbers of native species, which may not affect ecosystem function but threaten biodiversity

- setbacks or delays in succession

- accumulation or loss of biomass and/or changes in the ratio of living to dead biomass

- changes in gross or net primary production, reflecting changes in the amount of energy entering or leaving the system

- changes in proportions of energy processed by grazers and decomposers

- losses of mineral macronutrients

- breakdowns in mechanisms for controlling oscillations in structure and function

Biologists generally agree that wetlands in the Northern Tampa Bay WRAP area are less healthy than in predevelopment times. The direct and indirect effects of settlement and growth have had varying adverse effects on wetland quality throughout this part of Florida. The effects, for the convenience of discussion, can be considered as either direct or indirect. Direct effects are associated with filling, ditching, and draining of wetland areas. Direct effects typically lead to the complete elimination of wetlands. Indirect effects, on the other hand, usually involve changes to wetland hydroperiods or alterations to water levels in the area surrounding existing wetlands. Other important indirect impacts come about through changes in the quality of water entering wetlands, changes in atmospheric quality, alterations in fire frequency, and the invasion of non-native plants and animals.

Functionally, wetlands play an important role not only in supporting wetland-dependent biota but also in enhancing water quality, storing water, recharging water to the aquifer, and as buffers against damaging flood surges (Sather and Smith, 1984). Other functional values are discussed in Chan and others (1982), Kobriger and others (1983), and Richardson (1990).

The most common wetland type within the Northern Tampa Bay WRAP area is the cypress dome, which dots the undeveloped landscape. During periods of average summer precipitation, surface water is generally contained within the isolated wetland. When summer rainfall is above

average, however, isolated wetland systems often become connected with each other and with nearby rivers. Consequently, the concept of isolated wetlands is relative.

For many years, the SWFWMD has monitored the surface waters of nearly 60 cypress domes equipped with staff gages or recorders within the Northern Tampa Bay WRAP area and the Green Swamp. A representative sampling of seventeen of these domes shows that at times during the rainy season these systems reach an average maximum surface-water depth of 1.8 ft (range 1.2 - 2.8 ft). When maximum surface-water depths are present in the center of the domes (Figure 4-6), the full extent of the wetland is flooded. When antecedent conditions are low at the beginning and end of the wet season, or when rainfall falls below average during the wet season, the central part of the dome usually maintains water but the edges of the saucer-shaped depression remain dry.

The characteristic dome-like profile associated with the cypress domes is formed by the distribution of small cypress (*Taxodium ascendens*) at the edge of the wetland and larger ones toward the center. Within the dome, organic matter increases in thickness from the edge toward the center. Several types of geology underlying domes have recently been described by Watson and others (1990).

In contrast to contiguous riverine or flood-plain cypress stands, cypress domes are low-productivity ecosystems (Connor and Day, 1976). This is the likely outcome of low nutrient availability, low pH, low light penetration through the canopy and high light attenuation in the tannin-colored waters (Mitsch, 1984). Low productivity contributes to the low plant diversity of domes compared to other native Florida habitats (Wright and Wright, 1932). In spite of low productivity, a considerable number of animal species use cypress domes during their life cycle. For example, literature from the Green Swamp area of southwest Florida reports 5 fishes, 12 amphibians, 16 reptiles, 69 birds and 10 mammals from this habitat type (SWFWMD, 1985).

Although relatively low in productivity, cypress domes usually show high spatial heterogeneity (Ewel and Odum, 1984). High spatial heterogeneity results from the many vertical layers of vegetation in the dome. For example, the cypress overstory supports epiphytic bromeliads and orchids, while smaller trees such as red maple, sweetgum and bays occupy the mid-story.

Underneath the small trees, shrubs such as wax myrtle, buttonbush and fetterbush are usually abundant. At ground level, or on cypress stumps and buttresses, ferns, water-tolerant herbs, mosses and lichens often are found. At times when the dome has standing water, floating bladderworts, duckweed and water fern may be conspicuous. On the other hand, when standing water disappears, a dense ground cover of pipeworts, beaked rushes, yellow-eyed grasses, peat moss and other wetland plant species are typically found.

According to most reports, healthy cypress domes have standing water for more than six months of the year (Ewel and Wickenheiser, 1988; Bays and Winchester, 1986). Although a six month surface-water hydroperiod may apply to the deep-water central portion of the domes, the shallower edges are inundated for shorter periods. The depth and duration of standing water at any point within the dome is critical in determining plant species composition. Long-term monitoring of cypress dome vegetation in the Green Swamp and elsewhere in southwest Florida has shown floating rush (*Juncus repens*), arrowhead (*Sagittaria graminea*) and pickerelweed (*Pontederia cordata*) typical of deep-water dome areas (Rochow and Lopez, 1984). Moderately shallow waters, on the other hand, support lesser pipeworts (*Eriocaulon compressum*) and water hoarhound (*Lycopus rubellus*). Where water is most shallow, at the very outside of the dome, giant pipewort (*Eriocaulon decangulare*) and sandweed (*Hypericum fasciculatum*) are usually encountered. Domes therefore exhibit considerable horizontal as well as vertical stratification in plant types.

The characteristic structure and function of natural isolated wetlands is dependent on relative long-term environmental stability. Long-term monitoring in ground-water withdrawal areas has documented the vegetational trends expected when seasonal-high water levels are lowered and hydroperiods abbreviated (Rochow, 1985a,b, 1994; Winchester, 1986; Bays and Winchester, 1986; Dooris and others, 1990). Since the depressions in the land surface occupied by these wetlands slope gradually toward what in most instances are deep-water central areas, a surface-water drawdown of one foot from a natural annual hydroperiod would cause significant areas of wetland to be without surface water. A drawdown of one foot or less would represent a less severe drying of the wetland, but would still cause abnormal drying of the wetland edge.

Figure 4-9 presents hydrographs from two cypress wetlands in the Starkey Wellfield that clearly show the effect of a decreased hydroperiod on wetlands. Hydrographs in both wetlands are monitored by a surface-water staff gage and surficial aquifer monitor well located in the wetland. One hydrograph shows a pattern of normal surface-water response typically observed in wetlands unaffected by water-level drawdowns. This wetland is far removed from the most intensive area of water-table drawdown in the wellfield. The other wetland shows an abnormal pattern of surface-water response and is in an area of the wellfield where the water table is most depressed. Significant decreases in wetland biota have been documented in the dry dome while the wet dome is relatively rich in wetland flora and fauna (Rochow and Rhinesmith, 1991).

Wetlands with decreased hydroperiods and average water levels are subject to various indirect impacts, which can severely impact wetland structure and function. These impacts, extensively documented by SWFWMD (Dooris and others, 1990; Rochow, 1994) and Water Use Permit monitoring (HSW Environmental Consultants, Inc. and Water and Air Research, Inc., 1995; CCI Environmental Services, Inc. and Terra Environmental Services, Inc., 1995), include the invasion of competitive upland species, land subsidence and loss of overstory, destruction by fire, and loss of wildlife. The cypress dome impacts are illustrated in Figure 4-10, and discussed below.

When wetlands are abnormally dry, plant species such as pickerelweed (*Pontederia cordata*), rush (*Juncus repens*), arrowhead (*Sagittaria graminea*), lesser pipewort (*Eriocaulon compressum*), and blue hyssop (*Bacopa caroliniana*) decrease or disappear altogether from the wetland understory. Replacing these species are undesirable "terrestrial opportunists" such as dog fennel (*Eupatorium sp.*), broomsedge (*Andropogon virginicus*), blackberry (*Rubus sp.*), and blue-maidencane (*Amphicarpum muhlenbergianum*). Tree species such as slash pine (*Pinus elliottii*) and mesic hardwoods, including red maple (*Acer rubrum*), sweet gum (*Liquidambar styraciflua*) and laurel oak (*Quercus laurifolia*) also show a tendency to invade the dry understory. If conditions are sufficiently dry, the cypress canopy may undergo a noticeable thinning. Over many years, a combination of changes can lead to hardwood domination of the former cypress stand.

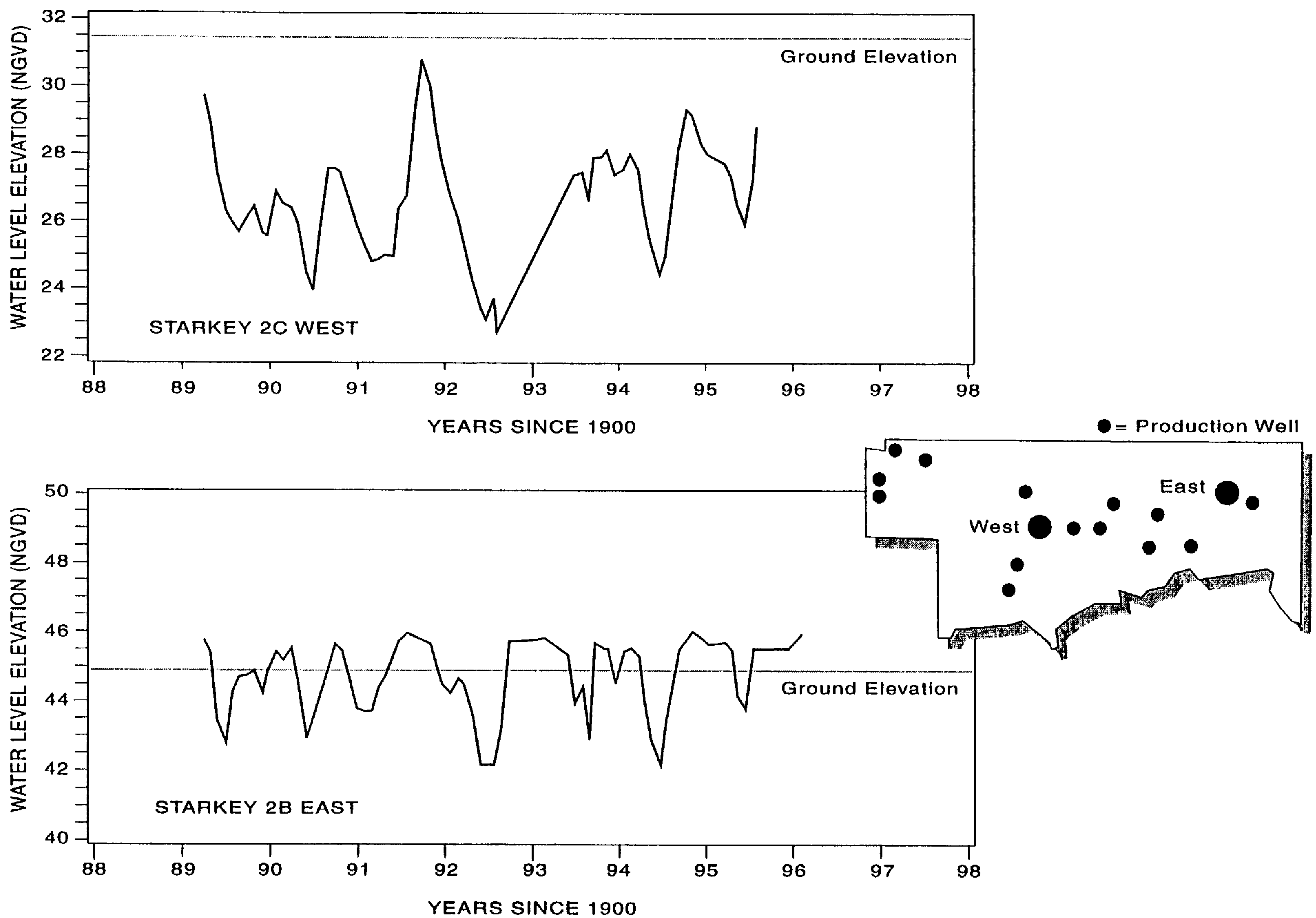


Figure 4-9. Example of an abnormal surface water hydrograph (top) and a normal surface water hydrograph (bottom) in two cypress domes at the Starkey wellfield.

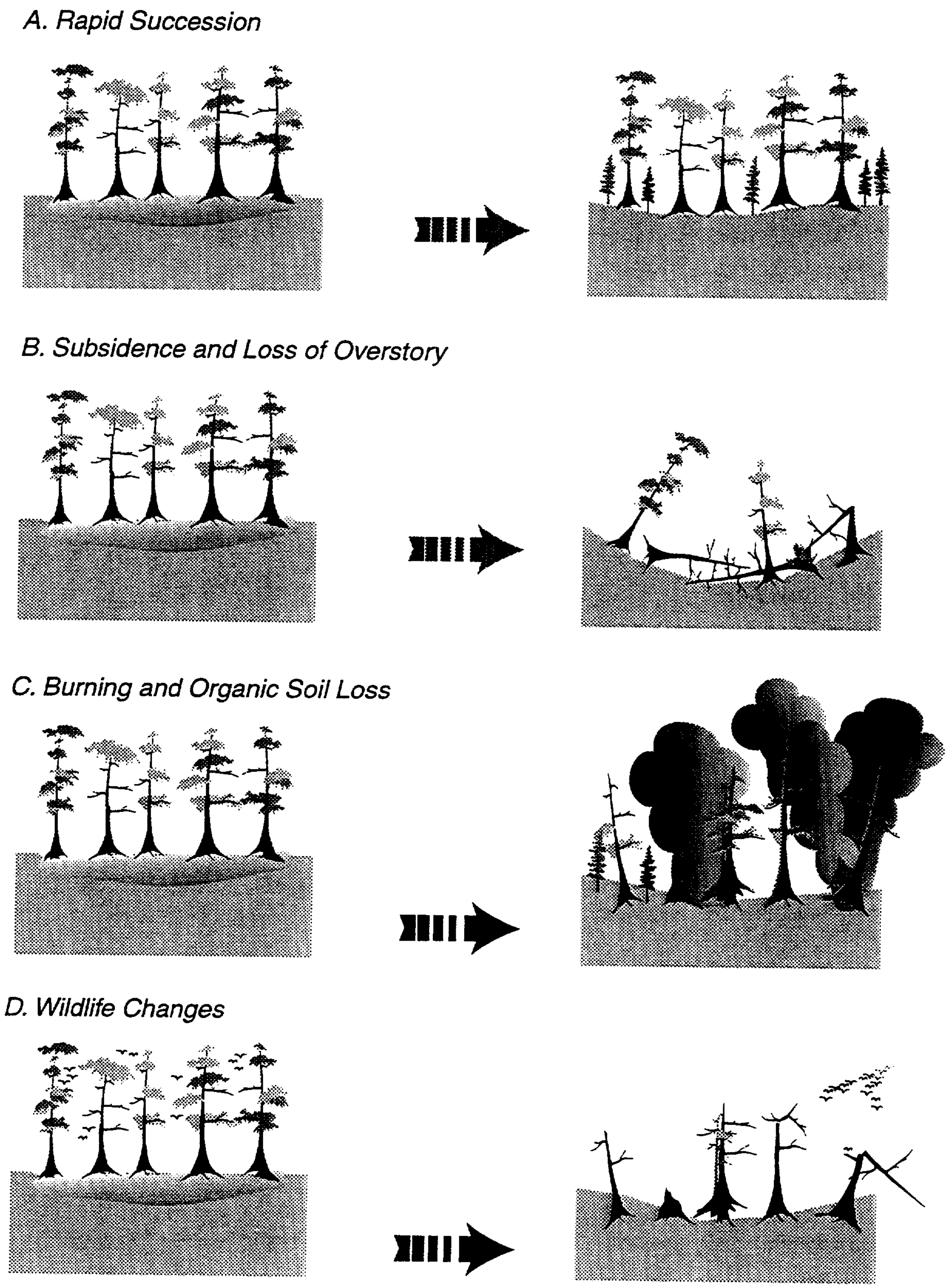


Figure 4-10. Vegetational and wildlife changes documented in major wetland water-table drawdown areas.

The effects of abnormally dry conditions in cypress wetlands have been noted in Collier County. When water levels were lowered in stands of cypress, the result was extensive thinning of the canopy and destructive wildfires (Carter and others, 1973; Burns, 1978). In other cypress areas, Marois and Ewel (1983) found that as water levels drop, midstory plants such as wax myrtle, buttonbush, fetterbush, bays, and dahoon holly become more common. Red maple and various weedy plant species then invade the forest understory. A number of other water level related vegetational changes in Florida's forested and non-forested wetlands are discussed by Bays and Winchester (1986).

Excessive dryness in forested wetlands may also result in oxidation, shrinkage, and subsidence of organic soils. The outcome of these soil changes is most often a decline in elevation or sinking of the affected wetland. The sinking may be accentuated by underlying karst features. Alone or in combination, these soil and geologic changes can undermine cypress support and lead to leaning and falling trees and rapid vegetational changes. Vegetational changes of this type have been studied on historic aerial photography in wellfields in and around the Northern Tampa Bay WRAP area (Rochow and Rhinesmith, 1991). In specific cases, Watson and others (1990) have documented underlying sink-like geological structures that probably have contributed to substantial ground subsidence at the study sites.

Under natural conditions, fire plays an important role in maintaining the normal structure and function of cypress domes (Wade and others, 1980; Winchester, 1986). Fires typically begin in the summer from lightning strikes directly in the domes or in the surrounding flatwoods. Since the domes normally have standing water at this time, natural fires are unable to spread very far beyond the forested fringe of the domes. However, at long-term intervals, possibly on the order of once each century, low rainfall enables fire to burn entirely through dry cypress domes. The most important role of these infrequent fires is generally recognized to be the elimination of pines and hardwoods from the cypress stands. Without fire at long-term intervals, forested cypress areas undergo a progression toward mesic hardwood forests with the eventual elimination of cypress.

The health of isolated forested wetlands in relation to fire is a delicate one. Both ground-water withdrawal and development can tip the balance that once existed in historic times. For

instance, when cypress areas are excessively dry, fire can be very destructive. This is particularly the case when wetlands are surrounded by rangeland that is burned frequently in winter or spring to stimulate regrowth favorable for cattle. The frequency and seasonality of this type of prescribed burning is quite different from the natural burning of flatwoods that occurred during the summer wet season at 3-5 year intervals. The most noteworthy consequence of burning in abnormally dry wetlands is the destruction of organic soils by combustion. If tree support by organic soil is lost, the trees may lean and fall. In any case, severe burning of peat-like soils drastically alters wetland basin topography and changes the environment sufficiently so that normal wetland structure and function are altered almost indefinitely.

In contrast to the situation where isolated wetlands are surrounded by rangeland, wetlands in developed or urbanized settings are likely to experience less frequent burning than in historic times. The consequence of infrequent burning is to stimulate the growth of hardwoods, pines, and shrubs. A decline in surface waters may hasten these successional trends. The shaded understory caused by the dense growth of shrubs will in all likelihood cause a decrease in herbaceous plant species diversity and decreased aquatic productivity. Although fire frequency is low in wetlands of developed areas, these wet areas may be susceptible to severe burning at long time intervals due to dense vegetative growth and low ground-water levels.

Despite extensive vegetational monitoring, the effect of lowered water levels and hydroperiods on wetland wildlife in the project area has not been monitored intensively. Based upon general knowledge of the ecology of many wetland species, it can be concluded that as surface-water hydroperiods become increasingly short, the use of wetland areas by fish, amphibians, many reptiles, and birds such as ibis, herons, anhinga, ducks, and wood storks will be curtailed or eliminated. The virtual absence of a functioning wetland foodchain in severely stressed cypress domes in and around the Northern Tampa Bay WRAP area has been studied by Rochow and Rhinesmith (1991). They found that cypress areas with normal surface-water levels support considerable fish and amphibian populations. However, fish were absent and amphibians almost nonexistent in the severely stressed wetlands.

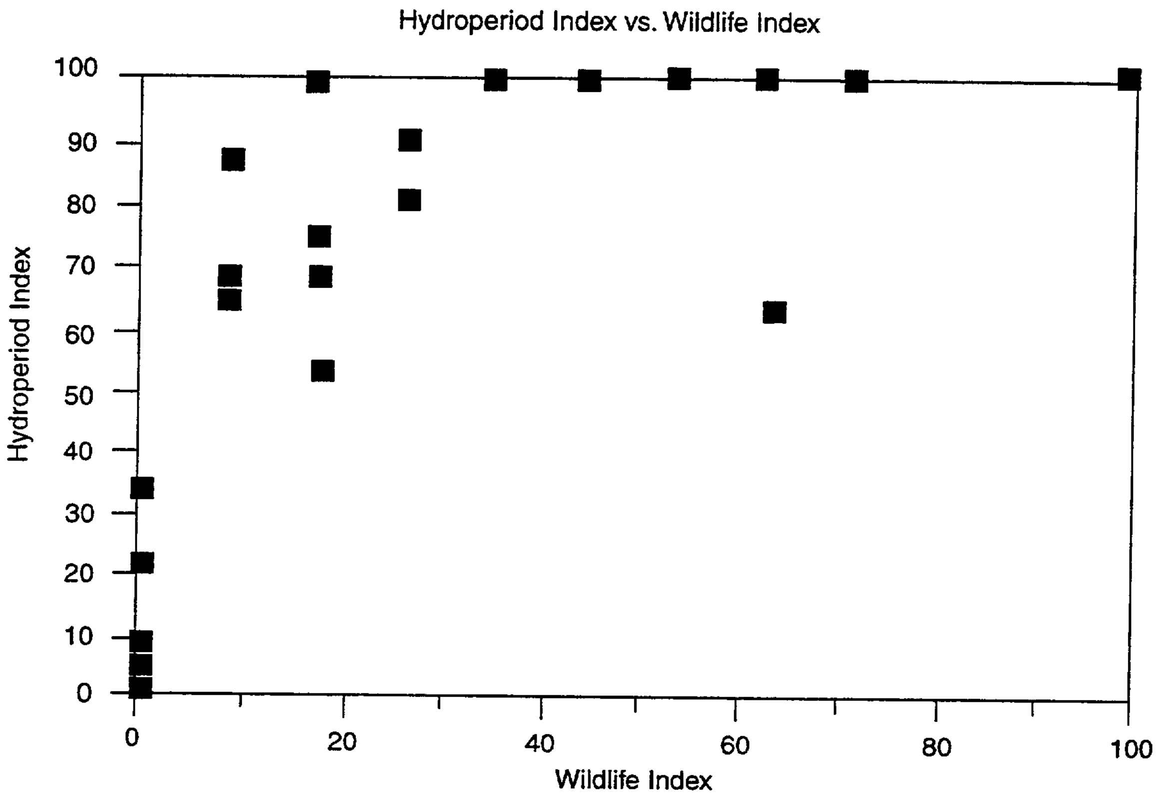
As a continuation of the wetland health analysis presented in Chapter 3, an evaluation of the relationship between hydroperiod and wetland health was performed. Because of the ecological

preferences of wetland plants and animals for wet environments, a direct relationship was expected between surface-water hydroperiod and the abundance of wetland biota at the 38 wetland sites studied intensively in the Northern Tampa Bay WRAP area. To investigate the nature of the relationship from study data, information from Table 1 in Appendix C is presented in Figure 4-11. Depicted are the Wetland Wildlife Index/Hydroperiod Index and the Wetland Plant Life Index/Hydroperiod Index. A detailed explanation of these indices is provided in Appendix C, but these indices are directly related to the abundance of wetland biota and to the duration of wetland inundation.

Both wetland wildlife and plant life are more abundant at wetland sites with long hydroperiods (Figure 4-11). In fact, wetland wildlife was not detected at study sites experiencing less than approximately three to four months of surface-water inundation. Although wetland plant life at the study sites also decreased as surface-water hydroperiods became more abbreviated, the sensitivity of wetland plant life to drier conditions was not nearly as great as that for wetland wildlife. The difference in response pattern might be explained by the fact that wetland wildlife responds immediately to annual hydrological conditions while wetland plant life likely responds to hydrological conditions over several years.

Although no site-specific studies on the relationship of plants and wildlife to lake water levels have been performed in the Northern Tampa Bay WRAP area, changes in the biologic structure and function can be expected if water level fluctuations are altered. These changes may include accelerated accumulation of unconsolidated bottom sediments, decline in dissolved oxygen, nutrient enrichment, vegetational changes, and reduction in fish and wildlife populations (Dooris and Moresi, 1975; Dooris and Courser, 1976). The impact of lowered water levels in lakes is dependent on the morphometry of the lake, since the ecologic system of the lakes will depend on depths. If perimeter littoral areas are dried, plant and fish diversity and abundance would be expected to decrease.

River and estuary ecosystems can also be expected to be altered with decreased streamflow and river stage. The rivers and creeks in the Northern Tampa Bay WRAP area have the potential to affect the estuarine environment by influencing the quantity, timing, and water quality of freshwater discharged to coastal areas. Depending upon the degree of development in their



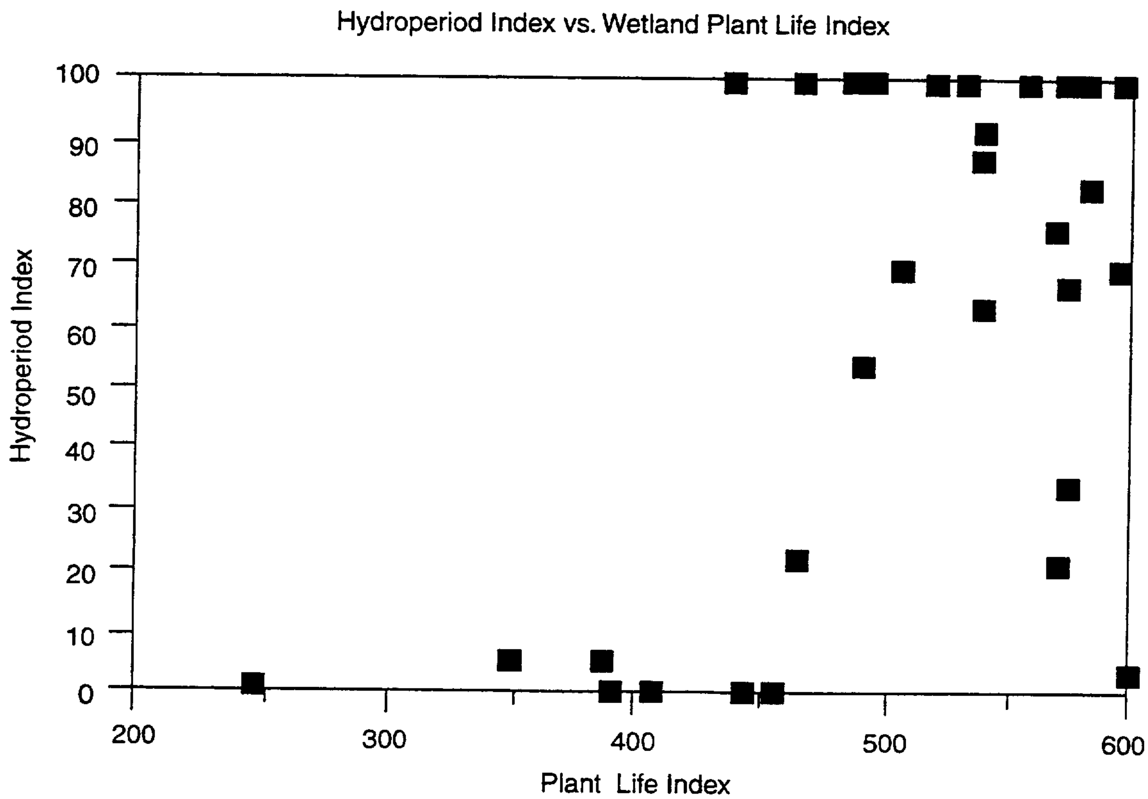


Figure 4-11. Hydroperiod Index compared to Wetland Wildlife Index (A), and Wetland Plant Life Index (B). Data are from Table 2 in Appendix C.

associated watersheds, certain estuaries in the Northern Tampa Bay area show signs of environmental degradation attributable to water quality degradation associated with land use changes within their drainage basins. Since some evidence of decreased flows also exists in the study area, changes in river discharge may have some impact on the deterioration of estuaries in the Northern Tampa Bay WRAP area.

4.2 Causes of Water Level Decline in the Upper Floridan and Surficial Aquifers

This section examines possible causes of water-level declines in the Northern Tampa Bay WRAP area. Rainfall, surface-water and ground-water flows, drainage, and ground-water withdrawals are examined. This section will demonstrate that although all of these parameters have some contribution to impacts to the water resources, ground-water withdrawals are responsible for the greatest subregional adverse impact to the water resources.

4.2.1 Rainfall

Rainfall is the water source of the hydrologic system in the Northern Tampa Bay WRAP area, and all of Florida. Regardless of the source or degree of impacts to the water resource system, rainfall will remain the chief component of the system. Low and excessive rainfall periods have and will continue to cause swings in the water levels of surface-water features, the surficial aquifer, and to a lesser but significant degree, the Upper Floridan aquifer system. However, as long as the long-term rainfall amounts do not significantly decline, and no other stress is applied to the system, the long-term water levels of the hydrologic system should remain stable.

Although periods of variable rainfall have been identified throughout the past 95 years at various rainfall stations, decade by decade rainfall in the Northern Tampa Bay WRAP area has been relatively consistent over the past 40 years. Table 4-2 presents ten-year annual-average rainfall for the last four decades at long-term rainfall stations throughout the WRAP area. The 1950s did show a period of relatively high rainfall at some stations (in particular at St Petersburg), and the 1970s was a relatively low period of rainfall at most stations, but, with some exception, most 10-year averages are within two to three inches of each other. Therefore, long-term reductions in rainfall are not apparent. Analysis in Chapter 3 and other referenced studies have

Table 4-2. Ten-year averages for long-term rainfall gages in the Northern Tampa Bay WRAP area (in inches).

Station	Period of Record	1950s	1960s	1970s	1980s	Period of Record Average
Brooksville	1901-1995	55.0	56.2	51.8	56.8	55.7
Cosme	1945-1995	54.3	52.9	54.2	56.7	54.4
St. Pete	1915-1995	64.1	49.6	46.3	52.3	51.9
St. Leo	1901-1995	54.8	54.5	53.9	57.2	55.2
Tampa	1901-1995	52.9	45.5	43.4	46.0	47.4
Tarpon Sprgs.	1901-1995	52.4	52.4	50.6	53.6	52.0
Average		55.6	51.9	50.0	53.7	52.8

also shown no long-term decline in rainfall. Shorter periods of low rainfall are identified, and, as shown in Chapter 3, the average rainfall in the current 34-period (1961-1995) has been lower than the average of the previous 50 or 60 years. However, the timing, magnitude, and spatial variability of declines in water levels can not be entirely explained by low rainfall.

In a water balance analysis performed by Camp, Dresser, and McKee (1985) on various lakes in the northwest Hillsborough County area, net rainfall minus evapotranspiration accounted for between 16 to 42 percent of measured water-level decline in the lakes over a three-month period. The remainder of the lake water-level decline was attributed to other parameters, including natural seepage and induced seepage from Upper Floridan aquifer drawdown. Regression analysis performed as part of this study, presented later, shows similar results. Periods of prolonged below-average rainfall, such as that experienced from 1989 to 1993, will be reflected in water level hydrographs of lakes, wetlands, and monitor wells, but have historically been offset by higher rainfall amounts in other years. Therefore, although rainfall is a major component in the variation of water levels, it is not the only component. A discussion of the effects of rainfall versus other hydrologic components is presented later in this report.

4.2.2 Surface-Water Flow

Within the Northern Tampa Bay WRAP area, changes in natural surface-water flow may be a local concern for water-table elevations and surface-water quality, but these changes have little to no effect on the Upper Floridan aquifer. For some aquifers in other parts of the United States, such as the Edward's Aquifer in Texas, rivers and streams are an important source of recharge to regional confined or semi-confined aquifers. However, most of the rivers in the Northern Tampa Bay WRAP area are small, intermittent, and in hydraulic connection with the surficial aquifer. The Hillsborough River has the strongest connection to the Upper Floridan aquifer, but has not shown long-term downward trends in flow. If Upper Floridan aquifer potentiometric levels are lowered well below surficial aquifer levels, and leakage below the streambed is increased, streams formerly in areas of Upper Floridan aquifer discharge can begin to act as recharge sources to the Upper Floridan aquifer. However, unless the natural system in the Northern Tampa Bay WRAP area is highly disturbed, natural changes in streamflow will not significantly affect semi-confined aquifer water levels.

4.2.3 Ground-Water Inflow

As discussed in Chapters 2 and 3, the regional ground-water flow system of the Northern Tampa Bay WRAP area begins in the potentiometric high areas of the Green Swamp and the Pasco High (see Figure 2-26). If ground-water inflow from areas up-gradient from the areas of observed impacts was reduced, water-level declines may be partially or entirely attributed to this reduction. However, two important points concerning water use and the hydrogeologic system reduce this concern. First, the Northern Tampa Bay WRAP area represents the entire contributing regional ground-water system. Therefore, the areas of water use outside of the study area currently have had no significant effect on water levels in the area of concern. Water use in the up-gradient areas, including the Green Swamp, is minimal, with very little increase over the past 50 years. However, increased ground-water withdrawals in this area could affect this relationship in the future. Secondly, the leaky confinement throughout the study area makes localized recharge an extremely important component of the hydrologic system. Although the regional origin of the ground-water system of the Northern Tampa Bay WRAP area begins in the potentiometric high areas of the Green Swamp and the Pasco High, much of the Upper

Floridan aquifer recharge for a specific area along the flow lines from the potentiometric highs to the coast is derived from local recharge. Because of this, the effects of reductions in recharge on water levels up-gradient to any given point along the regional flow lines are greatly dampened. As will be demonstrated later in this chapter and through the regional modeling analysis in Chapter 5, the subregional nature of depressed ground-water levels in the Northern Tampa Bay WRAP area is caused by the overlapping and expansion of more localized water-level declines, rather than a more equally distributed lowering of ground-water levels in the entire area.

Depending on the ground-water withdrawal quantities and the local hydrogeologic conditions, up-gradient drawdowns may or may not impact down-gradient water-levels. Change of inflows from outside of the Northern Tampa Bay WRAP area are generally not a concern due to the low levels of water use to the north and east of the study area. To the south, in Eastern Tampa Bay, the influence of the large Upper Floridan aquifer potentiometric drawdowns has historically not affected the potentiometric surface in the Northern Tampa Bay region, due to increased leakage in the north. These concepts are further discussed in Chapter 5.

4.2.4 Man-Induced Stress

Beyond variations in the natural components of the hydrologic cycle, trends in man-induced components also affect ground-water levels. Although there are many man-induced factors that can alter the various hydrologic components, the two most important factors are extensive surface-water drainage and ground-water withdrawals.

Drainage

In the first half of the 1900s, citrus, dairy, vegetable, and timber operations cleared much of the land in the Northern Tampa Bay area, and ditch systems were constructed to locally lower water tables and accelerate runoff. In some cases, such as in Brooker Creek, natural stream channels were dredged to increase surface-water drainage for agricultural areas along the stream. During the 1950s and 1960s, the natural interconnections of several lakes in the area were dredged, and canals were constructed between some lakes where no prior connection existed. In many cases,

structures were placed on lakes to maintain lake levels and control flooding. Prior to the 1970s, however, much of the land in northern Hillsborough, northern Pinellas, Pasco, and Hernando Counties was either agricultural, sparsely populated, or undeveloped land. In recent years, extensive urbanization has replaced much of the citrus and pasture land in northwest Hillsborough County and northern Pinellas County, while many parts of Pasco and Hernando Counties are becoming increasingly developed. Roadside ditches and swales have been constructed, and some canals have been excavated both from uplands (usually to connect lakes) and from the mouths of several rivers (i.e., Sweetwater and Rocky Creeks). Additionally, many existing agricultural ditches on rezoned residential property are retained as surface-water management systems.

Surface water management structures and alteration of drainage that have occurred as part of the land use alterations in the Northern Tampa Bay WRAP area. Drainage has been mostly limited to the construction of ditches, and in some case, control structures, for the purpose of either conveying water during high intensity rainfall events (to control flooding), or locally lowering the water table by providing nearby storage. Examples of the former type include Channels A and G located near Old Tampa Bay, the Hillsborough County Interceptor Canal near the Section 21 wellfield, the Tampa Bypass Canal in eastern Hillsborough County, and the Masaryktown Canal in southern Hernando County. These drainage projects were constructed to primarily alleviate flooding in coastal or somewhat internally drained areas, although in the case of Channels A and G, the ditches do provide some lowering of water tables due to their size and configuration (Corral and Thompson, 1988). An area containing an extensive canal network can experience cumulative adverse impacts on the water table. Several studies have been performed in southern Florida, where an extensive system of ditches has been installed since the turn of the century. These ditches were specifically designed to regionally drain much of the wetland system that once dominated southern Florida. Bays and Winchester (1986) assembled a summary of several of the drainage studies that have been performed in southern Florida. The studies show that the large canal networks have caused water-table levels to decline as much as two feet within a mile of the canals. Canals or ditches that transect natural ground-water divides in the surficial aquifer can also cause large water-table drawdowns.

Examples of the latter types of drainage projects, designed primarily for water conveyance or localized lowering of the water table, include the roadside swales and ditches found throughout the area, as well as much of the agricultural ditching. The primary purpose of such ditching is to remove water from below a roadbed or crop field by providing downgradient storage in ditches or ponds. Such facilities rarely have outfalls, although many may drain to lakes and/or wetlands. Therefore, although water is removed from one area, it usually remains in the ditches until it infiltrates to the water table or evaporates. Areas with this type of drainage can be subject to local impacts to surface features, depending on the ditching design, but usually remain quite wet because of the lack of offsite outfalls. Specific examples include the Cone Ranch property, the ditched property south of the Cypress Creek wellfield in central Pasco County (now owned by the SWFWMD), and numerous roadside swales in northwest Hillsborough County.

Drawdowns caused by ditches, either on a large or local scale, depend on many factors, including the horizontal hydraulic conductivity of the soil, head gradients in the water table, and the width, depth, and slope of the ditch. Although agricultural and residential/commercial drainage alterations have taken place within the Northern Tampa Bay area, effect of the ditches, canals, and swales on the water table are limited. Since the soils in much of the Northern Tampa Bay WRAP area have low horizontal hydraulic conductivity, and head gradients are relatively flat, the water-table lowering is localized. Natural drainage is so poor in many areas that it is often necessary to design an underdrain system for roadside swales to control the water table below the road base, with the swale providing conveyance and storage of the road bed drainage. Reported horizontal hydraulic conductivities range from 3 to 13 feet per day in the northwest Hillsborough County area, and from 7.5 to over 30 feet per day in Pasco County (SWFWMD, 1993a). The low hydraulic conductivities in this area are reflected by the low base-flow contributions from the water table to the streams throughout the area. Sands in the Brooksville Ridge area are more well-drained and may have higher hydraulic conductivities, so canals in this area may have a greater effect on the water table.

Several analytical methodologies are available to quantify drawdown caused by a ditch. One such method is the Dupuit-Forchheimer with Accretion equation. This steady-state equation is based on Darcy's law (Bear and Verruijt, 1987). This method assumes horizontal flow only,

so the slope of the topography near the ditch is assumed to be minimal. To calculate the distance away from a ditch from which drawdown in the water table will be zero, the equation is:

$$d = \frac{\sqrt{\frac{4K}{R} * H_m}}{2}$$

where:
- d = distance to zero drawdown (ft)
- R = annual effective rainfall (ft/day)
- K = hydraulic conductivity (ft/day)
- H_m = saturated aquifer thickness to be dewatered

As an example, for a 10 foot deep canal, with an effective rainfall of 0.003 ft/day (52 in/yr of precipitation minus 39 in/yr of evapotranspiration), and a soil with 10 feet/day hydraulic conductivity, the distance to zero drawdown would be 577 feet. Since a horizontal hydraulic conductivity of 10 feet/day represents the higher end of reported values in the northwest Hillsborough County area, actual drawdowns in the Northern Tampa Bay WRAP area would usually be lower. In addition, very few drainage ditches approach 10 feet in the urbanized sections of the study area.

Although drawdown from a single ditch has a limited area of influence, an area containing many ditches can experience cumulative effects on the water table. However, a large network of canals does not exist within the Northern Tampa Bay area, and therefore the hydrology is more locally effected. Data collected near Channels A, G, and H in Hillsborough County shows large effects on the water table within several hundred feet of each canal, depending on canal depth, hydraulic conductivity of the soil, and tidal influence. Drawdowns are minimal beyond 400 to 500 feet. Water-table data collected as part of a stormwater study near the Tampa Bypass Canal (Rushton and Dye, 1993) shows drawdown effects limited to a radius of 300 feet or less, although the canal is approximately 300 feet in width and up to 20 feet deep. Soils in the vicinity of the study have a high clay content, and therefore have a very low hydraulic conductivity.

A major canal can cause changes in the relationship between the surficial and Upper Floridan aquifers. In the case of the Tampa Bypass Canal, the layer of confinement between the two aquifers has been dredged away, so a connection occurs in areas where it previously did not exist. Knutilla and Corral (1984) state that in areas where the confining layer was removed, Upper Floridan aquifer potentiometric levels have lowered. In areas where the surficial water level was previously below the Upper Floridan aquifer water level, the lowering of the Upper Floridan aquifer water levels has caused greater induced recharge, and subsequent lowering of the water table. This effect is spatially variable, and measured water-table declines have been less than two feet in some areas very near the canal.

Several reports discuss the possibility of drainage impacts on lakes within the Section 21 wellfield (City of St. Petersburg, 1973; Palmer, 1988; Emery, 1992; Wiley, 1992; SWFWMD, 1995). The City of St. Petersburg's 1973 assessment, on which many subsequent reports have been based, contends that the construction of the Dale Mabry Highway, finalized in 1957, and the construction of the Northwest Hillsborough Interceptor Canal, finalized in 1960, are the cause of low lake levels experienced in Starvation, Simmons, Jackson, and Crum lakes. All of these lakes are located on the wellfield property (Figure 4-12).

Of all the lakes on the Section 21 wellfield, Starvation Lake is the most analyzed. Figure 4-12 presents the location of Starvation Lake, along with other surface-water features in the area. The figure also displays the approximate pre-development drainage basin of Starvation Lake. This delineation was determined by examining current USGS and SWFWMD topographical mapping for the area, USGS mapping from the 1940s, and field review of current drainage basins. Natural features, such as wetland conveyances, were examined to help determine the direction of surface flow before any of the man-made alterations were constructed. The area surrounding Starvation Lake is very flat, and was historically internally drained by several lakes and wetlands. These lakes and wetland areas were mostly isolated, but would become interconnected during periods of high rainfall. Although the watershed of the Starvation Lake is topographically defined as shown, the area is very flat and dotted with wetlands, so runoff from this area was probably very small. During flooding events, water levels could breach land contours and flow in many directions. However, it is likely that most of Starvation Lake's water inflow was, and still is, obtained by direct rainfall and groundwater contributions in the

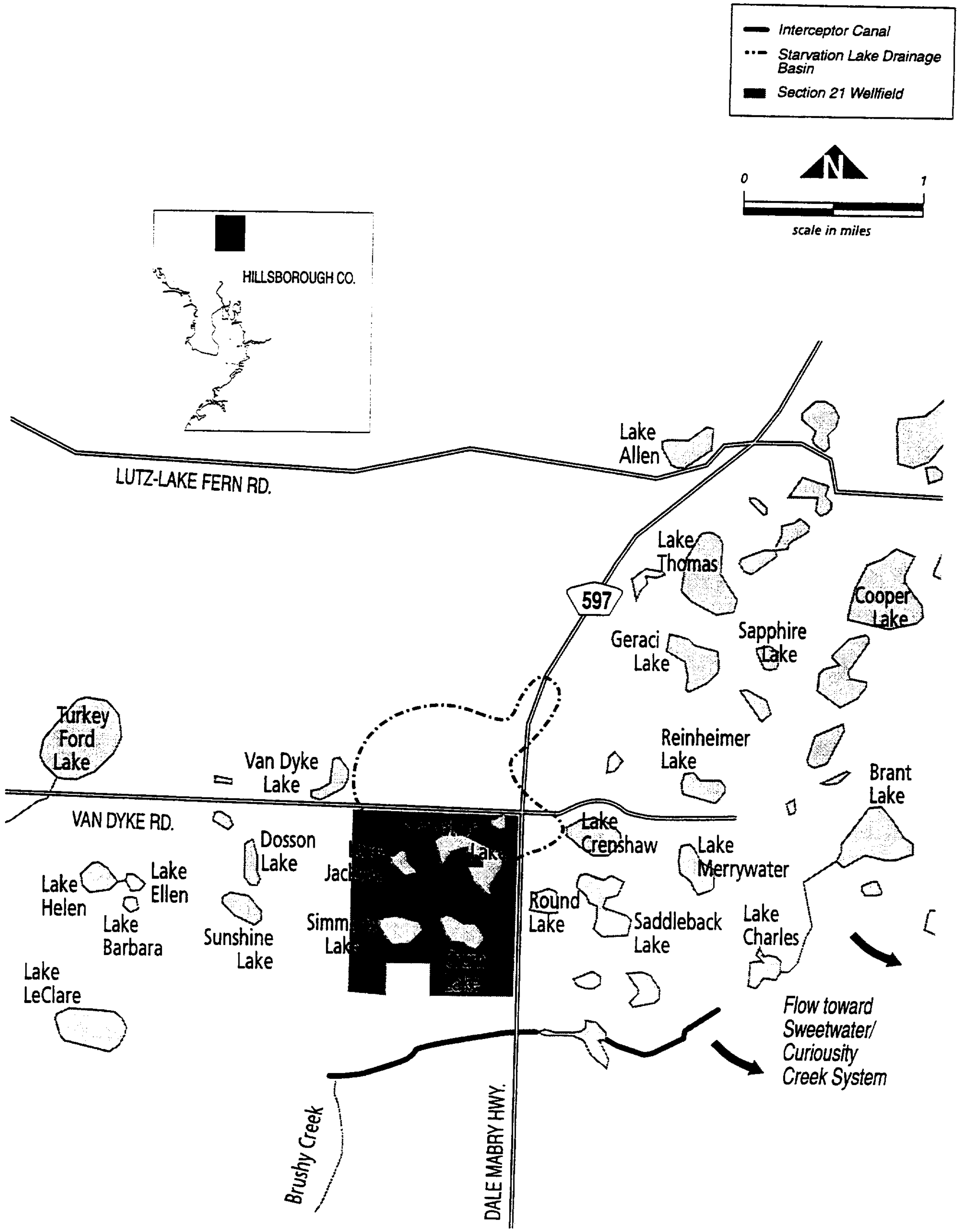


Figure 4-12. Pre-developed drainage basin of Starvation Lake.

immediately surrounding watershed area. Overflow from Starvation Lake would continue into the Brushy Creek system, flowing toward the southwest. Starvation Lake and the other Section 21 lakes are located in a depressional area, and it is possible that backflow from the Brushy Creek watershed could have occasionally flooded the area.

As can be seen from the figure, Dale Mabry Highway was constructed through the eastern portion of the Starvation Lake watershed, and Van Dyke Road was constructed through the northern portion. It is apparent that most of the flow to the area east of Dale Mabry Highway naturally flowed toward Crenshaw and Saddleback Lakes. The flow channels have since been enhanced by interconnecting canals. From the lakes, runoff could flow toward Curiosity and Sweetwater Creeks, or in higher events, overflow towards Brushy Creek south of Starvation Lake. The effect of the highway on surface-water flow is questionable, since no runoff or water level data is available prior to its construction. However, because the area is very flat, and because a bridge originally used as a cattle crossing was constructed along this stretch of highway, which allowed flowed surface-water flow to pass, reduction of runoff to Starvation Lake was probably negligible. Recent improvements to the highway added more culverts. The area to the north is also very flat, with several wetland areas providing storage, so surface drainage would also be expected to be minor. It is reported that culverts have existed under the Dale Mabry Highway since original construction, and more drainage improvements were performed in the early 1970s (City of St. Petersburg, 1973). However, lake levels continue to remain low. Concerns have been raised over the activities of recent urban development in the northern portion of the drainage basin, although no change in current lake levels is apparent in the Starvation Lake hydrograph.

Over the years, many lakes east of Starvation Lake were interconnected with canals, mostly for recreational or flood protection purposes. Because of the internally drained nature of this area, flooding was a problem to property owners who built homes on the shores of these lakes. During high rainfall events, water that did not infiltrate would flood the area, and overflow to either the Brushy/Rocky Creek system to the west or to the Sweetwater/Curiosity Creek system to the south. To alleviate this problem, Hillsborough County constructed the Interceptor Canal from Lake Heather and the other upstream interconnected lakes directly to Brushy Creek. The canal functioned to eliminate the bottleneck of flow from these lakes to the creek systems. Since

it appears that little to none of the area drained by the canal had previously been part of the Starvation Lake watershed, the canal had a negligible effect on overland flow to the lake. However, it is possible that the occasional backflow from Brushy Creek could have been reduced, and because of the elevation of the canal bottom, the possibility exists that some lowering of the water table could have affected Starvation Lake water levels.

Fortunately, some data are available from the period immediately following the construction of the canal. Figure 4-13 presents water level data from Starvation Lake, the Hillsborough 13 surficial aquifer monitor well, and the Hillsborough 13 Upper Floridan aquifer well, from 1950 to 1970. The land surface in the wellfield is approximately 55 to 56 feet NGVD, and the water levels of both Starvation Lake and the surficial aquifer ranged from two to four feet below the surrounding land surface throughout the early 1960s. Before the early 1960s, the Hillsborough 13 Upper Floridan aquifer monitor well recorded a relatively similar fluctuation five to 10 feet below land surface before approximately 1963. Until the advent of ground-water withdrawals from the wellfield, the water levels of the lake and Upper Floridan aquifer monitor well show no obvious trend. Therefore, although there is no water level data for the lake or the surficial aquifer monitor well before the Interceptor Canal was completed in 1960, Starvation Lake was consistently full, with little fluctuation for several years after the canal was constructed. These fluctuations are also consistent with existing biological indicators. Given the low hydraulic permeability of the soils in the Section 21 area, and the available water level data, the water table drawdown effect of the Interceptor Canal is limited to a radius much less than the mile between the canal and the lake. Therefore, the canal has had a minimal effect on the water levels of Starvation Lake.

Many other lakes in the area adjacent to the Section 21 wellfield have been augmented for some time, and therefore it is difficult to assess the impact of drainage on other lakes. Many of the non-augmented lakes in the area are interconnected with canals with control structures, which may help retain water in the lakes. Some non-augmented lakes have experienced low water levels, but are not near significant drainage alterations. Therefore, other drainage impacts in the Section 21 wellfield area are not obvious.

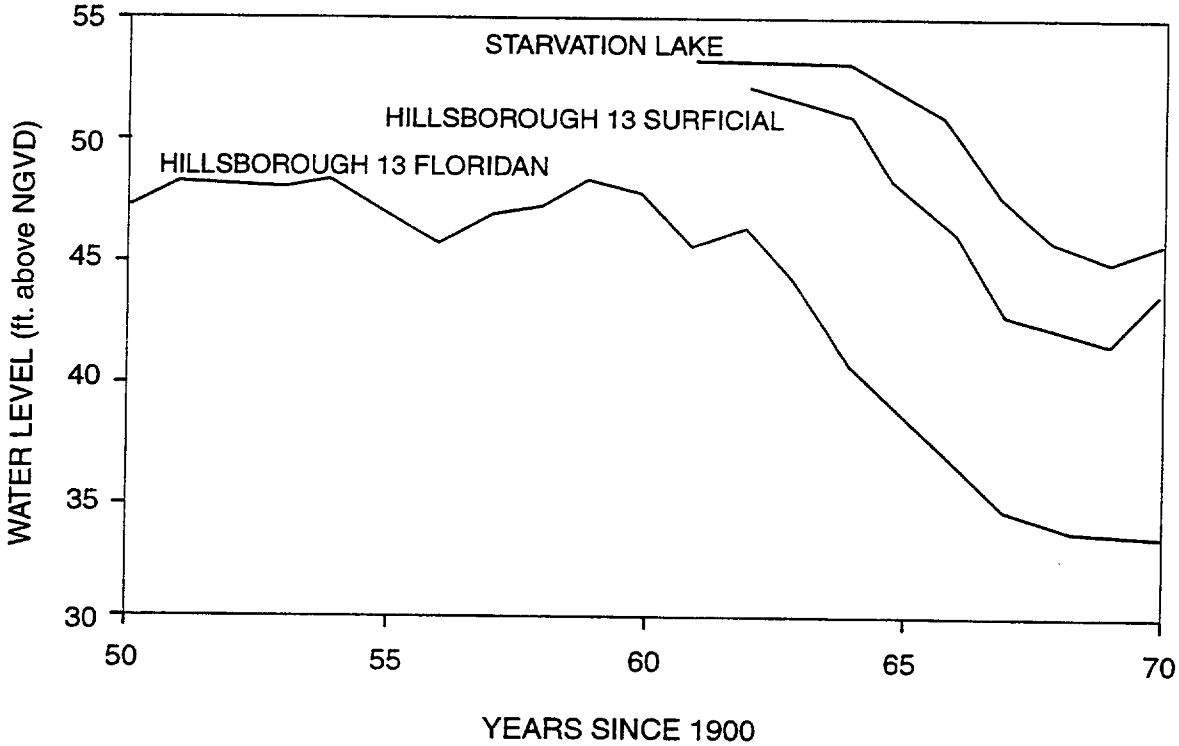


Figure 4-13. Water-level data within the Section 21 wellfield.

Ditching and development effects near other wellfields have also been investigated. Emery (1992) performed a site inspection and a historical aerial survey of the area surrounding the Cosme-Odessa wellfield. He found no significant differences from the 1948 to the 1991 aerial photos, and concluded that compared to the Section 21 wellfield area, the Cosme-Odessa wellfield area was relatively free from major developments and drainage alterations. Some smaller drainage alterations are noted by both Emery and Wiley (1992). Although water level impacts caused by drainage alterations in the Cosme-Odessa wellfield appear to be very limited, observed lowered lake levels in the area of the Cosme-Odessa wellfield are some of the most documented and severe in the Hillsborough County. Such lakes include Lake Rogers and Lake Raleigh, located on or immediately adjacent to the wellfield.

The land encompassing the Cross Bar Ranch and Cypress Creek wellfields has been used either currently (in the case of Cross Bar Ranch) or in the past (Cypress Creek) for cattle operations. Some drainage alterations have occurred in conjunction with these operations. While the land on either wellfield has not been extensively drained, the Cross Bar Ranch wellfield property does have some agricultural ditching. Some of the property surrounding these wellfields does contain some significant ditching. Two such areas include the Polk Ranch property to the immediate north of the Cypress Creek wellfield, and the SWFWMD-owned land to the south of the Cypress Creek wellfield. The Polk Ranch property continues to be operated as a cattle and sod operation, and includes an extensive ditch system designed to control the water table in the areas of agricultural operation. The lowered water table was a subject of debate in the 1980s, as a complaint was raised by the property owner claiming impacts from the nearby Cypress Creek wellfield. Although the Cross Bar Ranch wellfield is also located nearby, ground-water withdrawal amounts from this wellfield had not yet reached the levels occurring today. Heaney and others (1986) assessed the impacts of the Cypress Creek wellfield, and concluded that although lowered water level impacts were clear within a limited area surrounding the wellfield, the extensive ditching effort on the Polk property (referred to as the Oakes Pond watershed in the report) made differentiating between the effects of ground-water withdrawals and drainage impossible on the Polk property. However, it was also stated that impacts caused by the ditching on the Polk property do not have a major impact to other areas within the Cypress Creek watershed due to their more localized nature.

A portion of the Cypress Creek watershed south of the Cypress Creek wellfield property is also extensively ditched. This property was acquired by the SWFWMD as part of the Save Our Rivers land acquisition program. The ditching occurred prior to the SWFWMD acquisition as a part of citrus and cattle operations, as well as land preparation for a once-proposed residential development. This property, however, contains much less naturally drained soils, and although extensively ditched, is consistently wet. Although some wetlands have been impacted by rim ditching, the ditches are full of water throughout most of the year, and adjacent the water table is mostly maintained from preexisting condiitons. Therefore, because the ditching in this area was designed with little to no outfall, water has been maintained on site, and the impacts to the overall hydrology of the area has been minimized.

Various levels of ditching occur throughout the Northern Tampa Bay area. Although some localized areas of extensive ditching have been chronically dry, with extensive impacts to water resource systems observed, other factors are also involved. Some areas with extensive ditching, such as the Bexley property located east of the Starkey wellfield, or the Cone Ranch property located in the northeast corner of Hillsborough County, are very wet, with ditches and wetlands consistently inundated or operating within natural hydroperiods. Conversely, other areas, such as the central Starkey wellfield area, the Eldridge-Wilde wellfield area, the Cypress Creek property, or the Cross Bar Ranch property, which have much less extensive or no ditching, are showing severe water resource impacts. In some areas in the Northwest Hillsborough Linear wellfield area, which is the most highly urbanized wellfield area in the Northern Tampa Bay area, some drainage alterations have actually provided benefits to previously impacted wetlands by diverting runoff into these systems. Thus, impacts of drainage on individual wetlands can be positive, negative, or neutral, depending on the specifics of the site.

Besides ditching, another parameter potentially affecting the water table in parts of the Northern Tampa Bay WRAP area is the increase of impervious area. As residential and commercial developments increase the amount of paved and compacted land surface, local recharge to the water table may decrease. Current design regulations of surface-water management systems require the utilization of retention ponds, which provide areas of some surface-water recharge in urban areas. The storage volumes and soil percolation rates are low, however, and much of the surface water that is stored throughout the area is lost to evaporation and runoff. As

described in Section 4.1.1, significant increases in the flow rate of Rocky Creek may be due to the increases in urbanization (i.e. increases in impervious area) and wastewater discharges within the watershed. However, an assessment of urban effects by Law Environmental, Inc. (1994) found that stormwater retention has probably increased ground-water recharge, although possibly in areas different than it occurred naturally. If urbanization increases to the levels forecast by future land use maps of the various county comprehensive planning documents, loss of recharge to the water table may be very significant. However, current effects on recharge to the Upper Floridan aquifer due to land use alterations are probably limited to within the urbanized sections of the Northern Tampa Bay WRAP area, since most of the area experiences moderate natural Upper Floridan aquifer recharge.

Drainage alterations in the Northern Tampa Bay area are limited to localized areas. In an attempt to evaluate effects of drainage, Law Environmental, Inc. (1994) performed a baseflow analysis and a comparison of SCS runoff curve numbers to estimate changes in runoff due to changes in land use. The assessment was not able to detect significant differences between current and predevelopment curve numbers for the Rocky Creek and Brooker Creek drainage basins.

Impacts to surface-water systems may be caused directly or indirectly by several other processes associated with urban development within the Northern Tampa Bay WRAP area. Such parameters include water-quality degradation, control structures, culverts, greater access by domestic animals and humans, and illegal dumping. The degree of impact caused by these sources is not regional, but can be highly significant in specific areas.

Ground-Water Withdrawals

Ground-water withdrawals have a direct impact on water levels of the Upper Floridan aquifer. While the effects of rainfall, evapotranspiration, and surface-water hydrologic components are buffered by the semi-confining layer, ground-water withdrawals directly remove water from the Upper Floridan aquifer system. While small amounts of water are withdrawn directly from the surficial aquifer in the Northern Tampa Bay area, when compared to Upper Floridan aquifer withdrawals, it is insignificant. However, the leaky nature of the semi-confining layer

throughout the Northern Tampa Bay WRAP area allows ground-water withdrawals from the Upper Floridan aquifer to affect surficial aquifer water levels. The effects are greatest in areas of significant karst and sinkhole activity, including many of the surface-water features throughout the Northern Tampa Bay WRAP area.

Lohman (1972) explains that aquifers in the predevelopment state (i.e., before man began removing water from the system) are in a condition of "dynamic equilibrium". For the long-term, the amount of discharge from the aquifer system equals the amount of recharge. As a result, water levels in the aquifer fluctuate around a constant average level. If water is removed from the system (i.e. by pumping wells), a new dynamic equilibrium can not be reached unless one of the following is achieved; 1) recharge is increased (either naturally or artificially); 2) natural discharge is decreased; or 3) a combination of both. Simply stated, a removal of ground water by pumping is regained by a loss of water somewhere else: either from another aquifer (induced recharge), lateral movement, or storage.

Within the Northern Tampa Bay WRAP area, evidence shows that ground-water withdrawals are impacting both recharge and discharge, although in varying degrees spatially. Recharge has increased throughout the region, although increases are limited locally by confinement and amount of ground-water withdrawals. Evidence of decreased discharge from some coastal springs (see Chapter 3) indicates that some localized lateral discharge has decreased, but little evidence of a significant decrease in regional discharge exists. Finally, the decreasing trend of the potentiometric surface in subregional areas shows that water in storage is being lost.

This concept is demonstrated in Figure 4-14. When ground-water withdrawals occur, a cone of depression develops around the well. This cone will increase in size until the amount of water entering the cone equals the amount of water withdrawn. If the aquifer is infinite in areal extent and leakage is the sole source of recharge, ground-water withdrawals in an area of low leakage will affect water levels over a greater area than a well in an area of high leakage. If the source of recharge in the area of high leakage becomes depleted, or decreases due to low rainfall, the cone will expand until leakage over the cone of influence equals the ground-water withdrawal rate.

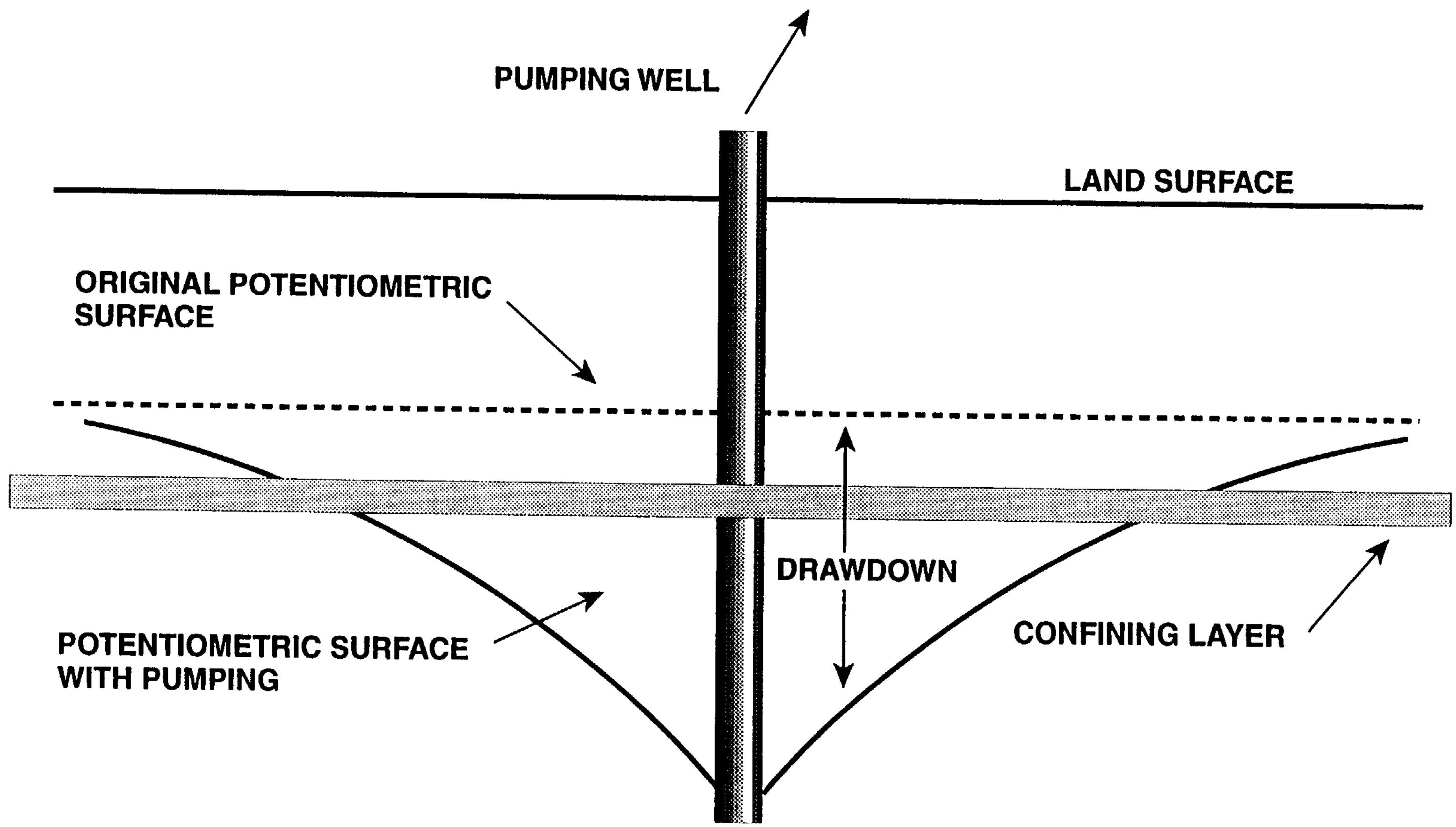


Figure 4-14. Schematic of drawdown in an Upper Floridan aquifer well.

A comparison of long-term declines in the Upper Floridan aquifer levels between the Northern Tampa Bay WRAP area and the Eastern Tampa Bay Water Use Caution Area (WUCA) (SWFWMD, 1993c) demonstrates this point. The Eastern Tampa Bay WUCA encompasses an area of 1,320 square miles, compared to an area of 1,800 square-miles in the Northern Tampa Bay WRAP area. Although the Northern Tampa Bay WRAP area is almost 500 square miles larger, much of the public supply withdrawal is located within a smaller area (Figure 2-32). Ground-water use for the Eastern Tampa Bay WUCA for 1990 is estimated to be 206 mgd, while 1990 estimated ground-water use within the Northern Tampa Bay WRAP area is estimated to be 248 mgd. Therefore, water use per unit area is similar between the Northern Tampa Bay WRAP area and Eastern Tampa Bay WUCA (approximately 0.14 mgd per square mile and 0.16 mgd per square mile, respectively).

Figure 4-15 presents the decline in annual-average water levels from predevelopment to 1991 for the entire SWFWMD. This map was derived by subtracting potentiometric surfaces derived by the USGS for predevelopment and the annual-average potentiometric surface for 1991. Because the set of wells and interpolation techniques used to determine the pre-development and post-development potentiometric maps have differed significantly, the declines often differ from what is expected. For this reason, and because of the scale of the map, local drawdowns do not always appear in the locations expected, particularly in the Northern Tampa Bay region, but the map demonstrates the local and regional extent of Upper Floridan aquifer drawdowns. An inspection of Figure 4-15 shows that drawdowns in the Eastern Tampa Bay WUCA are as much as 50 feet in a large portion of the project area. Within the Northern Tampa Bay WRAP area, maximum drawdowns are typically less than 20 feet in more localized areas. Cones of depression in Eastern Tampa Bay must expand to a regional size to equilibrate. With time, the growth of these depressions have overlapped, creating a regional drawdown.

Unlike the Upper Floridan aquifer drawdown in the Eastern Tampa Bay area, drawdowns in the Northern Tampa Bay WRAP area exist as several individual cones of depression because the confining layer is leaky enough to prevent the cones of depression from withdrawals to expand over the entire region. However, overlapping cones of depression in areas of concentrated ground-water withdrawals have created subregional areas of drawdown. Additionally, during periods of low rainfall, and as the surficial aquifer water levels decline, these cones of

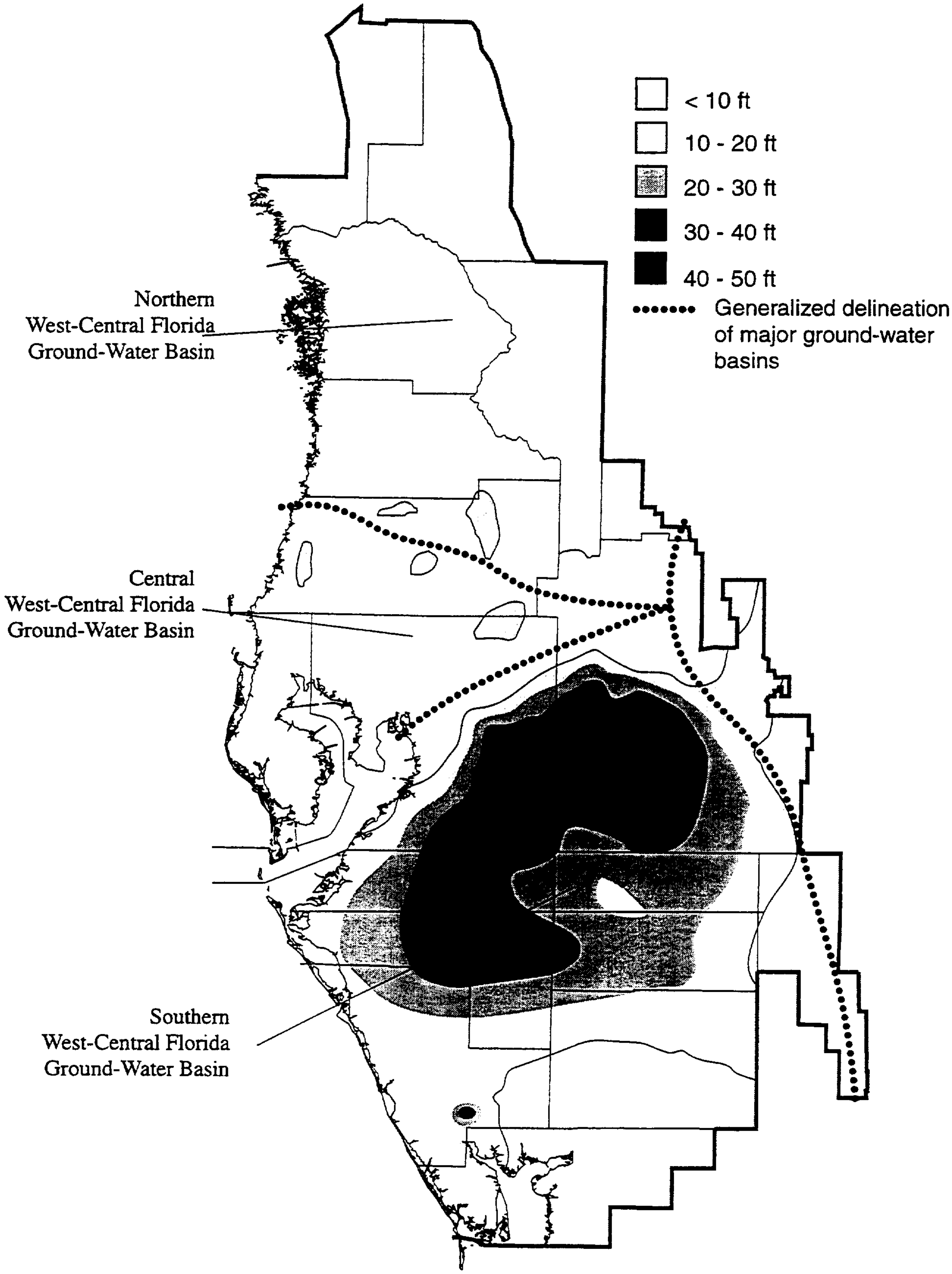


Figure 4-15. Potentiometric surface declines of the Upper Floridan aquifer as the difference between predevelopment and the 1991 annual-average surface.

depression have expanded. Although existing Upper Floridan aquifer drawdowns in the Cypress Creek wellfield area have had little to no impact on water levels in the areas of the Section 21 and Cosme wellfields, overlap of these two subregional cones of depression could occur with increasing withdrawal rates.

As stated by Lohman (1972), an aquifer system must acquire water from some source to balance ground-water withdrawals. In the Eastern Tampa Bay WUCA, this water source is limited to storage losses and decreased aquifer discharge at the coast. Increased recharge also occurs, although thick confinement in the area limits induced recharge from the water table. In the Northern Tampa Bay area, limited drawdowns in the Upper Floridan aquifer suggest that water-level declines are being attenuated by a vertical source of water, and loss of Upper Floridan aquifer storage is much less than in the Eastern Tampa Bay area. Little evidence is available that suggests coastal discharge has decreased regionally in the Northern Tampa Bay area. The discontinuous nature of the confining layer in the Northern Tampa Bay area allows induced recharge from the surficial aquifer to become a major source of water. This water source is attained through 1) increased recharge derived from loss of storage in the surficial aquifer; 2) a probable reduction in evapotranspiration, and 3) some decrease in baseflow to streams and runoff. Because Upper Floridan aquifer drawdowns in the Northern Tampa Bay area are much less than those of the Eastern Tampa Bay area, despite lower transmissivities in the Northern Tampa Bay area, the source of water that attenuates water-level decline in the Upper Floridan aquifer in the Northern Tampa Bay area must be from these three sources.

The relationship between ground-water withdrawals and water levels can be described as both a short- and long-term phenomenon. The large fluctuations in the hydrographs of Northern Tampa Bay WRAP area monitor wells generally represent the short-term effects of seasonal water use and climatic conditions. When ground-water withdrawals are seasonally decreased or stopped, the Upper Floridan aquifer water levels attempt to return to the equilibrium levels experienced prior to ground-water development. Because much of the water use in the Northern Tampa Bay WRAP area is for public supply, seasonal fluctuations in ground-water use throughout much of the study area are generally much smaller than those of agricultural areas. The fluctuations are therefore due primarily to changes in atmospheric conditions, such as high or low rainfall periods.

The natural long-term fluctuation of Upper Floridan aquifer water levels depends on the hydrogeologic properties of the local system, but the long-term change in fluctuations depends on the amount of Upper Floridan aquifer water locally withdrawn. Relatively continuous ground-water withdrawals lower the average water levels. Rainfall, however, continues independently. Because of the high leakage, recharge from rainfall events enters the Upper Floridan aquifer relatively quickly, and causes the lowered water level to quickly rebound. When the rainfall event stops (or is greatly diminished), the water levels quickly decline to the lower level. Thus, although ground-water withdrawals create an overall lowering of the ground-water levels, rainfall continues to periodically raise these levels, and the amplitude of the hydrograph increases. As water use continues to increase throughout the region, the amplitude of the short-term drawdowns will increase. This process is seen in many of the Upper Floridan aquifer hydrographs presented in Chapter 3, and is also seen in several surficial aquifer and surface-water hydrographs in areas of discontinuous confinement.

Assuming that all other components of the hydrologic cycle remain similar to predevelopment conditions, water levels in the Upper Floridan aquifer would eventually return to near predevelopment levels if all ground-water withdrawals were to cease. This was demonstrated when a temporary shut down of the Section 21 wellfield occurred in October 1975. Potentiometric levels rose to within two feet of the levels prior to the start-up of the wellfield (1963) within just five days (Oleson, 1985). Levels in the surficial aquifer would eventually increase, although there would be a lag time.

A new equilibrium may eventually be achieved if ground-water withdrawals and atmospheric conditions were to remain constant. However, the new equilibrium would be, as is explained by Lohman, at the expense of another water source (recharge or discharge). Since recharge for the Upper Floridan aquifer is derived almost exclusively from the surficial aquifer and surface-water features within the Northern Tampa Bay WRAP area, an increase in Upper Floridan aquifer recharge is reflected as loss of storage in the water table. In localized areas where the ground-water withdrawals exceed recharge, the system may not reach a new dynamic equilibrium until storage in the surficial aquifer is depleted.

Another concept important to the hydrogeologic system in the Northern Tampa Bay area is that more than fifty percent of the ground-water withdrawn in the area is by regional public supply wellfields, which supply water to coastal communities. The water is withdrawn from concentrated inland areas, used for various purposes, and then is discharged to coastal streams, the Gulf of Mexico, or, in some cases, injected to deep, non-potable aquifers in Pinellas County. Reuse irrigation systems have been in place in some areas for many years (particularly in the City of St. Petersburg), however, most of the reuse water has historically been reapplied to the ground in coastal communities, rather than to the inland area where the water was originally withdrawn. Therefore, essentially all of the water that is withdrawn from the regional wellfields is not returned as recharge to the areas of withdrawal. Most other users, including many smaller public supply withdrawals, use the water in the immediate vicinity of the withdrawal point, and the water is returned to the ground-water system as irrigation or wastewater percolation. While there are losses, the water has the potential to return to the surficial and Floridan aquifer systems with these local uses, while regional wellfield water use does not. Recent programs have begun to bring reuse water to inland areas, but currently these volumes are small compared to regional coastal discharges. However, even smaller scale transfers of water, such as from one side of a city to another, do not necessarily allow for the recharge of water back to the local system where it was originally withdrawn.

The following section summarizes past research that has attempted to establish and quantify these surface- and ground-water relationships within the Northern Tampa Bay area. Also presented are local and regional analysis performed during the course of this study.

4.3 Localized and Regional Analysis

Although the objective of the Northern Tampa Bay WRAP is to provide background on hydrologic relationships on a regional basis, local hydrologic relationships must also be addressed to document case studies of cause and effect. One important step in this process is a review of the many analyses that have been performed previously and during the course of the Northern Tampa Bay WRAP.

4.3.1 Previous Analysis

Many studies have been performed in the past which assess the cause-and-effect relationship between impacts to surface-water features and ground-water withdrawals in the Northern Tampa Bay area. Stewart (1968) prepared one of the earliest comprehensive reports on surface/ground-water interaction in the Northern Tampa Bay area. By analyzing hydrographs and other data collected in the area, Stewart assessed the effects to various surface-water features from ground-water withdrawals. Wetlands were not specifically addressed, although lakes and water-table fluctuations were analyzed. Stewart determined that several of these features were affected by Upper Floridan aquifer ground-water withdrawals. George Aase and Associates, Inc. (1965, 1968) reviewed all previous work performed in the Northern Tampa Bay area and performed separate analyses on the ground-water/surface-water interactions of the area. Through the use of statistical methods, stage-duration curves, and various data, they demonstrated the connection between Upper Floridan aquifer drawdowns and lakes, sinkholes, and surficial aquifer water levels. William F. Guyton and Associates (1974, 1975) provided a review of cause-and-effect relationships within Pasco County using geologic and hydrograph data, and confirmed the relationship between lowered Upper Floridan aquifer water levels and impacts to surficial features. Through the use of water budgets and other tools, Geraghty and Miller, Inc. (1976) performed a regional assessment of surface/ground-water interactions as part of a regional water resources management plan, and verified the previously defined relationships. Several regional and sub-regional ground-water flow models have been constructed in the Northern Tampa Bay area to help determine the relationship between the various hydrologic parameters (Ryder, 1978; Hutchinson and others, 1981; Hutchinson, 1984a; Bengtsson, 1987; Fretwell, 1988; SWFWMD, 1993a; Law Environmental, 1994; SDI Environmental Services, Inc. and Reynold, Smith and Hills, Inc., 1995, ERM-South, Inc., 1995).

The main focus of most of the earlier references was the effects of ground-water withdrawals on lakes. Stewart (1968) and William F. Guyton and Associates (1974) identified factors influencing lake-level decline, including ground-water withdrawals, atmospheric conditions, and drainage. George Aase and Associates, Inc. (1968) provided a positive correlation analysis between lake levels and ground-water withdrawals. Stewart and Hughes (1974) studied Section 21 wellfield withdrawal effects and augmentation of surrounding lakes. Stewart and Hughes

expressed concern that increased leakage through the lake bottoms may increase the rate of limestone dissolution, causing lakes to eventually be lost. Several reports have been written to analyze the hydrology of specific lakes, and discuss the lake's relationship with ground-water levels (Corral and Thompson, 1988; Henderson, 1986; Reichenbaugh, 1977; Hunn and Reichenbaugh, 1972; Hunn, 1974; Sinclair, 1974, 1977, 1982; Stewart and Mills, 1984; Henderson and others, 1985). Camp, Dresser and McKee, Inc. (1985) performed a water budget to calculate induced seepage at the Section 21 wellfield. Extensive hydrologic data was collected during an approximate 40 day period of zero withdrawal at the wellfield, followed by a period of withdrawal at 7.5 mgd. Through use of a water-budget analysis, lake and water-table effects were calculated. Measurable increases in lake and water-table seepage were induced during the period of ground-water withdrawals within a two to three mile radius, and, depending on proximity to withdrawals, between 33 and 63 percent of the lake water-level drawdowns were determined to be attributed to ground-water withdrawals. Extrapolated lake water-level drawdowns from the data show reasonable agreement with SWFWMD regulatory model predictions, while extrapolated water-table drawdown was greater than model predictions. More recently, Lopez and Fretwell (1992) used multiple linear-regression analysis to determine the impact of wellfield withdrawal at lakes and water-table monitor wells in northwest Hillsborough County. They produced regression relations that can be used to evaluate the effect of changing rainfall or withdrawal rates on water levels. They concluded that although rainfall clearly has an effect on lake levels, the closer a lake or water-table monitor well is to a wellfield, the greater the influence of ground-water withdrawal on water levels.

Reductions in stream flow from ground-water withdrawals were reported beginning in the early 1970s. Cherry and others (1970) compared two periods of streamflow in Brooker Creek and the Anclote River, 1951 through 1958 and 1959 through 1966. During the first period, the average annual rainfall was 49 inches, while the average annual rainfall for the second period was 59 inches. Although rainfall was greater during the second period, the annual-average Upper Floridan aquifer withdrawals had almost tripled beginning in 1958 (increasing from about 13 mgd to 34 mgd). The study demonstrated that both Brooker Creek and Anclote River had more low flow days during the period of high rainfall and increased ground-water withdrawals. Similar analysis performed on the low flows of two other rivers in areas of much less ground-water withdrawal (the Hillsborough River near Zephyrhills and the Withlacoochee River near

Holder) showed fewer low flows during the higher rainfall period. The SWFWMD (1987b) presented a similar analysis comparing streamflow at Brooker Creek with rainfall for the periods of 1951 through 1961 and 1973 through 1982. Monthly streamflow averages were used for this analysis. The results showed that a significant reduction in streamflow (32 percent) occurred in the latter period compared to the former, even though rainfall amounts were similar. Similar effects on the Anclote River and Brooker Creek systems were reported by Parker (1975) and SWFWMD (1984). Hernandez and Parker (1974) used double mass curves to demonstrate ground-water effects on Brooker Creek, and attributed lowered flows in the headwaters of the creek to regional wellfield ground-water withdrawals.

Stewart (1977) attempted to measure flow effects on the Hillsborough River by pumping from a nearby sinkhole, but did not find any measurable effects due to the variable nature of river flow. Ryder and others (1980) used a numerical model to simulate ground-water withdrawals at the Morris Bridge wellfield. Using a withdrawal rate of 40 mgd, Ryder found that only 10 percent of the water pumped was derived from the Hillsborough River when the river was completely connected to the surficial aquifer. Ryder acknowledged that the streambed leakance coefficient is the least understood parameter in the model. Wolansky and Thompson (1987) performed an aquifer test and analytical computations near the Hillsborough River, and determined that ground-water withdrawals could have negligible to significant effects on the river's flow, depending on streambed leakance coefficients. Heaney and others (1986) performed a water-budget analysis at the Cypress Creek wellfield in central Pasco County to determine ground-water withdrawal effects on streamflow and water-table elevations. Results showed that although declining streamflow was evident within the wellfield, effects on streamflow beyond the wellfield were difficult to determine. Recently, Fernandez (1990) performed statistical regression analysis on flow at the Anclote River to attempt to determine the impact of ground-water withdrawals from regional wellfields on river flow. The study used a multivariate analysis with rainfall, potential evapotranspiration, streamflow, and ground-water withdrawals from the Section 21, Eldridge Wilde, South Pasco, and Starkey wellfields. A statistical relation between annual or monthly streamflow and annual or monthly individual wellfield ground-water withdrawals could not be established, but a direct relation could be established between increasing regional wellfield withdrawals and decreasing annual streamflow.

The study does not answer the question about which wellfields to include in a regional analysis for any particular watershed.

Evidence of ground-water withdrawal effects on wetland conditions have been documented in studies on environmental conditions in and around several Northern Tampa Bay area wellfields. Those wellfields with the more extensive wetland monitoring include the Eldridge-Wilde, Starkey, Cypress Creek, and Morris Bridge wellfields. Biological investigations in and around the Eldridge-Wilde wellfield documented a number of instances of muck shrinkage, leaning trees, invasion of terrestrial plants, and fire (Courser, 1972, 1973; Black, Crow, and Eidsness, Inc., 1974). Aerial photographic investigations have shown that degradation of isolated wetlands has occurred in the wellfield during the time frame of intensive wellfield pumping. Rochow (1994) provides a summary of wetland analysis performed throughout the Northern Tampa Bay area, which shows significant impacts to wetlands within older wellfields, and increasing impacts to wetlands within newer wellfields. Rochow also summarizes correlation work that was performed to relate measured impacts to wetlands with predicted water-table drawdowns in regulatory stress-type models. The results substantiate the current SWFWMD presumption of adverse impacts to wetlands, which assumes wetland impacts will occur within areas of one foot or greater drawdown in modeled water tables. Rochow warns, however, that areas with less than one foot of predicted water-table drawdown may still experience significant impacts to water levels and biological health over time.

It has become evident throughout the study of the Northern Tampa Bay area that geology plays an important, if not dominating, role in the relationship between Upper Floridan aquifer water levels and surficial features. George Aase and Associates, Inc. (1968) were one of the first to stress the importance of these localized geologic conditions on determining the level of impact any particular surficial feature will experience from ground-water withdrawals in the Upper Floridan aquifer. Similar discussions are included in Sinclair's work (1974, 1977, 1982). Stewart and Hughes (1974) examined the effects of augmentation on lakes near the Section 21 wellfield, and expressed concern over the effects of limestone dissolution of the underlying aquifer.

4.3.2 Local Analysis

Because the leakance coefficient of the confining layer in the Northern Tampa Bay area is largely controlled by conduits formed by localized solution features, drawdowns in the Upper Floridan aquifer are often reflected as localized effects to the surface-water system. Depending on the magnitude of the Upper Floridan aquifer drawdowns and the proximity of other ground-water withdrawal points, these effects can become subregional in scope. As discussed previously, evidence of local cause-and-effect relationships in the data is also complicated by other factors, including lake augmentation, localized anomalies in geology, varying spatial rainfall patterns, and surface-water drainage alterations. Nonetheless, the localized nature of surface-water effects is reflected in the data.

The Cosme-Odessa and Section 21 wellfields in northwest Hillsborough County provide excellent examples of long-term data for the surficial aquifer, the Upper Floridan aquifer, rainfall, and local ground-water withdrawals. Figure 4-16 illustrates the relationship of Upper Floridan aquifer ground-water withdrawals on the hydrology of the Cosme-Odessa wellfield. The Lake Rogers and Cosme-Odessa Monitor Well No. 7 data were presented earlier in Chapter 3. Water levels in the monitor well do not pre-date ground-water withdrawals at the wellfield, but withdrawal quantities were relatively low in the early period of withdrawal. As withdrawals increased with time, levels in both the lake and the monitor well decreased. Although the levels in the Upper Floridan aquifer monitor well appear to respond rather quickly to changes in ground-water withdrawals, Lake Rogers does not appear to respond as quickly, and at times, responds little. During the mid-1950s to the mid-1980s, sludge discharge from the water treatment plant near Cosme provided an average of approximately 500,000 gallons per day of surface water to the Lake Roger's basin (Voakes, 1993). This was calculated to be approximately 22 inches to the basin, which also includes Horse and Raleigh lakes, or about 53 inches to the three lakes alone. These lakes received a significant amount of augmentation, and therefore did not react directly to changes in the Upper Floridan aquifer. However, with the cessation of augmentation in the mid-1980s, as well as a period of low rainfall, the level in Lake Rogers dropped significantly.

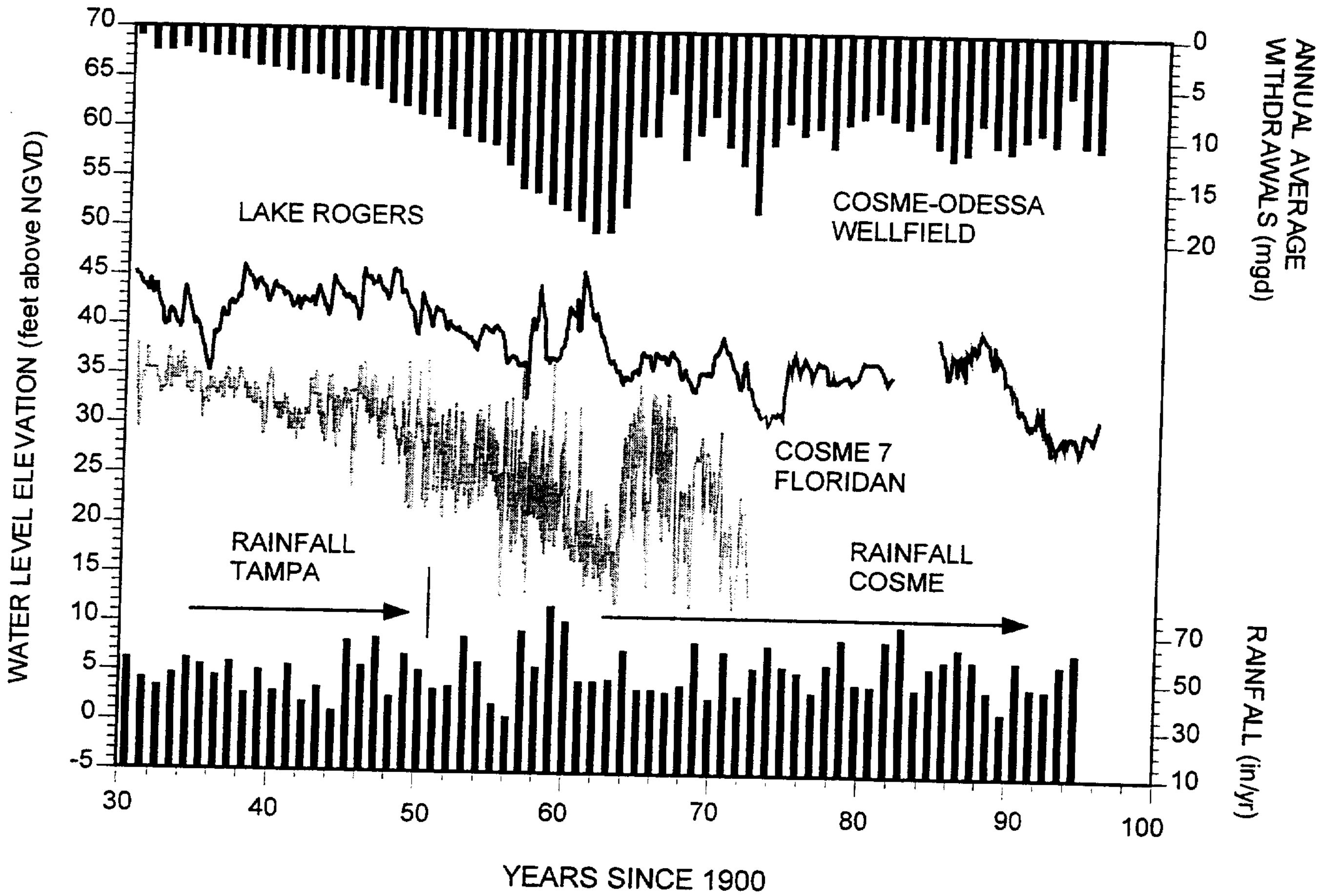


Figure 4-16. Ground-water withdrawal, water levels and rainfall at the Cosme-Odessa wellfield. (rainfall from Tampa and Cosme stations)

Similarly, Figure 4-17 illustrates the relationship of Upper Floridan aquifer ground-water withdrawals on the hydrology of the Section 21 wellfield. The Starvation Lake and Hillsborough 13 Upper Floridan aquifer monitor well data were presented earlier in Chapter 3. Water levels in the Hillsborough 13 Upper Floridan aquifer monitor well were relatively stable prior to the early 1960s, with a three to four foot seasonal variation. Likewise, Starvation Lake water levels were also very stable prior to 1963, with a seasonal fluctuation of one to two feet. A slight decline of one or two feet is apparent in the water levels in the early 1960s before the advent of Section 21 withdrawals, which coincides with the peak withdrawal period of the Cosme-Odessa wellfield (Figure 4-16), located less than five miles to the west. Water levels in the area declined sharply upon initiation of ground-water withdrawals from the wellfield in 1963. As withdrawals intensified in the mid-1960s, the levels of Starvation Lake and the Upper Floridan aquifer at the Hillsborough 13 Deep well declined significantly. Upper Floridan aquifer water-levels declined from about 47 feet above NGVD in 1963 to 29 feet above NGVD in 1974. Starvation Lake declined from about 51 feet above NGVD in 1966 to 42 feet above NGVD in 1973. From about 1966 to 1982, the City of St. Petersburg augmented Starvation Lake periodically from a wellfield collection main blowoff valve (Voakes, 1992). Augmentation did not occur regularly, however, and was reported to occur only during extremely dry periods. No augmentation has occurred since 1982. Since no quantification is available, the effect on Lake Starvation levels is unclear, although since augmentation was only periodic, little apparent effect is seen in the hydrograph. In the mid-1970s, withdrawals from the wellfield were cut in half from 18 mgd to 9 mgd. The effect of reducing withdrawals is strongly evident as water levels recovered to higher elevations, though not to prepumping levels. Upper Floridan aquifer levels recovered to about 35 feet above NGVD in the 1980s.

Another way of observing long-term trends at the Hillsborough 13 well is to compare the levels with another long-term well in an area more remote from ground-water withdrawals but in an area of similar hydrogeology. Figure 4-18 presents Upper Floridan aquifer levels at the Hillsborough 13 well with those at the Pasco 13 well, located in central Pasco County (Figure 3-36). Although the elevations of the two wells should differ due to the change in potentiometric surface between the two, it is obvious that the fluctuation and overall behavior of the water levels is very similar in the early period of record. With the advent of ground-water withdrawals in the early 1960s at the Section 21 wellfield, the normalized water levels and

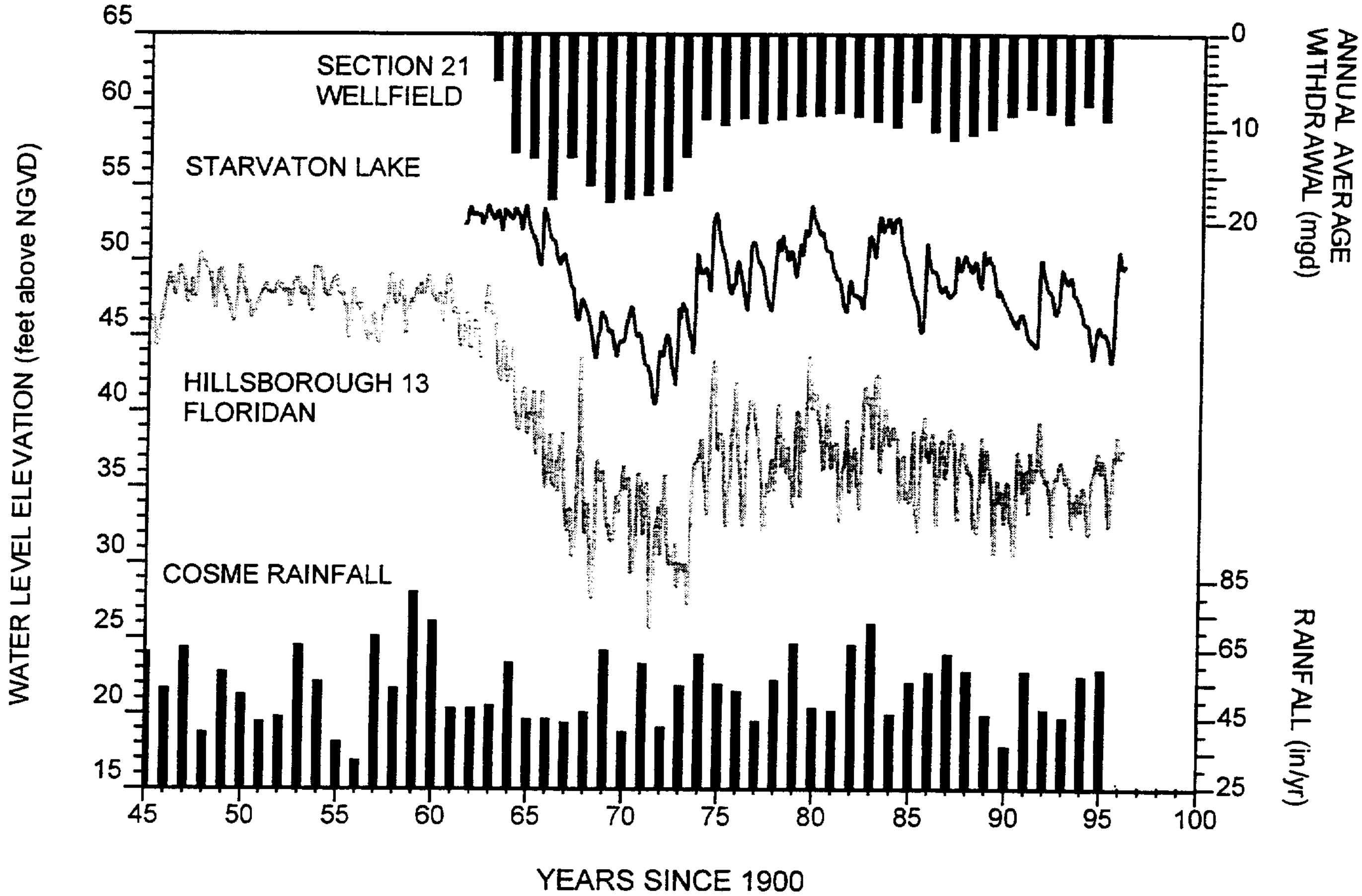


Figure 4-17. Ground-water withdrawal, water levels, and rainfall at the Section 21 wellfield. (rainfall from the Cosme station)

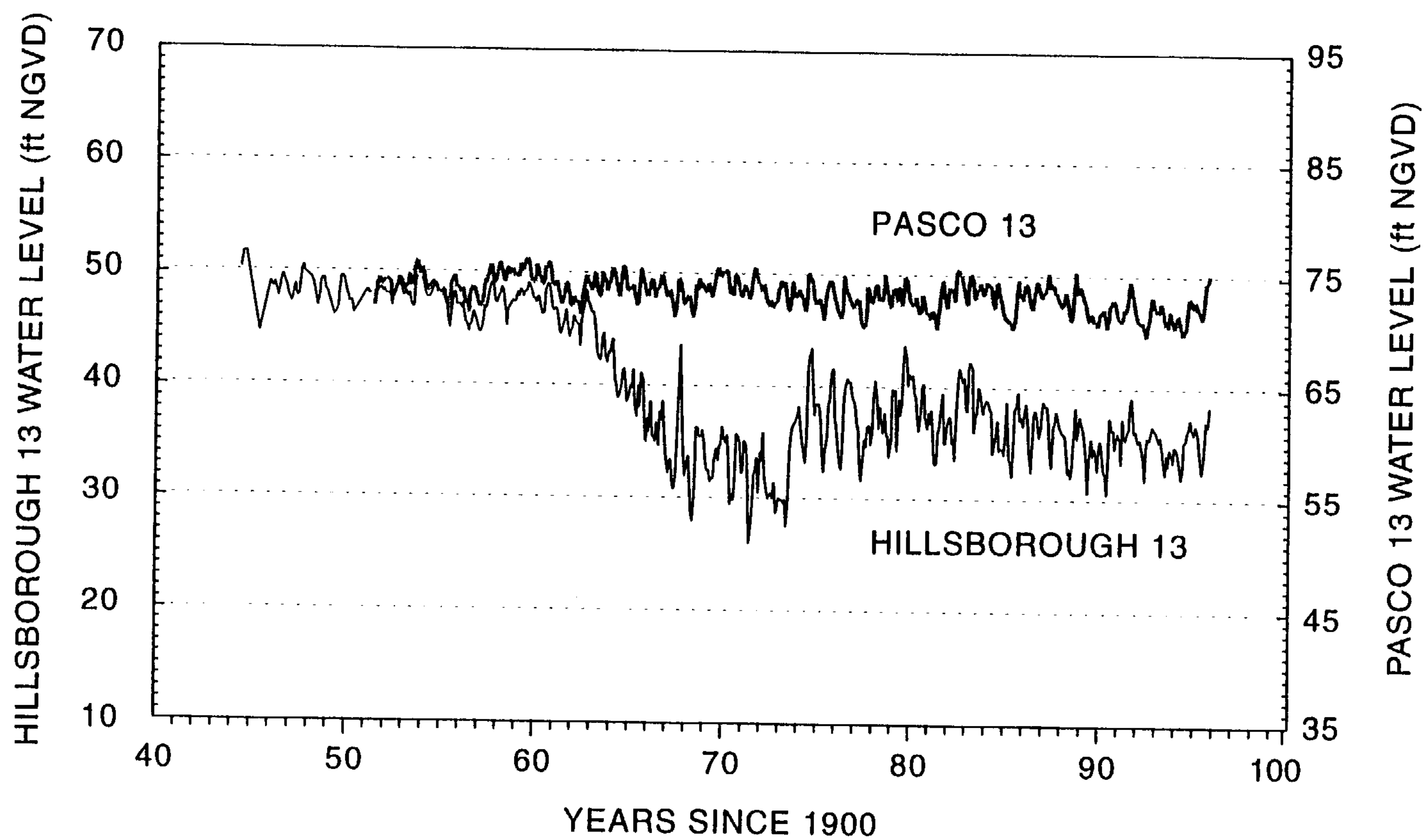


Figure 4-18. Comparison of water levels between the Pasco 13 and Hillsborough 13 Floridan aquifer monitor wells.

fluctuation characteristics change dramatically between the two wells. Although both are subject to relatively similar rainfall conditions, an obvious change occurs in the characteristics of the Hillsborough 13 well, while the Pasco 13 well remains relatively stable throughout the entire period of record.

A final method of demonstrating effects at the Hillsborough 13 well is presented in Figures 4-19 and 4-20. Figure 4-19, previously presented in Chapter 3, shows the seasonal fluctuation at the Hillsborough 13 well for 1954 and 1985. In 1954, the seasonal fluctuation at the Hillsborough 13 well was approximately 2 feet. In 1985, the fluctuation was over 10 feet, despite similar annual rainfall to 1954. Therefore, although the annual rainfall in both years was similar, the hydrographs are very different. Figure 4-20 presents a pair of annual hydrographs of water levels at the Hillsborough 13 Floridan aquifer monitor well from two different years. Although the comparison between these hydrographs from 1952 and 1987 look relatively similar to those in Figure 4-19, the annual rainfall for each year was very different. Rainfall in 1952 was well below average, while annual rainfall in 1987 was well above average. Despite the large amount of rainfall, the 1987 hydrograph is at least ten feet below the 1952 hydrograph, and the fluctuation is greatly increased. Therefore, although the increased rainfall has dampened the 1987 hydrograph as compared to the 1985 hydrograph, the effects of ground-water withdrawals near this well are substantial. A review of rainfall data from the Cosme wellfield station verifies an increase in annual rainfall average over the three decades from 1960 to 1990 in the northwest Hillsborough County area. The average annual rainfall for the 1960s, 1970s and 1980s was 52.9, 54.2, and 56.7 inches, respectively. Therefore, despite a slight increase in rainfall over each consecutive decade, water levels in Lake Starvation and the aquifers dropped. This cause-and-effect relationship demonstrates that ground-water withdrawals are the principal cause for the declines in water levels within the Section 21 wellfield.

Examples similar to Figures 4-16 and 4-17 for three other wellfield areas are presented in Figure 4-21 through 4-23. In all cases, long-term trends in Floridan, surficial, and surface-water levels are clearly related to ground-water withdrawals. The degree of impact in each area, however, is a function of several factors, including the rate of withdrawal, concentration of withdrawal

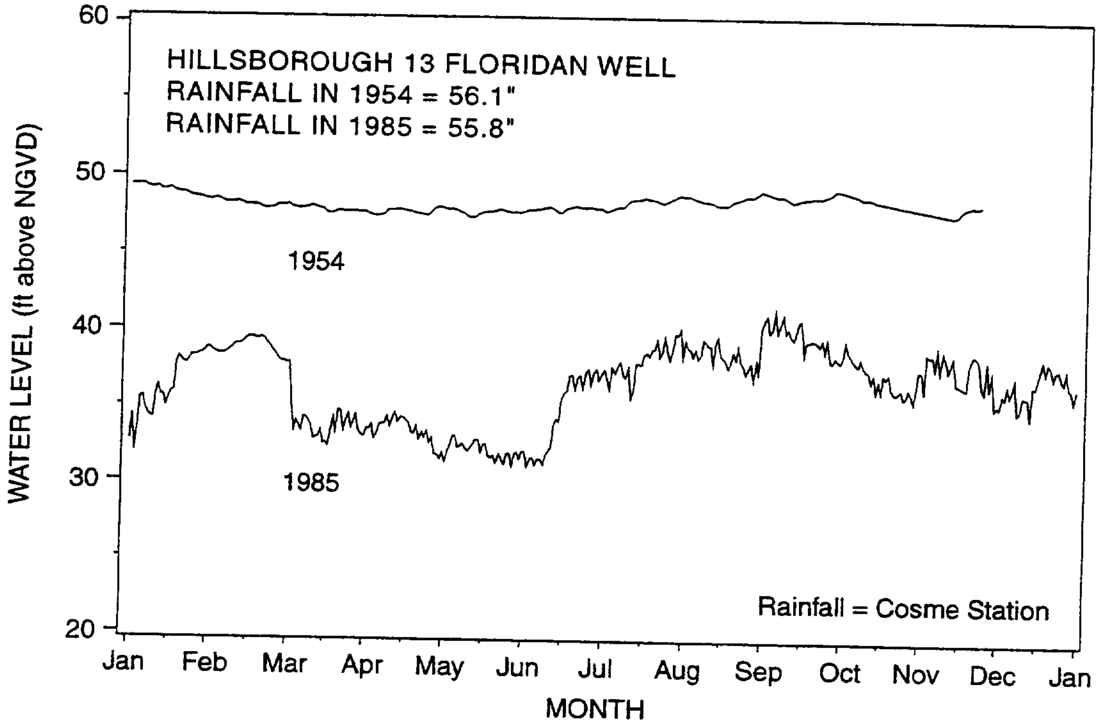


Figure 4-19. Comparison of the 1954 and 1985 Hillsborough 13 Floridan aquifer well water levels.

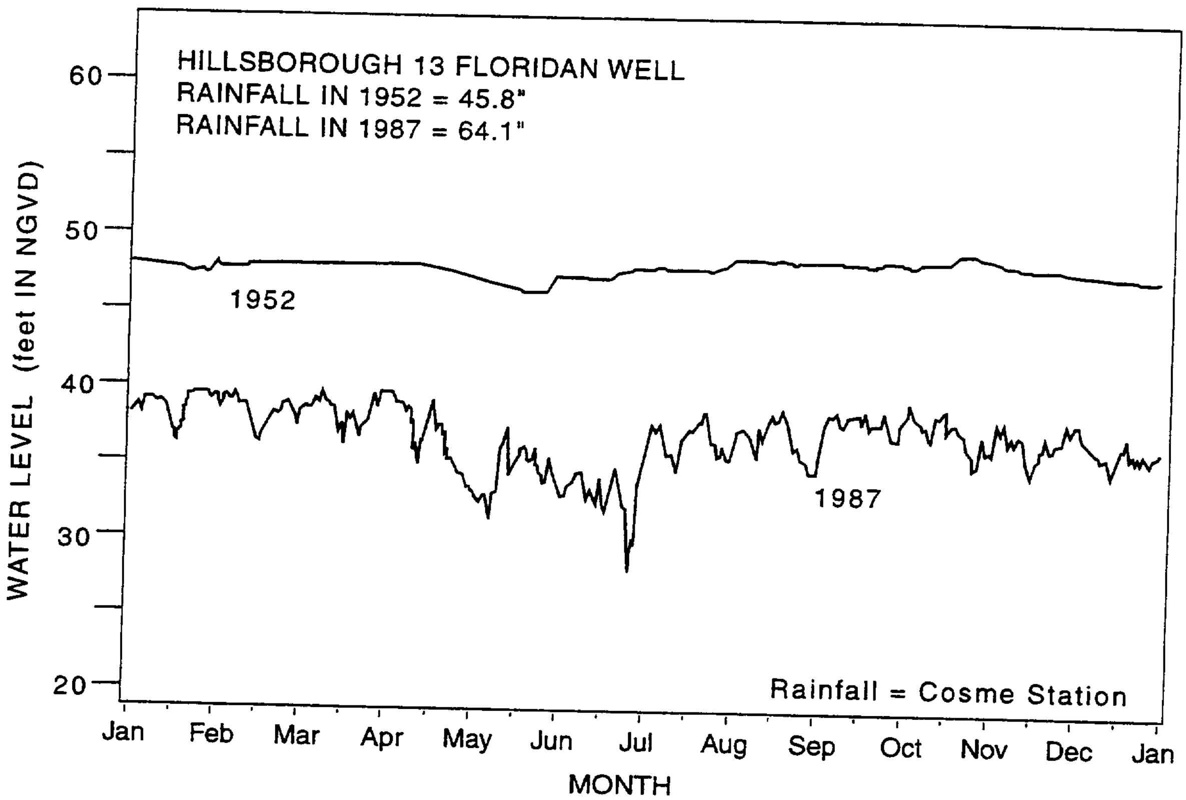


Figure 4-20. Comparison of the 1952 and 1987 Hillsborough 13 Floridan aquifer well water levels.

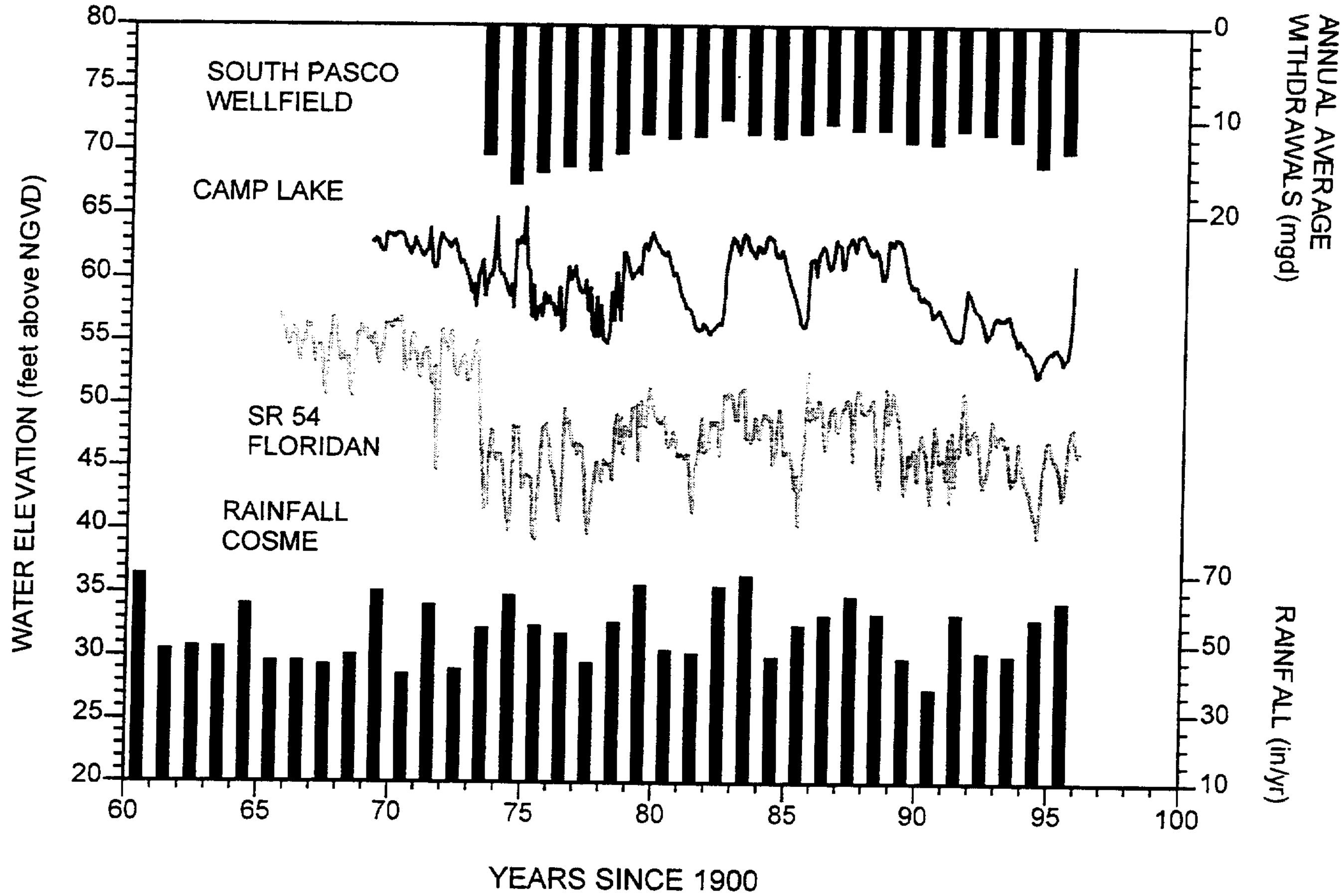


Figure 4-21. Ground-water withdrawal, water levels and rainfall near the South Pasco wellfield. (rainfall from the Cosme station)

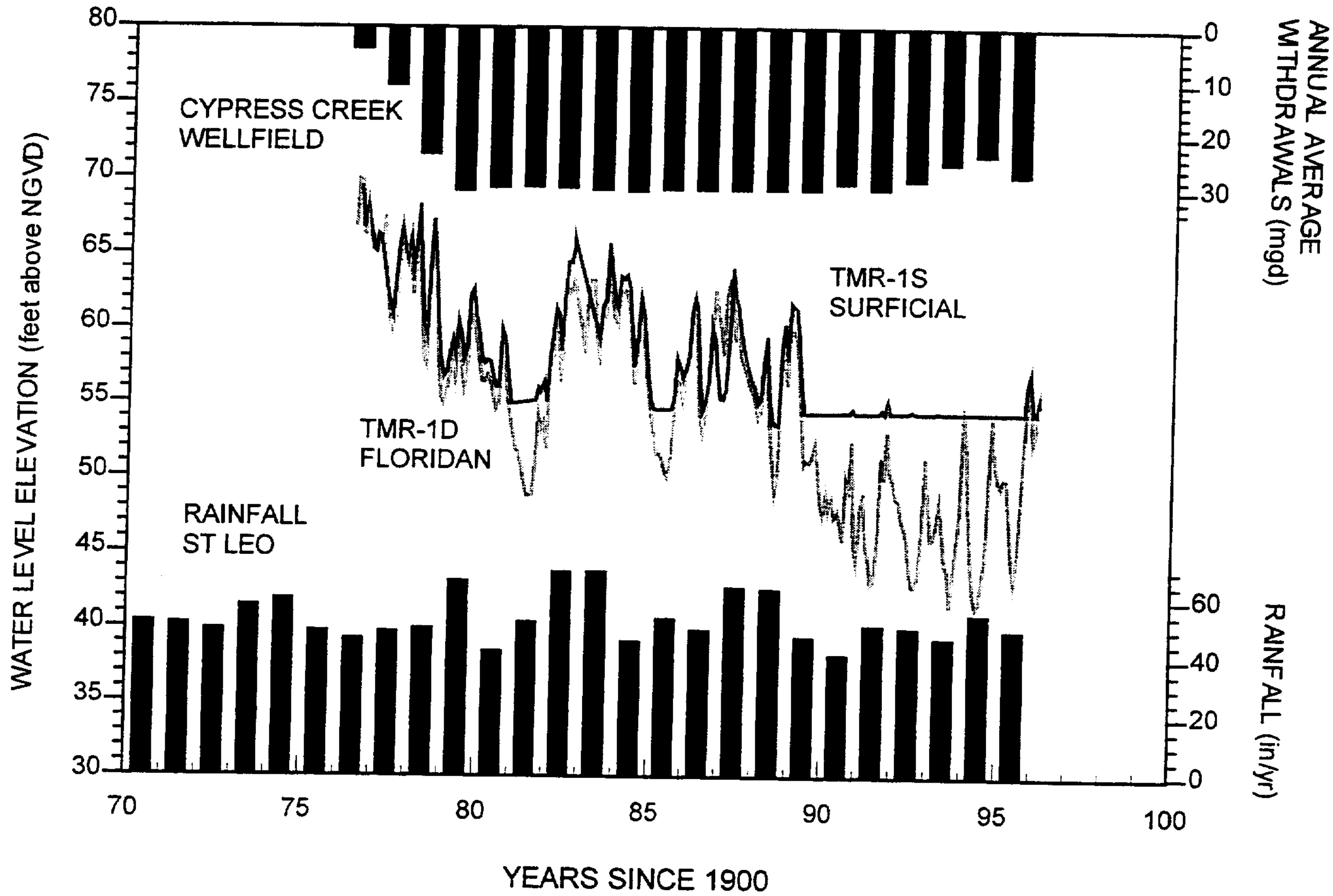


Figure 4-22. Ground-water withdrawal, water levels, and rainfall at the Cypress Creek wellfield. (rainfall from the St. Leo station)

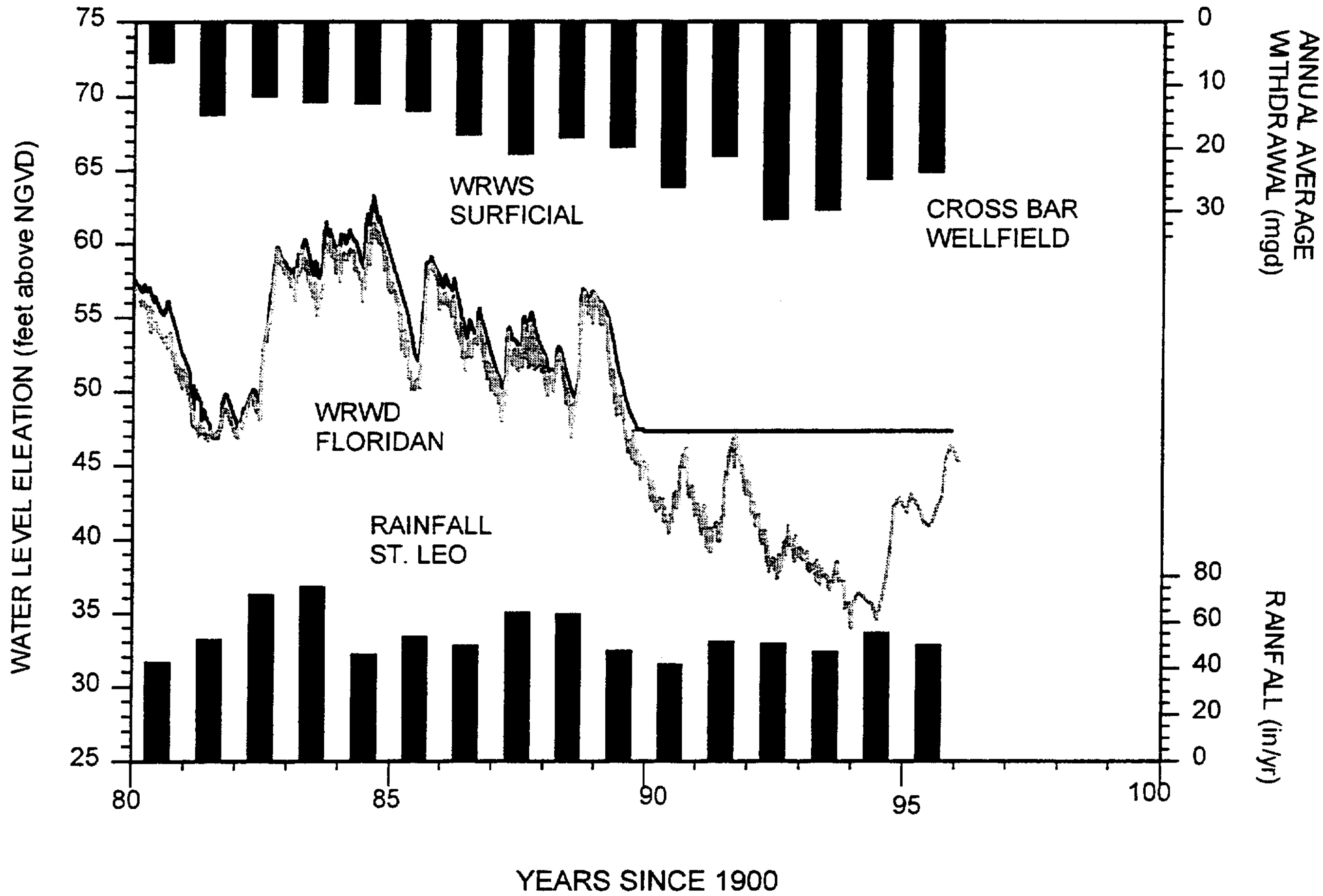


Figure 4-23. Ground-water withdrawal, water levels, and rainfall at the Cross Bar wellfield. (rainfall from the St. Leo station)

points, duration of withdrawal, proximity of the well or surface-water feature to the withdrawals, local integrity of the confining unit, and varying rainfall conditions.

Although these examples provide insight on effects to single wells or surface-water features, it is desirable to determine the spatial extent of the effects of ground-water withdrawals. The following section investigates the extent through the use of available hydrographs and other data.

Upper Floridan Aquifer

Figure 4-24 presents ground-water withdrawals at the Section 21 wellfield and hydrographs for three Upper Floridan aquifer monitor wells: Hillsborough 13 Deep, Berger Road Deep, and Debuel Road Deep. Annual maximum and minimum water levels for each well are also presented on each hydrograph. All three of these hydrographs were presented earlier in Chapter 3. The Hillsborough 13 Deep well is located within the wellfield, and the high correlation between ground-water withdrawals and the Upper Floridan aquifer water level within the wellfield is clear. The Berger Road Deep and Debuel Road Deep wells were constructed concurrently with the beginning of withdrawals at the Section 21 wellfield, and therefore have no prepumping data. However, similar variability in water levels can be seen in these two wells, although the variability decreases as distance from the wellfield is increased. Since the wells are located relatively close to each other, it is assumed that aquifer characteristics are similar. If rainfall was the cause of the water-level variation, this variability should be seen in all three wells more equally.

As another example of this relationship, Figure 4-25 presents ground-water withdrawals at the South Pasco Wellfield and Upper Floridan aquifer ground-water levels at four nearby monitoring stations; St. Pete 105 Deep, State Road 54 Deep, Lutz-Lake Fern Deep, and Bexley Well 2. Each well hydrograph shows the annual maximum, average, and minimum for the period of record. All of the wells' periods of record begin only three or four years before ground-water withdrawals began at the South Pasco wellfield in 1973. The St. Pete 105 well is directly in the wellfield, and has data beginning only one year prior to ground-water withdrawals at the wellfield. The downward trend between 1973 and 1974 is apparent at the beginning of the St. Pete 105 hydrograph, but is more apparent in the hydrograph of the State Road 54 Deep well,

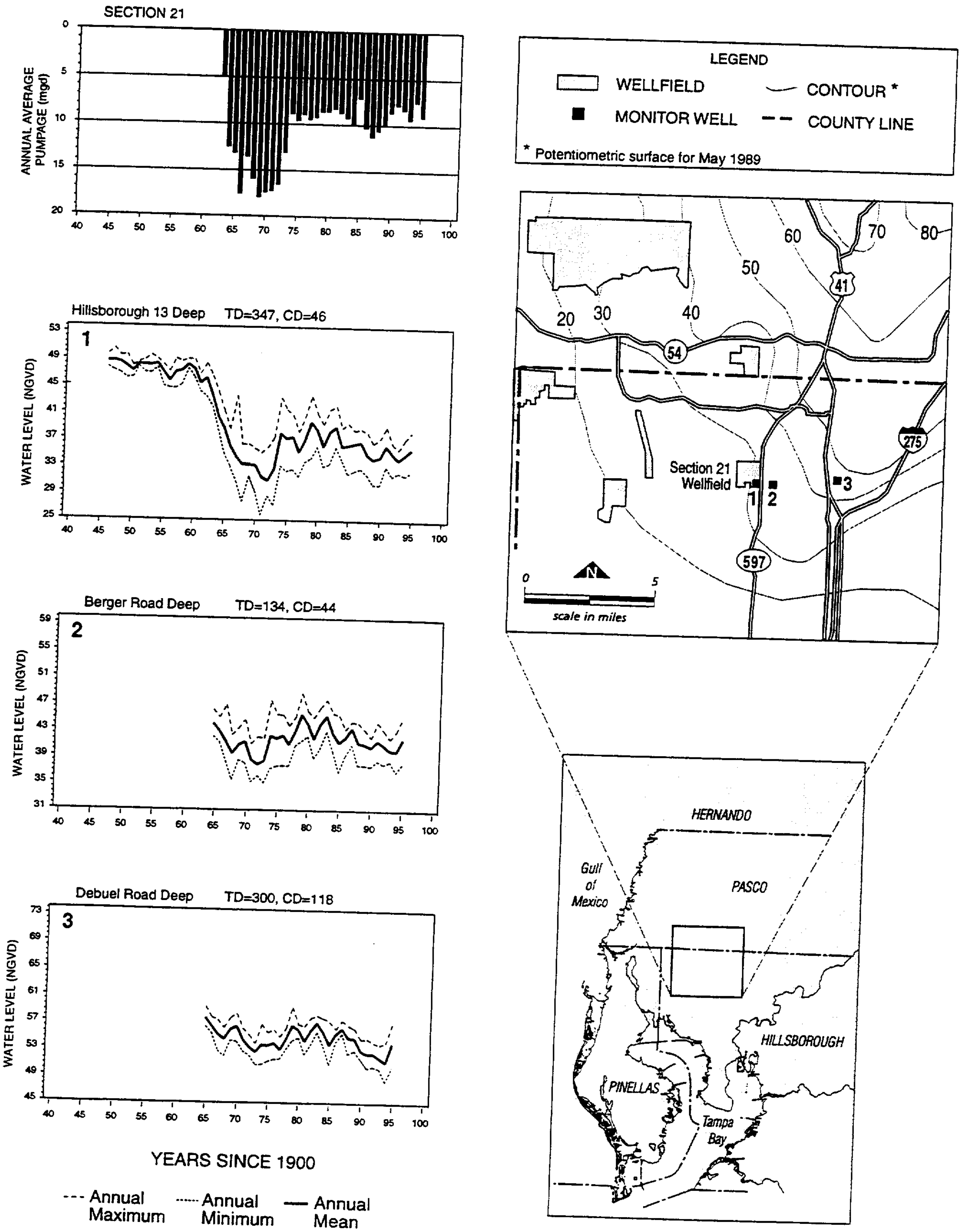


Figure 4-24. Ground-water withdrawals and water level trends near the Section 21 wellfield.

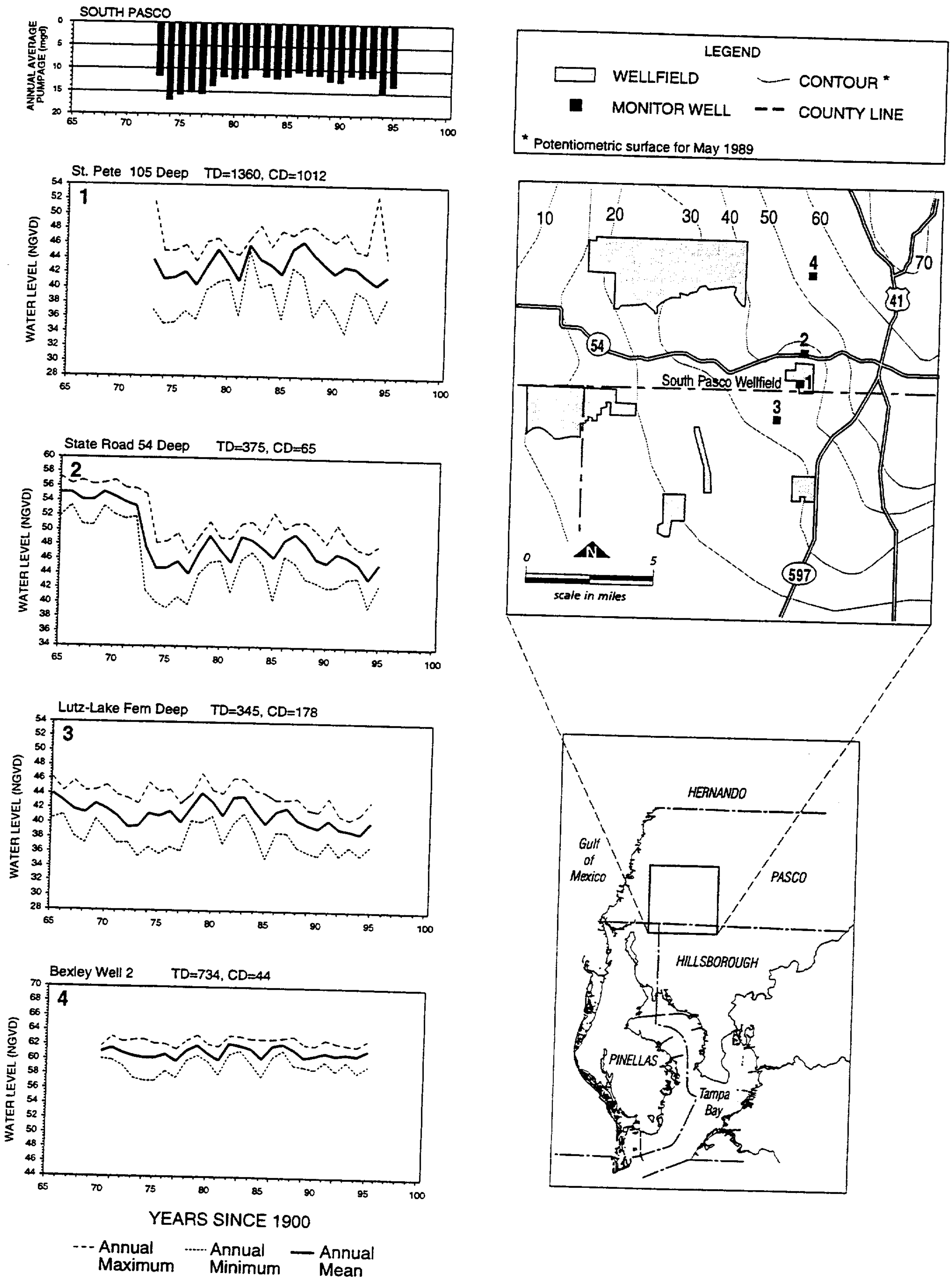


Figure 4-25. Ground-water withdrawals and water level trends near the South Pasco wellfield.

which has data back to 1965. This well is located just to the north of the wellfield. A drop of approximately 10 feet can be seen between the average annual water level before ground-water withdrawals and the average annual water level after withdrawals began. There is even a greater drop in the minimum annual water levels. Also apparent in both hydrographs is the recovery in water levels in the Upper Floridan aquifer as ground-water withdrawals were decreased in the early 1980s.

As the distance between each monitor well and the wellfield increases, the effect of the ground-water withdrawals on water levels is lessened. This can be seen in the Lutz-Lake Fern and Bexley wells. The effect of decreased ground-water withdrawals at South Pasco Wellfield is still somewhat apparent in both wells, but the magnitude of variation is much less than in the first two wells. The wells located close to the wellfield demonstrate much more variability than the relatively flat hydrograph of the Bexley well. Note that the ground-water withdrawals at Starkey Wellfield would not be expected to greatly affect water levels at the Bexley Well, since withdrawals at the Starkey Wellfield are mostly from the central portion of the wellfield property, located over five miles away.

The variability of the cone of depression caused by ground-water withdrawals is apparent in Figure 4-26, which presents ground-water withdrawals at the Cypress Creek Wellfield and hydrographs for four surrounding Upper Floridan aquifer monitor wells; Cypress Creek 3 Deep, SR 52 and 581 Deep, SR 52 East, and Pasco 13. The latter 3 wells were also presented in Chapter 3. As in the previous example, data at the Cypress Creek 3 well begins when ground-water withdrawal at this wellfield began. This well is located within the wellfield, and was constructed concurrently. However, the effects of ground-water withdrawals on the well water levels can still be seen. Although not directly in the wellfield, the "SR 52 and 581" Upper Floridan aquifer well displays a similar trend, with a better record before the period of ground-water withdrawals. Declines of over 10 feet are apparent, with an increase in the variation of water levels in both wells. Ground-water withdrawals at this wellfield have been relatively constant since 1979. Although periodic increases in water levels can be seen since ground-water withdrawals began, due to periodic high rainfall years, the longer term trend continues to be downward, with wide fluctuations in water levels. As a comparison, both the SR 52 East well and the Pasco 13 well, located to the west of the withdrawal center of the wellfield, display

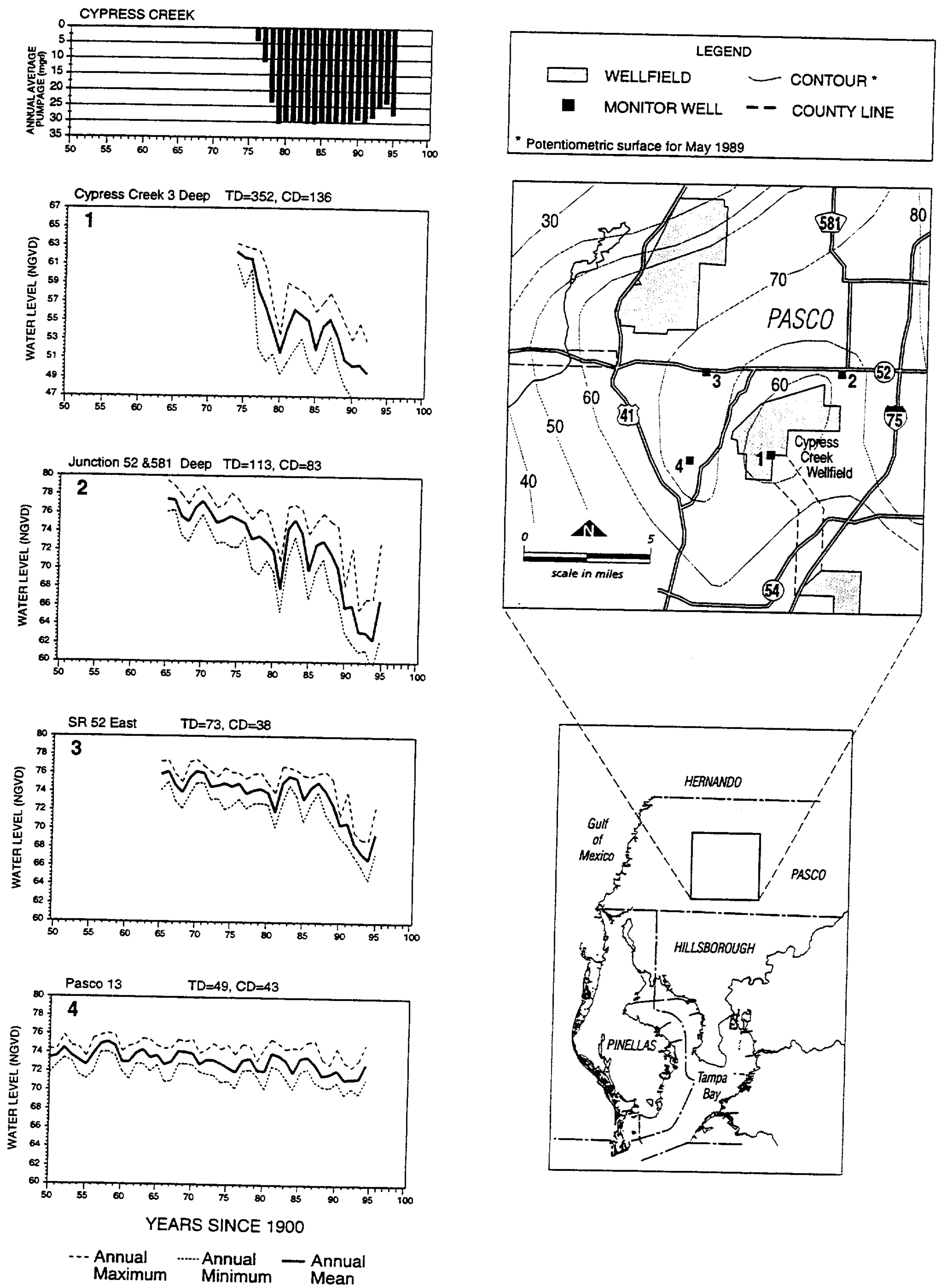


Figure 4-26. Ground-water withdrawals and water level trends near the Cypress Creek wellfield.

relatively flat hydrographs until more recent years, with a much smaller downward trend. The water levels of the SR 52 East well, located somewhat upgradient to the wellfield withdrawals (due in part to the larger cone of depression in recent years), has shown a sharp decline since approximately 1989. A combination of low rainfall and increased withdrawals at the Cross Bar wellfield have contributed to this recent decline.

Surficial Aquifer

The effects of ground-water withdrawals on the Upper Floridan aquifer are not as readily demonstrated in the surficial aquifer. Very few surficial aquifer monitor wells exist in the Northern Tampa Bay WRAP area that have a sufficient period of record to demonstrate the effect of wellfield withdrawals on the water table. Figure 4-27 shows annual average water-table hydrographs at two surficial aquifer monitor wells located in the vicinity of the Section 21 wellfield, as they compare to the hydrograph of the Hillsborough 13 Deep Upper Floridan aquifer monitor well. One of the wells, Hillsborough 13 shallow, is located within the Section 21 wellfield adjacent to Hillsborough 13 Deep Upper Floridan aquifer well. The second well is the Van Dyke surficial aquifer monitor well located some distance away outside the wellfield.

Both of these wells were presented in Chapter 3. As the figure shows, water levels at both surficial aquifer monitor wells correspond with the fluctuations of the Upper Floridan aquifer water levels. The Van Dyke well shows less fluctuation since it is located outside of the wellfield, but responds similarly to the other well data. Although the data record of the surficial wells is not complete, the approximate 17-foot drawdown in the Upper Floridan well is reflected as an approximate 10- to 14-foot drawdown in the Hillsborough 13 surficial aquifer monitor well, and an approximate 5-foot drawdown in the Van Dyke well.

For comparison, Figure 4-28 shows average annual hydrographs for the surficial and Upper Floridan aquifer monitor wells at Moon Lake, also presented in Chapter 3. These wells are located over 10 miles from the Section 21 wellfield and the other wells in Figure 4-27, and are believed to be relatively uneffected by ground-water withdrawals. As can be seen from this figure, natural fluctuation in the two aquifers unaffected by ground-water withdrawals is on the order of two to three feet. Water levels in both aquifers at these wells during the time of the

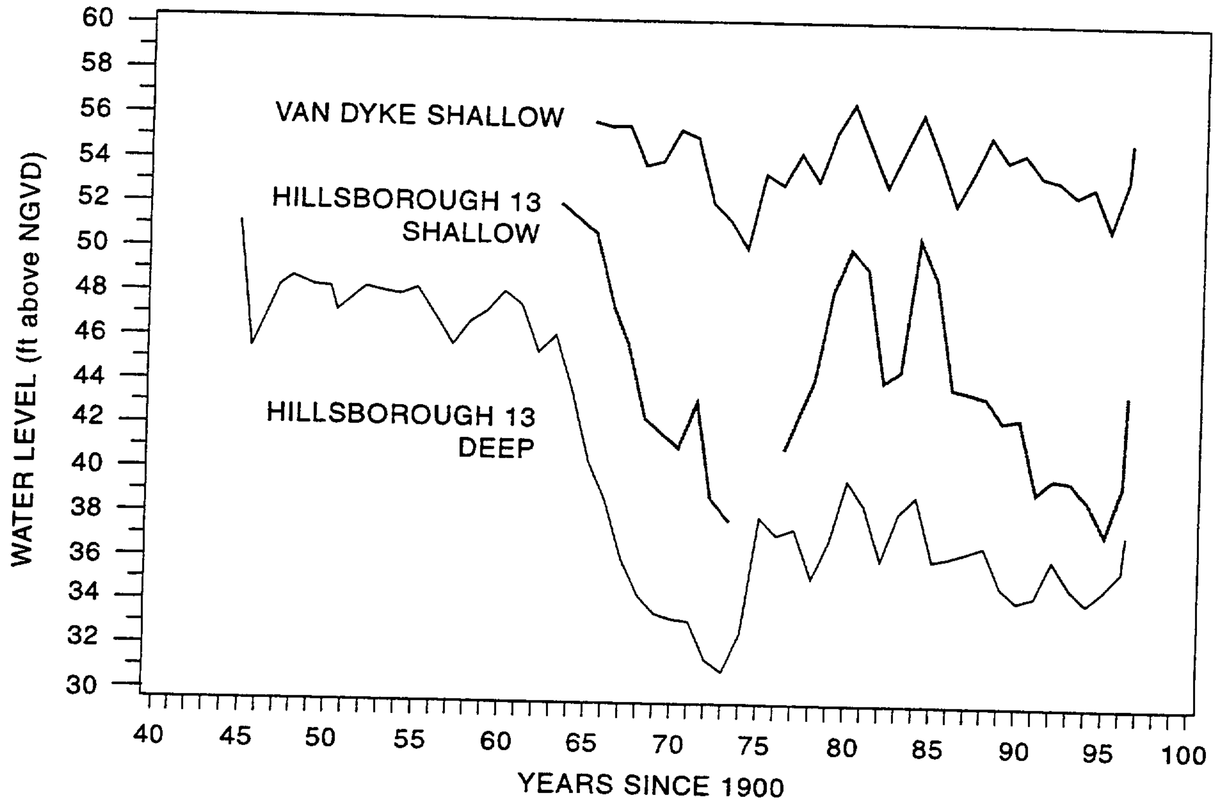


Figure 4-27 . Comparison of the water levels of two surficial aquifer monitor wells with the water levels of the Hillsborough 13 Upper Floridan aquifer monitor well.

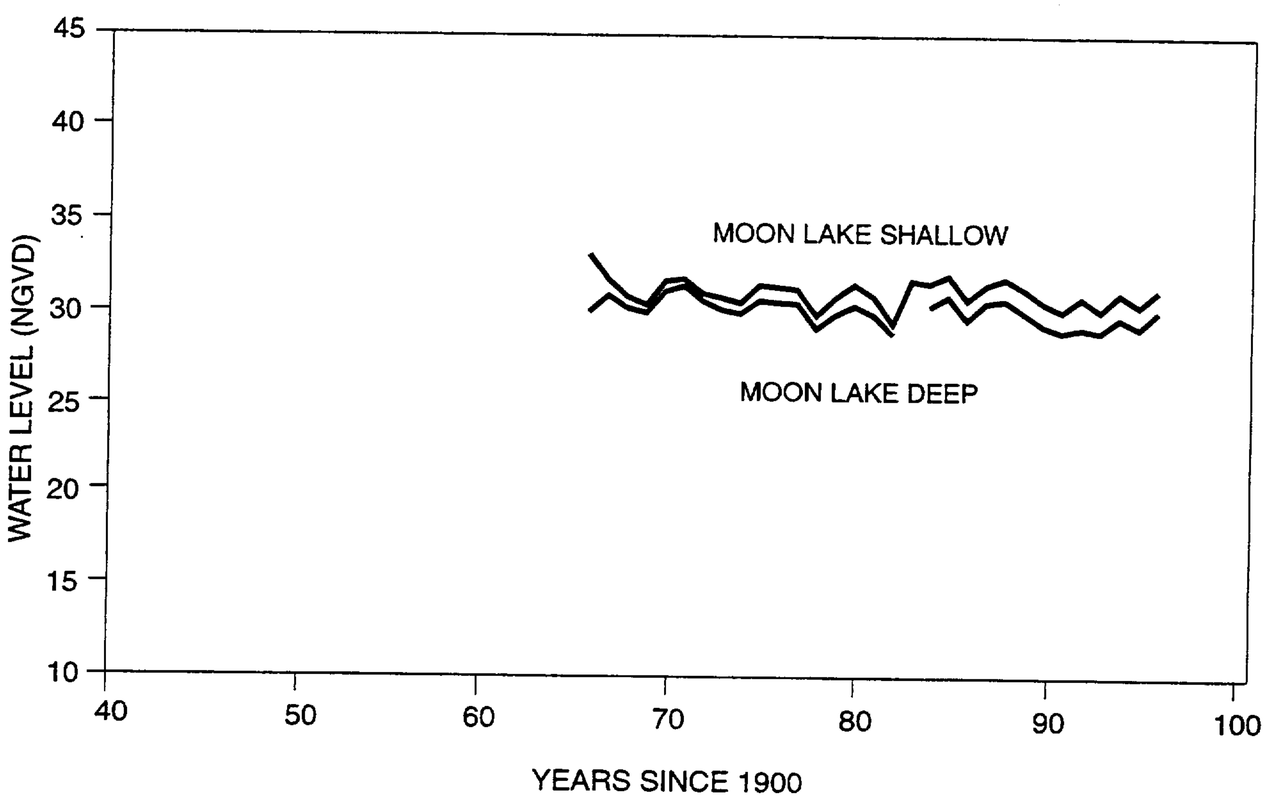


Figure 4-28. Water levels of the Moon Lake Upper Floridan and surficial aquifer monitor wells.

large variations near Section 21 do not show abnormal fluctuations. The two aquifers are very well connected at the Moon Lake site, so any drawdown in the Upper Floridan aquifer water levels would be expected to be reflected in the overlying water table. These wells may be affected by ground-water withdrawals at the Starkey and North Pasco wellfields with time and increased withdrawals.

Recently, Perry (1994) performed a multiple linear regression analysis to evaluate the effects of ground-water withdrawals from the Section 21, South Pasco, and Cosme wellfields on the Lutz-Lake Fern surficial and Upper Floridan aquifer monitor wells (Figure 4-29). Using average rainfall and withdrawal amounts, and assuming steady-state conditions, Perry concluded that ground-water withdrawal from the three wellfields has a combined effect at the monitor wells of over 15 feet of drawdown in the Upper Floridan aquifer and nearly four feet in the surficial aquifer. Because these values were determined for steady-state conditions, it is very difficult to measure these impacts in the field, but the ratio of drawdown levels between the Upper Floridan aquifer and the surficial aquifer appear reasonable upon inspection of actual hydrographs (see Data Appendices).

Wetlands and Lakes

Figure 4-30 presents long-term hydrographs from three of the 60 cypress wetlands which currently have staff gages within the Northern Tampa Bay WRAP area and the Green Swamp. The first three wetlands are located within the Cypress Creek wellfield, and were presented in Chapter 3. Ground-water withdrawal rates of the Cypress Creek wellfield are also presented along the top of the graphs. The wetlands are part of a network of monitor sites within the wellfield that have been observed and analyzed by the SWFWMD for many years (Rochow, 1985a,b). The fourth wetland hydrograph is from a Green Swamp wetland, located in an area of minimal ground-water withdrawal. This hydrograph serves as a control site for comparison purposes (Figure 3-110).

The first two hydrographs, sites D and B, are located in the central part of the wellfield where most of the ground-water withdrawal occurs. Although data collection was very limited before the start of ground-water withdrawals, the hydrographs show the relationship between ground-

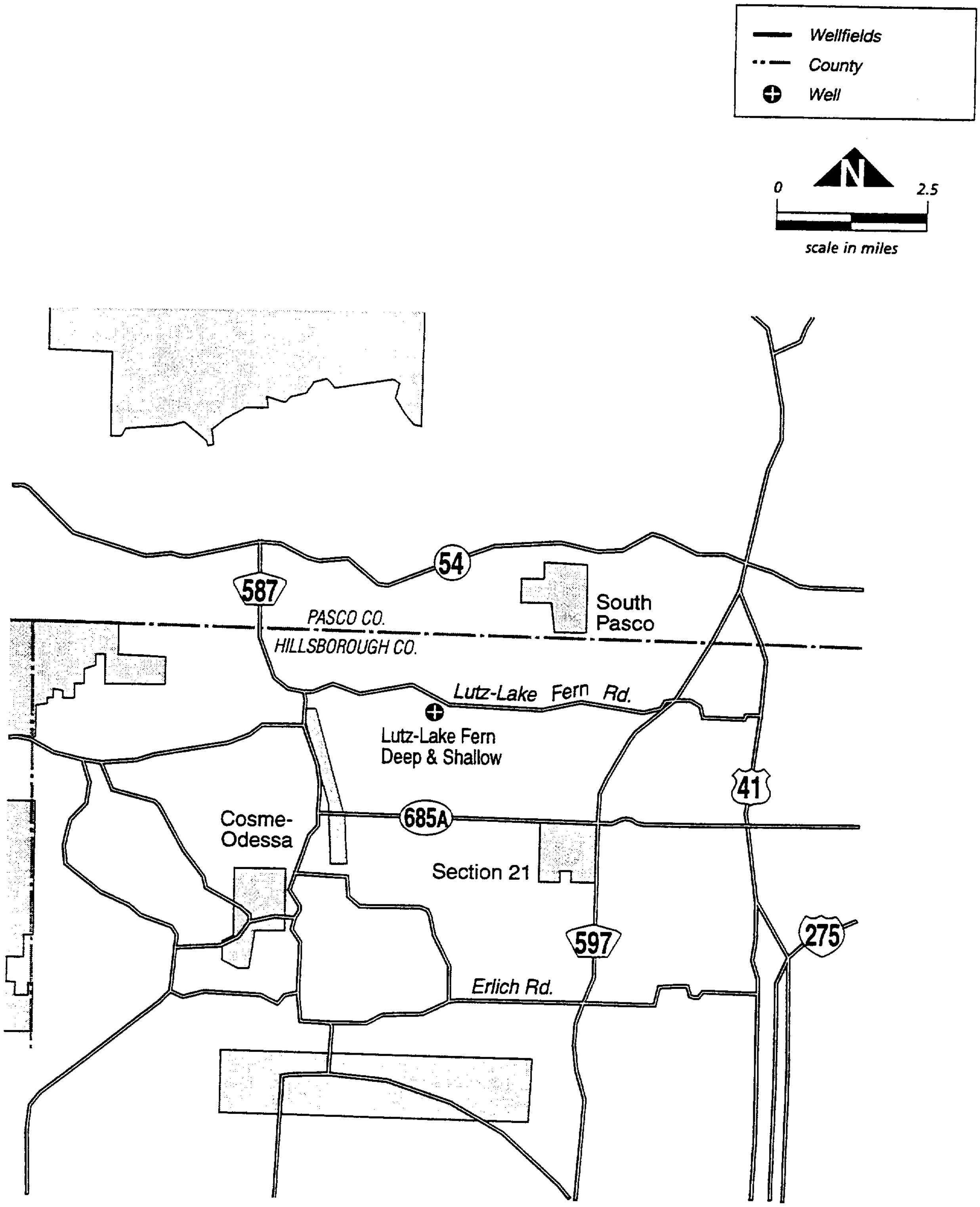


Figure 4-29. Location of wellfields near Lutz-Lake Fern monitor wells.

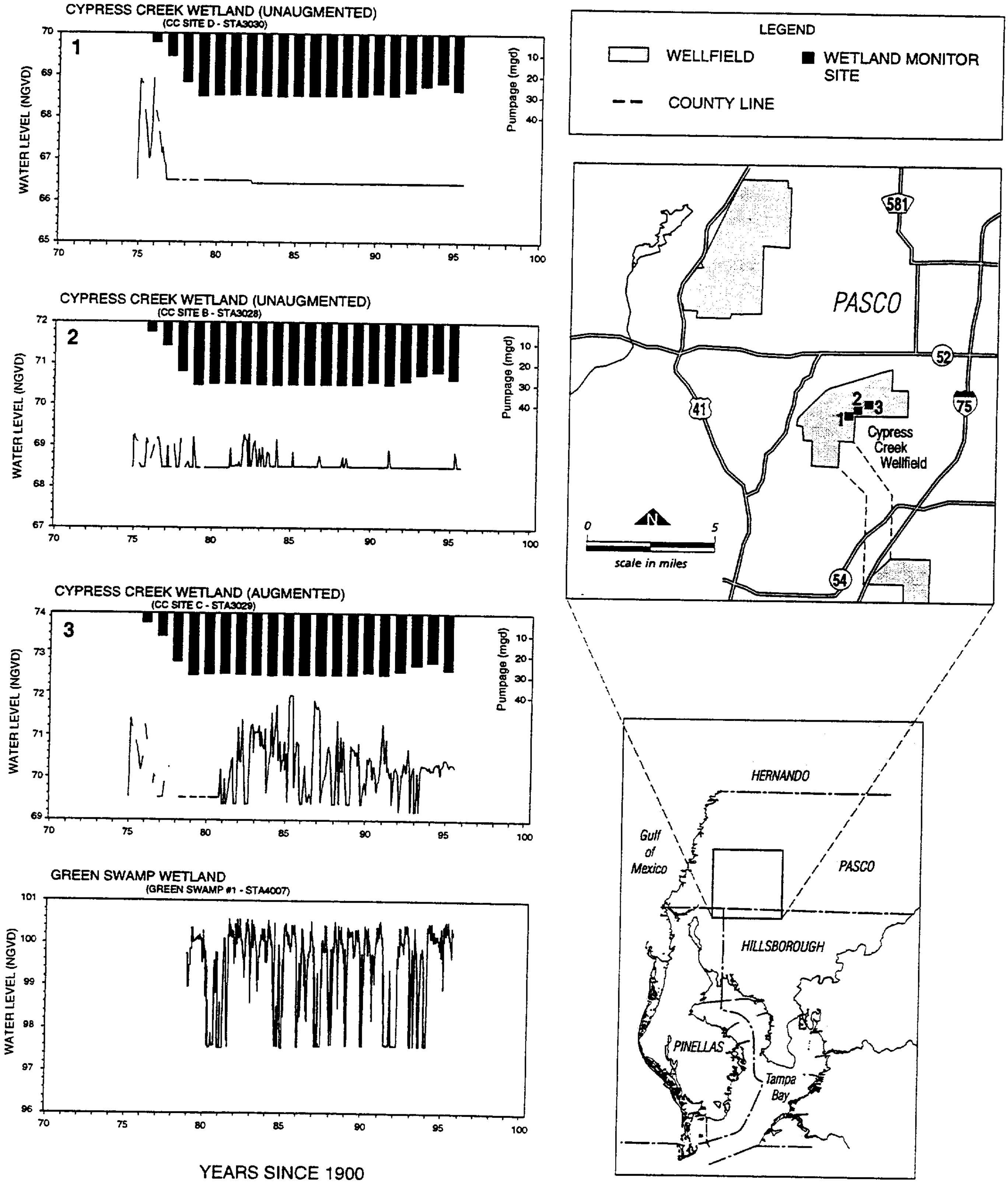


Figure 4-30. Ground-water withdrawals and wetland water level trends at the Cypress Creek wellfield.

water withdrawals and water levels in the wetlands. Site D was originally a deep marsh, but has been completely dry since ground-water withdrawals began. Site B is a shallow, somewhat perched cypress dome, and although it has been wet for short periods of time, the decline of water levels within the wetland is clear.

The Cypress Creek wellfield has several wetlands that have been augmented by water pumped from the Upper Floridan aquifer. The third wetland hydrograph in Figure 4-30 represents the water-levels of one of these wetlands. Wetland Site C is a cypress dome located toward the northeastern section of the wellfield, but still within the area of concentrated ground-water withdrawals. As the hydrograph shows, the wetland was dry for several years subsequent to the beginning of ground-water withdrawals at Cypress Creek. Upland species began increasing throughout the wetland, and fire caused severe damage in 1979. In 1981, the WCRWSA began augmenting the wetland, and the wetland began to recover. Wetland species replaced the invading upland species, and water levels consistently remained elevated. Although the water quality has changed due to the input of more mineralized water from the Upper Floridan aquifer, Site C has remained relatively healthy.

The Green Swamp #1 hydrograph shows a pattern of normal surface-water response in a cypress dome located in a natural flatwoods setting. Surface water is present most of the year in this wetland although yearly rainfall is variable. Further, maximum water levels are a common occurrence during the rainy season. When peak water levels are present, the entire extent of the wetland is flooded.

Figure 4-31 shows water-level hydrographs from three wetlands in the Starkey wellfield and the Green Swamp #1 wetland, along with ground-water withdrawals from the Starkey wellfield. The first wetland, Marsh B, is a large grass prairie marsh located near the western edge of the wellfield. Prior to 1984, all of the withdrawals were located in the western-most section of the wellfield, and were relatively low (less than 5 mgd). In 1983, ground-water withdrawals in this area were virtually stopped, and a much greater rate of withdrawal was begun in the central portion of the wellfield. As the hydrograph of Marsh B shows, there is a clear relationship between the reduction of nearby ground-water withdrawal and higher water levels in the marsh. Although withdrawal rates were low, the marsh was often dry during the period of ground-water

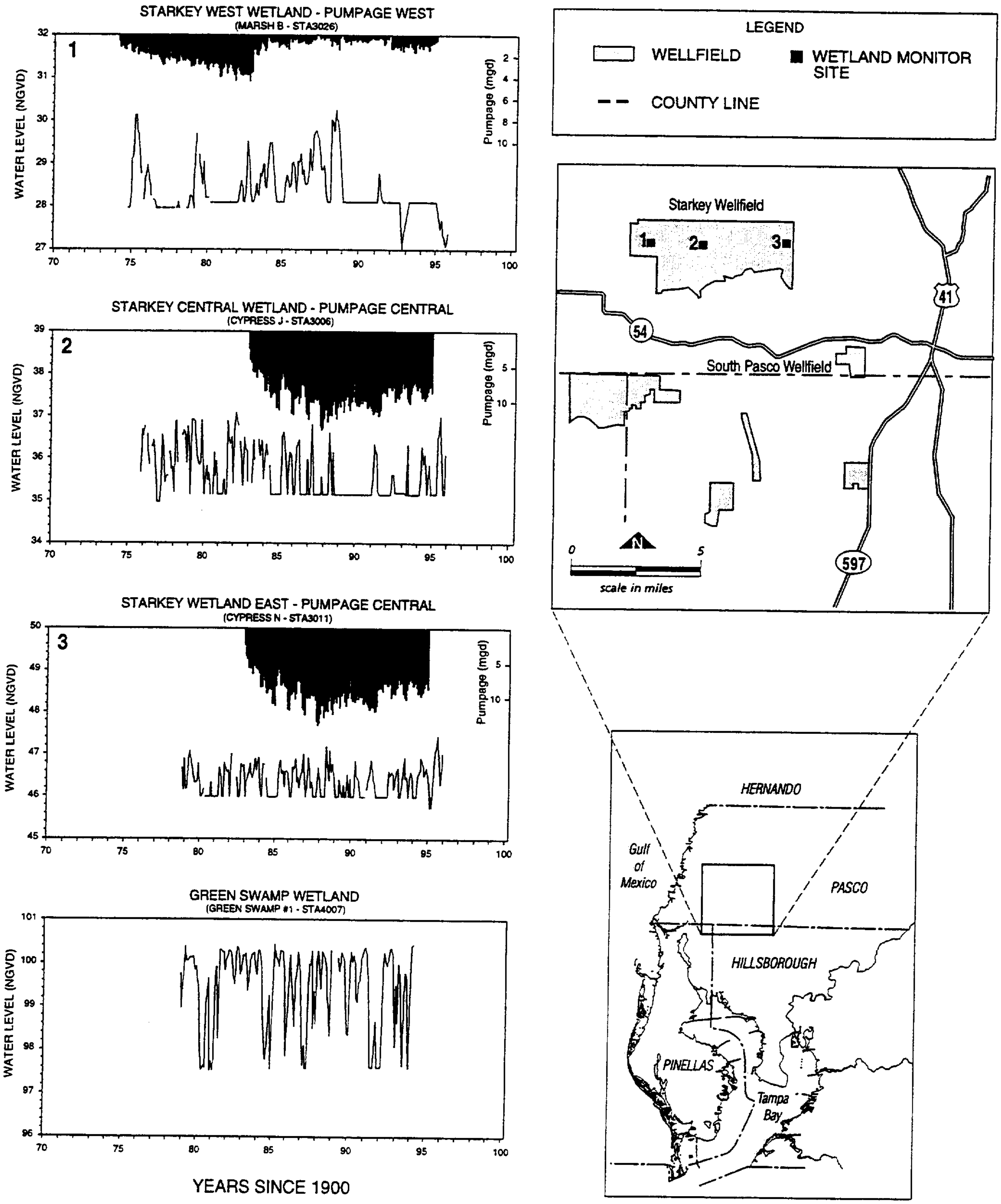


Figure 4-31. Ground-water withdrawals and wetland water level trends at the Starkey wellfield.

withdrawal, but recovered quickly when withdrawals were greatly reduced. Unfortunately, the marsh has been dry for the last couple of years, due to low rainfall and increased ground-water withdrawal rates in the center of the wellfield.

The second hydrograph on Figure 4-31 represents Cypress J, located in the center of the wellfield. This hydrograph is one of the few that has a water-level record beginning almost eight years before withdrawals began in the central area. Although this wetland does not remain dry constantly, the hydrograph shows that the wetland experiences long periods of dryness that were not common prior to central-wellfield withdrawals. When maximum annual surface-water levels decline, much of the wetland is dry during that particular year. Recent visual inspection of Cypress J confirms that its health is rapidly declining. Other wetlands in this area, as documented by Watson and others (1990), have shown similar or more extensive impacts, depending on the hydrologic connection to the Upper Floridan aquifer. At least one wetland in this area has collapsed entirely, and has experienced several feet of land subsidence over the last few years.

As a comparison, Figure 4-31 also presents two wetlands more removed from the effects of ground-water withdrawal at the Starkey wellfield. Cypress N is located approximately 2.5 miles from the center of Starkey withdrawals along the eastern property boundary, and Green Swamp #1 is located over 35 miles to the east of the Starkey wellfield. There is negligible Upper Floridan aquifer withdrawals near Green Swamp #1. When compared to Cypress J, Cypress N shows very little change in water-level fluctuation since the beginning of withdrawals in the central portion of the wellfield. Even the dry years of 1989 and 1990 show little effect on water levels in Cypress N, with very few dry periods recorded. The Green Swamp wetland hydrograph, representing a natural water-level fluctuation unaffected by Upper Floridan aquifer withdrawals, looks similar to that of Cypress N. The effects of ground-water withdrawals at Cypress N are much less than those at Cypress J due to the distance from the concentrated withdrawals and possibly the decrease in the leakage through the confining layer from west to east in the Starkey area. Cypress N may also be underlain by relatively impermeable clay or sediment layer. This integrity of the layer may change under the stress of increased ground-water withdrawals or current withdrawals coupled with low rainfall in the future, which may change the health of Cypress N with time. Since ground-water withdrawal has increased in the

eastern section of the wellfield in recent years, Cypress N may likely experience increasing impacts in the future.

As expected, the effect of ground-water withdrawals on lakes is similar. Figure 4-32 presents the water levels of three previously discussed lakes near the Cosme wellfield, along with the ground-water withdrawals of the Cosme wellfield. Lake Rogers is located within the Cosme wellfield, and has been discussed earlier in this chapter. Lake Raleigh and Church Lake are located nearby but outside of the wellfield. Lake Raleigh has a discontinuous period of record, but displays a downward trend similar to that of Lake Rogers. Lake Raleigh also received some settling pond overflow from the Cosme water treatment plant prior to 1987, when this process ceased. Church Lake displays less impact, although water level records only begin in the 1950s. In 1973, following a period of below average rainfall, the lake reached a record low of 29.8 feet NGVD. Church Lake recovered by five to six feet in mid 1974 due to heavy rains and a reduction in ground-water withdrawal at the Cosme-Odessa Wellfield. Church Lake is also thought to have been periodically augmented (Camp, Dresser and McKee, 1985), although no augmentation records are available.

As in other features, the effect a particular wellfield has on lake water levels depends not only on ground-water withdrawal quantity and manmade structures, but on the proximity to the ground-water withdrawal area. For example, Figure 4-33 presents the water level hydrograph of Starvation Lake, discussed earlier, along with water level data from two other lakes (Lake Saddleback and Lake Charles), and ground-water withdrawal data from the Section 21 wellfield. Lake Saddleback is located about 1,000 feet to the east of Starvation Lake, and Lake Charles is located about 1.2 miles east of Starvation Lake. Both Lake Saddleback and Lake Charles have been periodically augmented since 1968, although Lake Saddleback has been augmented more consistently. Although fluctuations in the water level of Lake Charles are not as great as those of Starvation Lake, the effects of ground-water withdrawals are still visible. Lake Saddleback has been more consistently augmented, and its fluctuation is less variable. Augmentation rates for Lake Saddleback are not available for further analysis. Camp, Dresser and McKee (1985) concluded that ground-water withdrawals at the rate of 7.5 mgd induces measurable increases in lake seepage rates within a two to three mile radius of the Section 21 wellfield.

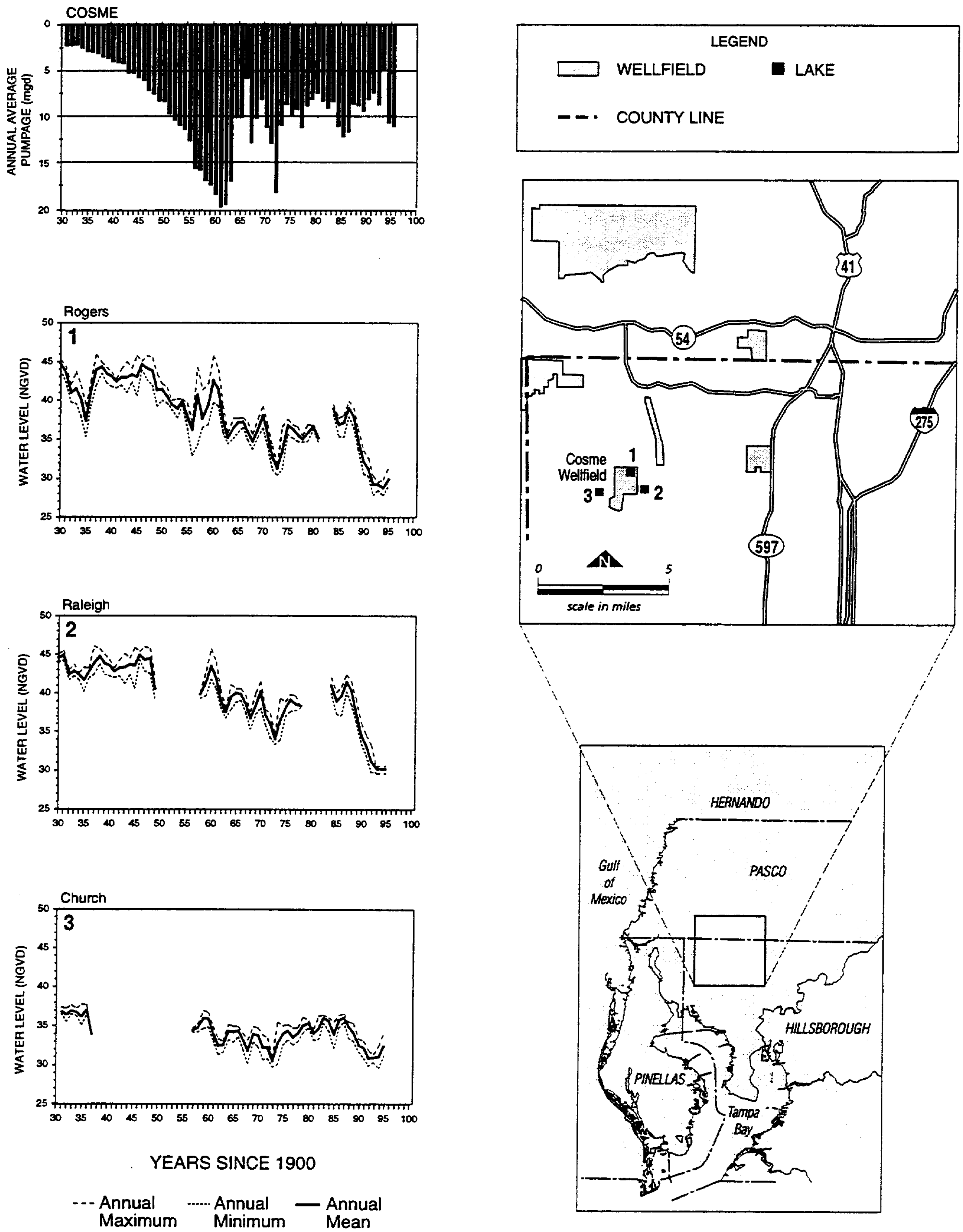


Figure 4-32. Ground-water withdrawals and lake level trends near the Cosme wellfield.

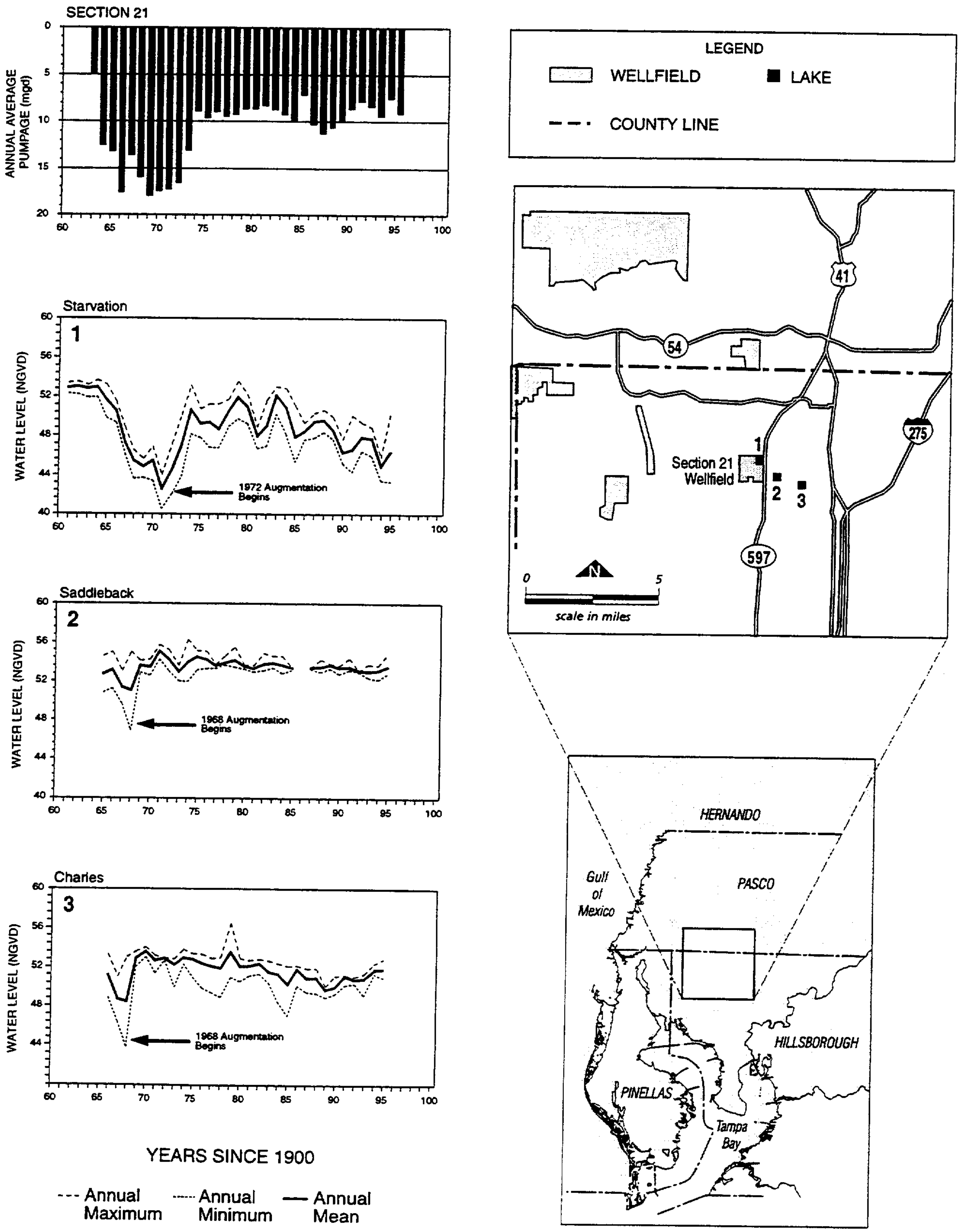


Figure 4-33. Ground-water withdrawals and lake level trends near the Section 21 wellfield.

The effect of regional ground-water withdrawals on Starvation Lake is also demonstrated through the use of statistical techniques. Schultz (1995) performed a multiple linear regression analysis as part of this study, assessing the effects of rainfall, evaporation, and ground-water withdrawals on the variation in annual water levels of Starvation Lake. The resulting equation was able to account for 82 percent of the lake stage variation, with the remaining percentage including unquantified parameters (augmentation, drainage alterations, etc.) and error.

The results of the regression model show that of the lake stage variation that can be accounted for by the model, ground-water withdrawal at Section 21 accounts for approximately 49 percent of the explained variation. The next most important parameter is rainfall, as measured at the Cosme-Odessa rain gage, which accounts for 28 percent of the explained variation. Finally, ground-water withdrawal from wells associated with the Northwest Hillsborough wellfield accounts for the remaining 5 percent of explained variation in Starvation Lake stage. Overall, the model estimates that ground-water withdrawal accounts for 54 percent of the explained variability, and rainfall accounts for the remaining 28 percent. That ground-water withdrawal at Section 21 is the single most important cause of lake stage decline at Starvation Lake is not surprising. Ground-water withdrawal from a wellfield several miles distant, the Northwest Hillsborough Dispersed wellfield, was also shown to be a statistically significant factor in decreasing lake stage. The implication is that ground-water withdrawal has effects that extend beyond their immediate vicinities. While withdrawal from Section 21 has the most affect upon Starvation Lake, located within its boundaries, it will also be having affects upon other lakes in the area, albeit with reduced intensity as the distance increases.

In more tangible terms, Schultz's model predicts that with average rainfall, an average withdrawal of 9 mgd at Section 21 would decrease lake stage by approximately five feet. To counteract this decline, an increase in average annual rainfall of 27 inches per year would be necessary to maintain stable lake levels. Unfortunately, it is not possible to provide rainfall, and an increase of 27 inches per year of average rainfall would be significant if it occurred. However, periodically there is sufficient excess rainfall to cause a rebound in the elevation of the lake. This alternating draining and filling of the lake results in increased variability of lake levels. As demonstrated in several hydrographs of lake and ground-water levels, and discussed in Section 4.2, the variability of water levels increases significantly in the presence of ground-water withdrawals, and fluctuations are

influenced mostly by rainfall variability. In the absence of ground-water withdrawals, the variation in the levels of Starvation Lake due to rainfall is two to three feet. Since ground-water withdrawals have begun, the variation has increased to approximately ten feet. The fluctuations are driven by rainfall, but ground-water withdrawals, both at Section 21 and in the region, have changed the relationship between lake levels and rainfall by increasing leakage through the lake bottom and creating more storage capacity for rainfall. The increased fluctuation of water levels, combined with the lower average lake level, causes lakes and wetlands to remain drier for longer periods of time, which is the root of the biological and recreational impacts observed. It is the presence of this variation in lake levels, rainfall, and ground-water withdrawal that allows regression analysis to be successfully employed to study lakes that are influenced by ground-water withdrawals.

Schultz's work supports the results of Lopez and Fretwell (1992), as well as the results of CDM (1985), concluding that Section 21 ground-water withdrawals, rainfall, and regional ground-water withdrawal all combine to affect the lake level of Starvation Lake. In the study performed by CDM (1985), arrangements were made to cease ground-water withdrawal at the Section 21 wellfield for 40 days. During this time and for approximately five months later, local lake stage and monitor well water elevations were measured. Simple linear regression was then used to quantify the changes in water level that occurred during ground-water withdrawal and non-withdrawal periods. CDM's study concluded that 63 percent of the Starvation Lake decline is attributable to ground-water withdrawal at Section 21 and other nearby wellfields, and the remaining 37 percent is attributable to natural phenomena. If one substitutes the word "variation" for "decline", then the results agree remarkably well with the multiple linear regression analysis.

Because regression analysis is site specific, and because of the diversity of hydrogeologic conditions beneath lakes in the Northern Tampa Bay area, the quantitative results of the Starvation Lake analysis cannot be applied to all lakes. However, the principles of the results can be applied, and other local analyses do confirm the conclusion that activities affecting the Upper Floridan aquifer also affect surficial features throughout the study area. To assess these impacts on a regional basis, a more broad perspective is necessary.

4.3.3 Regional Analysis

Potentiometric Maps

The potentiometric maps of the Upper Floridan aquifer produced by the USGS for May and September of each year are useful in visualizing the regional extent of ground-water withdrawal effects. By using the pre-development potentiometric surface developed by Johnston and others (1980), the current potentiometric maps can be subtracted to create an Upper Floridan aquifer drawdown map of the Northern Tampa Bay WRAP area. However, because the addition of new wells is incorporated into the USGS maps as years pass, many of the changes in contours can be representative of additional data rather than changes in water levels. This effect can be seen in Figure 4-15, presented earlier, where drawdowns in the Northern Tampa Bay area often appear in areas where no significant change in ground-water withdrawals have occurred. Therefore it becomes important to subtract actual data points from one another rather than contoured values. Because this greatly limits the ability to present a regional picture, the ground-water flow model will be used in the next chapter to demonstrate these regional changes in the potentiometric surface.

Regional Lake Analysis

Data from the lake analysis discussed in Section 3.6.2 were analyzed in an attempt to identify highly impacted lakes within the Northern Tampa Bay WRAP area on a regional basis. Data from the entire SWFWMD database were assessed to determine the number of lakes that have been under relatively consistent hydrologic stress throughout a long period of record. A period of 20 years (1973-1993) was chosen since a longer period of required data would eliminate most of the lakes in the area. Additionally, 20 years provide a reasonably sufficient amount of data to allow a determination of long-term stress. For comparison, a 15-year period (1978-1993) was also evaluated.

Of the approximately 175 lakes with water-level data throughout the study area, only 48 lakes have a consistent record of monthly data from 1973 to 1993. For each of these lakes, the minimum low management level (see Chapter 3) was compared to the monthly high water level

for each month of each year. Because a lake is determined to be stressed by the SWFWMD if the monthly high water levels remain at or below the minimum low management level for two-thirds of the time over a five-year period, similar criteria was applied to each year of lake data for each of the 48 lakes. Each year in which the high monthly water level remained at/or below the minimum low management level for at least two-thirds of the year (9 or more months) was considered a "stress" year. The results of this analysis are presented in Table 4-3.

The number of stress years over the 20-year period ranges from 0 to 20. As seen in other regional analyses, there is a wide-range of effects over small areas, probably reflecting the degree of confinement below the various lakes. Because of this wide-range of stress within a relatively small area, and because a 20-year period is used, the effect of rainfall can be assumed to be minimized. However, to further reduce the effects of rainfall, the number of low rainfall years were assessed over the 20-year period. Monthly rainfall data from the Cosme and St. Leo stations were averaged as an estimate of rainfall in the Northern Tampa Bay area. A low rainfall period was determined to be an annual rainfall amount five inches or more below the long-term average of the combined rainfall data. Because the standard deviation of the averaged rainfall data is approximately ten inches, five inches is considered to be conservative. Of the 20 years of rainfall data, six years were found to have experienced rainfall of five inches or more below the long-term average rainfall of 54.9 inches (period of record 1945 to 1993). Therefore, lakes in the area can be expected to show significant stress from rainfall no more than six years over the 20-year period.

Fourteen lakes in the area exhibited seven or more years of stress. These lakes are determined to be stressed for other reasons besides rainfall deficits. Note also that several lakes in Table 4-3 show zero to one year of stress, despite six years of low rainfall. Lakes in Table 4-3 are listed in order of decreasing stress years, along with information about the existence of inlets, outlets, and control structures. All but one of the lakes experiencing high levels of stress have no control structure, and most are isolated lakes. All but two of the lakes with zero or one year of stress have structures. When plotted on a map (Figure 4-34), all but two of the 14 lakes with high stress are located near the Cosme, South Pasco, and Section 21 wellfields. Lakes Neff and Iola are located in the northern reaches of the Northern Tampa Bay WRAP area, and as discussed in Chapter 3, are somewhat anomalous to the majority of the area.

Table 4-3. Regional analysis of Northern Tampa Bay area lakes with 20 years of record.

Lake	Years Below Minimum Low for 2/3 of the Year Since 1973	Years Below Minimum Low for 2/3 of the Year Since 1978	Inlet	Outlet	Augmented	Stressed as of 3/96	Control Structure
ALICE	20	14	No	No	No	Yes	No
BUCK	17	10	No	No	No	Yes	No
NEFF	16	11	Yes	No	No	Yes	No
IOLA	13	8	No	No	No	Yes	No
BRANT	12	7	No	No	No	Yes	No
CAMP	11	7	No	No	No	Yes	No
STARVATION	10	8	No	No	No	Yes	No
RAINBOW	8	6	Yes	Yes	No	Yes	No
CRYSTAL	8	6	Yes	Yes	No	Yes	No
HOBBS	8	3	No	Yes	No	Yes	No
STRAWBERRY	7	5	Yes	Yes	No	Yes	No
CRENSHAW	7	7	No	Yes	No	Yes	No
STEMPER	7	3	Yes	Yes	No	Yes	Yes
TURKEY FORD	7	6	No	Yes	No	Yes	No
SUNSET	6	5	No	No	No	Yes	No
CALM	6	2	No	No	No	Yes	No
HARVEY	5	4	Yes	Yes	No	Yes	No
CHURCH	5	0	Yes	Yes	No	Yes	No
JUANITA	5	4	No	Yes	No	Yes	No
CHARLES	5	4	Yes	Yes	Yes	Yes	No
TAYLOR	4	3	No	Yes	No	Yes	No
CLEAR	4	3	No	Yes	No	Yes	No
THOMAS	3	2	No	Yes	No	Yes	No
CRESCENT	3	1	Yes	Yes	No	No	Yes
MAGDALENE	2	1	Yes	Yes	Yes	Yes	Yes
CHAPMAN	2	0	Yes	Yes	?	No	Yes
CARROLL	2	0	No	Yes	No	No	Yes
KEENE	2	2	Yes	Yes	No	Yes	Yes
ALLEN	2	1	Yes	No	No	No	No
LINDA	2	2	No	No	No	Yes	No
PLATT	1	0	Yes	Yes	No	No	Yes
HANNA	1	1	Yes	Yes	No	Yes	Yes
ISLAND FORD	1	1	Yes	Yes	No	No	Yes
KEYSTONE	1	0	Yes	Yes	No	No	Yes
MOON	1	1	Yes	No	No	Yes	No
MOUND	0	0	No	No	No	No	No
THONOTOSASSA	0	0	Yes	Yes	No	No	Yes
LIPSEY	0	0	Yes	Yes	No	No	Yes
SADDLEBACK	0	0	Yes	Yes	Yes	No	Yes
GENEVA	0	0	No	Yes	No	No	Yes
THOMAS @ DREXEL	0	0	No	Yes	No	No	No
PRETTY	0	0	Yes	Yes	No	No	Yes
PARKER	0	0	Yes	Yes	No	No	Yes
KELL	0	0	Yes	Yes	No	No	Yes
TARPON	0	0	Yes	Yes	No	No	Yes
WHITE TROUT	0	0	Yes	Yes	No	No	Yes
KING	No Data	3	No	Yes	No	Yes	No
KING (EAST)	No Data	4	No	Yes	No	Yes	No
WEEKS	No Data	2	Yes	Yes	No	No	Yes
COW (EAST)	No Data	0	No	Yes	No	No	No

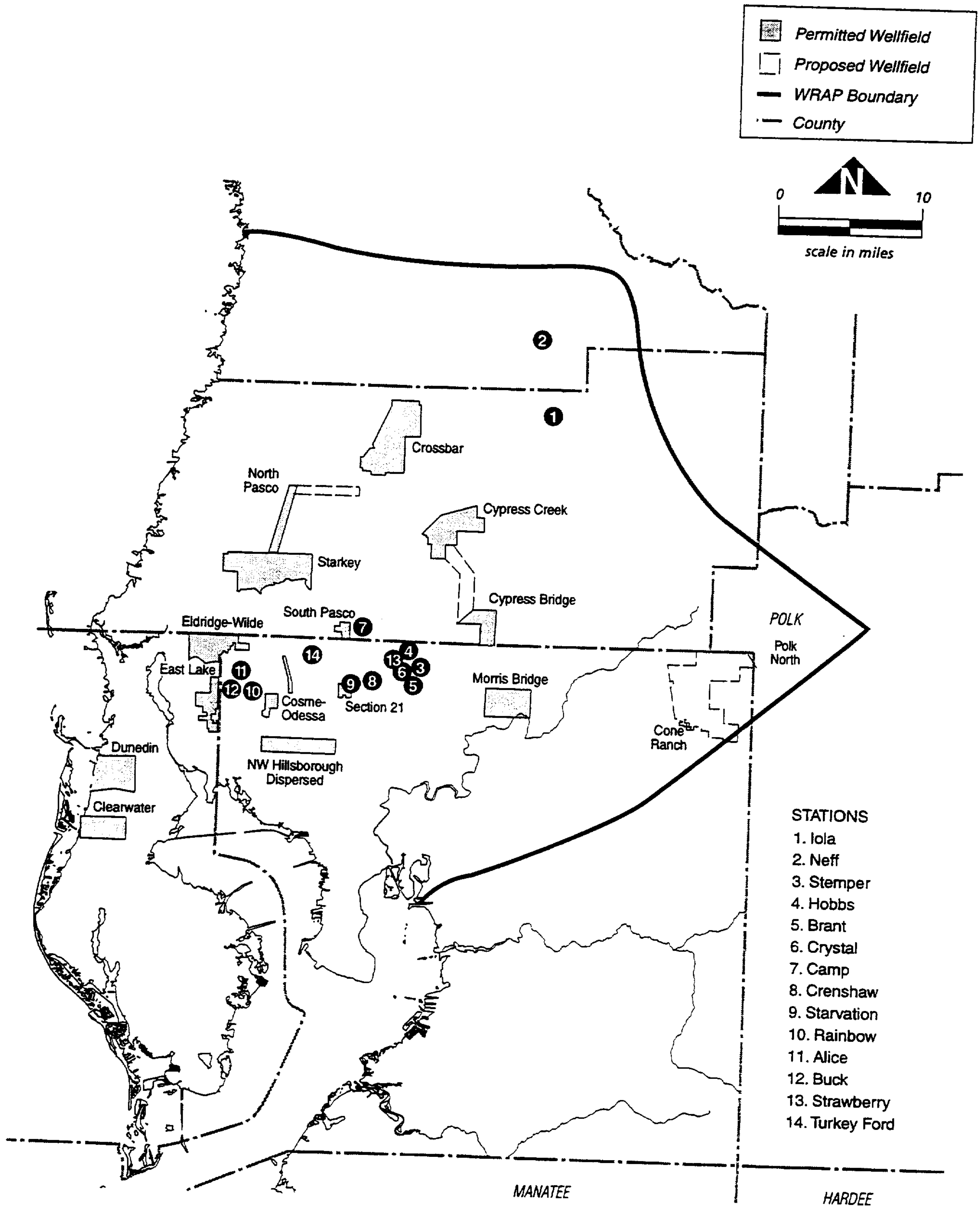


Figure 4-34. Highly stressed lakes (as per 20-year data analysis within the Northern Tampa Bay WRAP area).

Unfortunately, this assessment does not provide a complete evaluation of lake impacts in the study area for several reasons. First, many lakes with otherwise well-documented long-term impacts, including Lake Dan, Lake Raleigh, Lake Merrywater, and others, are excluded from the analysis since they do not have a complete set of data over the 20-year period. If the period of analysis is reduced to 15 years, only four more lakes are added to the data set (Table 4-3). Second, several lakes in the area are augmented with pumped ground water (Appendix A). Although these lakes are probably impacted by ground-water withdrawals, most of the effect is masked by the augmentation. Third, the stressed-lake designation, as applied in this exercise, is very conservative, since a lake designated as stressed by the SWFWMD criteria is highly impacted. Lakes that do not meet the stressed criteria, but have shown consistently low water levels, are subject to impacts that could cause severe ecological consequences over time. Because lakes have varying shapes, depths, underlying geology, and biological characteristics, similar drawdowns in different lakes can have varying levels of impact. For example, a very shallow pond with gently sloped banks will experience a greater adverse impact when subjected to one foot of water level decline than a very deep pond with steep banks.

The analysis implies that isolated, internally-drained lakes near wellfields appear to be the most affected by ground-water withdrawals from the Upper Floridan aquifer. Isolated lakes receive nearly all of their recharge from either direct rainfall or surficial aquifer discharge. Most of the significantly impacted lakes with too few data to be included are also isolated lakes. Although the lakes interconnected with man-made or improved canals can be adversely affected by the drainage improvements, these lakes are generally the most healthy. In most cases, the additional flow of water into lakes from other sources, or the existence of a control structure which holds back water, may counteract any water losses potentially caused by ground-water withdrawals. The effect of inlets, outlets, and control structures is highly dependent on the control elevations and other characteristics of such features. An inlet from a small wetland provides little additional water to a lake, whereas an inlet from a series of lakes and wetlands, or even a creek system, provides a significant water source. Similarly, the control elevation of an outlet, regardless of the existence of a control structure, can be a major factor in determining additional water loss or water retention in a lake.

This analysis is conversely affected by the fact that most of the lakes are located in two general areas, the northwest Hillsborough County area and the Land O' Lakes area. Therefore, there are few good control areas for surficial features within the Northern Tampa Bay WRAP area. However, because the analysis does agree with the results in Section 3.6.2 of Chapter 3, which includes a much larger data set, and uses high levels of impact (i.e. the SWFWMD stressed lakes definition), the results do add to the evidence of ground-water withdrawal effects on the region's lakes.

Regional Wetland Analysis

Regional assessment of impacts to wetlands was performed in several ways as part of this study, including spatial assessments of wetland health, a study of temporal trends in wetland hydrology and biological health, and by the use of regional correlation analysis. Methodologies using spatial patterns and temporal trends were introduced previously in Chapter 3.

An attempt at regional correlation analysis was performed early in the Northern Tampa Bay WRAP process. Changes in land use in areas surrounding wetlands have the potential, along with the influences of ground-water withdrawals, of causing adverse impacts to wetlands. Therefore, during the initial stages of the Northern Tampa Bay WRAP, a data base of more than ninety wetland evaluations was compiled and provided to the Center for Wetlands at the University of Florida. The evaluations were for wetlands in the northwest corner of Hillsborough County, northern Pinellas County, and southern Pasco County. This area encompasses a number of regional wellfields and also shows many land use alterations. In addition to evaluations of wetland health in the area, the Center for Wetlands was provided with materials to develop regional data bases of what was felt to be the most important variables thought to affect wetland health in the study area.

A summary of the correlation analyses is found in Appendix C and discussed in detail in Brown (1991). The study was unable to statistically document significant effects between the indices of development or hydrologic parameters and wetlands quality ranking. The results of this analysis indicated that due to the complexities of the area, a successful regional statistical analysis would require much more detail concerning factors thought to influence the health of each current

wetland site, and would require additional sites before any relationship between regional wetland health and the various potential causes of impact might emerge. Although the relationship between lowering water tables and wetland health has been well established on a case by case basis, the variability of the karst geology and other factors complicate the regional picture in the Northern Tampa Bay WRAP area. A complete regional statistical analysis would require considerably more detail for each current site, and would require additional sites before the relationship of regional wetland health and water levels emerges. During the remainder of the Northern Tampa Bay WRAP, efforts were directed toward assessing more wetland sites and developing spatial and temporal information on wetland health.

Figure 3-123 of Chapter 3 shows the most recent health of wetlands monitored by SWFWMD for many years, and Figure 3-124 shows similar information for wetlands monitored by others for water use permit purposes. The evaluation of wetland health of WUP monitored wetlands in Figure 3-124 was made by SWFWMD based on information submitted to the District. Additional information on evaluation methodology is provided in Chapter 3 and Appendix C.

By examining both Figure 3-123 and Figure 3-124, as well the wetland hydrographs presented in Chapter 3, it is apparent that many highly impacted wetlands are found in the areas regional wellfields. However, it is highly useful to review the temporal trends for subregional areas to better address cause and effect. Wetland health in the Northern Tampa Bay area has been monitored intensively for many years by SWFWMD and others. However, the temporal history of individual wetland sites depicted in Figures 3-123 and 3-124 is known better in some areas than others. Additionally, cause and effect relationships for changes in wetland health are more apparent in certain areas of the WRAP area where ground-water withdrawal and various other land use alterations do not occur in close proximity. For both these reasons, the history of wetlands in Pasco County is discussed first. Property boundaries of the regional wellfields in the following discussion are shown on Figures 3-123 and 3-124, and are identified by name in Figure 2-34.

The oldest program of wetland monitoring in Pasco County is associated with the South Pasco wellfield. SWFWMD began an intensive program of monitoring in 1973, which was the same year water production began at South Pasco (Bradbury and Courser, 1982). Several of the

wetlands that were part of the original SWFWMD monitoring program are depicted within the wellfield in Figure 3-123. In recent years, monitoring in and around the South Pasco wellfield has also been conducted by others for water use permit purposes (Water and Air Research, Inc. 1994b; HSW Environmental Consultants, Inc. and Water and Air Research, Inc. 1995). Figure 3-124 shows wetlands monitored for WUP purposes. A considerable number of moderately to severely impacted wetlands are evident in and immediately around the wellfield especially to the north and east. Early reports indicate that adverse impacts in the wellfield began to take place in the 1970s. A recent WUP report notes that the lowering of the water table has allowed uncontrolled fire burns to several cypress domes within the wellfield, and that soil subsidence and tree fall are evident. Land use at the South Pasco wellfield, other than a few minor access roads and several well pump sites, has not changed significantly since the wellfield was established. Although adverse biologic and hydrologic impacts are evident at the wellfield, wetland conditions are variable. For example, a large centrally located cypress wetland has been rated by SWFWMD as "normal to slightly impacted". Due to the karst geology of the area, this variability can be expected throughout the Northern Tampa Bay area.

In the mid-1970s, SWFWMD began wetland monitoring programs in the Starkey and Cypress Creek wellfields. A number of monitoring sites with histories of 10 to 20 years appear in Figure 3-123. From the 1970s until the early 1980s, all water production from the Starkey wellfield came from the far northwestern part of the wellfield. During the late 1970s and early 1980s, SWFWMD biologists noted altered hydroperiods and adverse biologic impacts to the wetlands monitored in this area of the wellfield property. These effects were not seen in the central and eastern areas of the property where ground-water withdrawal had not yet begun. Beginning in 1983, most water production at Starkey wellfield was transferred to production wells in the central part of the wellfield. In the years following expansion of water production, SWFWMD biologists observed adverse impacts to wetland monitoring sites in the central portion of the wellfield, including destructive fires, treefall, and soil subsidence. Impacts initially observed in the western wellfield area have generally worsened. In contrast, virtually all wetlands in the eastern portion of the wellfield, where ground-water production has only recently begun, have remained in good ecological health. One exception is a small marsh that is very close to a far eastern water production well. The spatial pattern of wetland health for the Starkey wellfield shown in Figure 3-123 reflects changes that have occurred during the long period of SWFWMD

monitoring. Figure 4-31, presented earlier in this chapter, shows wetland water level trends for three of the wetlands monitored at the Starkey wellfield in the western, central, and eastern regions of the wellfield. The western and central wetlands have shown a decline in health over the years.

In addition to SWFWMD's monitoring, the Starkey wellfield has been monitored by others since the early to mid-1980s to comply with SWFWMD Water Use Permit requirements. Many annual environmental reports have been submitted to the District which describe this monitoring (Environmental Science & Engineering, Inc., 1995). A large number of the WUP wetland monitoring sites are depicted in Figure 3-124. It is evident from the map that many "Moderately to severely impacted" wetlands exist in the western and central portions of the Starkey tract; only "Normal to slightly impacted" wetlands occur in the eastern area. Descriptions of wetland conditions supplied with WUP environmental reports indicate that the health of impacted wetlands has declined over the years of monitoring. The two patterns of wetland health depicted by Figures 3-123 and 3-124 are quite similar although one map is based on SWFWMD's long-term monitoring experience while the other is based on information supplied to the District from a separate program of monitoring. A discussion summarizing monitoring by SWFWMD and others at the Starkey wellfield and other regional wellfields is found in Rochow (1994).

The North Pasco wellfield, immediately north of the Starkey wellfield, is a relatively new regional water production facility with low-level production beginning in 1992. Although the SWFWMD does not have an on-ground program to monitor the wellfield, a number of wetlands have been monitored since 1989 for water use permit purposes (HDR Engineering, Inc., 1994). WUP monitoring reports note relatively low wetland water levels around production wells and deteriorated environmental conditions in associated wetlands. Figure 3-124 shows these wetlands, which are interpreted to be "Moderately to severely impacted". It is evident that many wetlands to the east, north, and west of the North Pasco wellfield are in relatively good condition.

SWFWMD's wetland monitoring at the Cypress Creek wellfield began in 1975, or one year prior to water production. Water production from the Cypress Creek wellfield commenced at a low rate in 1976, and reached an annual rate of near 30 mgd in 1979. A number of

SWFWMD's monitoring sites with histories of 10 to 20 years appear in Figure 3-123. Shortly after ground-water production began, low water levels and shortened hydroperiods were noted in many monitored wetlands. During this time biological conditions began to deteriorate in these wetlands. A general trend in wetland deterioration has been evident in Cypress Creek wellfield wetlands through the 1980s and 1990s. Figure 4-30 shows water level trends for three of the monitored wetlands at Cypress Creek. Two of the wetlands have declined considerably in health over the twenty-year period of monitoring; the third has been augmented with ground-water since about 1980. Although impacted, the third wetland continues to maintains many wetland functions. The spatial pattern of wetland health for the Cypress Creek wellfield shown in Figure 3-123 reflects the deterioration in health of the wetlands that has occurred while the wellfield has been studied by SWFWMD.

In addition to SWFWMD's monitoring, the Cypress Creek wellfield has been monitored by others for many years to provide information for water use permits (WUPs). A large number of WUP environmental reports have been submitted to SWFWMD describing this monitoring (Environmental Science and Engineering, Inc. and HSW Environmental, Inc., 1995). Many WUP monitoring sites are depicted in Figure 3-124. Recent monitoring notes progressive deterioration in wetland vegetation at certain wetland sites. Low water is reported for many wetlands in and immediately around the wellfield, and the opinion is expressed that extreme dryness in some wetlands is causing organic matter oxidation and soil subsidence. Biological changes over the years have resulted in the deterioration of wetland health to a degree that many wetlands in the Cypress Creek wellfield and the immediate vicinity are now interpreted as being "Moderately to severely impacted" in Figure 3-124. Note that not all wetlands within the wellfield have been impacted to this degree, since a few remain in relatively good health. Several wetlands on the wellfield are augmented with ground-water from water production wells.

For fifteen years, Biological Research Associates, Inc. (BRA) has conducted a program of biological monitoring in and around the Cross Bar Ranch wellfield (Biological Research Associates, Inc., 1994). BRA's monitoring began at the wellfield prior to water production in Water Year 1978. Recently the monitoring program has been continued by CCI Environmental Services, Inc. and Terra Environmental Services, Inc. (1995). SWFWMD has not maintained an on-ground program of wetland monitoring within the Cross Bar Ranch wellfield although the

District has monitored two wetlands for many years in the Pasco Trails development immediately to the south of the wellfield. Even though SWFWMD has not conducted a long-term monitoring program at the Cross Bar Ranch, in recent years SWFWMD has studied environmental conditions on-ground within the wellfield, in the region between the Cross Bar Ranch and Cypress Creek wellfields, and in other north Pasco areas. Figures 3-123 and 3-124 depict the wetlands monitored by SWFWMD and others in this area. Monitoring reports for the WUP program indicate a reduction in wetland water levels, an abbreviation of hydroperiods, and general deterioration in wetlands health in and immediately around the Cross Bar Ranch wellfield. These effects began to become evident in the mid- to late-1980s and have become even more noticeable in the 1990s. Deterioration in wetland health began to become noticeable not long after wellfield water production was increased in the mid-1980s. In Figures 3-123 and 3-124, a large number of moderately and severely impacted wetlands are shown both within the Cross Bar Ranch wellfield and in the region between the Cross Bar Ranch and Cypress Creek wellfields. Additional information on monitoring performed in the Cross Bar Ranch wellfield can be found in the reports cited. Rochow (1994) presents a summary of some of this information.

The Cypress Bridge wellfield is located southeast of the Cypress Creek wellfield just north of the Hillsborough County line. The Cypress Bridge wellfield is a relatively recent regional wellfield with low-level production beginning within the last several years. Wetlands at the wellfield have been monitored for water use permit purposes since the late 1980s (USF Institute for Environmental Studies & Terra Environmental Services, Inc. 1995). SWFWMD does not maintain a wetland monitoring program at the Cypress Bridge wellfield. However, on-ground inspection and evaluation of monitored wetlands has been recently conducted by SWFWMD. For this reason, wetland evaluations at the Cypress Bridge wellfield are shown on Figure 3-123. The figure indicates that wetlands in and close to the wellfield are for the most part in relatively good health. However, several wetlands just to the north in the Saddlebrook development have been ranked as either impacted or severely impacted. Activities associated with the Saddlebrook development may have contributed to these impacts.

It is significant that a great number of the wetland monitoring stations depicted in Figure 3-124 have been studied for more than ten years as part of long-term monitoring programs providing

environmental information for water use permits. WUP monitoring reports document changes in environmental conditions in individual wetlands during the duration of monitoring. A detailed study of these reports indicates that for nearly every wetland in Pasco County presently rated moderately to severely impacted in Figure 3-124, a clear decline in wetland health occurred during the course of monitoring. More specifically, many wetlands that were once healthy in or near the Starkey, North Pasco Regional, Cross Bar Ranch, and Cypress Creek wellfields have declined in health to the degree that they are now ranked as "moderately to severely impacted".

In Hillsborough and Pinellas counties, ground-water production at several regional wellfields, including the Eldridge-Wilde, Cosme-Odessa, and Section 21 wellfields, pre-dates on-ground monitoring programs by many years. Further, in parts of the Hillsborough and Pinellas counties, considerable development had begun to take place before active wetland monitoring programs were established in the 1970s and 1980s. Because of historic ground-water withdrawal and historic land use alterations, cause and effect relationships for changes in wetland health are often less clear than in other areas of the Northern Tampa Bay WRAP area.

In far northwestern Hillsborough and northeastern Pinellas counties, SWFWMD has monitored Eldridge-Wilde wellfield wetlands since the early 1970s (Courser, 1973). There is no known wetlands surveillance program being performed by others at the Eldridge-Wilde wellfield. Water production at the wellfield began in 1956, and increased during the 1960s. Initial investigations of this wellfield by SWFWMD in the 1970s described a number of dehydrated wetlands accompanied by biological impacts, including muck shrinkage, leaning trees, and invasion of terrestrial plants and fire. A limited number of observations suggested that impacts decreased at a short distance from the wellfield. SWFWMD has examined historic aerial photography which indicates that wetland were in good health in the 1940s, but had deteriorated considerably by the early 1970s (SWFWMD, 1982a; Rochow and Rhinesmith, 1991). Observations of the wetlands at Eldridge-Wilde during the 1980s and 1990s have indicated that the majority of wetlands remain dehydrated. Wetland impacts initially observed during the 1970s remain and in some cases have worsened. Most historic wetlands have progressed considerably toward upland ecological systems. As in most other cases, not all wetlands in the wellfield are severely impacted. Some wetlands recognized as "Impacted" or "Normal to slightly impacted" are

apparent in eastern and western wellfield areas. SWFWMD's ranking of wetlands at the Eldridge-Wilde wellfield appears in Figure 3-123.

Wetlands throughout northwestern Hillsborough County have been monitored for nearly fifteen years by Water and Air Research, Inc. for water use permit purposes (Water and Air Research, Inc. 1992; HSW Environmental Consultants, Inc. and Water and Air Research, Inc. 1995). SWFWMD's program of wetland monitoring in northwestern Hillsborough County for the most part dates from the late 1980s. As noted previously, water production from the Cosme-Odessa and Section 21 wellfields predates monitoring by both programs by many years. Additionally, land use changes have taken place over the years in the vicinity of the two wellfields that complicate analysis of cause-and-effect relationships in the area. SWFWMD's wetland monitoring program for northwestern Hillsborough County is depicted in Figure 3-123; the WUP monitoring program is shown in Figure 3-124. Examining the figures together indicates a considerable number of "Moderately or severely impacted" wetlands in and around the Cosme-Odessa and Section 21 wellfields. Monitoring by SWFWMD and others indicates that low water levels are an important factor in poor wetland health in this general area. An examination of aerial photography by SWFWMD for the Section 21 wellfield shows that healthy wetlands existed in this area in the 1940s, but that considerable deterioration in wetland health occurred a few years after Section 21 wellfield ground-water withdrawals began in the early 1960s. The impacted wetlands at the Section 21 wellfield have remained at this level of health during the period of SWFWMD's observation in the 1980s and 1990s. Moderately and severely impacted wetlands can also be found elsewhere in northwestern Hillsborough County. In these locations the wetlands are usually in areas where land use has changed considerably. In contrast to the wetlands just discussed, impacted wetlands as recognized in Figure 3-123 are scattered in distribution in northwest Hillsborough County. "Normal or slightly impacted" wetlands shown in both figures are common to the area north of Section 21, in the area of the Northwest Hillsborough Regional Wellfield, and in various other parts of the county.

Wetlands at the Morris Bridge wellfield have been monitored by SWFWMD since 1977. Water production from the wellfield began in 1978. SWFWMD's wetland monitoring sites are depicted in Figure 3-123. Wetland monitoring for water use permit purposes commenced in 1985, or several years after initial ground-water withdrawal (Biological Research Associates, Inc. 1994).

Figure 3-124 shows the WUP monitoring sites. Adverse impacts to the wellfield wetlands were noted by SWFWMD's monitoring program not long after water withdrawal began and were attributed to reduced wetland hydroperiods. Deterioration in wetland health at the wellfield has resulted in several of SWFWMD's wetlands at the wellfield now being assessed as "Impacted or severely impacted". As shown in Figure 3-123, "Normal or slightly impacted" wetlands can be found elsewhere in or immediately around the Morris Bridge wellfield. WUP monitoring has likewise shown wetland deterioration attributable to abbreviated hydroperiods. Figure 3-124 shows that "Moderately to severely impacted" wetlands exist in the same general area of the Morris Bridge wellfield as shown by SWFWMD to be an area of wetland impacts. Average annual ground-water withdrawals were reduced at Morris Bridge in the late-1980s, and monthly withdrawals became more variable. Since that time, SWFWMD's monitoring indicates that there has been a stabilization of earlier adverse vegetational trends, and in some instances, an improvement in wetland health. A similar stabilization or improvement in wetland health has not been noted at other regional wellfields where withdrawals have been relatively stable from month to month, and where large reductions in average annual ground-water withdrawals have not occurred. A discussion summarizing monitoring by SWFWMD and others at this wellfield and other regional wellfields is found in Rochow (1994).

The Cone Ranch property is located in the far northeastern corner of Hillsborough County. No ground-water withdrawals for public supply purposes have yet occurred at the Cone Ranch property. However, in anticipation of future ground-water withdrawals, wetlands have been monitored since the late-1980s (Henigar & Ray, Inc. and Center For Wetlands, 1993). SWFWMD has not established a wetland monitoring program at the Cone Ranch property. However, as in the case of the Cypress Bridge wellfield area, on-ground inspection and evaluation of wetlands monitored by others at Cone Ranch has been recently conducted by the District, so wetland evaluations in this area are shown in Figure 3-123. The figure indicates that wetlands at Cone Ranch are generally either "Impacted" or "Normal to slightly impacted". The Cone Ranch lands have been altered considerably over the years and have been improved considerably for cattle grazing.

In the Hillsborough County area, loss in wetland health has been documented at a number of wetlands during the approximate twelve-year duration of WUP environmental monitoring in this

area. There is some evidence that the decline in health of many Hillsborough County wetlands during the period of WUP monitoring has not been as dramatic as in Pasco County. This may be attributed to the fact that many impacts, especially in northwest Hillsborough County, pre-date programs designed to monitor wetland health.

It is evident from the preceding discussion that there are clear patterns in the spatial distribution of moderately to severely impacted wetlands in the Northern Tampa Bay WRAP. The experience gained by SWFWMD's monitoring program, as well as the work of others, has shown that there is a strong tendency for these impacts to occur in and around regional wellfields, and sometimes to stretch from one regional wellfield to another. It was also noted that many of the wetlands depicted in Figures 3-123 and 3-124 have long monitoring histories dating back 10 to 20 years that are described in District and WUP reports. Deterioration in wetland health has been observed and described in detail for many of these monitored wetlands. For several regional wellfields, it has been possible to detect that wetland deterioration followed shortly after initial ground-water withdrawal. The deterioration documented in virtually all cases is associated with a dewatering of the wetlands. Once adverse impacts begin in this manner, a downhill trend in wetland health typically occurs over subsequent years. The result of this downhill trend is reflected in the pattern of deteriorated wetland health shown in Figures 3-123 and 3-124.

Model Analysis

The best available tool to evaluate regional effects of ground-water withdrawals and potentiometric drawdown is a regional numerical ground-water flow model. The benefits of a regional numerical model analysis include 1) the assistance in the understanding of relationships between various hydrogeologic parameters; 2) the ability to "infill" areas where data is missing, based upon the best available information; 3) the assistance in the determination of where further data collection is needed, and 4) the ability to test the effect of a future stress on the hydrologic system.

The statistical and data analysis presented thus far forms the basis of the conceptual model summarized in the next chapter. Because the regional model must be established using regional

(i.e. averaged) values, the local analyses presented earlier (and others) must be used in conjunction with the model to best describe the Northern Tampa Bay WRAP area. To best interpret the model results, the results of the numerical model must be combined with an understanding of the hydrogeologic system, raw data analysis, and empirical models. With these three tools, the best approximation of the regional extent and magnitude of impacts from Upper Floridan aquifer potentiometric drawdown can best be assessed.

4.4 Summary

Ground-water withdrawals are the principal cause of long-term declines in the potentiometric surface of the Upper Floridan aquifer within the Northern Tampa Bay WRAP area. These drawdowns are reflected in the surface-water features and the surficial aquifer because of the leaky nature of the upper confining layer. These effects are observed to the greatest degree in lakes and wetlands, but are also seen in streams and the surficial aquifer. Because most lakes and wetlands are formed through a solution feature origin, they often have the most direct connection to the Upper Floridan aquifer. However, because of the karst nature of the area, effects of ground-water withdrawals are seen throughout the surficial aquifer system to varying degrees. The effects of ground-water withdrawals are largest near the source of water production, but appear on a more subregional basis because of the overlapping cones of depression from the many wellfields in the region, and because of the growth of surficial aquifer drawdowns.

Several other factors besides ground-water withdrawals can cause long-term or short-term effects, which can be significant in localized areas. Urban development and drainage practices have caused significant impacts to many lakes and wetlands, but the impacts are limited to the areas of extensive alterations. Rainfall is and will continue to be an important parameter in the water budget of lakes. However, low rainfall periods are periodic, and the effects have not been long-term in the past.

CHAPTER 5 - HYDROLOGIC MODELS

Water budget analyses and numerical models are used to better understand the hydrologic system, quantify relationships, and to predict changes to the system in response to stress. The term "model" refers to any representation of a real system (Fetter, 1980). Our understanding of the regional hydrogeologic system is expressed in the development of a conceptual model that provides an interpretation of the physical framework, water resource trends, and the cause-and-effect relationships on the hydrologic system.

The simplest models are analytical models, or general equations that are utilized to express basic components of the water resources. Analytical solutions are difficult to achieve for complex problems because they require simplified assumptions about the system, such as homogenous, isotropic aquifers and constant water tables. Numerical models are used to handle these complex systems, and provide a more complete assessment of the water resources. Nonetheless, numerical models are applied using a given set of conditions or assumptions that approximate the natural state of the system. These assumptions are necessary because a complete understanding of the system is never attained, certain data on the system are often unavailable, and future conditions impart some degree of uncertainty.

The models developed for the ground-water system of the Northern Tampa Bay WRAP area include a conceptual model, a water budget, a ground-water flow model, and a sharp interface, coupled freshwater-saltwater model. The conceptual model consists of a description of our understanding of the basic hydrogeology of the Northern Tampa Bay WRAP area, based upon all available data and analyses. The water budget model is a simple analytical solution that is used to estimate inflow and outflow across boundaries, and solve implicitly for vertical leakage between aquifers in the Northern Tampa Bay WRAP region. Historical changes in the flow system are important since the amount of coastal discharge or outflow affects the rate of seawater intrusion. The change in the amount of leakage between the aquifers is important to determine the amount of water that is obtained from the surficial system.

To determine and measure more complex changes in the ground-water flow system, two types of numerical models were developed: a ground-water flow model and a sharp interface model. The ground-water flow model provides an instrument to increase our understanding of the regional flow system and to provide predictive results due to changes in ground-water withdrawals. The sharp interface model is applied to estimate the rate of movement of seawater under present and future ground-water withdrawal conditions. The sharp-interface model results are discussed in Volume Two of this report.

Future water availability in the Northern Tampa Bay WRAP area was assessed by examining our conceptualization of the hydrogeologic system, the cause-and-effect relationships on the hydrologic system, and through the use of numerical models to estimate both current and future regional effects of continued ground-water withdrawals on lakes, wetlands, and seawater intrusion.

5.1 Conceptual Model

The initial step in modeling complex hydrogeologic systems involves the development of a conceptual model. The purpose of conceptual model is to simplify the field problem and organize the associated field data so that the system can be analyzed more readily (Anderson and Woessner, 1992). In the Northern Tampa Bay WRAP area, development of the conceptual model involved an extensive review of published literature and the synthesis of exploratory drilling data from 36 well nests and four deep Upper Floridan aquifer wells installed during the data collection phase of the project. Much of the following information summarizes material presented in Chapter 2.

The Northern Tampa Bay WRAP area is underlain by a multi-aquifer system: a near-surface unconfined surficial aquifer and an underlying semi-confined Upper Floridan aquifer. The two aquifers are separated by a moderate-to-highly leaky clay confining layer that varies from less than one foot to several tens of feet in thickness. The semi-confining layer between the two aquifers is discontinuous and breached by karst features such as sinkholes and solution conduits which produce highly variable confinement over the project area. On a regional basis, the semi-

confining layer generally thins toward the north, except along the Brooksville Ridge physiographic feature.

The surficial aquifer is primarily comprised of quartz sand, silt, and minor clay. It ranges in thickness from less than 10 feet to greater than 100 feet in paleokarst depressions. The permeability of the surficial aquifer is low when compared to the Upper Floridan aquifer. Transmissivity generally averages less than 1,200 ft^2/day (SWFWMD, 1993). Recharge to the surficial aquifer primarily consists of the infiltration of rainfall. Ground-water use from the aquifer is minor and is limited to small diameter wells used for lawn irrigation and watering livestock. Water levels within the aquifer annually fluctuate less than five feet primarily in response to rainfall events, except near areas of high ground-water withdrawals from the Upper Floridan aquifer, where surficial aquifer water levels are affected by water level declines in the underlying Upper Floridan aquifer.

Recharge to the Upper Floridan aquifer occurs through vertical leakage from the surficial aquifer. The amount of leakage is dependent on hydraulic head differentials between the surficial and Upper Floridan aquifers and the integrity of the semi-confining layer. Hutchinson (1984) reports that in the tri-county area of Hillsborough, Pasco, and Pinellas Counties, net recharge to the Upper Floridan aquifer averaged about five inches annually prior to development. In the presence of ground-water withdrawals, this amount increased to nine inches. Over the entire Northern Tampa Bay WRAP area, net recharge has increased from less than four inches/year prior to development to greater than seven inches/year during 1989-1990.

The Upper Floridan aquifer consists of a continuous series of carbonate units that include portions of the Tampa Member of the Arcadia Formation (Hawthorn Group), Suwannee Limestone, Ocala Limestone, and the Avon Park Formation. The base of the Upper Floridan aquifer is the first occurrence of vertically persistent evaporites found in the lower portion of the Avon Park Formation. Over most of the project area, the Upper Floridan aquifer is semi-confined or under artesian conditions. Thickness of the aquifer ranges from 700 feet in southwest Hernando County to greater than 1,100 feet in central Hillsborough County. Transmissivity varies from 18,700 to 1,200,000 ft^2/day, generally several orders of magnitude more transmissive than the surficial aquifer (Dames and Moore, 1988).

The Upper Floridan aquifer contains two major producing zones, the upper production zone in the Tampa/Suwannee units and a lower production zone in the highly fractured dolomites of the Avon Park Formation. Based upon analysis of specific capacity data from four deep test borings completed for this project, about one-quarter of ground-water flow originates from the upper zone and the remainder from the lower zone. On a regional scale, the Ocala Limestone, a clayey, micritic limestone that lies between these two zones, tends to be much lower in permeability when compared to the rest of the carbonate units. However, locally the Ocala Limestone can exhibit large permeability due to secondary fractures or solution features. A conceptual diagram of the hydrogeologic system is shown in Figure 5-1.

5.2 Water Budget Analysis

A water budget equation expresses the basic components of the hydrologic cycle. The budget assesses the lateral flows into and out of the aquifer system and solves for vertical leakage or change in storage. In the Northern Tampa Bay WRAP area, water budgets were developed for both the surficial and Upper Floridan aquifers. The boundaries for this analysis coincide with the central portion of the Northern Tampa Bay WRAP area (1,500 of 1,800 square miles). It is useful to develop water budgets in the project area to show the relationship between ground-water withdrawals, changes in leakage between the aquifers, and coastal discharge. The budgets also provide information on inflows and outflows for use in the development of subsequent numerical flow models.

To evaluate historical changes in flows that have occurred since ground-water withdrawals began, the Upper Floridan aquifer water budgets were completed for both predevelopment and contemporary conditions. The period used for numerical flow model calibrations, June 1989 to May 1990, was used to represent contemporary conditions. The surficial aquifer budget was only produced for contemporary conditions, since predevelopment hydrologic information is not readily available for this system. The water budget analysis will be used for comparison to the numerical flow model analysis (Section 5.2). Because the numerical model simulates an area somewhat smaller than the entire Northern Tampa Bay WRAP area (Figure 5-3), the smaller 1,500 square-mile model area will be used for the basis of the water budgets.

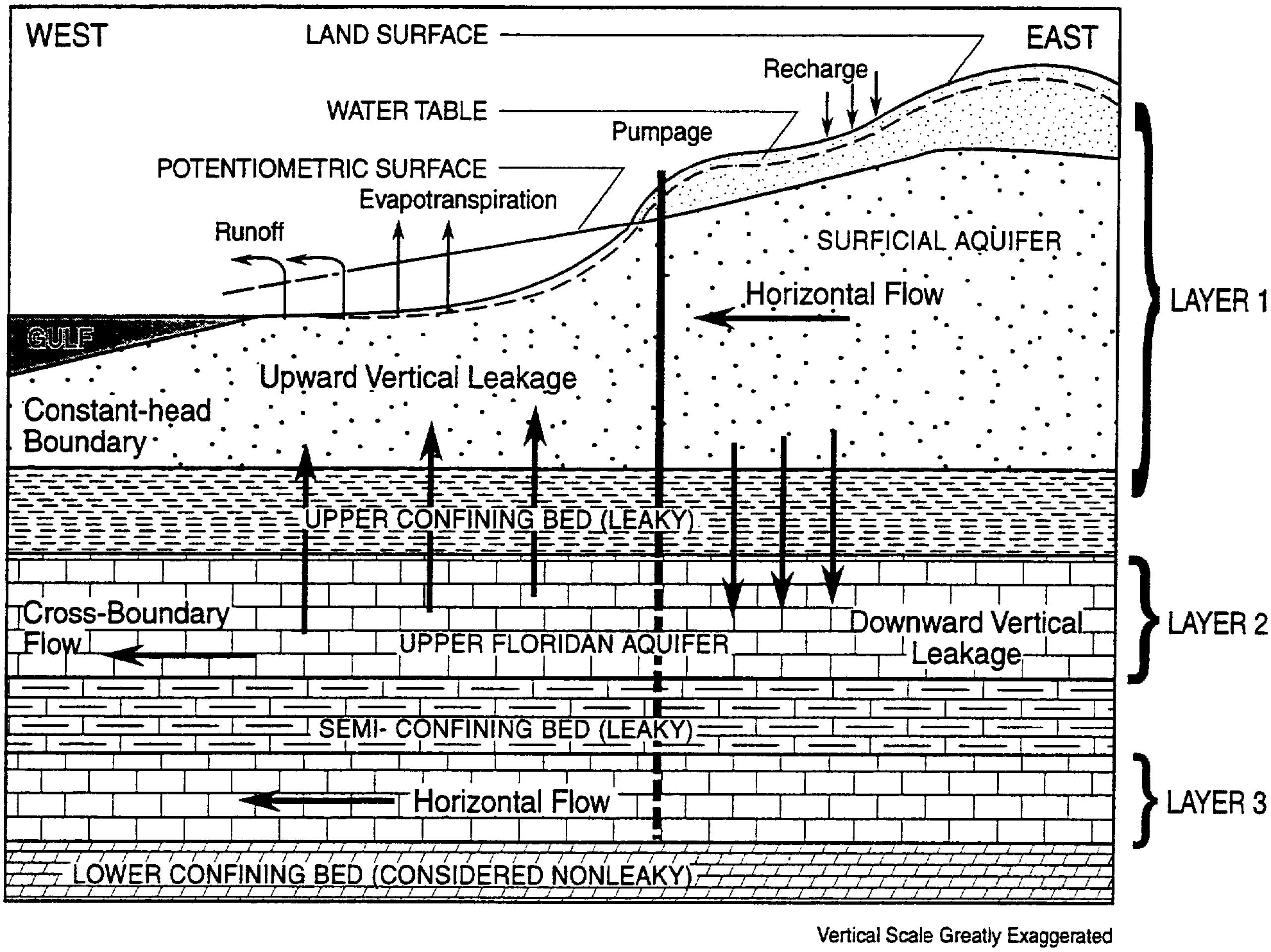


Figure 5-1. Conceptual diagram of Northern Tampa Bay Flow System (modified from Hutchinson, 1984).

The general equation for a water budget states that the sum of all inflows must equal the sum of all outflows if there is no change in storage in the system. The components of the general equation vary slightly, depending if the equation is used for the surficial or the Upper Floridan aquifers. To simplify the solution for each aquifer, steady-state conditions are assumed in each instance so that there are no changes in storage.

5.2.1 Surficial Aquifer Budget

The water budget for the surficial aquifer accounts for rainfall, surface water runoff, evapotranspiration (ET), ground-water inflow and outflow across boundaries, leakage to the Upper Floridan aquifer, and ground-water withdrawals. Other components include artificial recharge to the surficial aquifer in the form of imported irrigation water and sewage effluent. Estimates of known quantities are entered into the water budget equation to solve for leakage. The water budget equation for the surficial aquifer is:

(1) $\Delta S = R + OR + I - ET - SR - O - Q - L$

Rearranging to solve for Leakage (L)

(2) $L = R + OR + I - ET - SR - O - Q - \Delta S$

Where:

ΔS = Change in Storage
R = Rainfall
OR = Other Recharge
I = Boundary Inflow
ET = Evapotranspiration
SR = Surface Runoff
O = Boundary Outflow
Q = Ground-Water Withdrawals
L = Net Leakage to the Upper Floridan aquifer

Sources of inflow to the surficial aquifer consist primarily of rainfall and other sources of recharge. Mean annual rainfall for the Northern Tampa Bay WRAP area is approximately 52 inches with about 60 percent of rainfall occurring in the four month summer period from June through September. The average rainfall for the Northern Tampa Bay WRAP area from June 1989 through May 1990 was 48.6 inches. This average is based upon records from 73 stations

throughout the study area. Other sources of recharge to the surficial aquifer include about 52 mgd of potable water irrigation, public wastewater discharge, and discharges from other water users. The amount of artificial recharge averages 0.6 inches/year across the entire Northern Tampa Bay WRAP area for the 1989/1990 budget period.

Sources of outflow from the hydrologic system include ET, surface water runoff, ground-water withdrawals, and leakage to the Upper Floridan aquifer. Baseline ET losses range from 25 to 35 inches/year (Tibbals, 1978). Additional ET is lost from the water table, and maximum potential ET is in the range of 46 to 52 inches (Heaney and others, 1986). Since actual ET is difficult to measure in the field, the rate was approximated using pan evaporation data. The following formula was applied to convert pan evaporation to evapotranspiration:

(3) $ET = K1 \times K2 \times PE$

Where:

ET = Evapotranspiration (inches/year)
K1 = Coefficient that converts pan evaporation into potential ET
K2 = Coefficient that converts potential ET into ET
PE = Pan evaporation (inches/year)

In Florida, Gibney (1983) suggests a value of 0.70 for K1 and 0.89 for K2. Pan evaporation data from Lake Padgett, located in southern Pasco County, averaged 54.5 inches for the period of analysis (1989-1990). Applying this evaporation to Equation 3 above yields an actual ET of 34 inches/year. Because the coefficient values suggested by Gibney are averages for Florida, and much of the Northern Tampa Bay WRAP area is an area of high water table, this estimate is probably low. Dames and Moore (1988) estimated actual ET to range from 35 to 40 inches in the Northern Tampa Bay WRAP area.

Surface water runoff was quite variable for the 1989/1990 period throughout the project area, ranging from less than 0.5 inches/year for the Pithlachascotee River Basin to nearly 11 inches/year for the Rocky Creek Basin. A weighted average by area, which includes adjustments for several ungaged watersheds (Hollin Creek, Duck Slough, coastal and internally drained basins), Sweetwater Creek, coastal basins, and parts of the Hillsborough River, is 4.4

inches/year of surface water runoff. Hutchinson (1984) reported an annual-average of ten inches/year of runoff under nonpumping conditions. However, individual stream gages recorded an average of 30 percent of the long-term recorded runoff during the June 1989 to May 1990 period.

The amount of ground water withdrawn from the surficial aquifer is small when compared to the major components of rainfall and ET. Based upon estimates of rural water use in the area, approximately 13 mgd or 0.2 inches/year of water was withdrawn from the surficial aquifer during 1989. Boundary inflows and outflows are negligible especially when much of the project boundary is along flow divides and permeability of the aquifer is low. The net effect is that the boundary inflows and outflows cancel out each other.

Net downward leakage from the surficial to the Upper Floridan aquifer is a major component of outflow. It is also the most difficult to calculate by itself unless approximated by more complex numerical models. However, if the other elements in the water budget are known, the amount of net leakage over the entire area can be estimated. For the Northern Tampa Bay WRAP area, a steady-state, average annual hydrologic budget for the surficial aquifer for the period June 1989 to May 1990 is estimated as follows:

$$
\begin{aligned}
(4) \qquad L &= R + OR - ET - SR - Q \\
L &= 48.6 + 0.6 - 34 - 4.4 - 0.2 \\
L &= 10.6 \text{ inches/year}
\end{aligned}
$$

The leakage value becomes 7.6 inches/year if an ET value of 37 inches is used, which is the average between the ET calculated by Equation 3 above and the high value suggested by Dames and Moore (1988). Therefore, the leakage estimate can be assumed to be between 7.6 and 10.6 inches/year for the Northern Tampa Bay WRAP area. Because of the low rainfall conditions in the 1989 to 1990 period, the assumption of zero change in storage may also add some uncertainty to this estimate.

5.2.2 Upper Floridan Aquifer Budget Components

The water budget equation for the Upper Floridan aquifer differs slightly from the one used for the surficial aquifer. The major components of inflow include net vertical leakage from the surficial aquifer and boundary inflow. The outflow portion of the equation includes ground-water withdrawals, springflow, and boundary outflow. A series of flow net analyses were employed to derive boundary inflow and outflow for the project area. The water balance equation for the Upper Floridan aquifer is as follows:

(5) $\Delta S = L + I - Q - SF - O$

Where:

ΔS = Change in Storage
L = Net Leakage to the Upper Floridan Aquifer
I = Boundary Inflow
Q = Ground-Water Withdrawals
SF = Springflow
O = Boundary Outflow

If steady-state conditions are assumed, then net leakage (L) to the Upper Floridan aquifer can be determined from Equation 5. As discussed previously, water budgets were produced for the Upper Floridan aquifer for predevelopment and contemporary conditions. The most recent budgets included May and September, 1989 and May 1990 periods since United States Geological Survey (USGS) potentiometric surface maps were published during these time frames.

Ground-water withdrawals for the predevelopment analysis were assigned a value of zero. During recent periods, ground-water withdrawals were obtained from metered data and estimates of agricultural use. Over 80 percent of the total ground water withdrawn from the Upper Floridan aquifer is metered in the project area. Additional information regarding ground-water use in the Northern Tampa Bay WRAP area is found in Chapter 2.

Flow net analyses were used to quantify boundary flow. The boundary flow quantities were estimated for lateral flow into the project area along a portion of the eastern side of the Northern

Tampa Bay WRAP area where flow enters the region from the Green Swamp potentiometric high. Lateral outflow was estimated along the Gulf of Mexico coastal margin and near Tampa Bay. Flows were calculated by the application of Darcy's Law in the following form:

(6) $Q = T \times I \times l$

Where:

Q = ground-water flow across boundary (gpd)
T = transmissivity (gpd/ft)
I = hydraulic gradient (dimensionless)
l = horizontal length along lateral boundary (ft)

To calculate boundary inflows and outflows, flow lines were drawn on potentiometric surface maps. The lines were constructed, where possible, to bracket sections of equal distance between equipotential contours. The transmissivity for each section between flow lines was estimated using the numerical flow model distribution. The hydraulic gradient was measured across the boundary for each section along with the boundary length.

USGS potentiometric surface maps of predevelopment conditions (Johnston and others, 1980), May 1989 (Barr, 1989), September 1989 (Knochenmus and Barr, 1990), and May 1990 (Knochenmus, 1990) were used in the flow net analysis. The more recent time periods were chosen because ground-water withdrawal data is available during these years.

Potentiometric surface maps are produced semi-annually by the USGS for May and September of each year. Annualized lateral flows were derived by averaging analyses for May and September. On a regional scale, seasonal fluctuations in the Upper Floridan aquifer potentiometric surface are small due to relatively consistent ground-water withdrawals throughout the year from public supply wellfields and the leaky nature of the aquifer system.

Changes in Upper Floridan aquifer head during the annual period generally average less than a few feet. Review of 51 Upper Floridan aquifer wells in the project area revealed an average change of 0.3 feet from May 1989 through May 1990. Based on the equation,

(7) $\Delta S = SC \times A \times \Delta H$

where:

ΔS = storage in aquifer (ft^3)
SC = storage coefficient (dimensionless)
A = aquifer area (ft^2)
ΔH = change in head (ft)

it can be demonstrated that the annual change in storage is very small. An average one-foot change in head in the entire 1,500 square-mile project area would result in a loss of storage in the aquifer of 860,000 gpd for a storage coefficient of 0.001. This amount of change in storage is less than one-half of one percent of the annual ground water withdrawn in the project area.

The results of the water budget analysis for the predevelopment conditions, May and September 1989, and May 1990 are presented in Table 5-1. A steady-state, average annual hydrologic budget for the Floridan aquifer for the period June 1989 to May 1990 is estimated as follows:

(8) $\Delta S = L + I - Q - SF - O$

$\Delta S = 7.7 + 0.6 - 4.0 - 2.5 - 1.7$

$\Delta S \approx 0$

Table 5-1. Water budget for the Upper Floridan aquifer in the Northern Tampa Bay WRAP area (mgd (inches)).

Period	Inflow	Outflow	Ground-water Withdrawals	Springflow	Leakage
Predevelopment	40 (0.6)	119 (1.7)	0	197 (2.8)	276 (3.9)
May 1989	49 (0.7)	122 (1.7)	369 (5.2)	170 (2.4)	612 (8.6)
September 1989	46 (0.6)	122 (1.7)	208 (2.9)	187 (2.6)	471 (6.6)
May 1990	40 (0.6)	127 (1.8)	288 (4.0)	180 (2.5)	555 (7.8)
Average 1989	48 (0.7)	122 (1.7)	289 (4.0)	179 (2.5)	542 (7.6)

Coastal discharge or outflow has varied little since predevelopment. This is significant since diminishing coastal discharge results in seawater intrusion on a regional basis. Additionally, lateral inflow has also remained relatively invariant since predevelopment. These results

generally confirm our understanding of the system in that vertical leakage from the surficial aquifer largely attenuates regional lowering of the Upper Floridan aquifer potentiometric surface. Further evidence of this conceptualization is demonstrated by the near doubling of net recharge to the Upper Floridan aquifer since predevelopment. Figure 5-2 displays the linear relationship between net recharge to the Upper Floridan aquifer and ground water withdrawn. Under average annual conditions, net recharge has increased from less than four inches/year during predevelopment to over seven inches/year during the 1989-1990 period in the project area. The 1989-1990 leakage calculated in the Floridan aquifer water budget corresponds to that calculated in the surficial aquifer when 37 inches of ET are used. This may suggest that the higher value of ET is justified.

5.3 Numerical Ground-Water Flow Modeling

To simulate more complex relationships within the ground-water system, a numerical flow model was developed for the Northern Tampa Bay WRAP area using the MODFLOW code (McDonald and Harbaugh, 1988). The purpose of developing the flow model included improving our understanding of the hydrogeologic system, identifying needs for future data collection, and evaluating the regional effects of current and future ground-water withdrawals on the ground-water and surface-water systems. A complete description of the flow model is contained in a separate draft publication entitled "Computer Model of Ground-Water Flow in the Northern Tampa Bay Area: Southwest Florida Water Management District" dated August 1993.

After a conceptual model is developed, a flow model is constructed and calibrated to a known set of conditions, usually field measured heads. The calibration and response of the model are evaluated by simulating a different set of hydrologic conditions.

5.3.1 Numerical Model Description

With some exceptions, the boundaries of the Northern Tampa Bay flow model correspond to the project area (Figure 5-3). This area essentially coincides with the Central West-Central Florida Ground-Water Basin, but also contains part of the Northern West-Central Florida Ground-Water Basin (Figure 1-2). The flow model is quasi-three dimensional, and consists of three aquifer

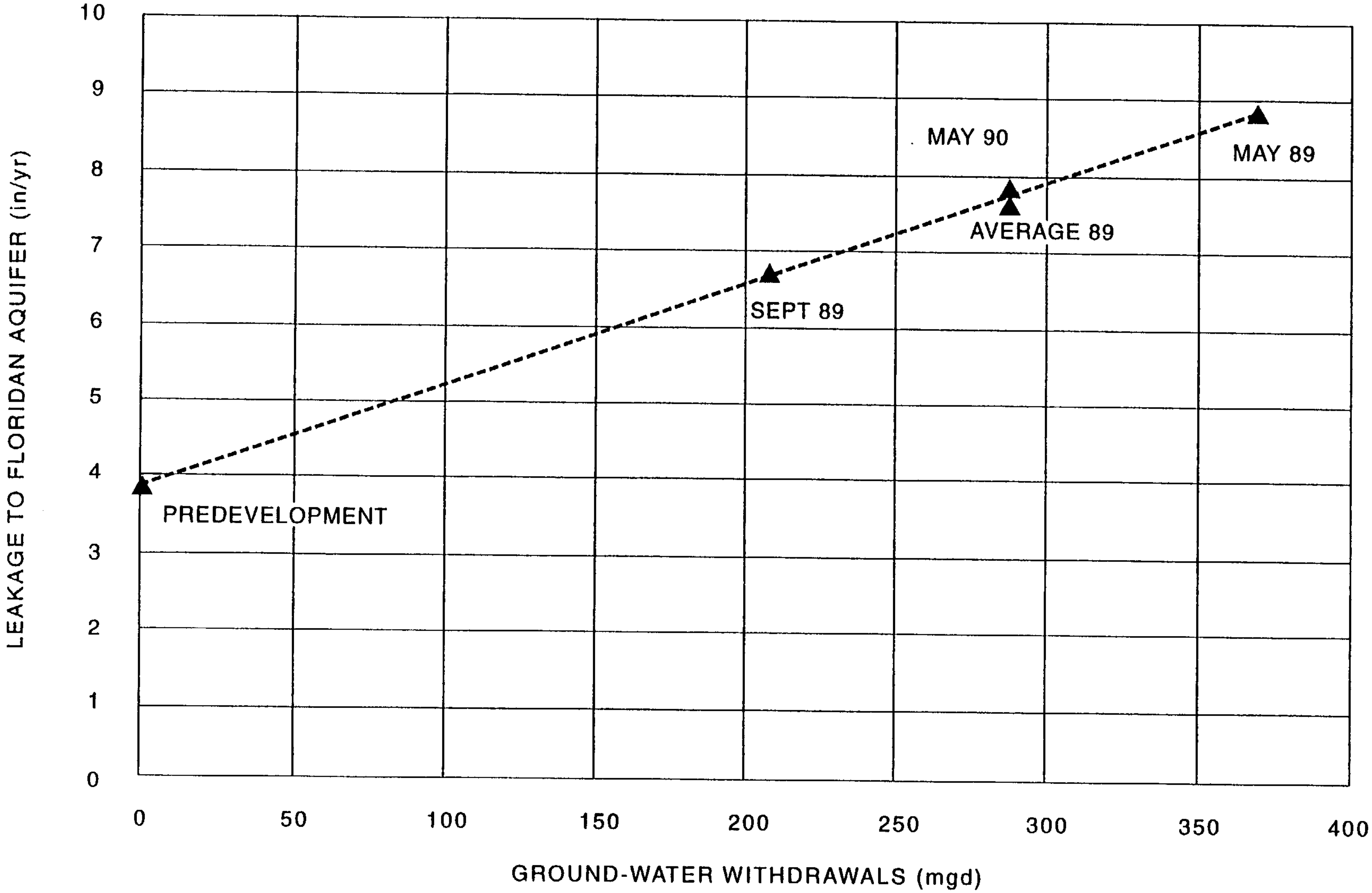


Figure 5-2. Floridan aquifer recharge vs. ground-water withdrawals in the Northern Tampa Bay WRAP area.

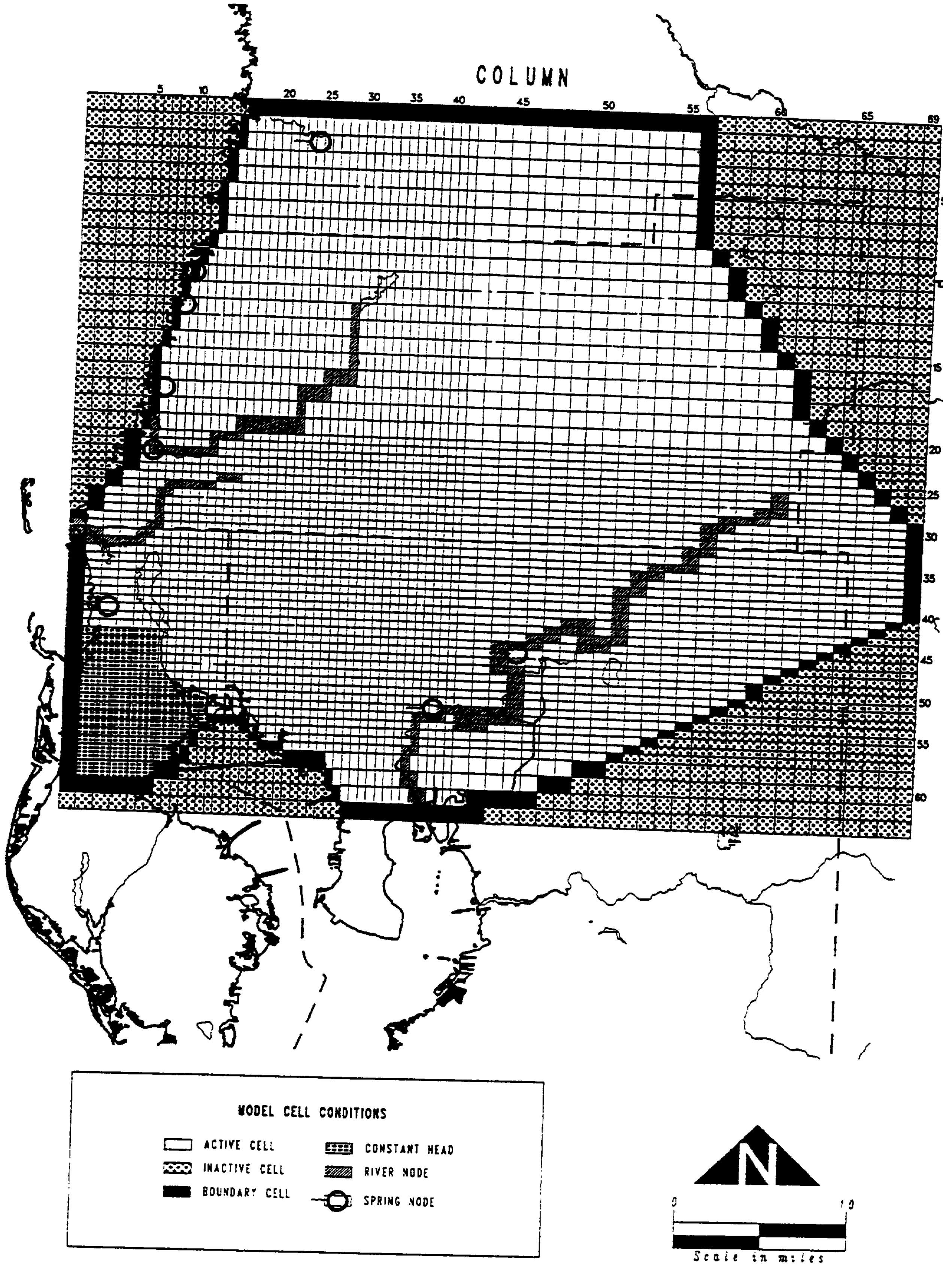


Figure 5-3. Northern Tampa Bay WRAP area flow model grid.

layers: the surficial aquifer (layer 1), the Tampa/Suwannee producing zone (layer 2), and the Avon Park producing zone (layer 3). The model grid is a north-south oriented rectangular mesh that contains 69 columns and 62 rows of variable grid spacing. The grid cells range from one-quarter to one mile in size. The finer discretized grid is located within the tri-county area where there is a high density of ground-water withdrawals from public supply wellfields. A detailed discussion of boundary conditions, input parameters, and assumptions is given in the model report (SWFWMD, 1993).

5.3.2 Water Use

The Upper Floridan aquifer is the primary source of ground-water withdrawn in the Northern Tampa Bay region. Surficial aquifer withdrawals occur primarily from small-diameter wells that are used for lawn watering or livestock watering and thus were deemed insignificant to warrant their inclusion in the regional model. The major use of ground water in the Northern Tampa Bay area is for public supply. With the exception of the City of Tampa, all other municipal water supply for the region is derived from ground water. Figure 2-34, presented earlier, shows the location of the major municipal wellfields within the model area.

Table 5-2 presents a summary of water use in the Northern Tampa Bay region by use type for the model calibration period. Water use was tabulated by summing metered data and estimating non-metered agricultural use for the period. Metered data accounted for over 80 percent of total ground water withdrawn in the area. Agricultural water use was based upon estimates reported by SWFWMD (1992). Non-metered, non-agricultural water use was assumed to be SWFWMD permitted quantities.

All of the ground-water use in the Northern Tampa Bay model was assigned to the Upper Floridan aquifer. Ground-water withdrawal rates from the Upper Floridan aquifer were divided into two zones. The upper zone (layer 2) included well withdrawals from the Tampa/Suwannee portion of the aquifer and the lower zone (layer 3) incorporated well withdrawals that are completed into the highly permeable section of the Avon Park Formation. The well withdrawals were partitioned based on the total and casing depths of the wells, along with the average depths

of the upper and lower producing zones. Additional information regarding model water use can be found in the model report (SWFWMD, 1993).

Table 5-2. Estimated ground-water use in the Northern Tampa Bay area for 1989 and 1990 (mgd).

	1989 Estimated	1990 Estimated
Agriculture	29.9	31.7
Industrial	16.2	18.0
Mining	0.3	0.2
Public Supply	202.0	186.4
Recreational	10.6	11.4
TOTAL:	259.0	247.7

Total water use from the Upper Floridan aquifer was approximately 238 mgd for the period from June 1989 to May 1990, and 248 mgd for the 1990 calendar year. Public supply accounted for 179 mgd, or about 76 percent of ground water withdrawn from June 1989 to May 1990.

Agricultural irrigation represented about 29 mgd or 12 percent of ground water withdrawn. Industrial, mining and recreational users accounted for the remainder of ground water withdrawn during the period.

5.3.3 Model Calibration

The Northern Tampa Bay flow model was calibrated to steady-state, May 1989 conditions. Because of the transient nature of ground-water pumping in the area, steady-state conditions are never absolutely attained. However, public supply water use does peak during this period, and the month of May is a period of low antecedent conditions whereby nearly all rainfall enters the surficial aquifer as recharge. Therefore, this period was selected since it is a time of "near" steady-state conditions and observed water level maps of the Upper Floridan aquifer are readily available for matching head conditions.

The results of the May 1989 simulation for the surficial and Upper Floridan aquifers are shown in Figures 5-4 and 5-5, respectively. Calibration of the model was achieved by comparing model simulated values with contours of the observed surface. Additionally, water levels from selected monitor wells were compared to simulated head in the model cell that the well occupied. The calibration error criteria for simulated water levels was 2.5-feet average absolute error and 10-foot maximum nodal error to define an acceptable calibration match based upon the comparison of simulated cell values with kriged observed water levels.

In addition to the steady-state simulation, a transient calibration was performed from June 1989 to May 1990 using monthly periods of ground-water withdrawals, recharge, and evapotranspiration (ET) rates. Starting heads for the transient run were generated from the May 1989 steady-state simulation. Specific yield of the surficial aquifer was varied with a uniform storage coefficient utilized for layers two and three. Hydrographs were produced that showed the comparisons between simulated and observed water levels at 100 match points where monitor wells and model cells were in close proximity. The principal calibration criteria involved matching the observed seasonal trends in water levels.

After the flow model was calibrated, a simulation was conducted using annual stress periods from 1960 through 1989. The simulation was performed to evaluate how well the calibrated model represents the observed flow system. The model simulation included 30 stress periods of varying ground-water withdrawals, recharge, and ET. Comparisons were made between simulated and observed water levels in the Upper Floridan aquifer at 26 match points. Additional information regarding the Northern Tampa Bay flow model calibration can be found in the model report.

5.3.4 Evaluation of Historical Ground-Water Resources Development

The regional numerical flow model is a tool to demonstrate and assess the cumulative impacts associated with ground-water withdrawals throughout the Northern Tampa Bay WRAP area. As a demonstration of the historical cumulative effects of regional ground-water withdrawals, the following is a decade by decade presentation of aquifer drawdowns in the Northern Tampa Bay WRAP area as simulated by the regional flow model. The simulations are performed using

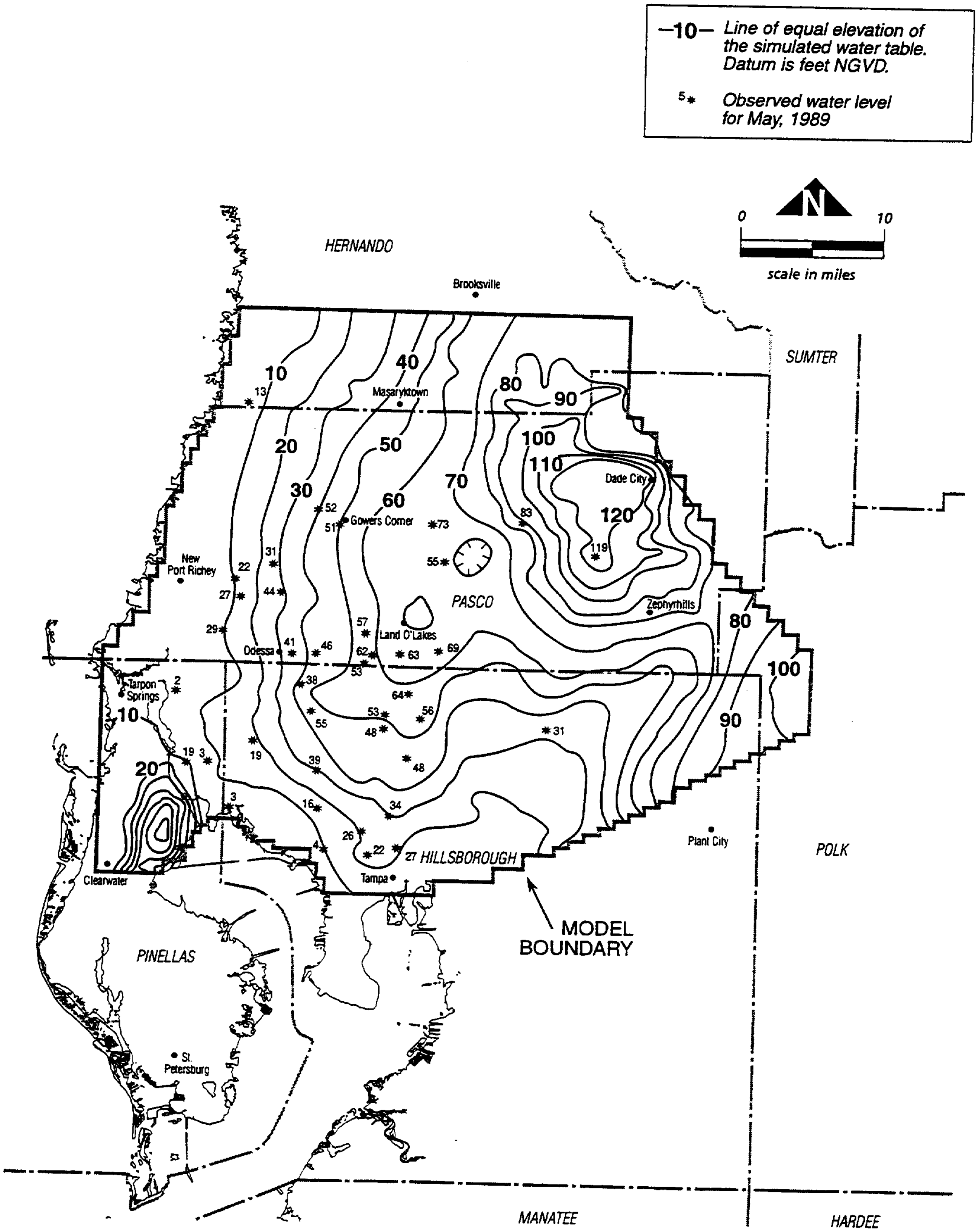


Figure 5-4. Simulated May 1989 water table using the Northern Tampa Bay model.

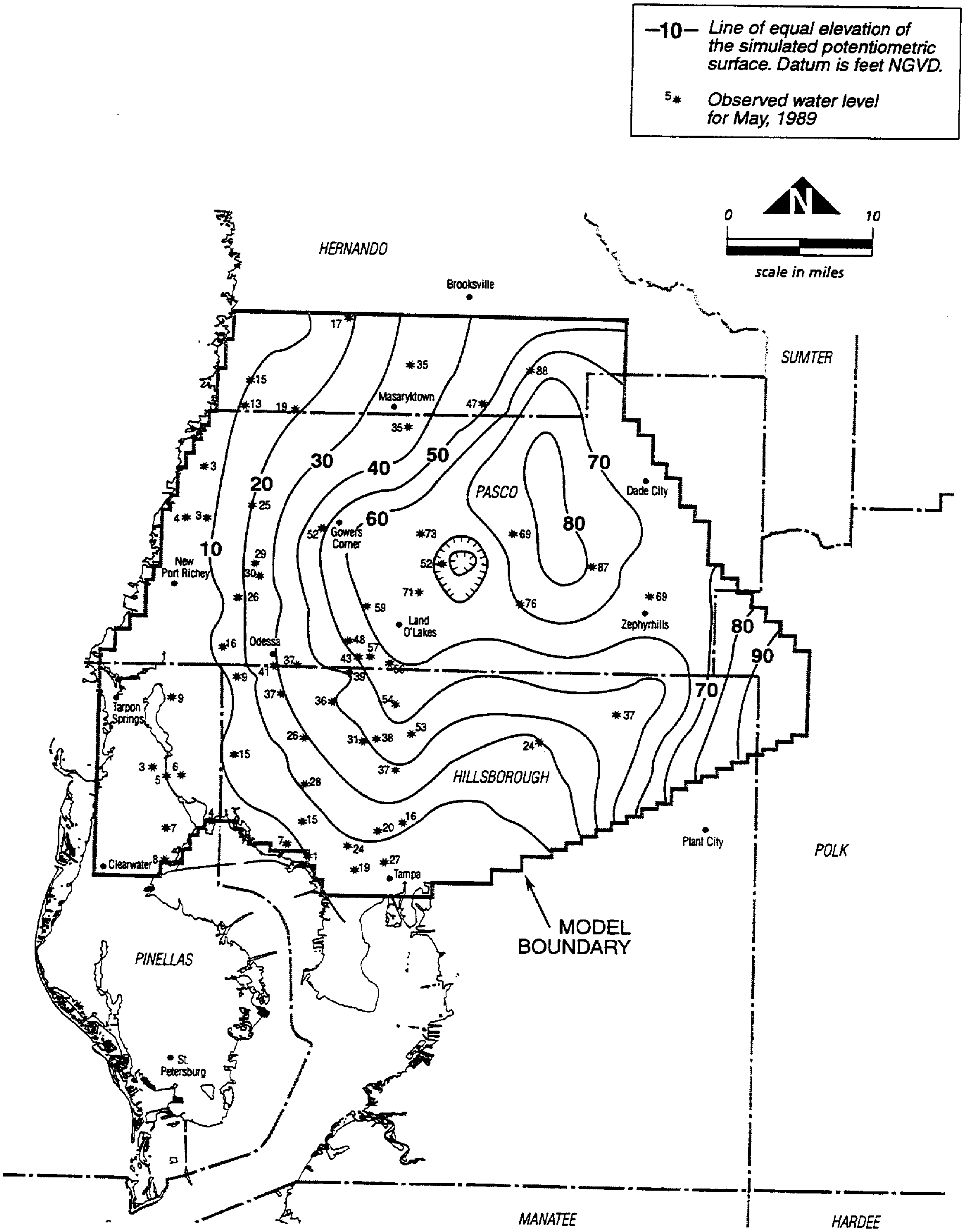


Figure 5-5. Simulated May 1989 potentiometric surface of the Upper Floridan aquifer using the Northern Tampa Bay model.

estimates of average ground-water withdrawals for the 1940s, 1950s, 1960s, 1970s, 1980s, and 1993 (current) conditions (Table 5-3). It must be understood that the following scenario results are based on a regional numerical flow model, and represent estimations of average drawdowns under averaged conditions. Local heterogeneity in the aquifer system will affect any measured drawdowns in specific locations, depending on time-specific stress conditions. The following scenarios should be viewed qualitatively to provide an "order of magnitude" regional demonstration of the cumulative impacts experienced by the region. Regional wellfields referenced in the text are presented on each figure.

Table 5-3. Regional ground-water withdrawals by decade for Northern Tampa Bay WRAP cumulative scenarios.

DECADE OR YEAR	GROUND-WATER WITHDRAWALS (MGD)
1940s	5.7
1950s	15.8
1960s	137.0
1970s	173.1
1980s	231.0
1993	241.2

For simplicity, the following assumptions are made:

1) Average-annual rainfall for the period of record is used as the basis of recharge for all runs. Although periods of high and low rainfall have occurred within each decade, the average rainfall by decade does not vary significantly (see Chapter 4). Future scenarios, presented in a later section, use the same average rainfall, so all scenarios are comparable.

2) The effect of non-public supply ground-water withdrawals was considered insignificant prior to 1960, and 1989-1990 water use for non-public supply ground-water withdrawals was used to represent non-public supply use for the 1960s, 1970s, and 1980s. Actual values prior to 1960 are not known, but Menke and others (1961) estimate irrigation in all of Hillsborough County (including the area outside of the Northern Tampa Bay area) to be approximately 15 mgd spread throughout the entire county. Industrial ground-water withdrawals are also unknown, but significant withdrawals would be associated with very localized mining or crop processing operations. According to estimates of non-public supply ground-water withdrawals (see Chapter 3), the decade by decade average

did not deviate by more than 5 mgd from the amount used in these simulations (approximately 60 mgd). Although it was estimated in Chapter 3 that non-public supply did peak to over 85 mgd around 1980, this four to five year period was split between two decades, and did not cause a large swing on the decade averages of the 1970s and 1980s. Short-term swings in specific areas have occurred for all water use types, and should be kept in mind when viewing the following scenarios.

3) All drawdowns are calculated by performing model simulations with and without withdrawals. Each simulation is run for one year. One year is assumed to be a reasonable period for the system to respond to applied stresses, without experiencing significant boundary effects. For purposes of this demonstration, induced recharge adjustments were not applied.

1940s - By 1949, the Cosme wellfield was the only major public supply wellfield within the study area, and produced water for the City of St. Petersburg. Other public supply sources were scattered throughout Pinellas County and near Tampa. Although pumping had begun in 1930, ground-water withdrawals increased at this wellfield to approximately 8.2 mgd in 1949. The City of Tampa began relying primarily upon the Hillsborough River reservoir in the mid-1940s. Figures 5-6 and 5-7 present the regional drawdown in the Upper Floridan and surficial aquifers in response to average 1940s ground-water withdrawals (5.7 mgd).

1950s - During the 1950s, the Eldridge-Wilde wellfield was constructed as a source of public water supply for Pinellas County, and pumped 8.2 mgd by 1959. Meanwhile, the Cosme wellfield was increased to 17.9 mgd by 1959. Withdrawals from other wellfields, including Dade City, Clearwater, and Dunedin were increased, but remained relatively small. Figures 5-8 and 5-9 show that during the 1950s, the drawdowns increased and expanded, while some drawdowns began in the Eldridge-Wilde area.

1960s - In 1963, the Section 21 wellfield began production for the City of St. Petersburg, and approached 18 mgd near the end of the decade. In conjunction, the production of the Cosme wellfield was reduced to approximately 8 mgd. However, production at the other wellfields increased, including an increase to 22.3 mgd at Eldridge-Wilde. Additionally, the irrigation of citrus became widespread, and is estimated to be approximately 50 mgd by the end of the decade. Industrial water, use associated mainly with citrus processing, is estimated to be

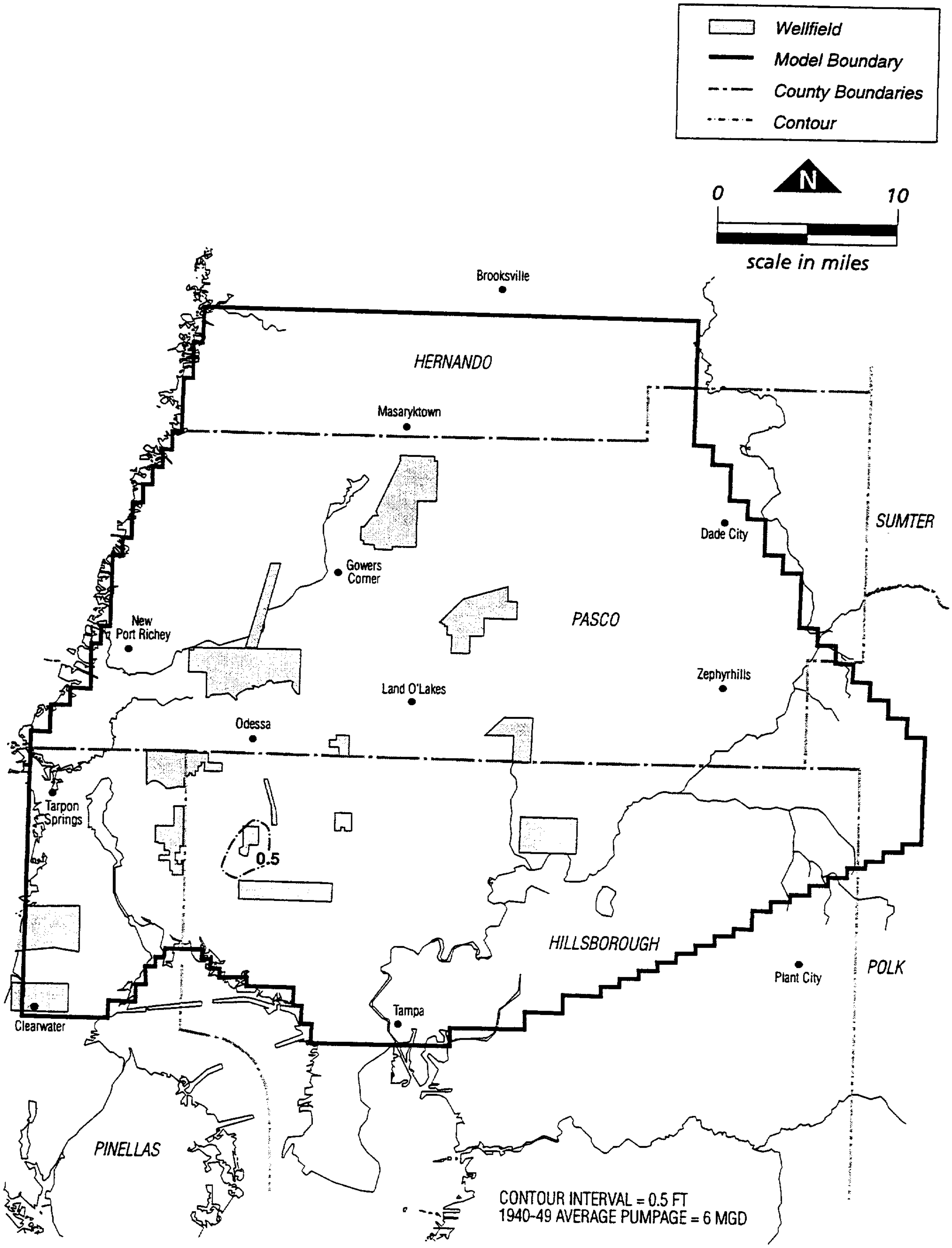


Figure 5-6. Estimated drawdown in the surficial aquifer from 1940s ground-water withdrawals within the Northern Tampa Bay WRAP area.

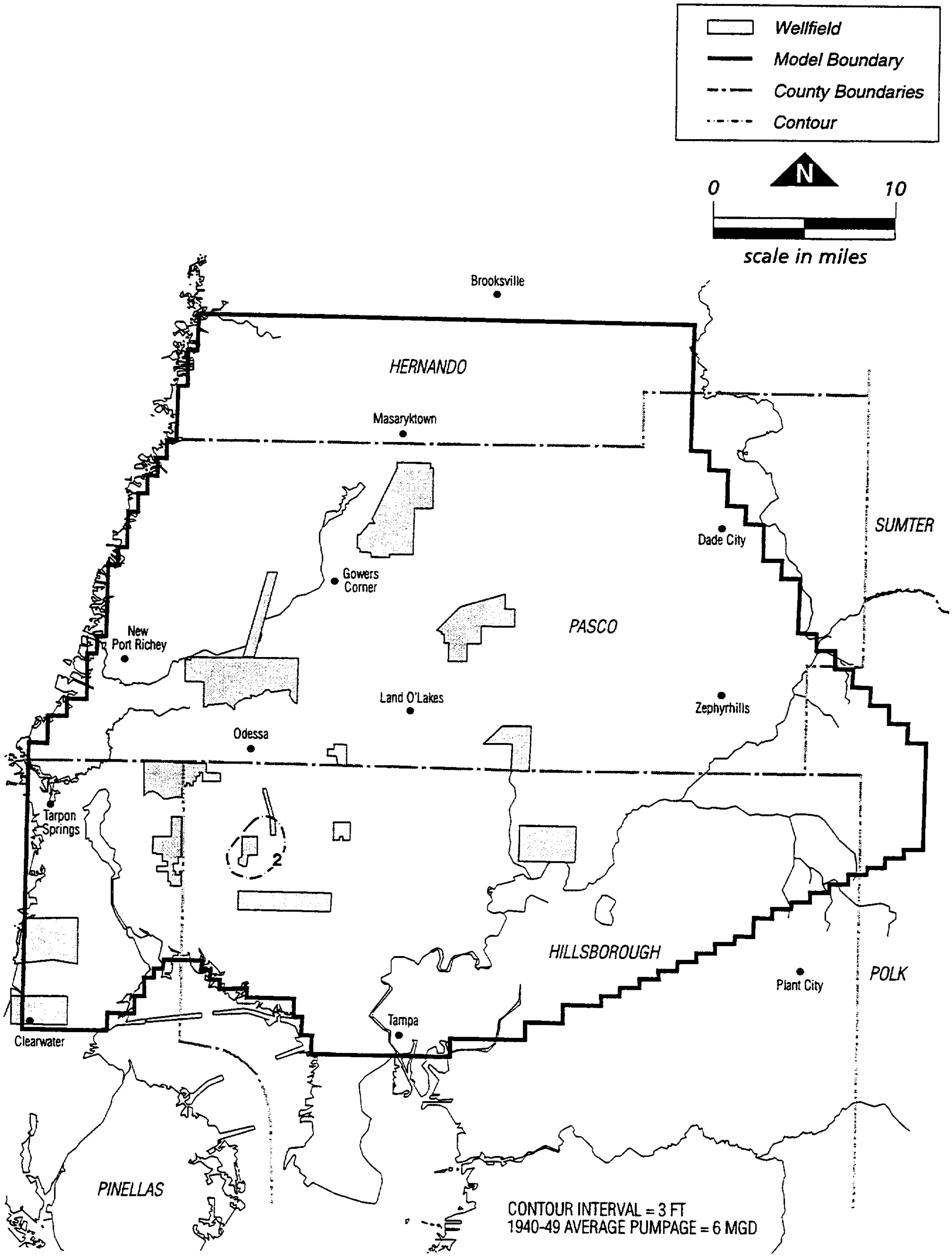


Figure 5-7. Estimated drawdown in the Upper Floridan aquifer due to 1940s ground-water withdrawals within the Northern Tampa Bay WRAP area.

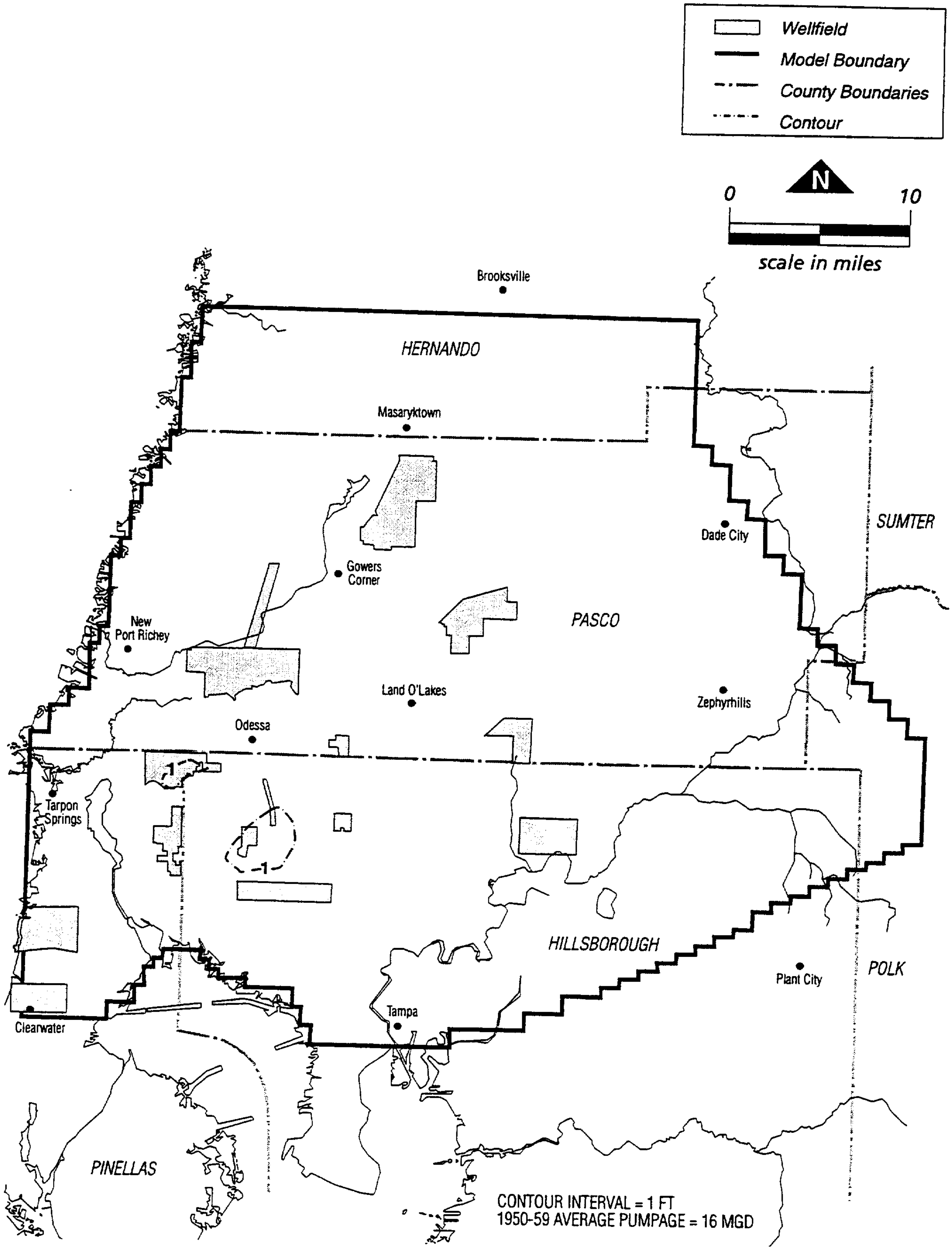


Figure 5-8. Estimated drawdown in the surficial aquifer from 1950s ground-water withdrawals within the Northern Tampa Bay WRAP area.

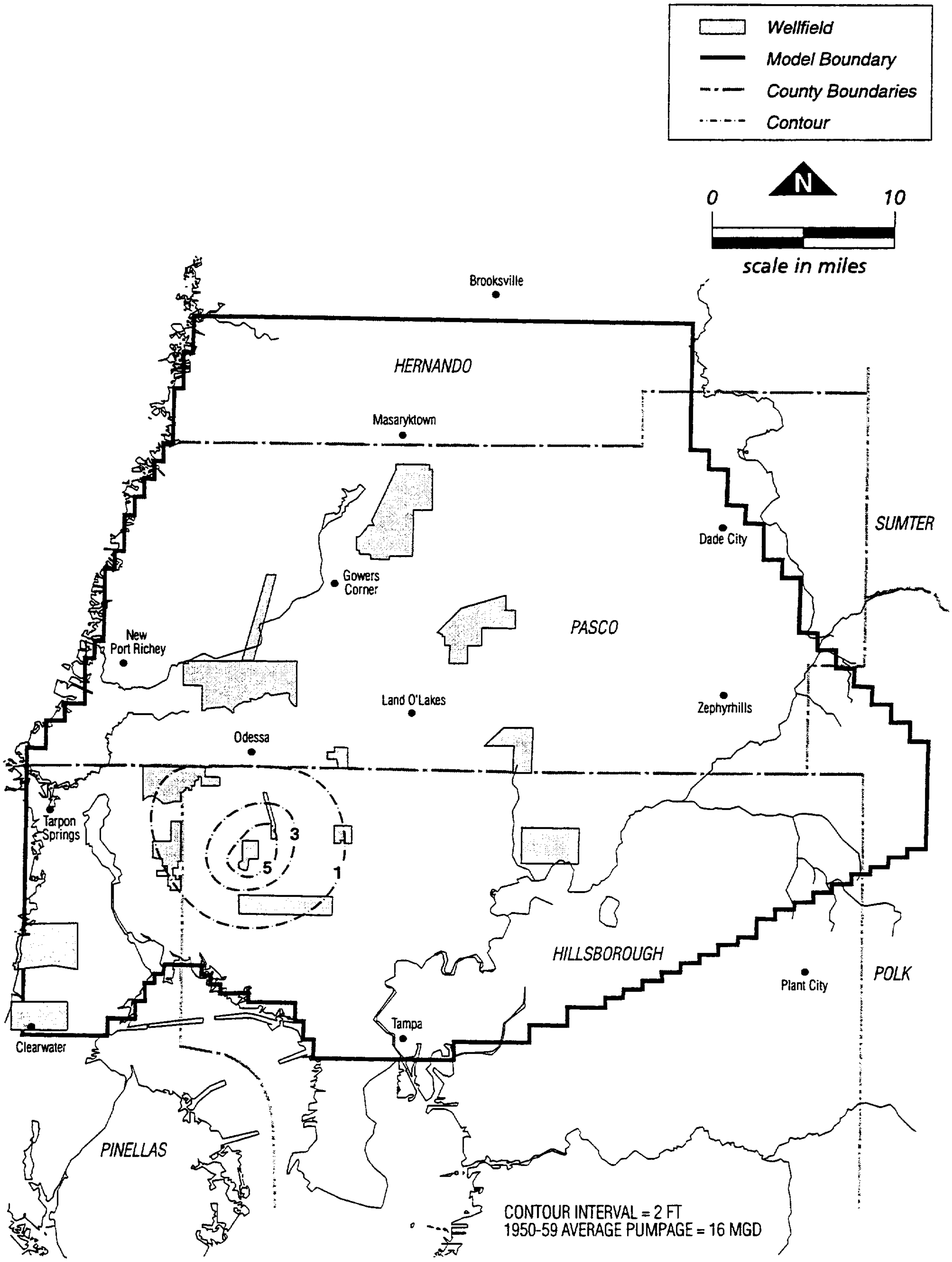


Figure 5-9. Estimated drawdown in the Upper Floridan aquifer due to 1950s pumpage within the Northern Tampa Bay WRAP.

approximately 30 mgd in the Dade City area alone by the end of the decade (Guyton and Associates, 1974).

Figures 5-10 and 5-11 show that drawdowns in the wellfield area of northwest Hillsborough County had become subregional in scope during the 1960s, with the largest drawdowns in the vicinity of the large wellfields. Upper Floridan aquifer drawdowns in the Dade City area also become apparent, in response to citrus and other agricultural irrigation. As explained in the assumptions earlier, the ground-water withdrawal amounts used for non-public supply use in this scenario were based on current use, so the magnitude of drawdowns in the eastern portion of the model area, which has always been dominated by agricultural water use, may have varied.

1970s - By 1979, all but three of the existing regional wellfields in the Northern Tampa Bay area, Cross Bar Ranch, Cypress Bridge, and North Pasco, were in operation. Average public supply ground-water withdrawals alone were approximately six times those of the 1950s. During the 1970s, both the Section 21 and Cosme wellfields reached peaks of over 17 mgd of average annual withdrawals, but were reduced to less than 10 mgd when the South Pasco wellfield began production. Withdrawals at the Eldridge-Wilde wellfield reached over 30 mgd. Both Cypress Creek and Morris Bridge wellfields, located in Pasco and Hillsborough Counties, respectively, began operation in this decade. By 1979, ground-water withdrawals for public supply in the Northern Tampa Bay area were in excess of 134 mgd. Figures 5-12 and 5-13 demonstrate the average drawdowns for this decade.

1980s - The Cross Bar Ranch wellfield was the only major public supply wellfield that began operation in the 1980s, and reached a production of approximately 20 mgd by the end of the decade. Total public supply ground-water withdrawals for the Northern Tampa Bay model area peaked at over 185 mgd in 1989, which is higher than current production. The effects of increased ground-water withdrawals at all of the wellfields is apparent in Figures 5-14 and 5-15. Two subregional areas of Upper Floridan aquifer drawdown are seen. The first subregion is the northwest Hillsborough area, including parts of Pasco and Pinellas Counties, which has grown over the various decades with the addition of new wellfields. The second subregion is central and eastern Pasco County, created by both agricultural and public supply ground-water withdrawals. Note, however, that the results of simulating eastern Pasco County withdrawals

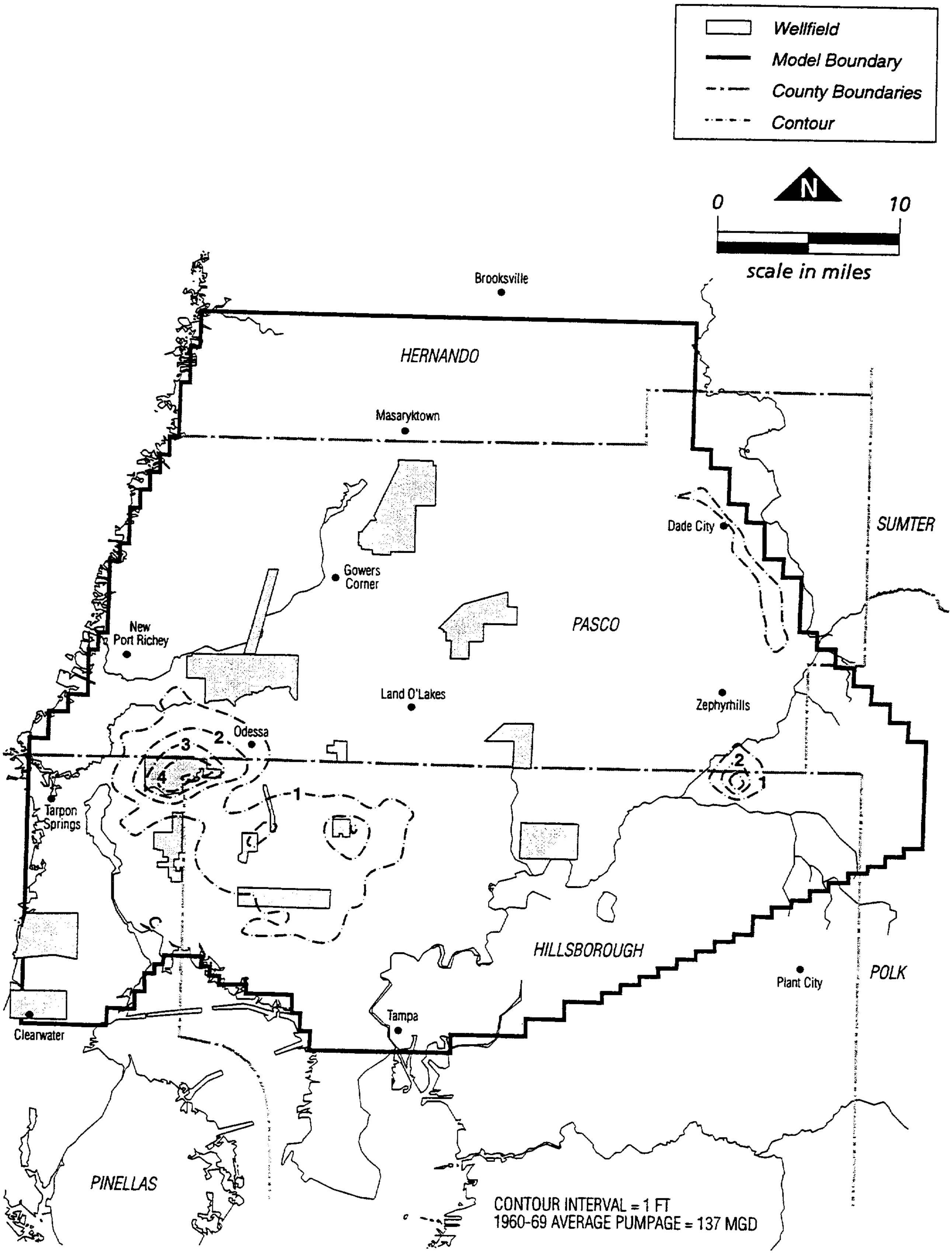


Figure 5-10. Estimated drawdown in the surficial aquifer from 1960s ground-water withdrawals within the Northern Tampa Bay WRAP area.

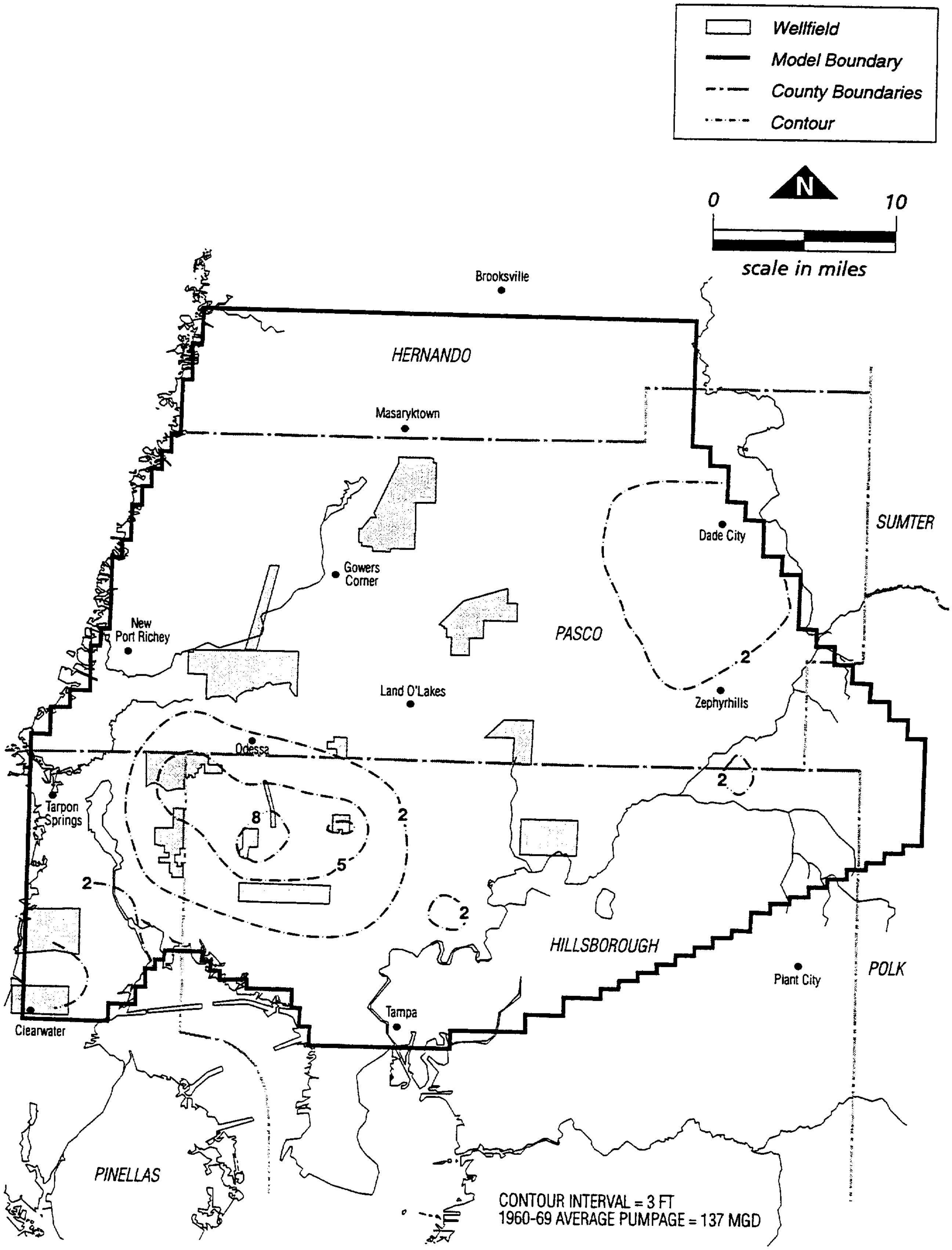


Figure 5-11. Estimated drawdown in the Upper Floridan aquifer from 1960s ground-water withdrawals within the Northern Tampa Bay WRAP area.

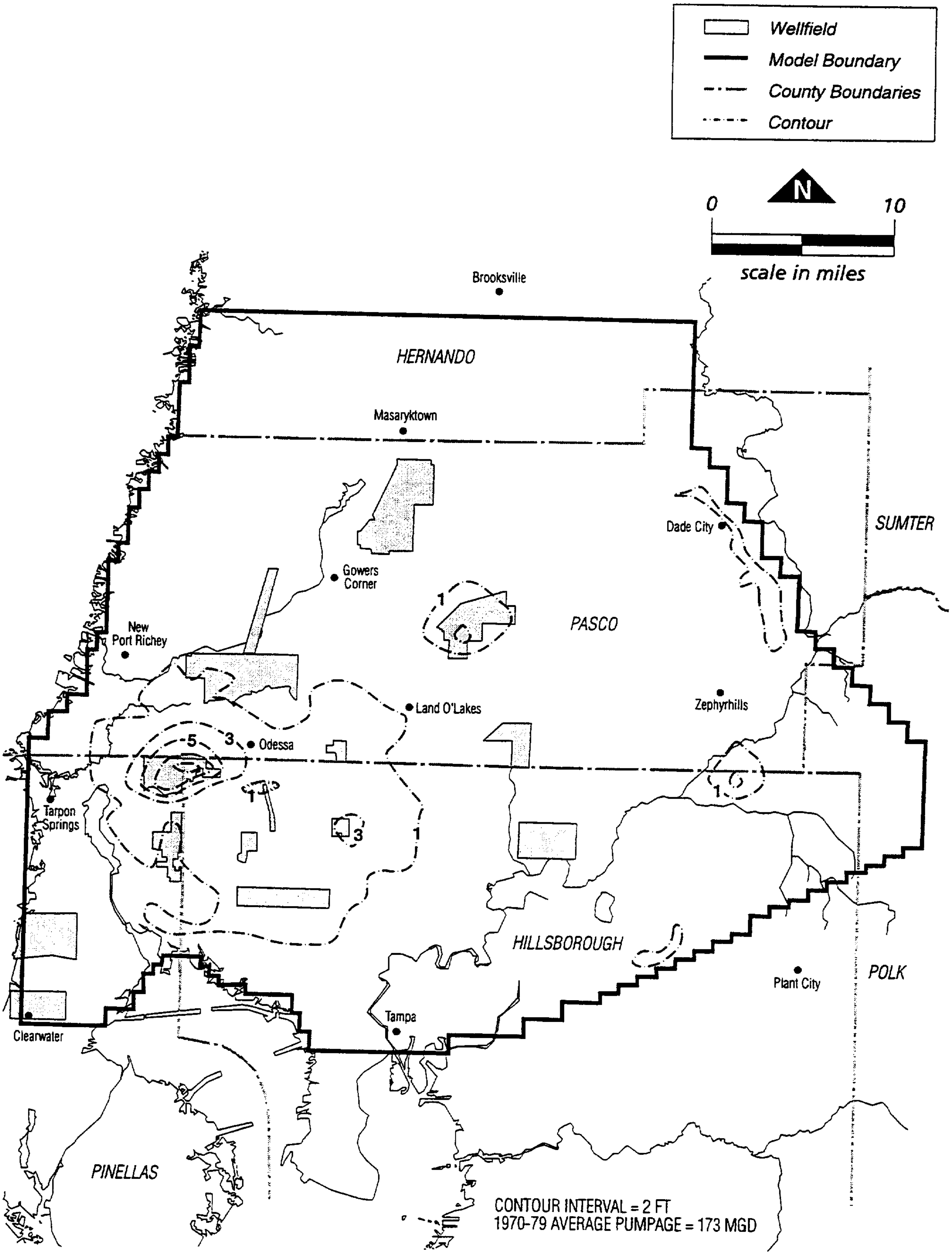


Figure 5-12. Estimated drawdown in the surficial aquifer from 1970s ground-water withdrawals within the Northern Tampa Bay WRAP area.

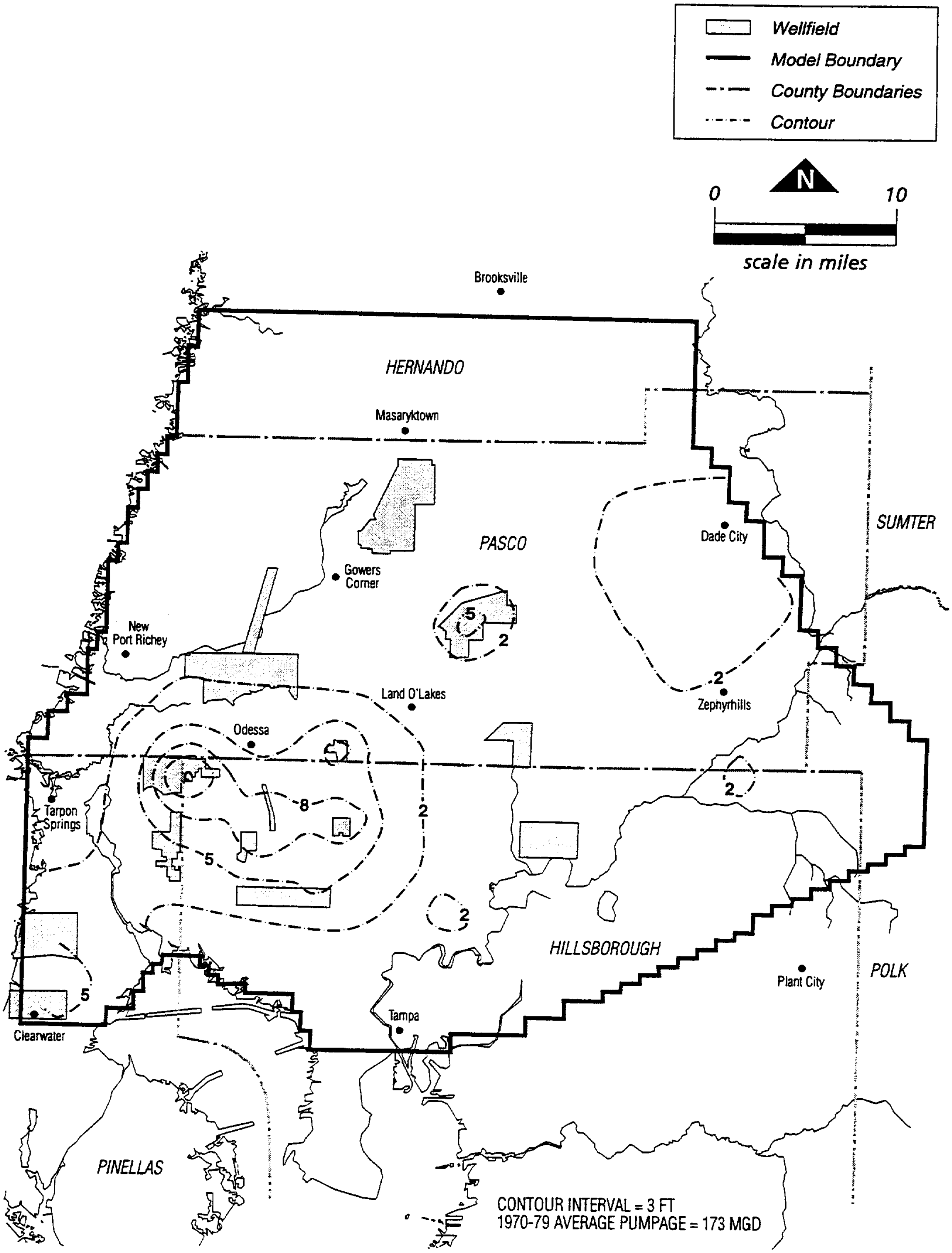


Figure 5-13. Estimated drawdown in the Upper Floridan aquifer from 1970s ground-water withdrawals within the Northern Tampa Bay WRAP area.

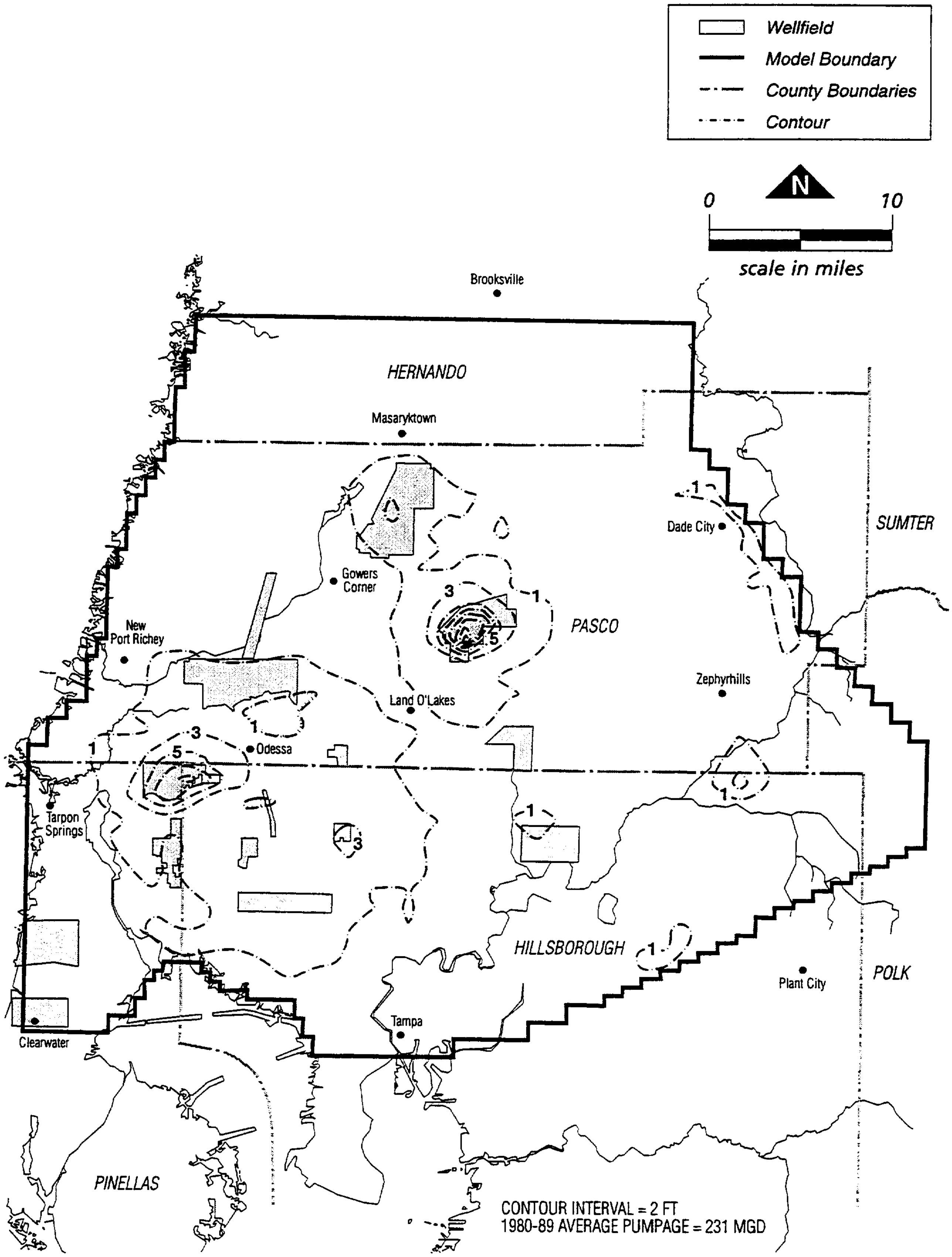


Figure 5-14. Estimated drawdown in the surficial aquifer from 1980s ground-water withdrawals within the Northern Tampa Bay WRAP area.

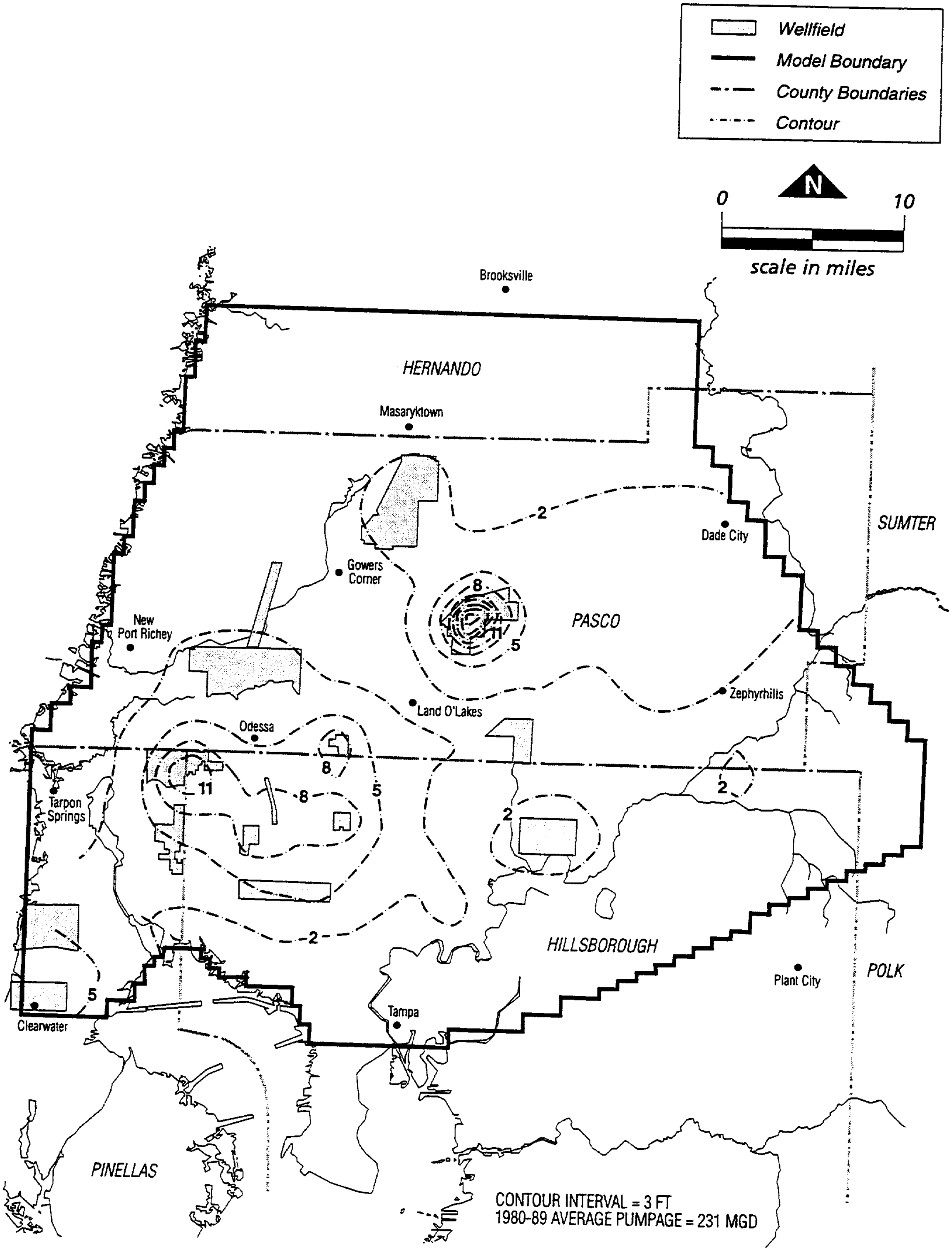


Figure 5-15. Estimated drawdown in the Upper Floridan aquifer from 1980s ground-water withdrawals within the Northern Tampa Bay WRAP area.

are less certain because of both inaccuracies in agricultural ground-water use estimates, and scale-dependent modeling difficulties along the rolling hills of the Brooksville Ridge. However, because of the greater thickness of the confining layer and high transmissivities of the Upper Floridan aquifer along the Brooksville Ridge, the Upper Floridan aquifer drawdowns are not subregionally reflected in the surficial aquifer model results (Figure 5-15).

1993 - The 1993 ground-water withdrawals for public supply in the Northern Tampa Bay model area are estimated to be approximately 180 mgd. Although total ground-water withdrawals for 1993 are not much more than the average of the 1980s, the distribution of withdrawals has changed over the years. Most notably, withdrawals at the Cross Bar Ranch wellfield increased to near permitted rates in 1993 (30 mgd), and the Cosme-Odessa wellfield was reduced to approximately five mgd while flow meter testing was conducted. Figure 5-16 and 5-17 present the surficial aquifer and Upper Floridan drawdowns for 1993. Figure 5-18 combines Figure 5-17 and Figure 2-32 to present the location and magnitude of all ground-water withdrawals included in the 1993 scenario.

The preceding scenarios demonstrate the areal increase in aquifer drawdowns over time in response to ground-water withdrawals. Although the distribution of withdrawals has changed over time, the regional rate of ground-water withdrawal from the Upper Floridan aquifer has steadily increased. Impacts have progressed from local drawdowns in the Upper Floridan aquifer to subregional areas of drawdown. Subsequent effects on the surficial aquifer, including surface-water bodies, are determined by the local or subregional integrity of the underlying confining layer. However, these effects have also become subregional in extent. The observed impacts in lake and wetland water levels, as well as biological health, are subject to shorter term stresses (i.e. high and low rainfall events, short-term increases in site-specific ground-water withdrawals, etc.), which cloud the relationship between field data and model results. However, the field data presented earlier in this report correlates very well to these results.

5.3.5 Model Scenarios

In addition to the model simulations performed for the historical cumulative impact analysis, other scenarios were conducted to estimate the magnitude of future water level decline under

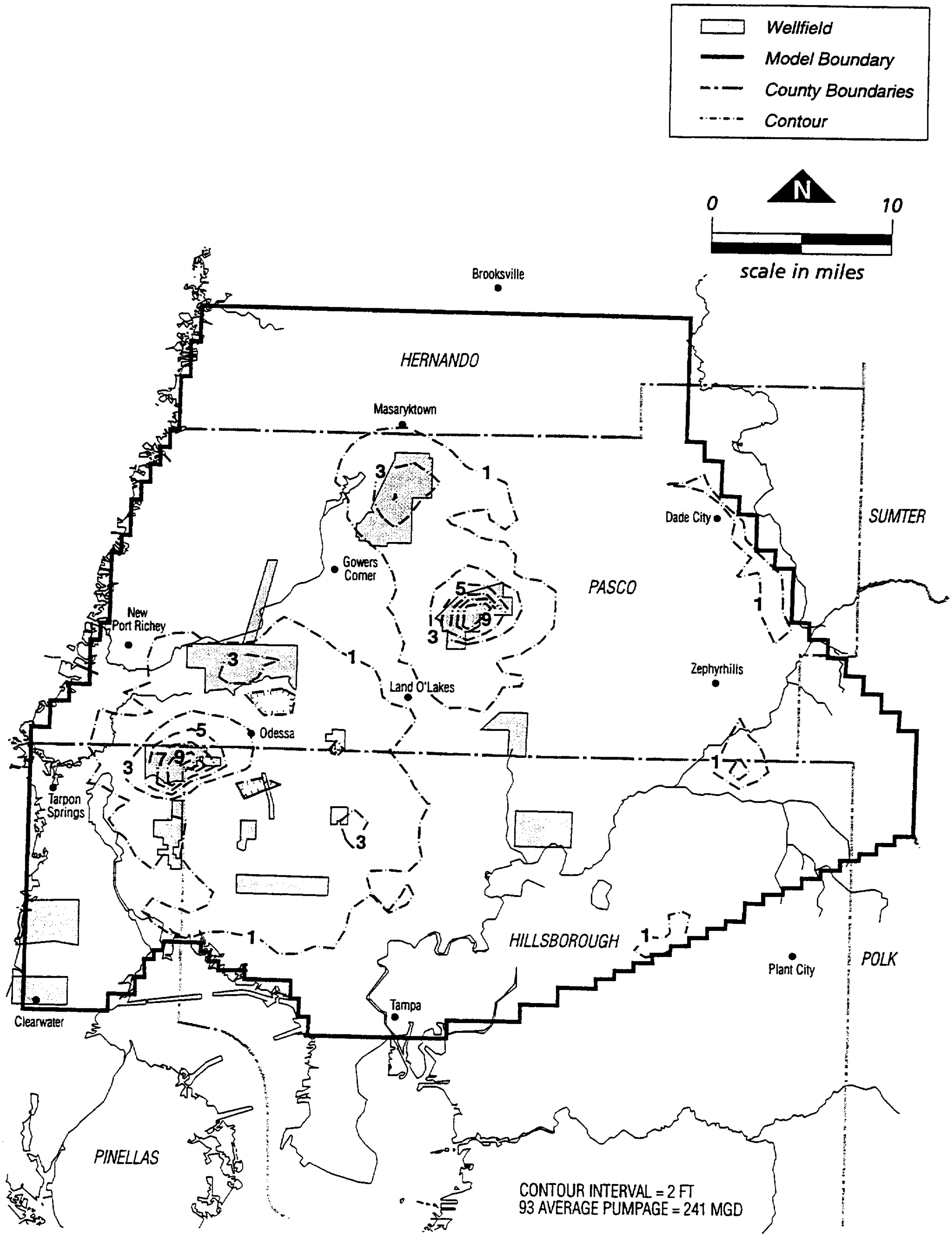


Figure 5-16. Estimated drawdown in the surficial aquifer using 1993 ground-water withdrawals within the Northern Tampa Bay WRAP area.

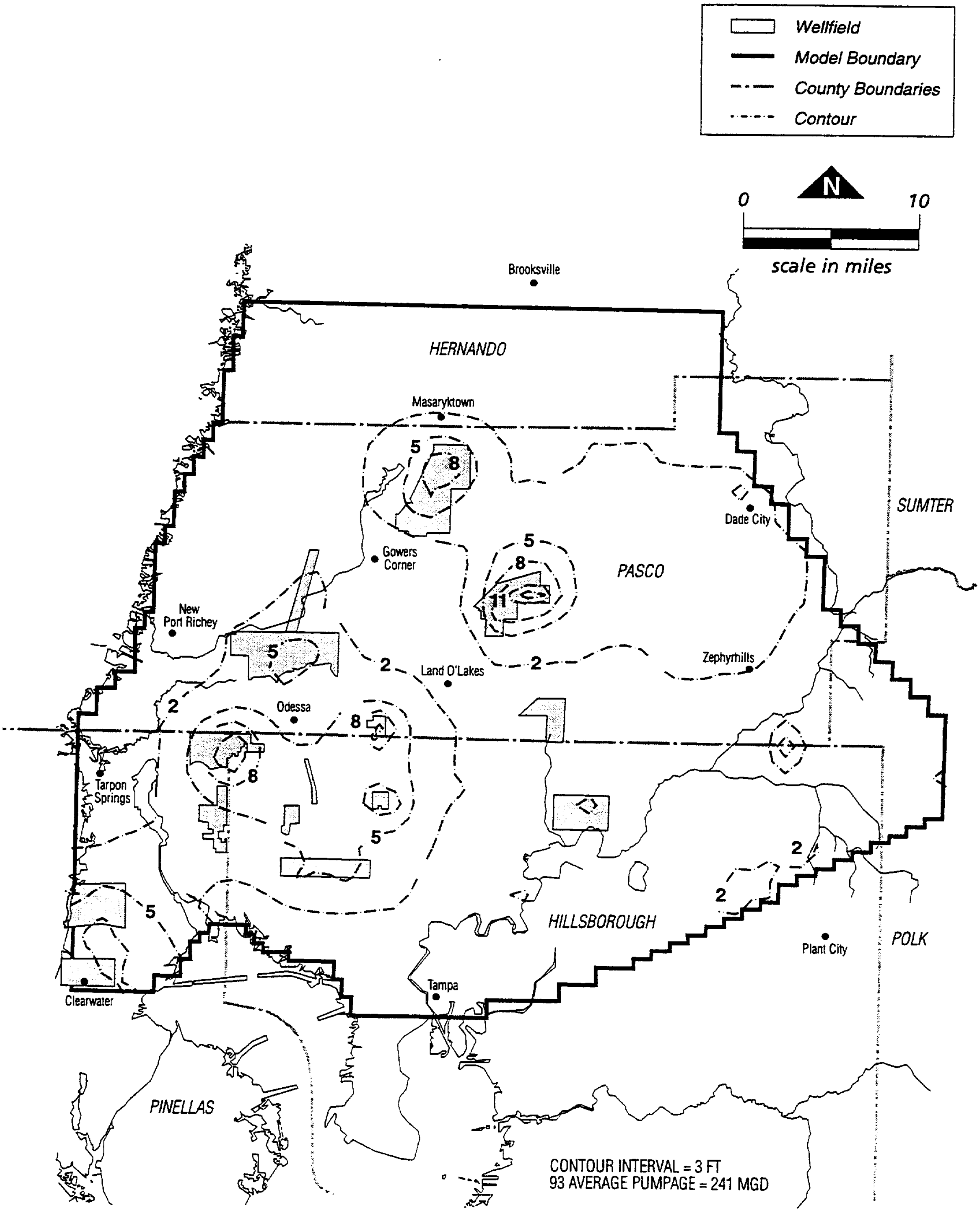


Figure 5-17. Estimated drawdown in the Upper Floridan aquifer using 1993 ground-water withdrawals within the Northern Tampa Bay WRAP area.

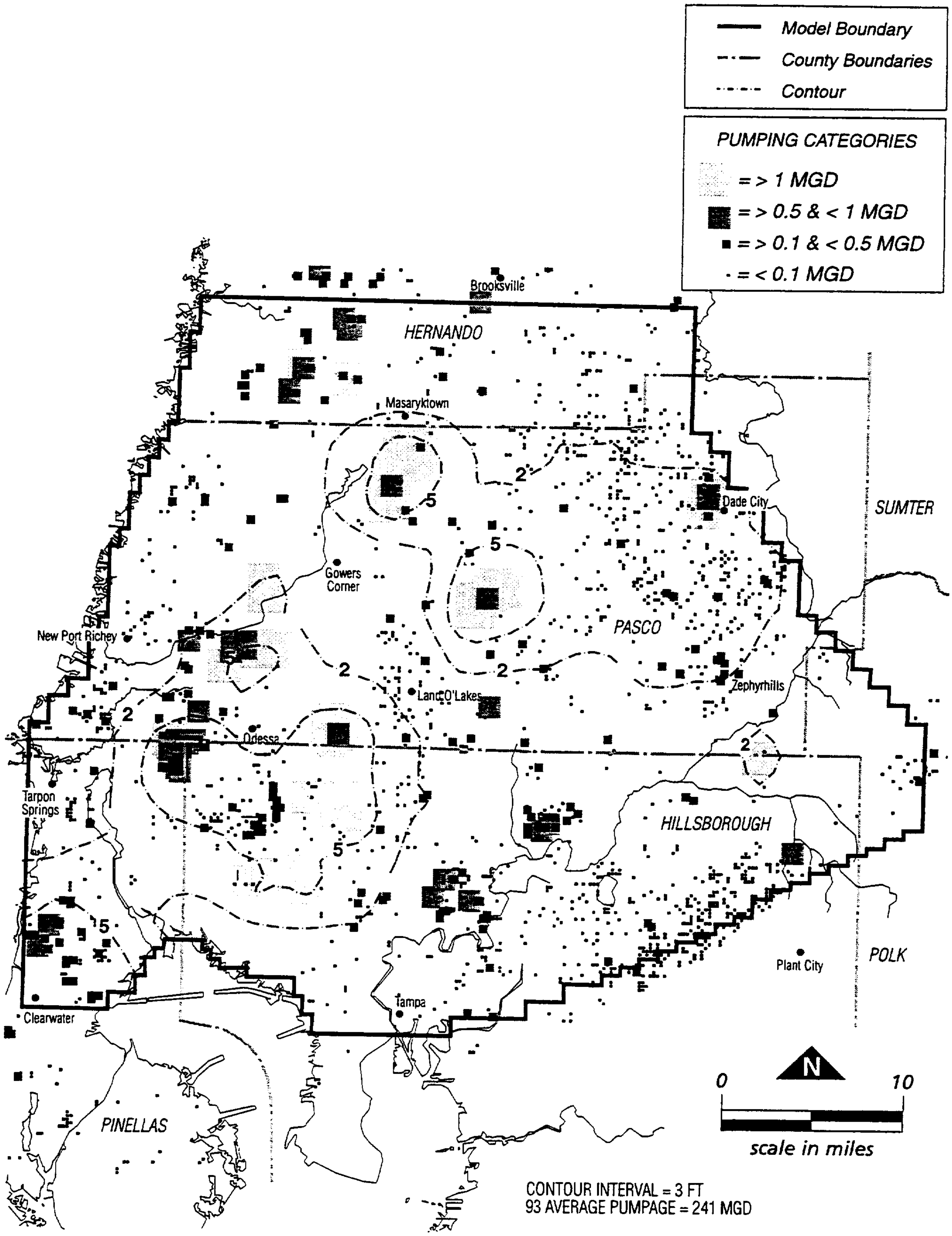


Figure 5-18. Estimated drawdown in the Upper Floridan aquifer from 1993 ground-water withdrawals, along with withdrawal locations and magnitudes within the Northern Tampa Bay WRAP area.

both current and future conditions. A scenario was constructed to evaluate the effects of reduced recharge (low rainfall) on simulated water levels. To accomplish this, the simulated water level drawdown, using current ground-water withdrawal rates and average recharge, was compared to the resulting water level drawdowns using the same pumping rates and below average recharge (two-in-ten year drought). In another scenario, the amount of water level decline attributed to non-regional wellfield use was examined using 1989-90 water use.

For future conditions, ground-water impacts were predicted using currently permitted and projected 2020 water use for the major regional public supply wellfields. In all simulations, unless otherwise noted, drawdown was calculated by measuring the difference in simulated head under pumping and non-pumping conditions for one year using average recharge (as in the previous scenarios). Table 5-4 indicates the ground-water withdrawal quantities associated with the major public supply wellfields for the various model scenarios.

Average vs Low Rainfall Conditions

In the Northern Tampa Bay region, and across the state of Florida, the fundamental question concerning ground-water impacts to lakes, streams, and wetlands revolves around the issue of natural versus anthropogenic stresses to the system. The question is often posed: Is it a lack of rainfall or presence of ground-water withdrawals that contributes to the majority of stress on the natural system? In an attempt to address this issue in the Northern Tampa Bay area, the numerical model was used to illustrate the magnitude of effects from pumping under average and below average rainfall conditions.

Figures 5-19 and 5-20 show the amount of predicted water level decline in the surficial and Upper Floridan aquifers using average recharge conditions and 1989-90 ground-water withdrawals (240 mgd). If another simulation is developed where low rainfall recharge (1989-90) is substituted in lieu of average recharge, water level declines associated with the same ground-water withdrawals increases several feet in the surficial and Upper Floridan aquifers when compared to drawdown predicted using average recharge (Figures 5-21 and 5-22).

Table 5-4. Ground-water withdrawal quantities used in the Northern Tampa Bay model scenarios (mgd).

WELLFIELD	89-90	1993	CURRENT PERMITTED	2020
CYPRESS CREEK	30.4	25.1	30.0	30.0
CROSS BAR	22.8	29.9	30.0	30.0
ELDRIDGE WILDE	32.3	27.6	35.2[1]	32.2
EAST LAKE	1.1	0	3.0[1]	1.1
SECTION 21	9.8	9.4	12.0[1]	9.8
COSME-ODESSA	11.2	5.7	12.0[1]	9.2
S. PASCO	12.3	12.3	16.9[1]	12.3
MORRIS BRIDGE	7.3	5.0	15.5	15.5
STARKEY	13.8	12.0	15.0[1]	13.8
NW HILLS.	8.2	9.4	8.8[1]	8.2
N. PASCO	0	2.7	8.5	8.5
CYPRESS BRIDGE	0	1.1	8.0	7.8
N. PASCO EXTENSION	0	0	0	6.3
CYPRESS BRIDGE EXPANSION	0	0	0	7.0
CONE RANCH	0	0	0	24.0
N. HILLS.	0	0	0	15.0
TOTAL OF MAJOR WELLFIELDS	149.2	140.2	194.9	230.8
ALL OTHER USE	90.8	101.0	90.8	90.8
TOTAL USE	240.0	241.2	285.7	321.6

[1] These wellfields were left at 89-90 withdrawal rates in this model scenario. Note that the East Lake wellfield has recently been removed from service.

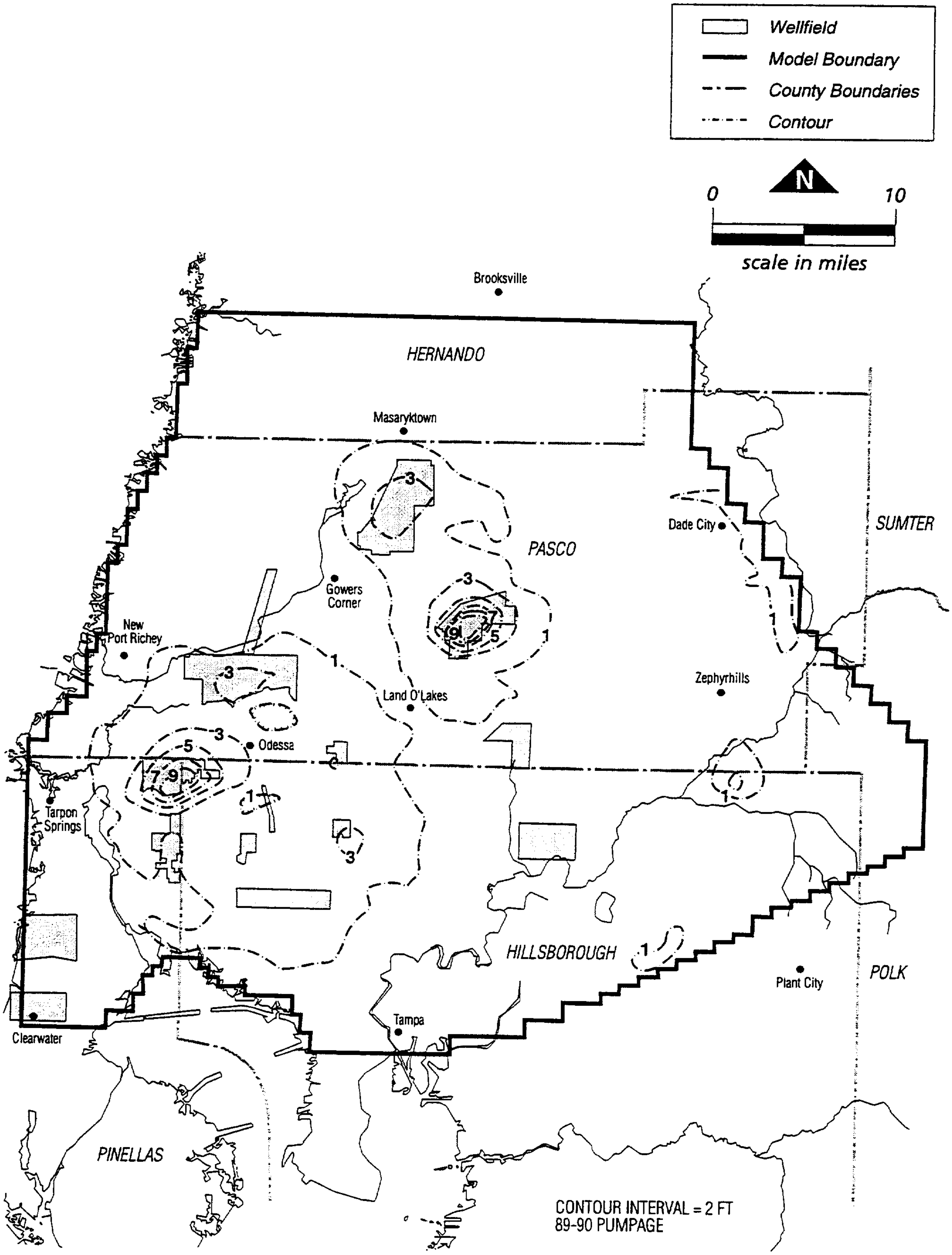


Figure 5-19. Estimated drawdown in the surficial aquifer using 1989-90 ground-water withdrawals and average recharge within the Northern Tampa Bay WRAP area.

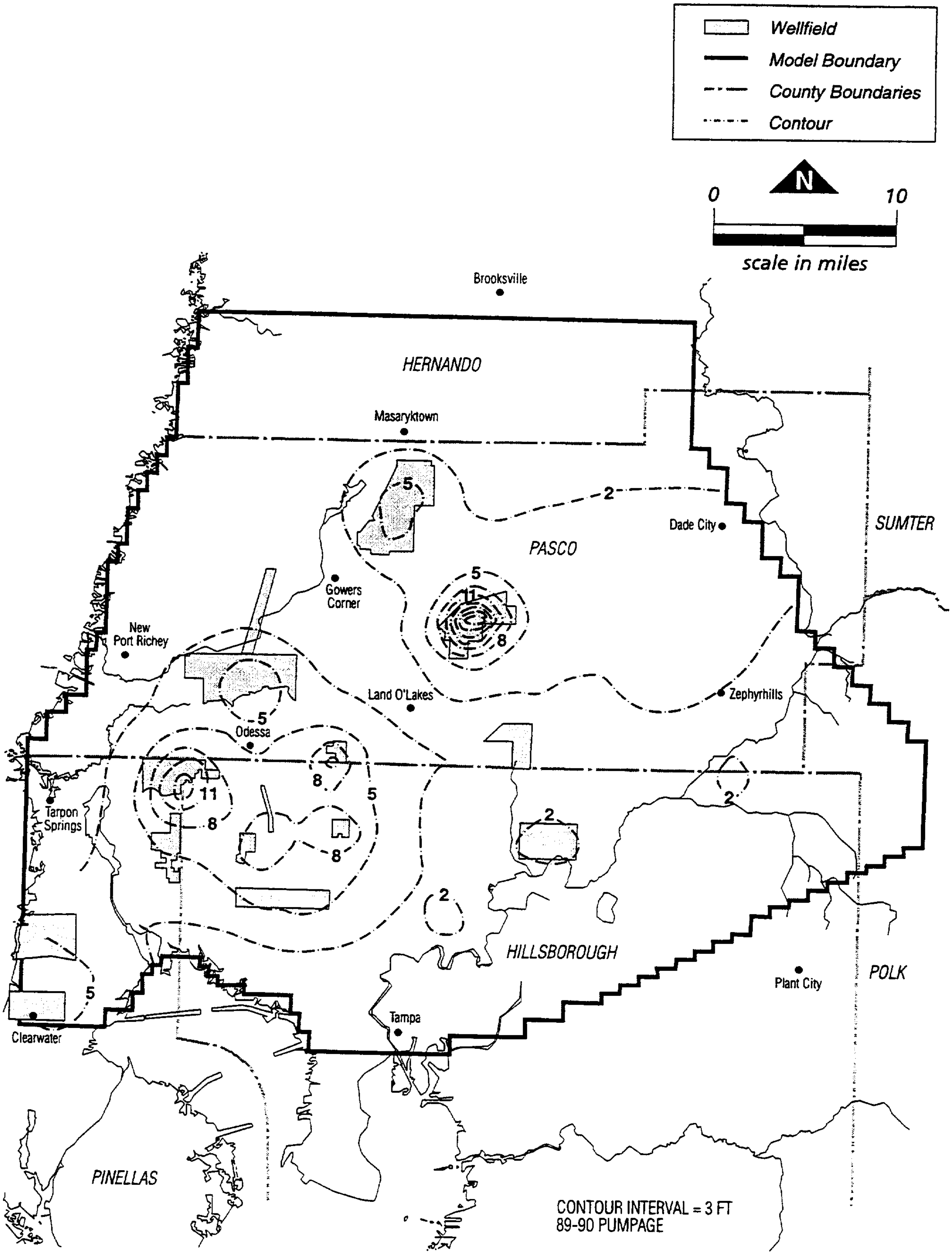


Figure 5-20. Estimated drawdown in the Upper Floridan aquifer using 1989-90 ground-water withdrawals and average recharge within the Northern Tampa Bay WRAP area.

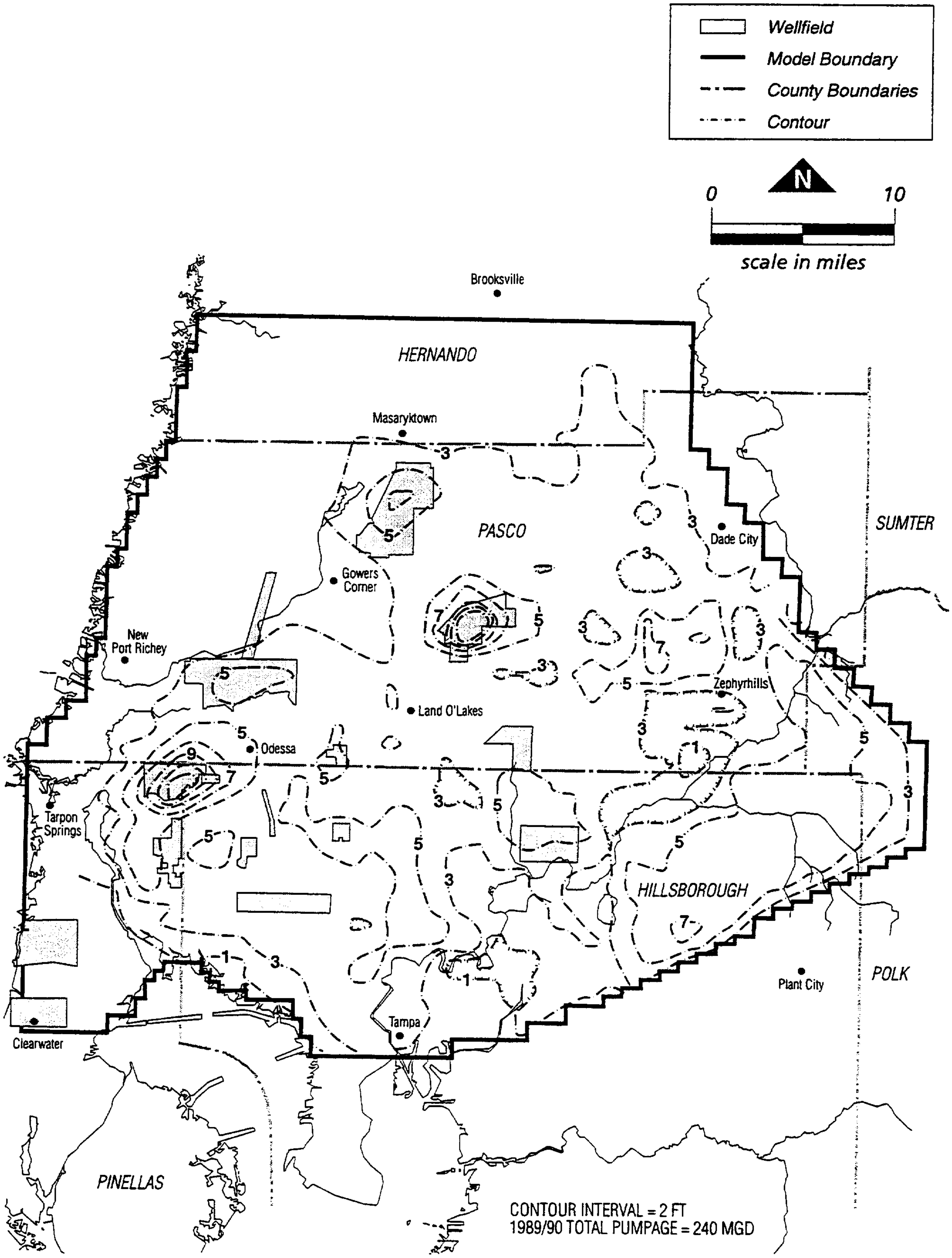


Figure 5-21. Estimated decline in the surficial aquifer using 1989-90 ground-water withdrawals and 1989-90 recharge within the Northern Tampa Bay WRAP area.

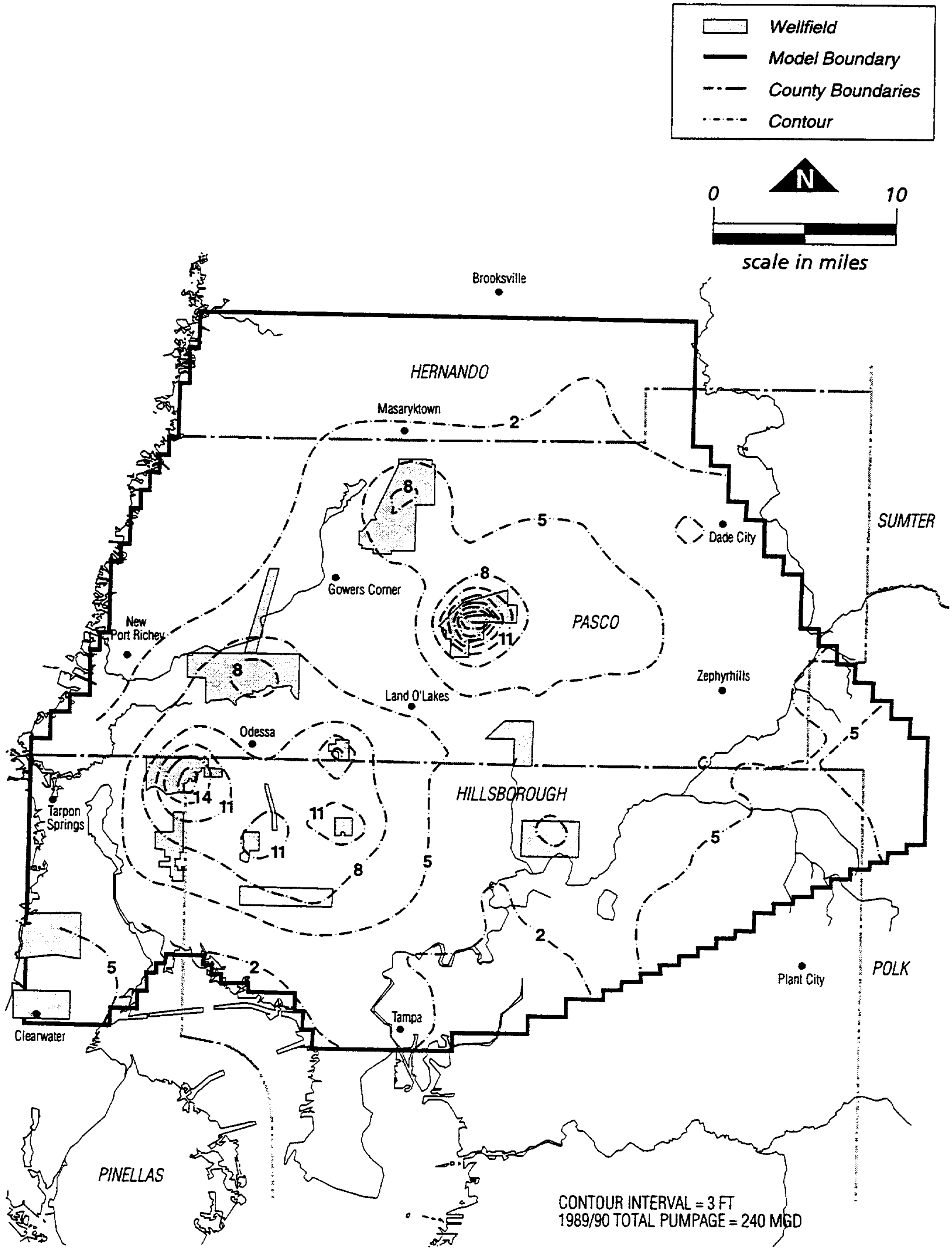


Figure 5-22. Estimated decline in the Upper Floridan aquifer using 1989-90 ground-water withdrawals and 1989-90 recharge within the Northern Tampa Bay WRAP area.

The 1989-90 simulation (June 1989 to May 1990) represents a period when rainfall was approximately 91 percent of average in the Northern Tampa Bay WRAP area, or about five inches below the annual-average of 52 inches/year based on data from 73 rainfall stations. When predicted water level drawdown is compared using average and reduced recharge conditions, a significant amount of water level decline occurs outside the area of the one-foot water table drawdown contour (depicted using average recharge conditions) due solely to reductions in rainfall recharge. This water level decline is associated with low rainfall only, i.e., the natural lowering of water levels expected due to low rainfall conditions, and is on the magnitude of one to four feet. However, the area of influence of the ground-water withdrawals increases several feet in the water table and Upper Floridan aquifer when compared to drawdown using average recharge (5-19 and 5-20). Conversely, during periods of above average rainfall, drawdowns in the vicinity of wellfields are expected to decrease. Therefore, low rainfall conditions compound the lowered water levels caused by ground-water withdrawals.

Water Level Decline from Other Users

The ground-water system in the Northern Tampa Bay area was modeled without the major public supply wellfields (Table 5-4) to estimate the effects other users have on water levels. If the regional wellfields are removed from the model, total ground-water withdrawals are approximately 91 mgd, or 38 percent of the total 1989-1990 model year ground-water withdrawals. Figures 5-23 and 5-24 illustrate drawdown in the surficial and Upper Floridan aquifers from other users. In the water table, predicted drawdown averages less than one foot over all sections of the project area, although greater amounts of drawdown are seen in the vicinity of the CF Industries mining operation in northeast Hillsborough County. In most other areas, water-table drawdown is less than 0.5 feet. In the Upper Floridan aquifer, the Dade City area of Pasco County shows from two to four feet of drawdown, due primarily to agricultural irrigation, although minimal drawdown is seen in the surficial aquifer. Potential localized impacts from ground-water withdrawals in this area are not reflected in the regional model.

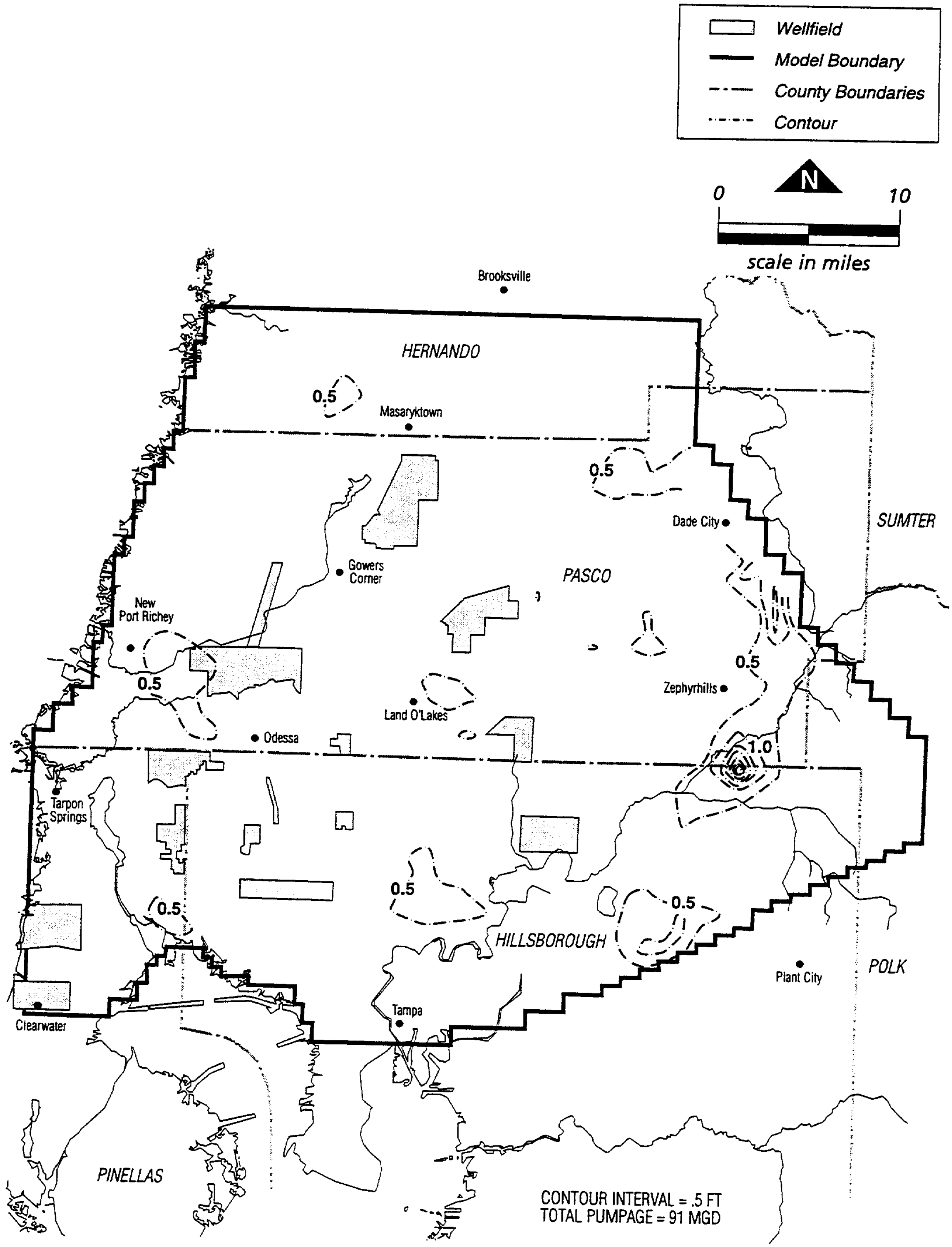


Figure 5-23. Estimated drawdown in the surficial aquifer if regional wellfield ground-water withdrawals are removed within the Northern Tampa Bay WRAP area.

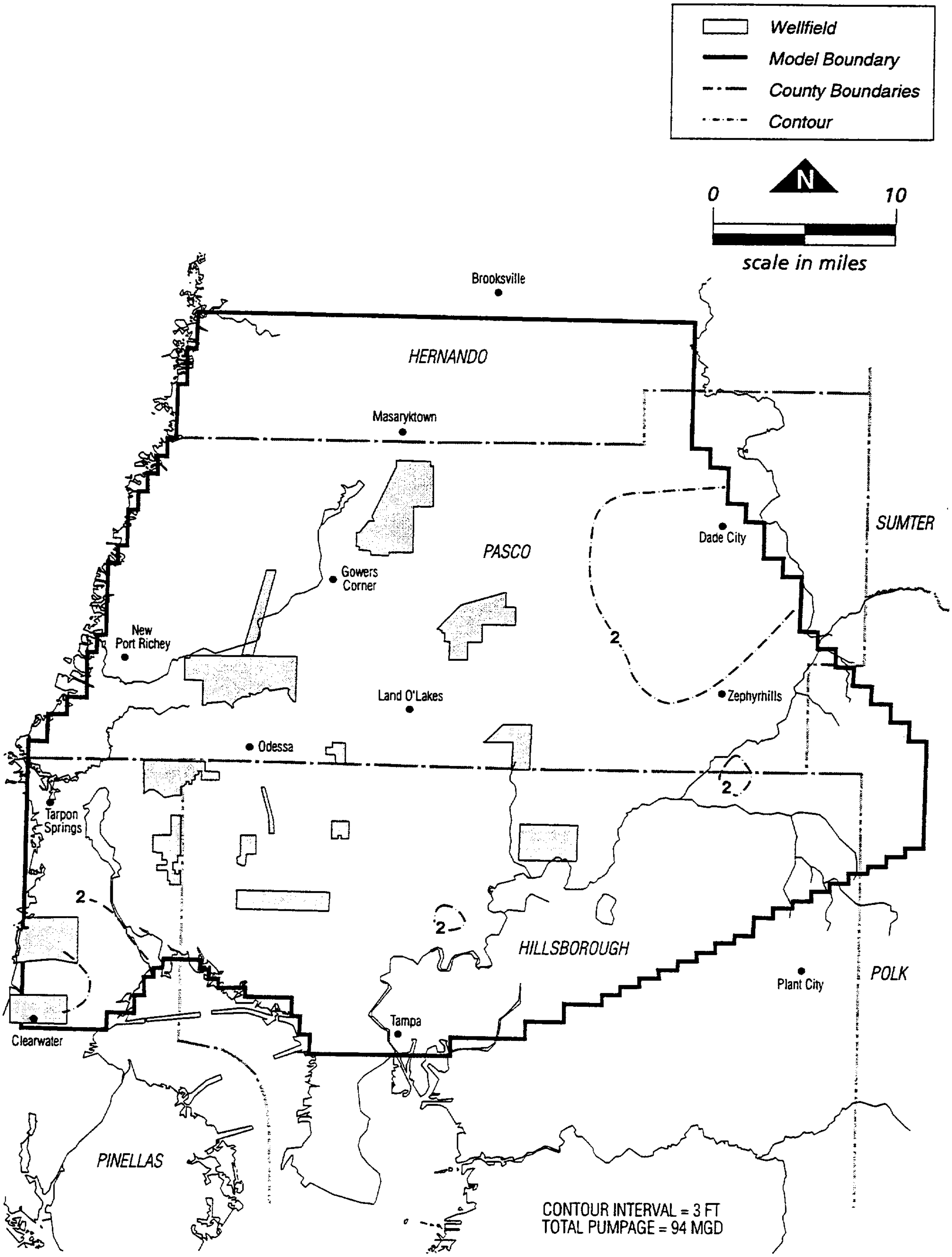


Figure 5-24. Estimated drawdown in the Upper Floridan aquifer if regional wellfield ground-water withdrawals are removed within the Northern Tampa Bay WRAP area.

Permitted and 2020 Public Supply Water Use

Two hypothetical situations were examined in the Northern Tampa Bay region to assess the likelihood of continued increases in ground-water withdrawals. In the first case, the regional wellfields were simulated at currently permitted quantities (Table 5-4). Total permitted ground-water withdrawals for these wellfields are 195 mgd. Ground-water withdrawals at selected wellfields were left at 89-90 rates since it was felt that regulatory ground-water levels or other constraints would limit these wellfields below permitted average daily quantities. In addition to the major wellfields simulated in the previous scenarios, this simulation also includes the permitted quantities associated with the two newest wellfields, North Pasco and Cypress Bridge (Figure 2-34), as well as the 89-90 water use for all other users (90.8 mgd). Note that the East Lake wellfield has been permanently removed from service since the time this scenario was run, but accounted for only 1.1 mgd of the total modeled withdrawal rates.

Figures 5-25 and 5-26 show total drawdown in the surficial and Upper Floridan aquifers, respectively, if all the wellfields were pumping at their permitted quantities. In the water table, impacts would continue to expand with the area of one-foot drawdown enlarging north of Starkey wellfield and south of Cypress Creek wellfield to Morris Bridge wellfield. In the Upper Floridan aquifer, drawdown is predicted to increase in the area of the two newest wellfields, and the drawdowns become nearly regional in extent.

If water use continued to increase for public supply, what would be the impact on the aquifer system in the year 2020? SWFWMD (1992) projections for regional wellfield expansion were utilized in a hypothetical simulation of future wellfield withdrawals (Table 5-4). In this scenario, recommended regional sources from the report were simulated in the project area. Four new sources, the Cone Ranch, Cypress Bridge expansion, North Pasco Extension, and North Hillsborough Linear wellfields were included in the scenario (Figure 2-34). Total regional wellfield withdrawals are projected to increase by 82 mgd from 1989-90 actual use, which includes increases in selected wellfields (Table 5-4). Other water use was simulated at the 1989-90 levels. Total ground-water withdrawals in the 2020 scenario are 322 mgd. Again, the East Lake wellfield has been removed from service since this scenario was run, but accounts for only 1.1 mgd.

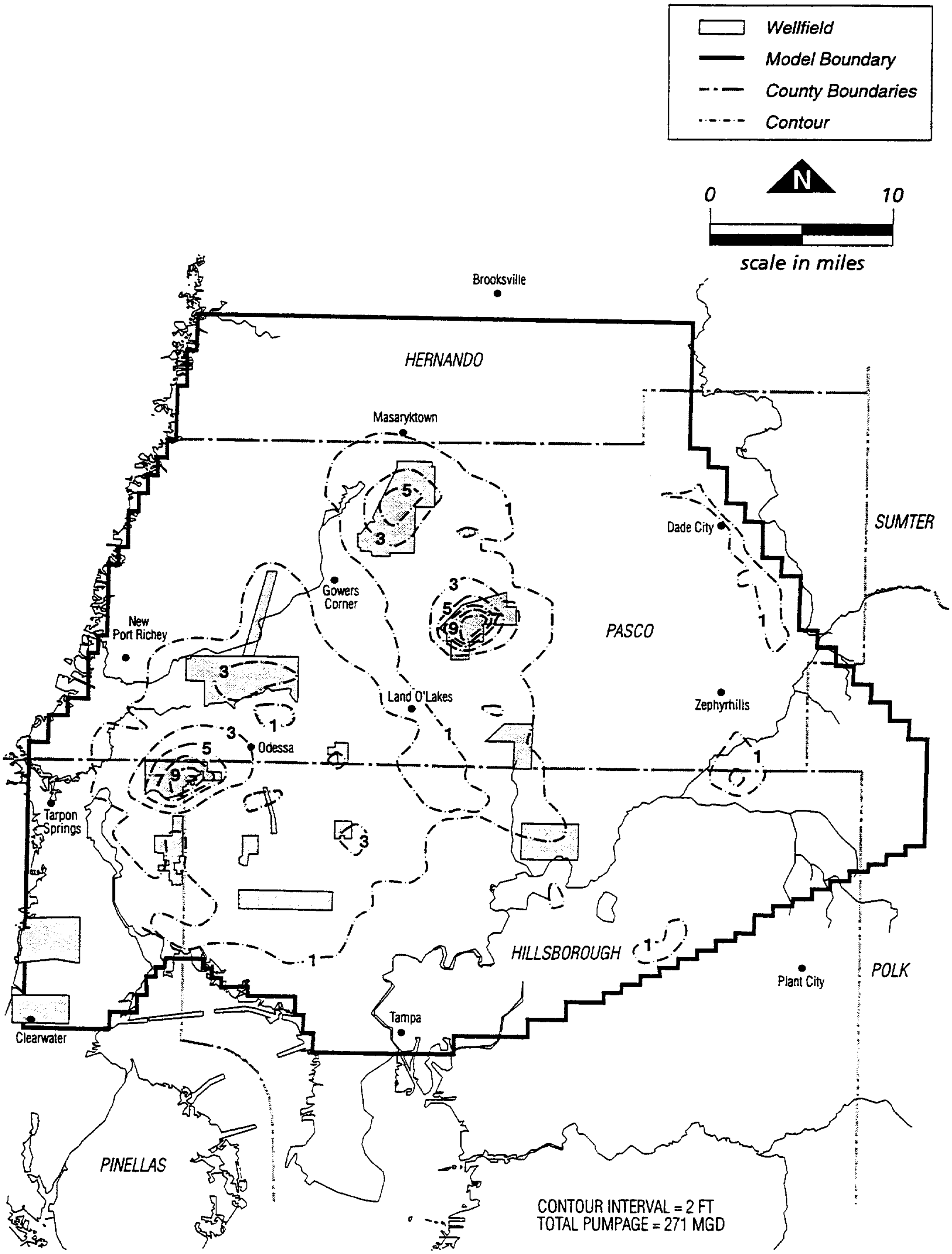


Figure 5-25. Estimated drawdown in the surficial aquifer due to regional wellfield permitted ground-water withdrawals within the Northern Tampa Bay WRAP area.

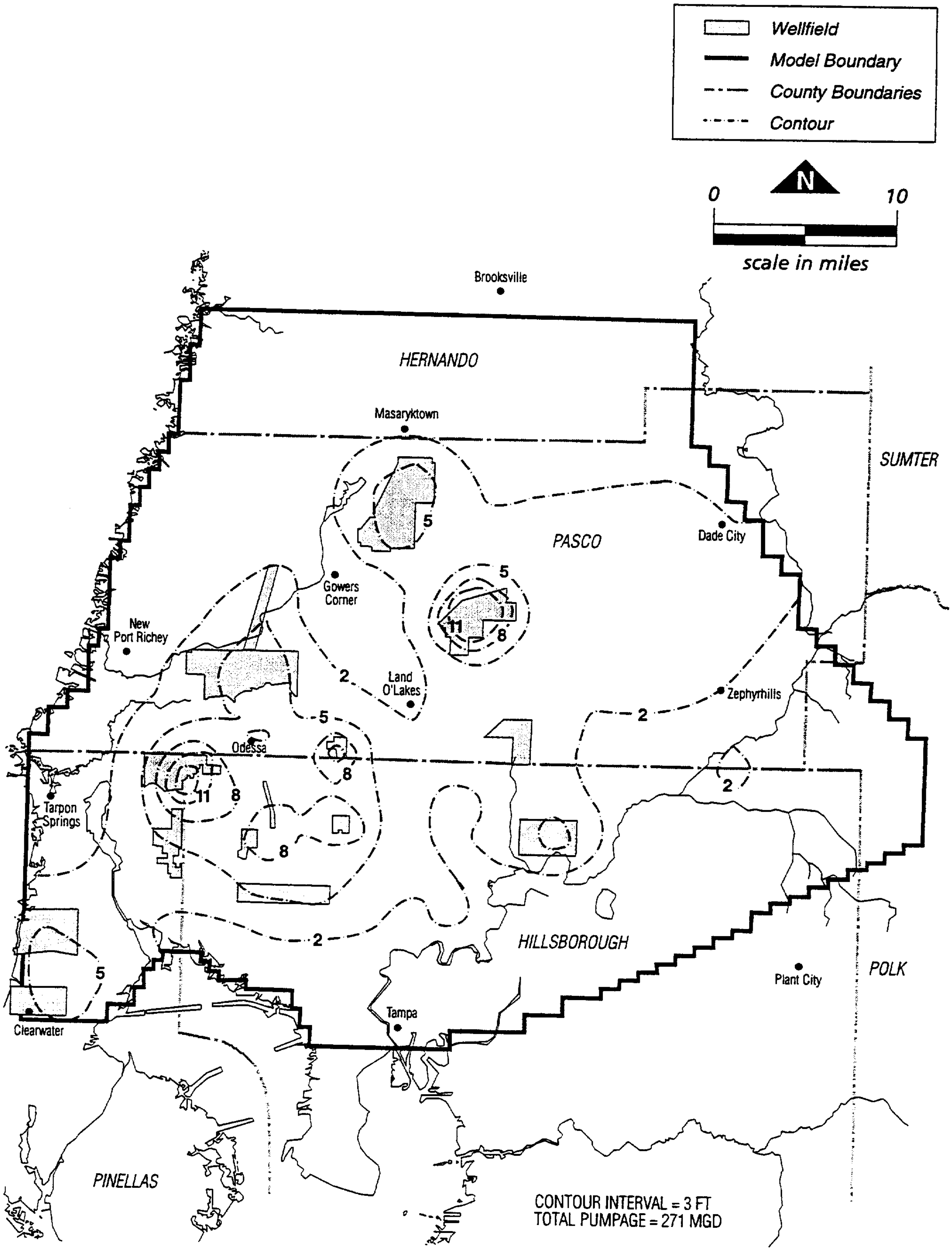


Figure 5-26. Estimated drawdown in the Upper Floridan aquifer due to regional wellfield permitted ground-water withdrawals within the Northern Tampa Bay WRAP area.

Figures 5-27 and 5-28 illustrate total drawdown in the surficial and Upper Floridan aquifers due to 2020 wellfield ground-water withdrawals. In this simulation, some degree of uncertainty exists concerning the drawdown predictions for the Cone Ranch wellfield, located in northeastern Hillsborough County, because of its close location to the boundary of the model. In the water table, the one foot drawdown areas around the central Pasco wellfields would merge with the one foot drawdown contour around the tri-county wellfields. Three feet or more of additional drawdown in the water table is predicted to occur in northeastern Hillsborough County due to 24 mgd of withdrawals from Cone Ranch wellfield. In the Upper Floridan aquifer, drawdown of six feet is projected to occur north of Morris Bridge wellfield and up to eleven feet in northeastern Hillsborough County.

5.4 Water Availability

As is demonstrated with the previous water use scenarios, ground-water withdrawal from the Upper Floridan aquifer will cause drawdown in the potentiometric surface and water table. However, the level of drawdown varies throughout the model area as leakance coefficient values, transmissivity values, and other parameters vary spatially. Since the formation of sinkholes and other breaches in the confining layer can result from large drawdowns, leakance properties between the surficial and Upper Floridan aquifers can change over time, at least in localized areas. Additionally, rainfall and evapotranspiration vary temporally, and can enhance or mask the impacts of ground-water withdrawals. Therefore, it is difficult to predict a constant amount of drawdown associated with a certain amount of ground-water withdrawal for all areas of the model for any time period. Due to the karst nature of the Northern Tampa Bay WRAP area, the system's hydrogeologic properties are highly variable.

It is the intent of current laws to avoid significant harm to water resources and natural systems. In summary, specific performance standards of the Basis of Review in Chapter 40D-2, FAC have specified that wet season water levels and hydroperiods of wetlands shall not deviate from their normal range and duration to the extent that wetland plant species composition, community zonation, and habitat are adversely impacted (Section 4.2.A.4). The Basis of Review includes similar standards for lakes, and includes the maintenance of recreational and aesthetic qualities

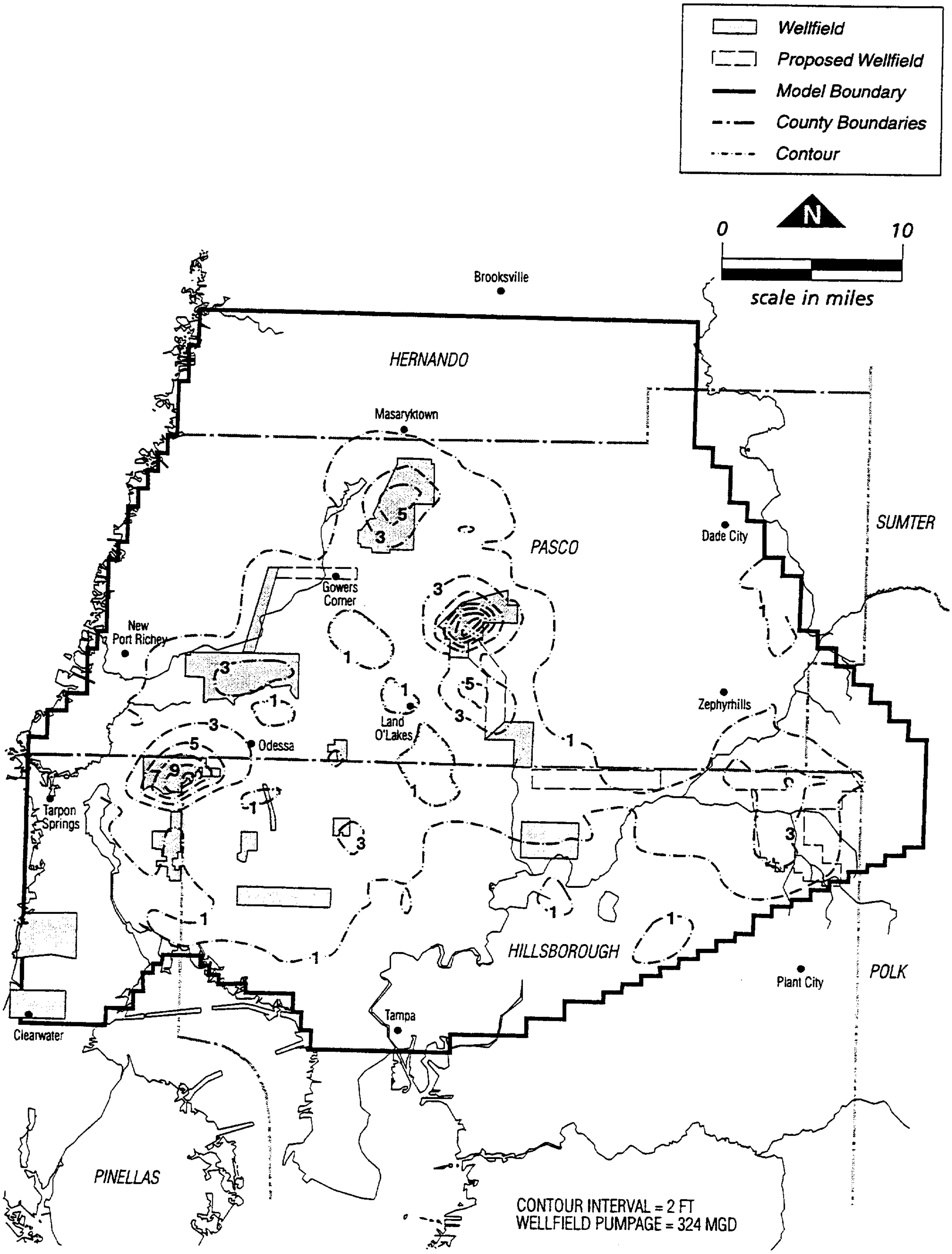


Figure 5-27. Predicted drawdown in the surficial aquifer due to 2020 regional wellfield ground-water withdrawals within the Northern Tampa Bay WRAP area.

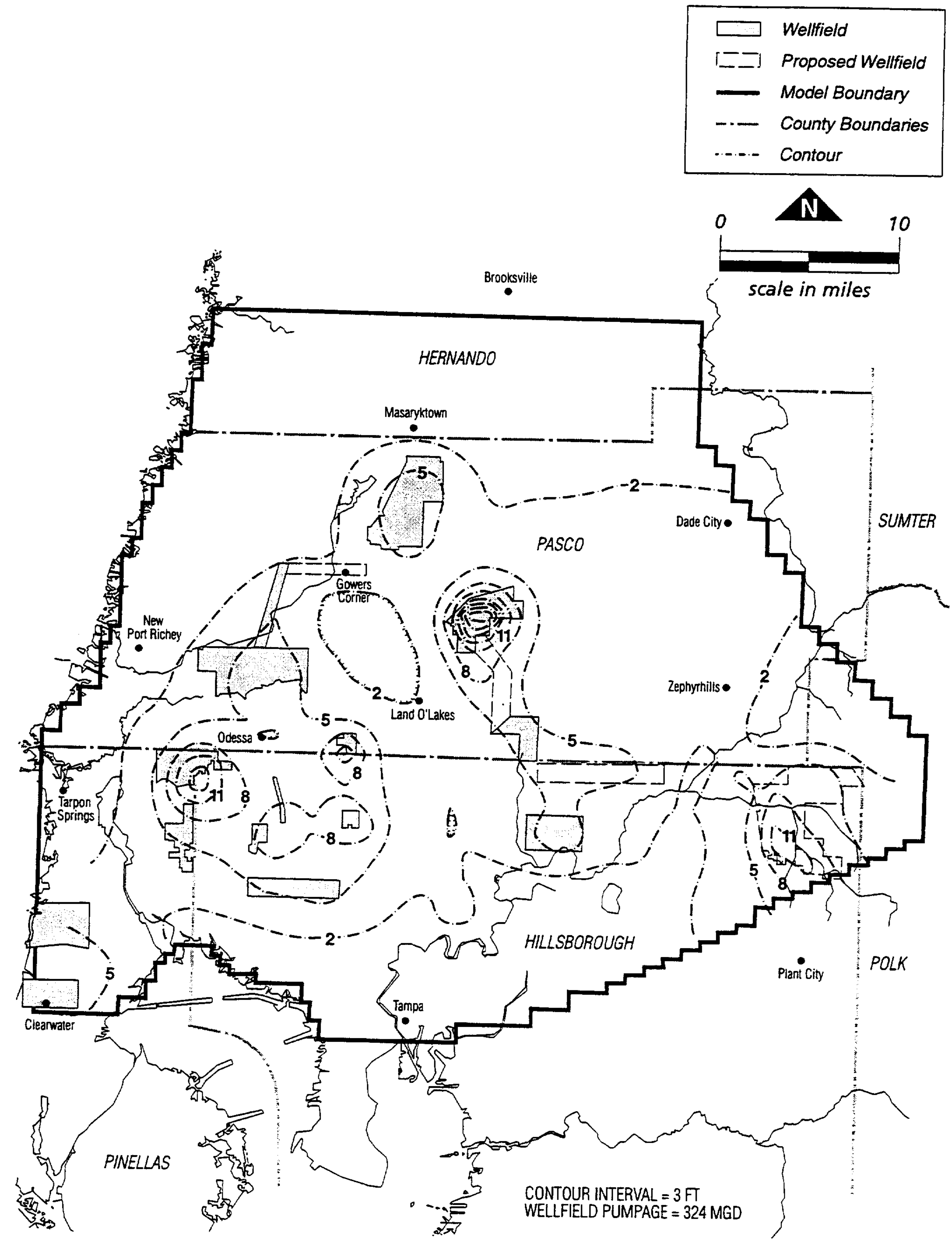


Figure 5-28. Predicted drawdown in the Upper Floridan aquifer due to 2020 regional wellfield ground-water withdrawals within the Northern Tampa Bay WRAP area.

(Section 4.2.B.1). Data and analysis presented in this report have shown that these standards have not been upheld in large regions of the Northern Tampa Bay WRAP area. Previous work (Rochow, 1989) found that the location of highly impacted lakes and wetlands corresponded with the area within the one-foot surficial aquifer drawdown caused by simulated ground-water withdrawals with regulatory numerical models. Subsequently, the SWFWMD has accepted the one-foot drawdown contour as a reasonable measure of significant water resource and natural system impact, and has included the measure as a presumption of unacceptable adverse impacts in the Basis of Review of Chapter 40D-2, FAC. Analysis presented in Rochow (1994), which presents data and analysis performed by the SWFWMD and independent consultants, supports the validity of this presumption. Data and analysis presented in this report is also consistent with the presumption. Based upon this presumption, many of the large ground-water withdrawals (most permitted under prior rules) have caused various levels of unacceptable adverse wetland, lake and streamflow impacts. Any future substantial ground-water withdrawals can be expected to have some level of impact to water levels, and subsequent impacts to surface-water features.

For this report, the regional assessment of water availability was performed through the use of the Northern Tampa Bay flow model and the hydrogeologic analysis presented in this report. Previously, the assessment of unacceptable adverse impacts in the Water Use Permitting process of the SWFWMD has been performed largely through the use of stress-type numerical models. Stress-type models assume no recharge, and are run for peak monthly quantities for a short time period (30 to 90 days). The one-foot water table drawdown presumption adopted in the SWFWMD permitting rules was based on a correlation analysis between impacts measured in the field and results from regulatory stress models (Rochow, 1989). The Northern Tampa Bay flow model is different from the regulatory models in that regional data are used, cumulative impacts are more easily addressed, and recharge is considered. Simulation periods, as demonstrated in this report, are also longer. Therefore, the one-foot water table drawdown presumption should be applied with caution when using the Northern Tampa Bay flow model. Because of the regional nature of the Northern Tampa Bay model, the drawdowns as defined by the model simulations in this report should be viewed primarily on a qualitative basis. The one-foot drawdown areas should be differentiated as having a higher potential for adverse surficial impacts than the region outside of the one foot drawdown contours. However, evidence of

unacceptable adverse impacts to surficial features, as defined by current rule criteria, has been documented in wellfield areas throughout this report. For example, as of July 1994, over 70 lakes within the Northern Tampa Bay WRAP area were defined as "stressed" by the District, the majority of which lie within the one-foot contour of current regional drawdown analyses. Although data and analysis documenting the impacts of ground-water withdrawals on the surficial aquifer is greater in and adjacent to wellfield areas, the data available in areas outside of the wellfield boundaries, but within the one-foot drawdown contour of the water table, show similar relationships as on wellfields. A comparison of the results of the regional model with stress-model results and field data shows that the one-foot water table drawdown in the regional model is also a reasonable basis for determining areas of expected unacceptable adverse wetland and lake impacts.

It is important that two additional points concerning the conceptual relationship of the drawdown contours produced by this model be well understood. First, the contours represent an estimate of average conditions in a highly variable water resource system. Too literal of an interpretation of the contours can lead to erroneous results concerning local impacts surrounding these contours. Because of the variability in the system, it is possible that surface-water features in proximity, yet on either side, of any simulated surficial aquifer drawdown contour will be impacted to a lesser or greater degree than is represented in the model results. Secondly, all of the model results presented in this report, and many other reports, are based upon average-annual rainfall conditions. Although a given ground-water withdrawal may produce acceptable levels of drawdown based upon average rainfall conditions, extended low rainfall periods compounded by the ground-water withdrawal may cause long-term environmental damage.

5.4.1 Areas of Existing Ground-Water Withdrawals

As demonstrated in the model scenario section, 1989-90 ground-water withdrawal rates in the Northern Tampa Bay region under average rainfall conditions produce two large sub-regional areas of one foot water table drawdown in central Pasco County and the tri-county section of northwest Hillsborough, northeast Pinellas, and southwest Pasco Counties. These drawdowns in the water table are largely the result of the cumulative effect of pumping nine wellfields at

approximately 140 mgd. In this "Most Impacted Area", or MIA, total ground-water withdrawals were 156 mgd in 1989-90.

To demonstrate a preliminary estimate of a regional "safe yield" based on the aforementioned one-foot drawdown constraint, two simulations were performed. In the first simulation, all ground-water withdrawals within the one-foot water table drawdown contour for the MIA, as determined from the 1989-90 simulation, were reduced by 50 percent (Figures 5-29 and 5-30). A total of 78 mgd was removed from this most impacted area. Results of reducing ground-water withdrawals by 50 percent indicate that the one foot drawdown contour within the water table would still be somewhat subregional in extent near the Eldridge-Wilde, Cypress Creek, Cross Bar, South Pasco, and Section 21 wellfields. Since the resulting drawdowns of this scenario are still relatively significant, a second simulation was performed by reducing ground-water withdrawals in the MIA by 75 percent from the 1989-1990 withdrawals. A total of 117 mgd of ground-water withdrawal was removed from the impacted area. Figures 5-31 and 5-32 illustrate the drawdown in the surficial and Upper Floridan aquifers from the second simulation. Results of the second scenario indicate that the one-foot drawdown contour in the water table would be significantly reduced, and would remain on the property boundaries of all wellfields except Eldridge-Wilde and Cypress Creek, where it would only slightly exceed the boundaries. Therefore, under the preceding presumption, 1989-90 ground-water withdrawals would have to be reduced nearly 50 percent in the MIA, and by 75 percent in the regional wellfields, to achieve a "safe yield" quantity based upon one foot of drawdown in the water table as predicted by the flow model. Note, however, that alterations to withdrawals in other portions of the Northern Tampa Bay WRAP area (beyond the MIA) may also be necessary, and a more localized analysis would be necessary to truly determine the appropriate alterations to individual permitted uses throughout the entire WRAP area. Therefore, the scenarios represent a first-cut regional estimate of safe yield.

5.4.2 Areas of Future Ground-Water Withdrawals

In reality, identifying the locations of a sustainable future ground-water supply is more complicated than simply choosing a productive ground-water location. Many factors have been investigated in the location studies for existing wellfields, including economic, land ownership,

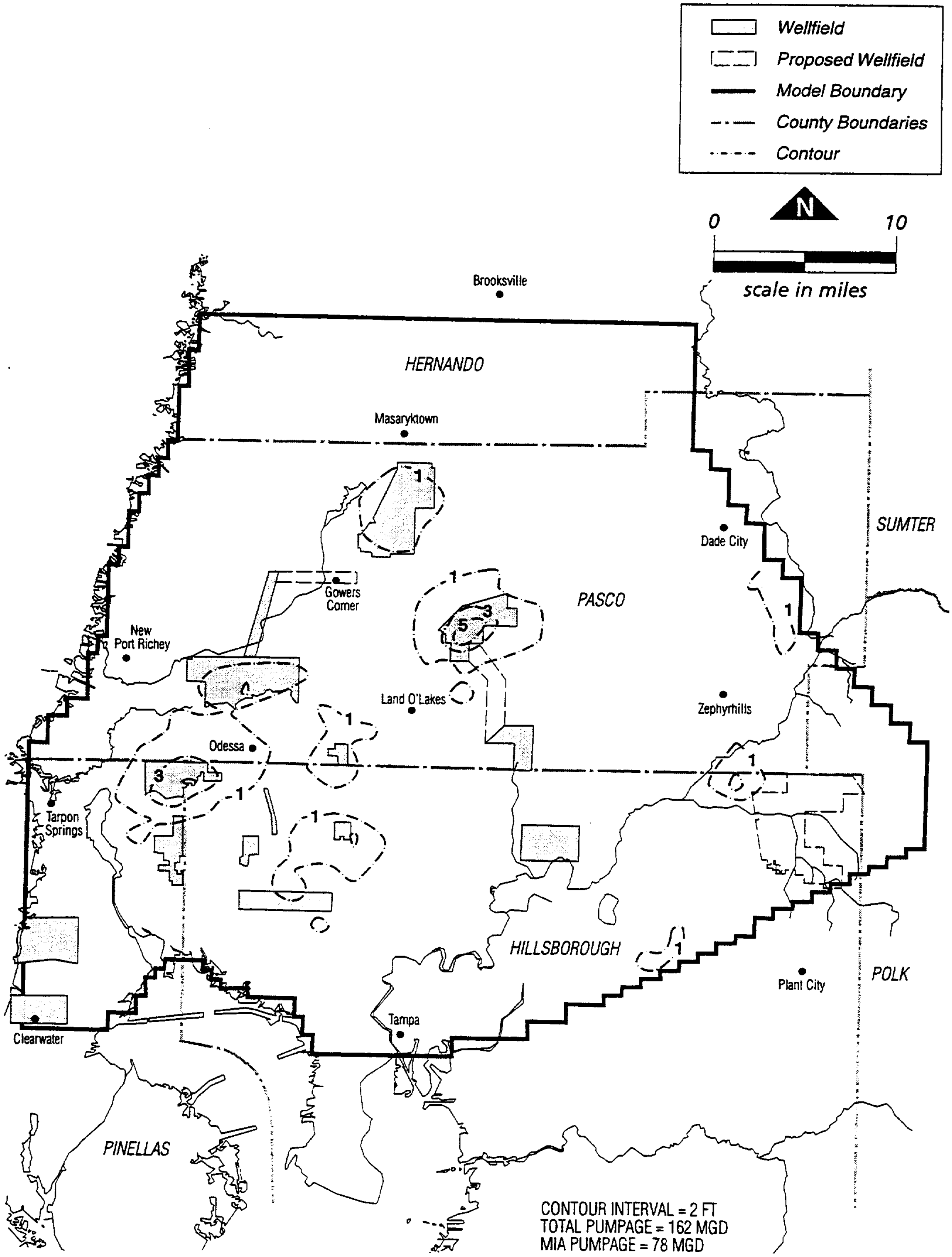


Figure 5-29. Estimated drawdown in the surficial aquifer with a 50 percent reduction in ground-water withdrawals in the most impacted area within the Northern Tampa Bay WRAP area.

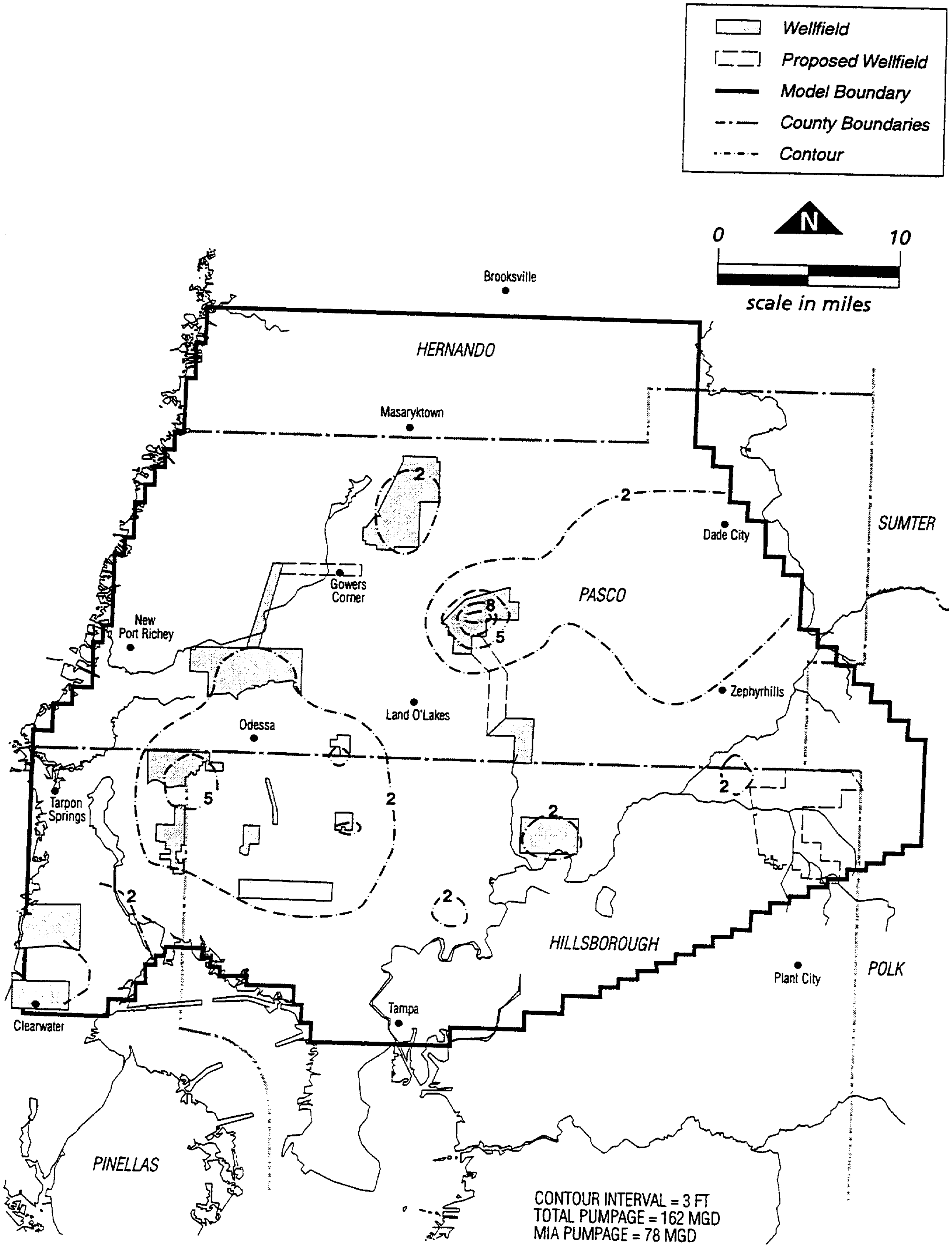


Figure 5-30. Estimated drawdown in the Upper Floridan aquifer with a 50 percent reduction in ground-water withdrawals in the most impacted area within the Northern Tampa Bay WRAP area.

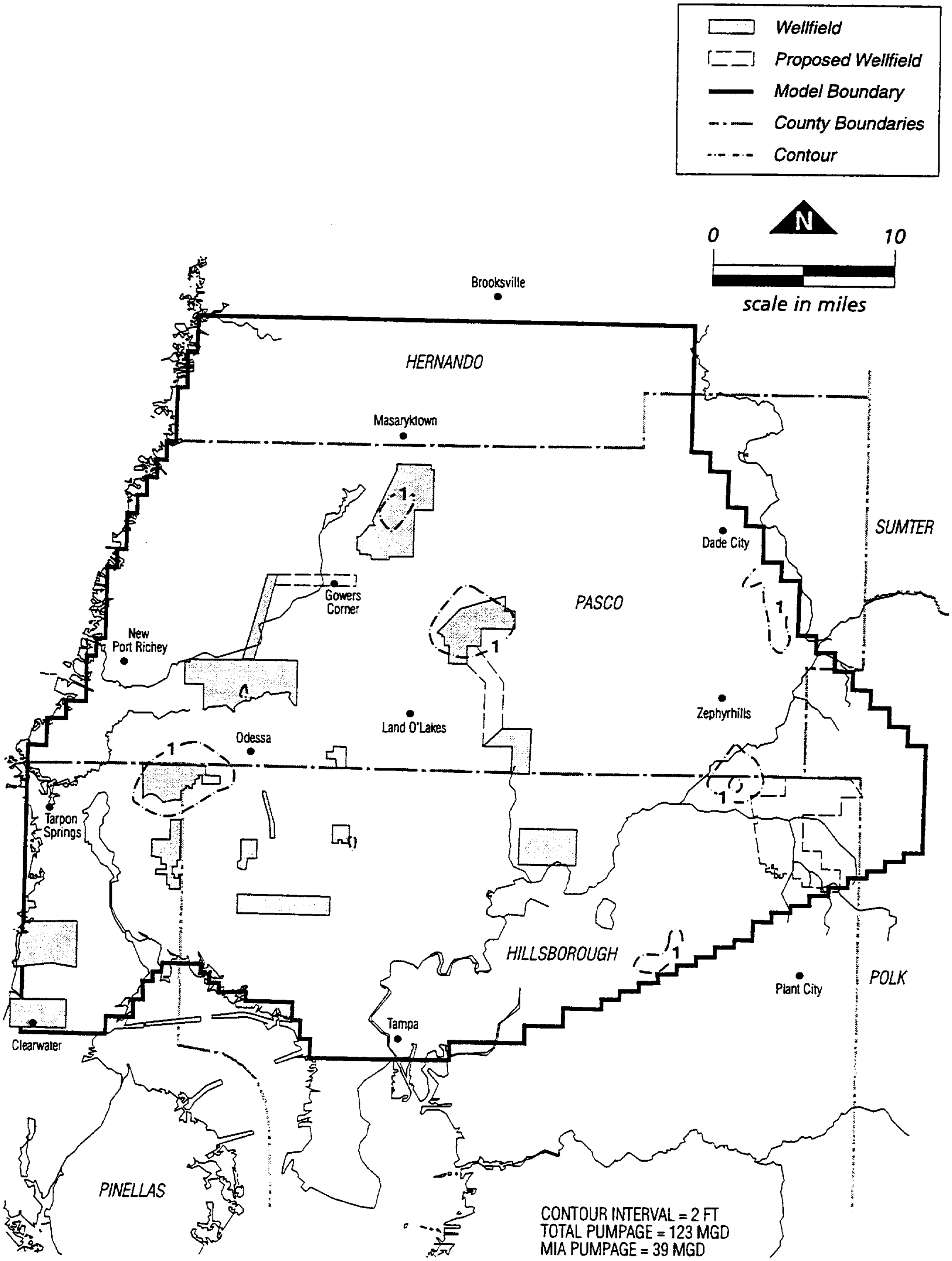


Figure 5-31. Estimated drawdown in the surficial aquifer with a 75 percent reduction in ground-water withdrawals in the most impacted area within the Northern Tampa Bay WRAP area.

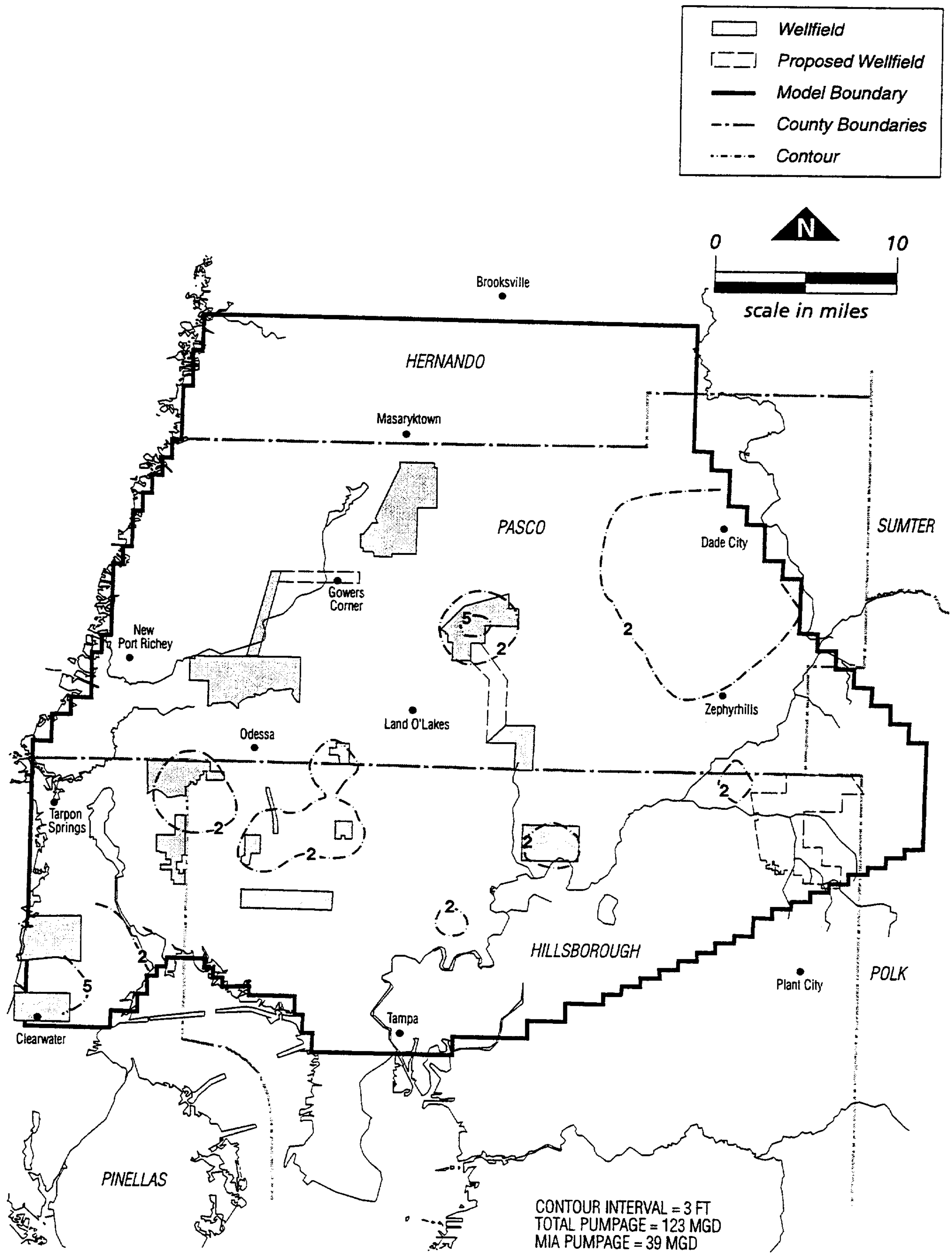


Figure 5-32. Estimated drawdown within the Upper Floridan aquifer with a 75 percent reduction in groundwater withdrawals in the most impacted area within the Northern Tampa Bay WRAP area.

planning impacts, as well as hydrogeologic and biologic parameters. The SWFWMD has little authority to control land use planning on privately owned lands, so it would be difficult to include the many socioeconomic considerations into formulating alternative future scenarios.

However, an analysis using the hydrogeological and biological parameters, as exhibited throughout this report, can be pursued. To incorporate the information and analysis of the Northern Tampa Bay WRAP, a series of overlays were produced. This information is used to produce zones of similar constraints, through which further scenario simulations are administered. These scenarios can be used to approximate future ground-water availability.

The following general analysis is presented to demonstrate a methodology of using various information presented in this report and others to identify possible future ground-water withdrawal locations. Currently, the West Coast Regional Water Supply Authority (WCRWSA) is devising a plan for future water requirements and the sources of future public water supply. One method used in their assessment (known as the Resource Development Plan) is very similar to the following discussion. It is the recommendation of this report that the following methodology, with refinements, be applied as a screening methodology for and future ground-water supply. Because the Northern Tampa Bay flow model is regional in scope, any identified ground-water withdrawals will require further localized assessment.

Although several factors that place limits on ground-water availability have been mentioned, accurately quantifying these factors is very difficult. The research performed during the Northern Tampa Bay WRAP has shown that few of the factors are independent, such as wetland health's dependence on water levels. The Northern Tampa Bay WRAP has also shown that only one noneconomic factor is of major concern regionally; wetland/lake deterioration. However, water quality deterioration (as seawater contamination along the coast) can also be considered more locally along coastal areas. Although the two factors are caused by the same action, they are not necessarily dependent on one another, and can be analyzed separately.

Seawater intrusion within the Northern Tampa Bay WRAP area is discussed and quantified in Volume Two of this report. Figures in Volume Two of this report identify the TDS content within the majority of the ground-water withdrawals zones of the Upper Floridan aquifer. The

extent of seawater intrusion can be defined as the area beyond the minimum potable water quality standard of 500 mg/l TDS. This area is used as part of the water availability analysis.

Other water quality concerns exist throughout the study area. As discussed in Volume Two of this report, landfills, hazardous waste sites, incinerators, urban stormwater and wastewater treatment plants all contribute to localized water-quality concerns, but not regional concerns (with the possible exception of incinerators). Those localized water quality concerns that are currently identifiable can be incorporated into a water management plan.

In both the ground-water management plans of Arizona and New Jersey (Arizona Department of Natural Resources, 1987 and Whipple, 1987), ground-water basins have been studied, and the areas of concern have been delineated with zones. Since the degree of adverse effects to the water supply aquifer varies throughout these states, the regulations that apply to each zone also vary. If areas of similar physical characteristics, ground-water withdrawal rates, or other concerns are grouped together with a zoning system, defining the water availability of the area may be simplified. This technique of simplification of a complex water-supply system is necessary for consistency and manageability of any ground-water regulatory program.

After analysis of various constraints identified during the study, the study area has been divided into four water availability zones, as defined below. These zones are based upon the Northern Tampa Bay WRAP's findings, including the modeling effort, hydrologic data analysis, ecological observations and research, and other pertinent information. The zones should be updated in the future as new information is gathered, and as ground-water withdrawal rates and development progress. Figure 5-33 presents the areas included in each water availability zone.

Each of the zones has been defined by overlays of the various identified constraints; modeled drawdown, observed data, previous studies, and wetland information. Each of the overlays were prepared through the Geographic Information System (GIS) using data presented in previous sections of this report. The overlays include the following:

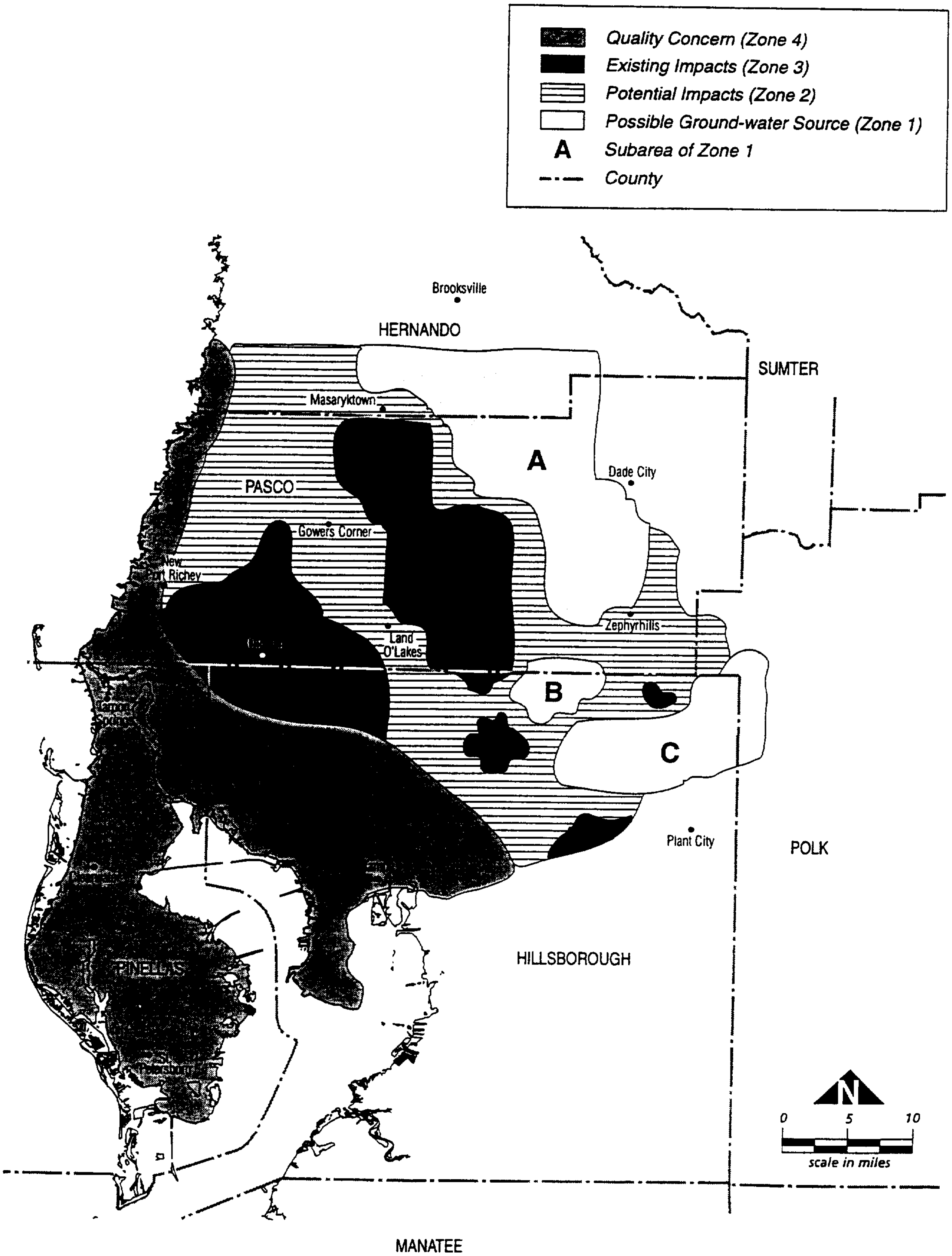


Figure 5-33. Water availability zones of the Northern Tampa Bay WRAP area.

Upper Floridan aquifer drawdown - obtained from the Northern Tampa Bay flow model. The model was run with the currently permitted ground-water withdrawal conditions, as was discussed earlier, and average long-term rainfall conditions.

surficial aquifer drawdown - also obtained from the Northern Tampa Bay flow model. The same scenario used for the Upper Floridan aquifer drawdown was used.

leakance properties of the upper confining layer - this is based on the leakance coefficients between Layer 1 (surficial aquifer) and Layers 2 and 3 (Upper Floridan aquifer) of the Northern Tampa Bay flow model. The leakance coefficient distribution is presented in SWFWMD (1993a).

land use - this overlay uses the best available land use information as described in Chapter 2.

sinkhole existence and susceptibility - two overlays were used for this constraint, both of which are presented in Chapter 2. The first overlay is an inventory of existing sinkholes compiled by the Florida Sinkhole Research Institute. The second overlay presents the zones of potential sinkhole formation.

existing pumping well density - this overlay uses the pumping distribution used in the Northern Tampa Bay model from the June 1989 to May 1990 period. This data is presented in SWFWMD (1993a).

water quality - the 500 mg/l TDS contour line, as presented in Volume Two, was used.

wetland quality - the wetlands quality inventory and rating system, as presented in Chapter 3, was used.

lake quality - the lake quality inventory and rating system, as presented in Chapter 3, was used.

It is important to realize that although annual-average rainfall is used, periods of low rainfall coupled with ground-water withdrawals can result in significant impacts to lakes and wetland systems. Although drawdowns may exist with average rainfall, long-term damage to biological systems in drawdown areas can result from extended periods of low rainfall. The damage is often inflicted during these dry periods (e.g. fires, sinkhole formation, etc.), but the cause is the ground-water withdrawal. In the absence of ground-water withdrawals, the water levels of lake and wetlands systems would not be as low, so the damage would be less or none. Therefore, any analysis performed under annual-average rainfall conditions is conservative toward water supply.

Using the various overlays, the Northern Tampa Bay flow model grid was subdivided into four zones by a series of analyses. Figure 5-33 presents these zones described in the following discussion. First, all nodes outside the model boundaries or within two nodes of the boundary were eliminated from consideration. Next, nodes within two nodes of the boundaries were eliminated, since these nodes may be more sensitive to uncalibrated changes to the model. All of these nodes are not considered in the scenario simulations, and are not categorized within the four zones.

Next, all nodes with TDS concentrations equal or greater than 500 mg/l in the Upper Floridan aquifer were placed in Zone 4, or **Quality Concern** nodes. All nodes highly susceptible to water quality degradation due to commercial, industrial, and urban development were also placed in Zone 4. This was determined using land use coverages. Also, all nodes within two miles of the coast were included in Zone 4. This distance is considered a safety measure to keep large production wells from causing upconing or possible seawater intrusion.

Upon inspection of the wetland and drawdown overlays, it was discovered that the majority of observed wetland impacts occurred within the range of three feet of drawdown or greater within the Upper Floridan aquifer during average recharge conditions. On an average basis, this same range of potentiometric drawdown causes two feet or more of drawdown in the water table. Both water-level records from wells and wetland studies can be used to regionally link these adverse effects to ground-water withdrawals. Therefore, all nodes with three or more feet of Upper Floridan aquifer drawdown during average recharge conditions were included in Zone 3, or **Existing Impacts** nodes, with the following exception. Once all nodes with greater than three feet of Upper Floridan aquifer drawdown were delineated, all nodes with few to no existing wetlands or less than two feet of drawdown in the surficial aquifer were removed from Zone 3 and reserved for Zone 2, or **Potential Impacts** nodes, as described below.

There are areas where little ground-water withdrawals exist, and no adverse water-table drawdown and subregional biological effects are simulated or observed. These areas also have land use and geological parameters that may be more favorable for lesser drawdown with current permitted ground-water withdrawal quantities. Although these areas may be susceptible to adverse drawdown effects due to future withdrawals, they are the areas where further

investigation for future withdrawals can be pursued (providing that they are designed to avoid lake, wetland, and streamflow problems, and that current land use is appropriate). To delineate this zone (Zone 1), all areas with less than two feet of drawdown within the Upper Floridan aquifer were initially labeled as Zone 1, or **Possible Ground-water Source** nodes. Upon inspection of other overlays, several nodes were eliminated from Zone 1 and categorized as Zone 2. These nodes included heavily developed urban areas, areas containing large wetland systems, nodes of the Hillsborough River, and areas of high leakage and/or sinkhole potential. Upon completion, three major areas of future ground-water withdrawal potential are identified as Zone 1 (Figure 5-33). These areas are discussed in detail below.

A large portion of the Northern Tampa Bay WRAP area is within an area of highly mixed surface-water impacts radiating from major ground-water production areas. Much of this area is within the range of some surface-water drawdown influence. Effects caused by urban and commercial development or agricultural practices do overlap these areas in some cases. Although impacts to biological and surficial aquifer systems caused by ground-water withdrawals may not be presently evident in some areas, the model results and field observations indicate that there is a great potential for future damage in this mixed zone, caused by expanding cones of depression. These impacts include reduced hydroperiods, increased leakage, dehydration of peat layers, ground subsidence, or sinkhole formation. These impacts must be linked to temporal and spatial variability. Since these aspects of the surface-water impacts can not be completely addressed for the entire ground-water basin, the mixed area (Zone 2), must be treated on a case by case basis, with an underlying set of assumptions. This zone can also be thought of as a buffer between areas of obvious impacts (Zone 3), and areas of potential future ground-water withdrawals (Zone 1). Much of Zone 2 has an existing Upper Floridan aquifer drawdown of two to three feet, but contains wetlands that are relatively unimpacted by ground-water withdrawals.

As ground-water withdrawal rates and distribution change in the future, and as existing and future monitoring and geological investigations indicate, the four zones should change. Zone 1 is used for the future ground-water withdrawal scenarios. This area of Zone 1 is limited to approximately 260 square miles in Hillsborough, Pasco and Hernando Counties, and is divided into three subareas (A, B, and C) described below.

Subarea A

Subarea A encompasses 170 square miles of the northeastern corner of the Northern Tampa Bay WRAP area. The area lies to the west of the Green Swamp and the Withlacoochee River, south of Brooksville, and north of Zephyrhills. The Pasco High section of the potentiometric surface lies within much of this subarea. The topography is hilly, with several large lakes scattered throughout the area. Relatively few wetlands exist in this subarea, and transmissivities are high in much of this area.

Subarea B

Subarea B consists of 18.5 square miles along the Pasco - Hillsborough County line, northeast of the Morris Bridge wellfield. The Hillsborough River lies about one mile to the east. The area is characterized by pasture and ranch land, as well as scattered cypress domes and marshes. Several creeks, tributaries to the Hillsborough River, flow through the property. A linear wellfield has been proposed in a part of Subarea B.

Subarea C

Subarea C is the second largest Zone 1 area, including 72 square miles in the northeast corner of Hillsborough County. Subarea C is across the Hillsborough River from Subarea B, although no closer than one mile at any point. The Cone Ranch wellfield proposed by the WCRWSA includes most of the eastern half of this subarea. The Green Swamp lies to the north and State Road 582 lies to the south. The eastern half is characterized by pasture and rangeland, with many scattered cypress domes and marshes. Blackwater and Itchepackesassa Creeks flow through the eastern half, eventually discharging to the Hillsborough River to the west. The western half of Subarea C consists of mixed pasture, wetlands, urbanization, and floodplain. Holloman's Branch flows through this subarea toward the Hillsborough River.

Once the water availability zones were established, ground-water withdrawal scenarios were proposed. Countless possibilities of withdrawal scenarios are plausible. Current hydrologic conditions suggest that the areas delineated as Zone 1 may be the best choice for future ground-water withdrawals, although existing land uses, natural habitat, and legal considerations may prove otherwise in some cases. Also, a Zone 1 status does not necessarily mean that the particular area will show no unacceptable adverse impacts if ground-water withdrawals occur.

Zone 1 simply identifies those areas within the study area that presently show little to no impacts to ground-water levels, and, in an area of karst geology, show the best potential for ground-water development in the Northern Tampa Bay WRAP area. Some of the proposed wellfields presented in the previous scenario overlap the areas delineated as Zone 1. To construct a practical set of scenarios for future public supply, varying combinations of ground-water withdrawal involving the proposed wellfields and areas delineated as Zone 1 can be evaluated using the Northern Tampa Bay model.

As an example application, the required additional public water supply projected by the Needs and Sources study (SWFWMD, 1992) was evenly distributed throughout the three Zone 1 areas using a total of 57 mgd. This ground-water withdrawal rate equals approximately 4.5 inches per year over each Zone 1 segment. Figures 5-34 and 5-35 present the drawdowns in the surficial and Upper Floridan aquifers resulting from these ground-water withdrawal rates only. With the exception of just a few nodes, the results of this run produced potentiometric drawdowns in Zone 1 subareas limited to less than five feet in the Upper Floridan aquifer, and just a few areas of water-table drawdowns greater than one foot. Of course, impacts are spread to a larger area, but the magnitude of the maximum drawdown is reduced.

The baseflows of the Hillsborough River were also analyzed for this scenario. The Northern Tampa Bay flow model predicts that flows at the Morris Bridge station reduced by nearly six percent when compared to 1989-1990 modeled conditions. Although this reduction is a concern, withdrawal points could be optimized over a larger area, therefore lessening the flow reductions. Since portions of the zones near the Hillsborough River are not within the surface watershed, corresponding overland flow reductions may also decrease. Since the ground-water flow model is not designed to accurately simulate surface-water, other methods of analyzing Hillsborough River flow reductions will more accurately identify future impacts.

Although this scenario shows that the areas of Zone 1 warrant further investigation for future public supply, four important points concerning the need for additional detailed analysis must be kept in mind when reviewing these results:

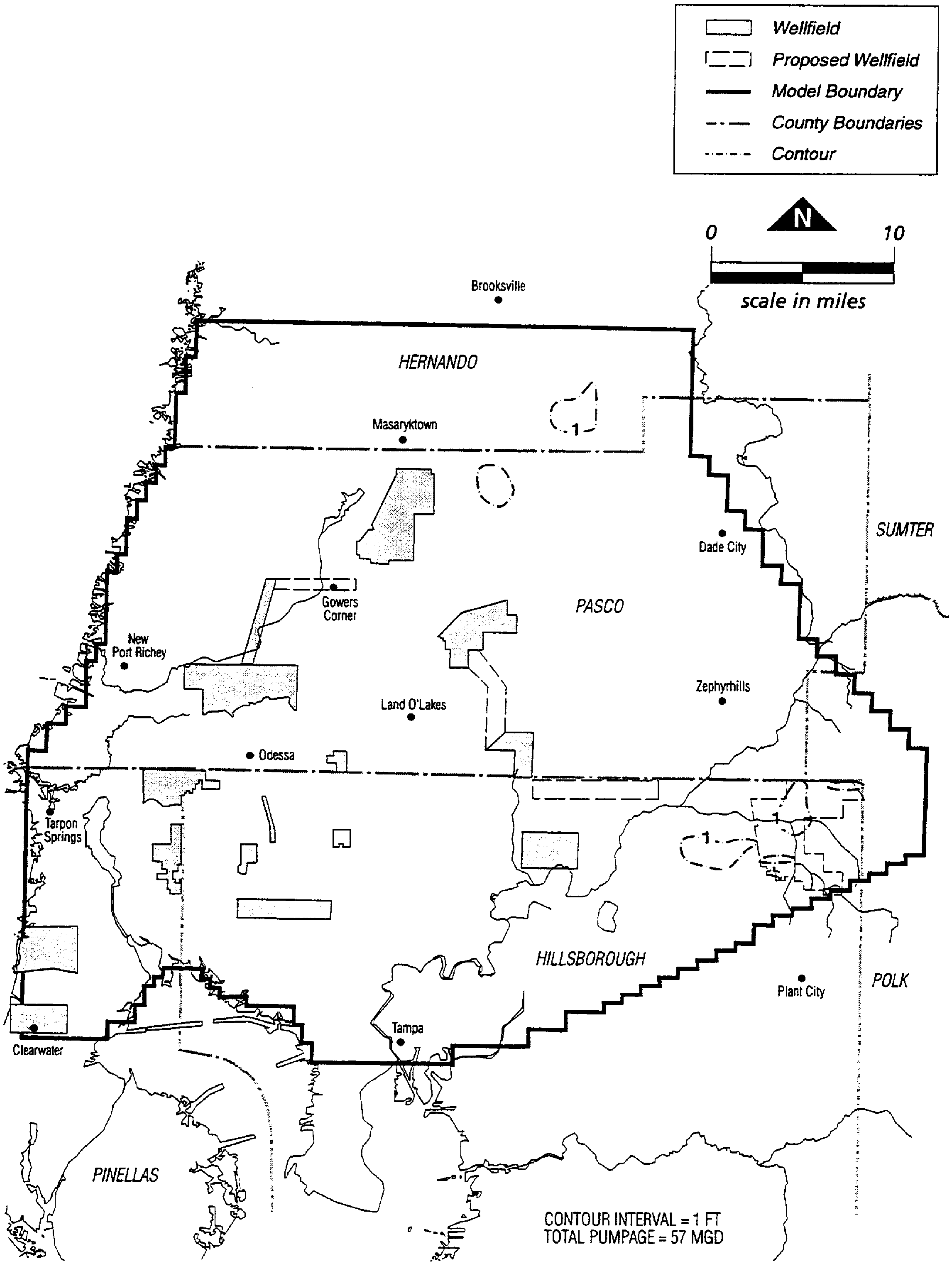


Figure 5-34. Estimated (non-cumulative) drawdown in the surficial aquifer caused by ground-water withdrawals in subareas A, B, and C within the Northern Tampa Bay WRAP area.

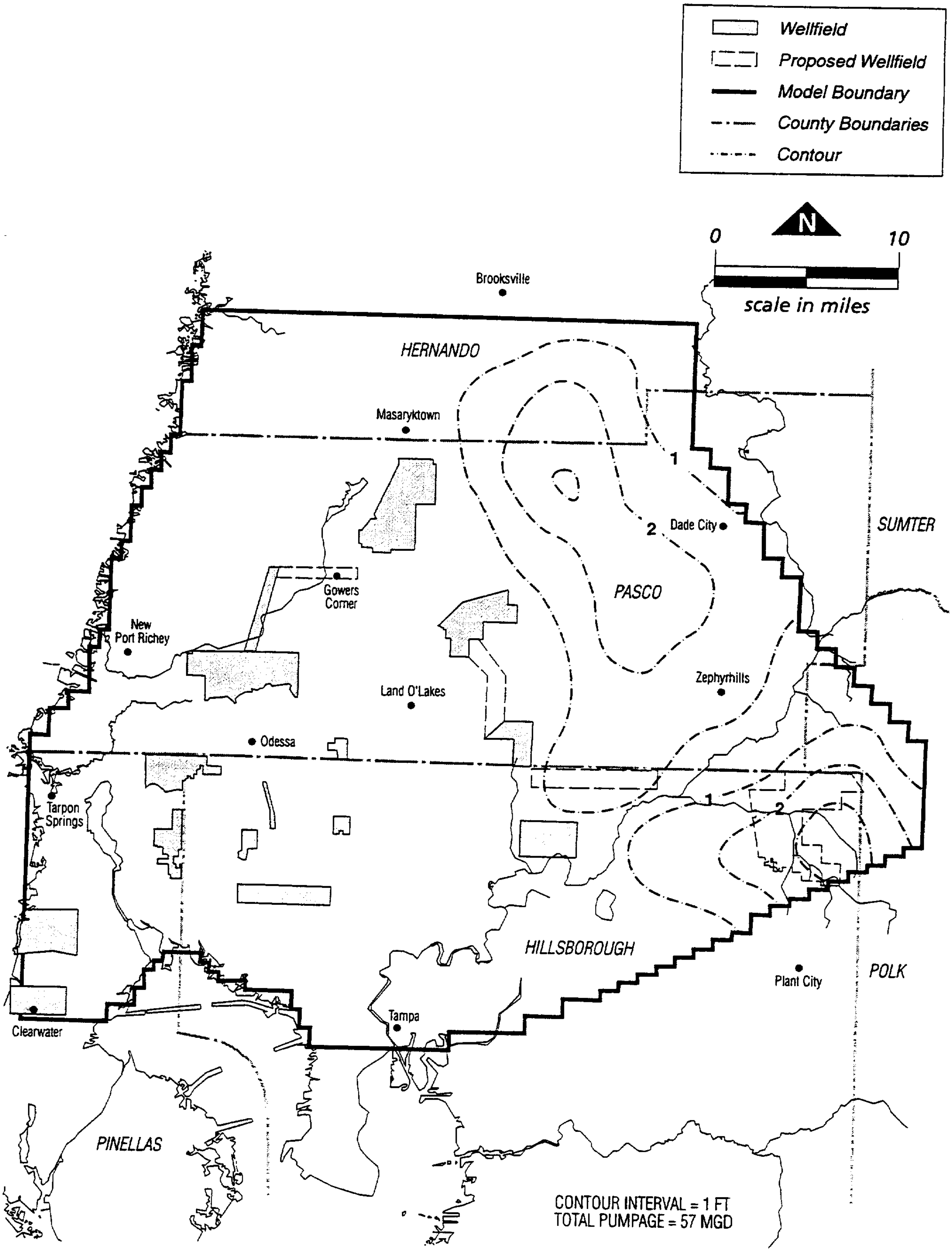


Figure 5-35. Estimated (non-cumulative) drawdown in the Upper Floridan aquifer caused by ground-water withdrawals in subareas A, B, and C within the Northern Tampa Bay WRAP area.

1) The portion of the Northern Tampa Bay model incorporated by Zone 1 is based upon the least amount of information. That is, although the majority of the model is based upon extensive data collection and analysis, relatively little data collection and analysis of the area designated as Zone 1 has been performed by past and present studies. Although a firm understanding of the current status of the water resources in this area exists, a more thorough understanding of the hydrogeology is needed in this area.

2) The drawdowns presented in Figures 5-34 and 5-35 are based upon the 57 mgd of new withdrawals only. This is not a cumulative analysis because existing users would need to be added. Fortunately, existing ground-water withdrawals are much less in this area as compared to other Zones, so the cumulative analysis using existing users does not increase the surficial aquifer drawdowns to a large degree. However, future non-public supply water use must also be considered. The Needs and Sources study (SWFWMD, 1992) projects an approximate 40 mgd of additional non-public supply ground-water use within the Northern Tampa Bay area, of which as much as 30 mgd of additional ground-water withdrawal may be needed for future citrus and nursery requirements. Most citrus water use is expected to be distributed in Subarea A. If this water use is added to the scenario discussed above, potentiometric surface drawdowns become significant (5 to 10 foot maximums) when simulated in the Northern Tampa Bay flow model, and water-table impacts increase.

3) The 57 mgd of ground-water withdrawals in this scenario have been spread evenly over the 260 square-mile area included in Zone 1. In all likelihood, future public supply ground-water withdrawals would not be distributed as evenly as in this scenario, so local impacts may be much greater than depicted.

4) Much of the Zone 1 area is adjacent to the boundary of the model. Drawdown predictions in the immediate vicinity of the boundaries of numerical models are subject to additional errors which are not of concern in the majority of the model domain. This point is of lesser importance in this screening process scenario, but is notable.

Previous analysis has shown that the karst nature of the hydrogeologic system throughout the Northern Tampa Bay area precludes a more exact assessment of local impacts to the surficial aquifer and surface-water features. However, based upon the analyses and observation presented in this report, the probability of the occurrence of surface-water impacts if new ground-water sources are established is high.

5.5 Summary

The scenarios of this chapter indicate that existing regional wellfield ground-water withdrawals have created subregional areas of significant water-level declines. Data and analysis have been presented in this and other reports which demonstrate that the drawdown of surficial aquifer

water levels, as simulated in various numerical models, of one foot or more, indicate areas of likely unacceptable adverse impacts to surface-water features. These impacts have been documented in this and other reports, and assessed with various numerical and analytical models. The scenarios also indicate that additional ground-water withdrawals will most likely significantly lower the potentiometric surface and water table, with resulting environmental impacts. Numerical modeling results indicate that all wellfields of a size comparable to existing wellfields with cost-effective withdrawal rates will cause significant water-table drawdown, and consequent impacts to wetlands, lakes, and streamflow.

CHAPTER 6 - CONCLUSIONS

The Northern Tampa Bay WRAP area has experienced a steady increase in water use since the 1930s. Due to the increase of the population in the area, the majority of this water use has been for public supply. With the exception of the City of Tampa's Hillsborough River reservoir and Tampa Bypass Canal, essentially all public supply water has been derived from ground water within the Upper Floridan aquifer.

Beginning in the 1960s (and in some cases earlier), much research has been performed to assess the effects of ground-water withdrawals on surface-water features within the Northern Tampa Bay WRAP area. It has been well established that withdrawals from the Upper Floridan aquifer have caused significant and subregional impacts to surface-water features, including lakes, wetlands, and streams, because of the leaky confining layer separating the surficial and Upper Floridan aquifer. Further, new and/or expanded impacts can be expected if significant additional quantities of ground water are withdrawn from the Upper Floridan aquifer throughout the Northern Tampa Bay WRAP area.

Analysis has also shown that seawater intrusion is not a regional concern in the Northern Tampa Bay WRAP area (Volume Two). The leaky nature of the confining layer, while a major factor regarding water levels in surface-water features, minimizes the conditions which cause regional seawater intrusion. Evidence is provided, however, to support concern for local, or possibly subregional, water quality degradation along the coast, particularly in areas affected by coastal ground-water withdrawals.

Specific conclusions of the Northern Tampa Bay WRAP report from both volumes are presented in this chapter.

6.1 Water Demand

- **Water use within the Northern Tampa Bay WRAP area has increased significantly from the 1920s to the present.** Surface-water and ground-water withdrawals for public supply purposes alone have increased by over 400 percent from 1960 to 1993, increasing from just over 60 mgd to over 250 mgd.

- **Annual-average ground-water withdrawals by all permitted users in the Northern Tampa Bay WRAP area for 1993 were estimated to be 246 mgd.** In 1993, public supply water use comprised approximately 74 percent (183 mgd) of the estimated total ground-water withdrawals in the Northern Tampa Bay WRAP area. Wellfields controlled by the West Coast Regional Supply Authority and its member governments account for over 75 percent (140 mgd) of the public supply ground-water withdrawals within the Northern Tampa Bay WRAP area in 1993.

- **The 65 largest permits (500,000 gallons per day or greater) in the Northern Tampa Bay WRAP area account for over 80 percent of the ground-water withdrawn in 1993.** These permits account for only five percent of the total number of permits in the WRAP area. Approximately 85 percent of this use is for public supply, mostly withdrawn from concentrated regional wellfields. Other users, with a few exceptions, are smaller, more periodic, and dispersed throughout the WRAP area.

- **Annual-average surface-water withdrawals in the Northern Tampa Bay WRAP area for 1993 were estimated to be 88 mgd.** In 1993, public supply water use comprised approximately 77 percent of the total surface-water withdrawals in the Northern Tampa Bay WRAP area.

- **Approximately 375 mgd of ground-water withdrawals are permitted as of 1994, of which 70 percent is for public supply use.** In addition, approximately 139 mgd of surface-water withdrawals were permitted as of 1994, of which 73 percent is for public supply use. The permitted amount of water withdrawals are meant to be limited by regulatory levels and environmental factors.

- **Based on historical trends, projected ground-water demand for 2020 could be as high as 425 mgd (SWFWMD, 1992).** This is approximately a 70 percent increase over current withdrawals, and a 13 percent increase over current permitted amounts. Projects currently underway to develop alternative water sources to ground water should reduce this demand.

6.2 Rainfall

- **No long-term upward or downward temporal trends in rainfall have been identified in the past century within the Northern Tampa Bay WRAP area.** However, average rainfall for the period from 1961 to 1994 was found to be

lower compared to the average rainfall for the period from 1901 to 1960 in some areas.

- **Short-term rainfall can be highly variable from one station to another within the Northern Tampa Bay WRAP area. Long-term spatial distribution patterns in rainfall have been identified.**

- **Multi-year, cyclic patterns of high and low rainfall have been identified in most rainfall stations in Central Florida. These patterns can be expected in the future.**

6.3 Water Levels and Potentiometric Surfaces

- **The water resource system of the Northern Tampa Bay WRAP area is strongly influenced by the local karst geology.** The hydrologic system is characterized by a significant connection between streams, lakes, wetlands, and the surficial and Upper Floridan aquifers. This connection causes these hydrologic components to be similarly affected by natural and man-induced stresses. The degree of connection between aquifers and surface-water features is highly variable. This non-uniformity is due to variability in leakage caused by sinkholes, conduits in the confining layer, thinning or absence of the confining layer, clay lenses, and depth-related variations in hydraulic conductivity.

- **Declines in the potentiometric surface of the Upper Floridan aquifer have occurred in areas surrounding ground-water withdrawals throughout the Northern Tampa Bay WRAP area.** In some areas of ground-water withdrawal, drawdowns have approached an annual-average of 20 feet below historical averages. Because public supply ground-water withdrawals comprise approximately 74 percent of the total ground-water use in the Northern Tampa Bay WRAP area, and are withdrawn primarily from concentrated wellfields, the majority of the water level declines are found near regional wellfields. However, significant drawdowns in the potentiometric surface have been identified with a few non-public supply ground-water withdrawals.

- **Due to the effect of cumulative withdrawals in the Northern Tampa Bay WRAP area, two areas of significant subregional drawdown have been identified: one in the northwest Hillsborough County area, and one in east-central Pasco County (Figures 5-16 and 5-17).** The subregional drawdown has not been reflected subregionally in the surficial aquifer of eastern Pasco County because of the increased level of confinement which separates the surficial aquifer from the Upper Floridan aquifer. However, localized impacts in surficial features due to the drawdown of the Upper Floridan aquifer in eastern Pasco County are probable.

- **The decline in heads of the Upper Floridan aquifer has caused annual-average declines in heads of the overlying surficial aquifer and surface-water features.** The magnitude of this decline depends on several factors, including the rate of withdrawal, concentration of withdrawal points, duration of withdrawal, local or subregional characteristics of the confining layer between the Upper Floridan and surficial aquifers, and varying rainfall conditions. Although varying in degree, all major wellfields within the Northern Tampa Bay WRAP area have shown an associated drawdown in water tables, lakes, and wetlands with increased ground-water withdrawals.

- **The decline in head of the Upper Floridan aquifer has also caused increased annual fluctuations in the overlying surficial aquifer and surface-water features.** The amplitude of these fluctuations has increased, while the period of high water levels in lakes and wetlands has decreased.

6.4 Environmental Effects

- **Lowered water levels in surface-water features, including wetlands, lakes, and streams, have resulted in environmental (biological) impacts.** These impacts are caused not only by annual-average drawdowns, but also by decreased hydroperiods in wetlands and lakes.

- **Environmental impacts to lakes and wetlands observed in the Northern Tampa Bay WRAP area are variable, and include wetland species changes, intrusion of upland species, ground subsidence, rapid and severe desiccation and oxidation of soils, loss of overstory, severe fire damage, wildlife loss, and complete loss of habitat.** The spatial magnitude and severity of these impacts can not be attributed to variations in rainfall.

- **Subregions of existing and potential unacceptable adverse impact have been identified, associated with subregional water-level drawdown.** Biologic impacts from the subregional drawdowns are expected to increase over time.

- **The size of the area surrounding each ground-water withdrawal that has shown environmental impacts is dependant on the rate of withdrawal, concentration of withdrawal points, duration of withdrawal, local or subregional characteristics of the confining layer between the Upper Floridan and surficial aquifers, and varying rainfall conditions.** In addition, these impacts depend on the type of surface-water features that exist in the area.

- **The areas of potential unacceptable adverse impact to surface-water systems for various ground-water withdrawal rates have been identified throughout this report.** The term "potential" is used because the degree of impact to individual lakes and wetlands depends largely on the degree of local confinement between the feature and the underlying aquifers, as well as the type of surface-water feature.

- **Analysis of surface-water flow records, as well as past studies, show that ground-water withdrawals have had effects on streamflow in several rivers, although these effects may be offset by developmental effects in highly urbanized areas.** Most rivers within the Northern Tampa Bay WRAP area are highly dependent on overland flow as a water source, so changes to streamflow may be influenced more by urban development. Several rivers outside the northwest Hillsborough County area, such as the Hillsborough and Pithlachascotee Rivers, rely more on ground water as a water source. These rivers may be more susceptible to impacts from increased ground-water withdrawals in the future.

- **The Northern Tampa Bay WRAP area has experienced a subregional decline in the water levels of many lakes during the past 30 years.** Several lakes require control structures and augmentation to maintain "normal" levels of fluctuation. Ground-water withdrawals have largely contributed to the lowering of water levels in many lakes, although in some cases, such impacts have been attributed in part to other causes.

- **Regional public supply wellfields are the primary cause of the subregional drawdowns and associated impacts to lakes and wetlands.** Although all ground-water withdrawals contribute to these impacts by some degree, several factors provide strong evidence that the regional wellfields are responsible for the large majority of the impacts. These factors include the magnitude and concentration of public supply ground-water withdrawals and the increased observed environmental impacts in regional wellfield areas.

- **Land use and drainage practices have caused some impacts on a more localized scale.** In highly urbanized areas, such as southern Pinellas County and densely populated areas of the City of Tampa, these impacts can become more subregional in extent. Some individual wetlands in less populated parts of the Northern Tampa Bay WRAP area have experienced very local impacts created by direct ditching. However, the subregional impacts are not experienced in these areas unless a regional wellfield is present. In areas of mixed urban development and regional wellfields, data analysis shows that the level of impact from the ground-water withdrawals overwhelms evidence of subregional drainage impacts.

- **Unacceptable adverse impacts to wetlands and lakes, and the associated impact to fish and wildlife habitat, are the main regional concerns within the Northern Tampa Bay WRAP area.** Although effects from causes other than ground-water withdrawals exist, the large ground-water drawdowns existing in the Northern Tampa Bay WRAP area have caused impacts that are expected to increase with time. Current wetlands regulations (Chapter 373, F.S., 40D-2 F.A.C., and 40D-4 F.A.C.) do not allow significant harm to wetlands, lakes, and streams.

- **Successful mitigation of the subregional impacts experienced in the Northern Tampa Bay WRAP area will require a restoration of a more natural water balance of the water resources system.** This restoration can be accomplished

by a combination of transient and/or long-term ground-water withdrawal reductions, and methods of returning or replacing the quantities of water removed from the water resource system that are currently discharged along the coast by wastewater facilities.

6.5 Seawater Intrusion and Water Quality (see Volume Two)

- **Because of the high degree of connection between the Upper Floridan aquifer and the overlying surficial aquifer and surface-water features, contamination of the Upper Floridan aquifer ground-water from the surface is more of a concern on the local scale.** Subregional concerns of ground-water contamination in areas of high urban development or agricultural operations may also be of concern, but information is preliminary. Ground-water degradation caused by induced recharge from the surficial aquifer, although a concern, will be assessed in a separate effort.

- **Due to the combination of the karst hydrogeology and the spatial pattern of water use in the Northern Tampa Bay WRAP area, regional saline water contamination is not a concern.**

- **Upwelling of mineralized water in not a regional concern in the Northern Tampa Bay WRAP area.** Some evidence of the upwelling of mineralized water exists along the Hillsborough River, but ground-water degradation has been controlled by local management of ground-water withdrawals.

- **Analysis of the available water-quality data is inconclusive about subregional saline water contamination in coastal areas.** The existing coastal monitoring network should continue to be closely monitored in the future.

- **Subregional seawater intrusion may be a concern in Pinellas County and parts of northwest Hillsborough County in the future with the ground-water withdrawal rates presented in this report.** However, the current water-quality data base is not extensive enough for a clear assessment in these areas.

- **Localized seawater intrusion is a concern in some areas within several miles of the coast.** Although evidence of water quality degradation along the coast exists in areas of ground-water withdrawals, wellfield management strategies, such as well rotation, can minimize local water-quality impacts. The area of concern may extend somewhat further inland along major rivers or dredged areas, such as the Hillsborough River and Tampa ByPass Canal.

- **Seawater intrusion is not the regional limiting element for ground-water supply in the Northern Tampa Bay WRAP area.** The degree of water level decline necessary to cause unacceptable adverse impacts to wetlands and lakes is much less than that required to cause subregional seawater intrusion (Volume

One). Seawater intrusion may be the limiting element controlling ground-water supply within five miles of the coast in the absence of surface-water features.

- **Because unacceptable adverse impact to surface-water features is the limiting constraint on the development of water resources in the Northern Tampa Bay WRAP area, safe yield may be determined as the rate of ground-water withdrawal that does not cause unacceptable adverse impacts to these features in all but coastal areas.** In coastal areas, both seawater intrusion and adverse impacts to surface-water features should be addressed.

6.6 Water Availability

- **Because unacceptable adverse impacts to surficial features is the limiting constraint on the development of water resources in the Northern Tampa Bay WRAP area, safe yield may be determined as the rate of ground-water withdrawal that does not cause unacceptable adverse impacts to these features.** The karst nature of the hydrogeologic system throughout this area makes the probability of any significant amount of ground-water withdrawal causing some lake or wetland impact quite high.

- **By any definition, the safe yield to protect wetlands and lakes has already been exceeded subregionally in parts of the Northern Tampa Bay WRAP area.** At current withdrawal rates, unacceptable adverse impacts to biological systems within the area of these subregional drawdowns are expected to increase.

- **Some future water supply in areas of subregional potentiometric drawdown may be available, but in very limited quantity.**

- **Additional ground-water withdrawals from within the Northern Tampa Bay WRAP area will create or increase Upper Floridan aquifer drawdowns, and may cause current subregional drawdowns to expand into new areas where significant impacts do not currently exist.** Impacts can be expected in all types of surface-water features as a result of these lowered potentiometric surfaces.

- **Future proposed wellfields pumped at the rates identified in the Needs and Sources study (SWFWMD, 1992) have a great potential to cause large-scale impacts to the surrounding water table, wetlands, and lakes.** Impacts to streamflow at the Hillsborough River and other rivers may also be expected at these proposed rates.

- **Alternative areas of future ground-water withdrawal have been identified, but, unless mitigated on a large scale, unacceptable adverse impacts to wetlands and lakes in these areas are also expected with most economically feasible wellfield scenarios.** A large section of northeastern Pasco County (Section A) appears to be an area requiring more localized analysis (Figure 5-33).

- **With the ground-water withdrawal rates for the existing and proposed future wellfields cut in half, impacts are projected to be reduced in spatial distribution and overall intensity, but not eliminated.** Impacts to surficial water resource features are expected to continue in these areas unless ground-water withdrawal rates are drastically reduced, and/or a large-scale mitigation plan is devised and implemented. More site-specific analysis for more accurate reduction values will be necessary.

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