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GROUND WATER AVAILABILITY ASSESSMENT FOR THE SURFICIAL AQUIFER ON PINE ISLAND, LEE COUNTY, FLORIDA

by
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Hydrogeology Division
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EXECUTIVE SUMMARY

The sole source of fresh ground water on Pine Island is the Surficial Aquifer System. While most of the residential potable water is provided by the Pine Island Reverse Osmosis Plant, many users depend on the Surficial Aquifer System to supply fresh water for drinking and agricultural irrigation. The Surficial Aquifer System on Pine Island is semi-unconfined and therefore influenced by coastal salt water. The location of the salt water/fresh water interface is controlled by rainfall, evapotranspiration, drainage, and pumpage. Lowering of water levels in the Surficial Aquifer System for extended periods could result in landward migration of sea water, possibly damaging groves and contaminating water supply wells.

Pine Island is an excellent area for frost-sensitive agricultural development. Agricultural activities have the potential for causing long term drawdowns in the Surficial Aquifer System through drainage practices as well as pumpage. Growing agricultural water demands have the potential to cause competition with existing users on Pine Island. Without proper management, cumulative impacts could result in landward movement of the salt water interface.

In 1985, a requested allocation for a new citrus development threatened a neighboring mango grove located along the coast. A regulatory constraint was adopted which limited impacts of withdrawals to no more than 1/4 ft. drawdown along the coast. This approach, however, did not provide estimates of regional development potential for future growth.

In order to help determine an equitable allocation for users, as well as plan for additional development of Pine Island, the South Florida Water Management District sought to develop estimates of available shallow ground water. A numerical flow model was developed to assess the ground water resources of the Surficial Aquifer System. The assessment was based on the assumption that a minimum of four ft. (NGVD) of fresh water head near the coast was necessary to assure the aquifer was fully saturated with fresh water. Well withdrawals or drainage would be limited to those areas on the island where the water table elevation exceeded +4 ft. NGVD during the dry season. Drawdowns from these areas were not allowed to exceed +4 ft. NGVD.

Using these criteria, a non-unique estimation of regional withdrawals was made for each node in the model based on pre-development conditions under three sets of rainfall conditions. Based on the conditions of the assessment, it is concluded that under normal conditions, present use should not have major regional impacts on the salt water interface. During 2-in-10 year dry season conditions, however, safe withdrawal can be maintained only in a small area in the north central portion of the island. Several existing wells are located in areas where pumpage could impact the salt water interface under these conditions. While salt water may not reach all the wells themselves, the coastal properties are at risk. The longer the reduction in ground water levels, either from drainage or pumpage, the greater the potential impacts. For this reason, requests for water use or dewatering on Pine Island, whether new uses or renewals of existing uses, should be evaluated with careful consideration for water conservation potential, monitoring for salt water intrusion impacts, and use of alternate sources in order to protect the resource and existing user rights.

It is recommended that the existing two dimensional model be used to assess cumulative impacts and to support management decisions regarding water use from the Surficial Aquifer System on Pine Island. The estimates of available yield produced in this study are based on many assumptions and, therefore, should be used to supplement water use allocation decisions but not replace existing permitting criteria. Individual permit decisions should consider the information provided here with existing pertinent rules to arrive at specific allocations.

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ABSTRACT

Increased demands for fresh water from the Surficial Aquifer System on Pine Island have made it necessary to develop methodologies to evaluate water use in terms of potential landward migration of the coastal salt water interface.

A two-dimensional numerical simulation of the Surficial Aquifer System was developed to produce estimates of available water based on several explicit constraints. Empirical data collected along the coastal margin suggested one foot of fresh water head displaced approximately 12 feet of salt water. Based on this assumption, combined with the average thickness of the Surficial Aquifer System, maintaining a minimum fresh water head of four feet was considered necessary in order to prevent salt water intrusion. Using several different rainfall scenarios, an iterative optimization routine was run to produce non-unique estimates of simultaneous pumpage which would not significantly impact the salt water interface. Existing permitted uses as of January 1988 were evaluated and compared with the estimate of available water generated during the optimization modeling.

The results suggest that while actual use may exceed the yield estimates produced by the optimization model in several localized inland areas, the overall criteria for maintaining the salt water interface along the coast is being upheld. The results of this analysis also suggest that under a 2 in 10 dry season there is a potential for salt water to encroach on coastal properties in response to pumpage. For this reason, it would be difficult to allocate additional water from the Surficial Aquifer System on Pine Island and still be able to maintain the salt water interface under 2-in-10 year deficient rainfall conditions.

INTRODUCTION

Pine Island is a coastal barrier island in Lee County (Figure 1). It is approximately 15 miles long but seldom over 2.5 miles wide. It is bordered by the warm waters of Pine Island Sound to the west and by Matlacha Pass to the east making the area ideal for raising frost-sensitive plants and fruit. Pine Island is also attractive for urban development. It has an estimated permanent population of 5,000 which increases to 5,200 during the winter season. Most of the residents live in the two main population centers: St. James City, at the southern tip of the Island, and Bokeelia located to the north. Potable water for most residents is supplied by either the Pine Island Utility which treats brackish water from the mid and lower Hawthorn aquifers by reverse osmosis, or by private supply wells into the surficial aquifer.

Beginning in the mid 1980s, after several hard frosts severely impacted the citrus industry in the central portion of the State, many grove owners moved to southwest Florida to rebuild their industry. Several small groves were planted on Pine Island.

In 1985, the SFWMD received applications for water use from two neighboring properties located in northeastern coastal Pine Island. One property, GNS Partnership, was located along the coast line. The GNS property had 42 acres of established mango trees which, due to the proximity of the salt water interface, were extremely sensitive to salt damage during the dry season. The second property, Blind Hog Grove, located immediately east and inland of the GNS tract,was proposing to convert pine flatland into 60 acres of citrus. The owner of the second property, Blind Hog Grove, sought a water use permit for 254,000 gallons per day for supplemental irrigation, plus a surface water drainage plan which would lower the water table to three feet above sea level. GNS then sought a water use permit to protect his rights to water and to prevent any landward migration of salt water which could destroy the mango grove.

Elsewhere on Pine Island several other owners of agricultural properties, both new and existing, applied for water use permits to protect their interests. Due to the limitations on fresh water, it was necessary to develop an improved understanding of the available water under differing rainfall conditions. This information, combined with the cumulative impact of existing users, would be necessary to direct water management decisions for Pine Island.

The purpose of this study was to: a) develop a flow model capable of estimating available yield from the surficial aquifer, and b) evaluate the impacts of existing permitted users to determine the potential for salt water intrusion due to pumping. This study was constrained to existing available data. Evaluation of water use was limited to general and individual permits with daily allocations exceeding 5,000 gpd. No information on private home wells was incorporated in the modeling effort.

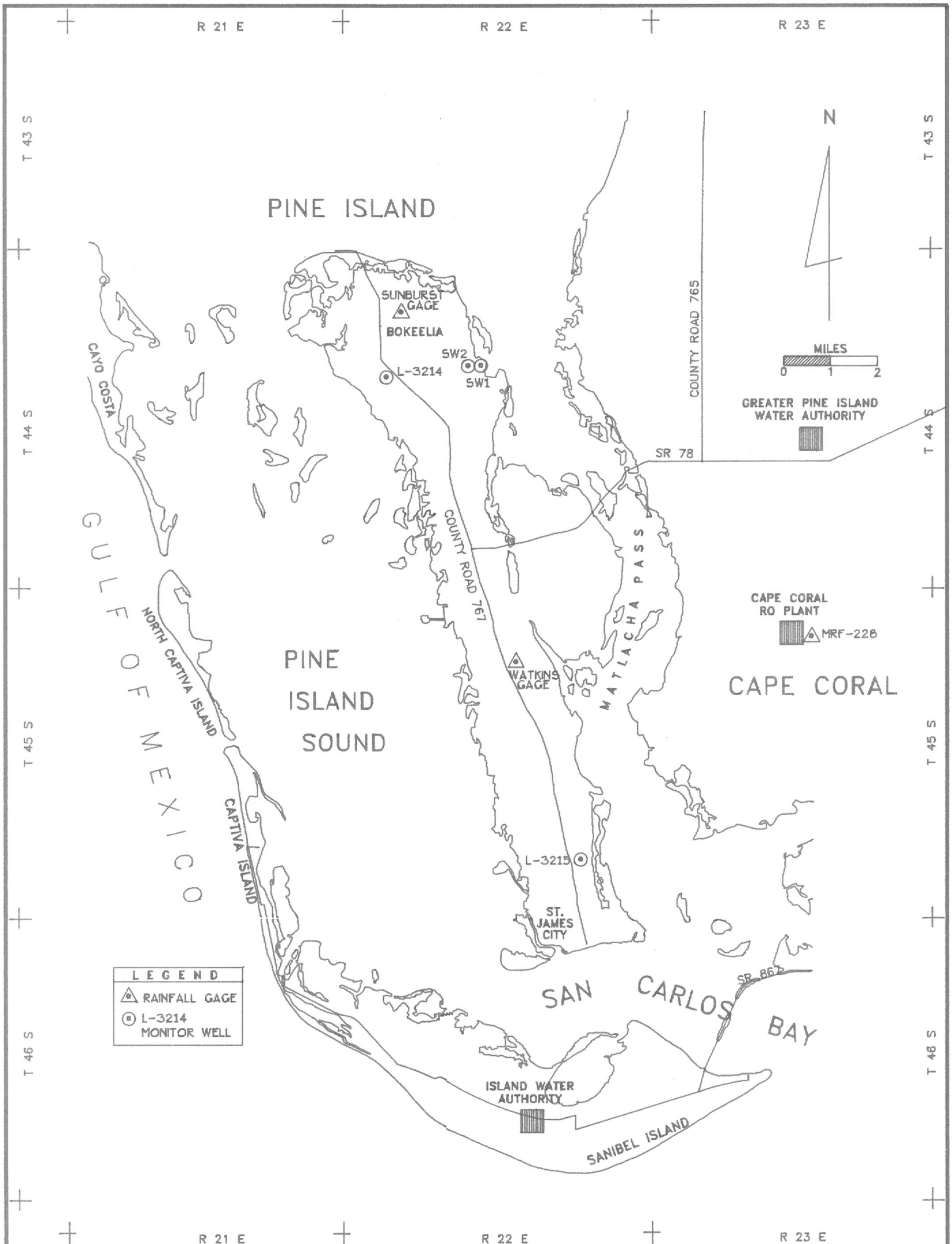


Figure 1 LOCATION OF THE STUDY AREA

HYDROGEOLOGIC OVERVIEW

The sequence of rocks which underlie the study area can be divided into three major aquifer systems (Fla. Geo. Survey, 1986): the Surficial, Intermediate, and the Floridan (Figure 2). The Surficial Aquifer System includes all hydraulically connected units above the first regionally contiguous confining bed of the Hawthorn Group. The Intermediate Aquifer System consists of two aquifers – the sandstone and the mid-Hawthorn, and three regional confining units – the upper, mid, and lower Hawthorn confining zones.

Surficial Aquifer System

The Surficial Aquifer System on Pine Island is composed of a series of clastic and carbonate sediments which range between 40 and 80 feet in thickness (Appendix). The uppermost sediments are primarily loosely consolidated sands and shell beds with varying amounts of silt and clay. The lower sequence consists of grey biogenic limestones interbedded with thin sandy green silts. Most production wells develop water from the lower carbonate portion of the aquifer.

Due to the variable permeabilities associated with the complex lithologic sequence, the Surficial Aquifer System responds as a semi-unconfined aquifer. Delayed yield characteristics are usually observed after 24 hours of pumpage. Therefore, pump tests should be at least 36 hours in duration to allow for the calculation of specific yield values.

Aquifer coefficients for the Surficial Aquifer System have been calculated from three pump tests on northern Pine Island. Reported transmissivity values range between 16,000 and 133,000 gpd/ft. Specific yield values have been reported between 0.2 and 0.3.

Recharge to the Surficial Aquifer System occurs primarily through rainfall. Two rainfall gauging stations, one long term (nine year period of record) and one short term (one year period of record) are located on the Island. Regional rainfall data reported by MacVicar (1983) suggests the annual average rainfall for the island is 56 inches. Ground water levels respond rapidly to recharge events, are highest along the central ridge (+7 to +9 ft. NGVD), and drop to sea level along the coast. Seasonal fluctuations range between 2.5 to 3.5 feet in the central portion of the Island and are minimal along the coast.

Natural outflow from the aquifer occurs through evapotranspiration and coastal seepage to the Gulf. Evapotranspiration rates vary seasonally based on depth to water, temperature, and type of vegetation. Outflows to the Gulf are dependent on the water table gradient and hydraulic conductivity of the aquifer.

Little information regarding water quality has been collected on Pine Island. Missimer (1981) inventoried wells located in the northern end of the island. Chloride levels ranged between 30 and 1,310 mg/l and exceeded 1000 mg/l in shallow lakes located near the coast. Water quality data from well L-3215 (total depth 18 ft.) located in the southern end of the Island, has been increasing from a value of 190 mg/l in April 1984 to 840 mg/l in October 1987 (the highest recorded value was 1000 mg/l in Oct. 1985). This data, although limited, suggests the availability of fresh water may be limited in the south where the island is less than two miles wide and ground water levels rarely exceed +4.5 NGVD.

Because Pine Island is surrounded by salt water, water quality in the Surficial Aquifer System is primarily a function of fresh water head. The position of the the salt water interface in coastal areas is generally approximated using the Gyben-Hertzberg relationship, where for every foot of fresh water above sea level, the corresponding thickness of the fresh water lens above the salt water is approximately 40 feet. Test data collected from northwestern Pine Island (Murray-Milleson,1986b) suggest the salt water interface may occur further inland than the Gyben-Hertzberg relationship would imply (Figure 3). Data collected from the two test wells near the coast suggest a wedge-shaped non-linear interface occurs along the island. Data from well SW1 showed that with 2.5 feet of head (not corrected for specific gravity), the 250 mg/l isochlor occurred at about 18 feet below sea level. However, further inland, data from well SW2 implies the depth to the interface in relation to fresh water head is approximately 12 to 1 (4.3 ft. of head; 52 ft. to the 250 mg/l isochlor). It is felt the data from well SW2 is more reliable for predictive purposes.

The Surficial Aquifer System is the only aquifer beneath Pine Island which contains significant quantities of potable water. While the majority of drinking water is provided by the Pine Island Water Authority, many single family homes continue to rely on privately owned wells to provide drinking water. In addition, several agricultural wells develop water from this source for irrigation supply. For these reasons, careful regulation is necessary to protect this resource.

GEOLOGY				LITHOLOGY	HYDROSTRATIGRAPHY	
SYSTEM	SERIES	FORMATION			HYDROLOGIC SYSTEM	HYDROLOGIC UNIT
QUARTER.	PLEIST.	UNDIFFERENTIATED		FINE TO MED QUARTZ SHELL AND SILT; NEAR BASE OF SEQUENCE	SURFICAL AQUIFER SYSTEM	WATER TABLE AQUIFER
TERTIARY	PLIOCENE	TAMIAMI FORMATION		SANDY BIOGENIC LIMESTONE WITH VARIABLE INDURATION. VERY FOSSILIFEROUS INCLUDING MOLLUSKS,ECHINOIDS,CORALS AND BRYOZOANS. GOOD MOLDIC POROSITY,HIGH YEILD.		TAMIAMI CONFINING BED
						LOWER TAMIAMI AQUIFER
	MIOCENE	HAWTHORN GROUP	UPPER CLASTIC	HETEROGENEOUS MIX OF PHOSPHATIC SANDS, CLAYS LIMESTONES AND DOLOMITES. WELL DEFINED PHOSPHATIC RUBBLE BED MARKS THE BASE OF THE SERIES. LOW PERMEABILITY IN SANDY SILT FACIES. REGIONAL LIMESTONE UNITS PROVIDE MODERATE WELL YIELDS.	INTERMEDIATE AQUIFER	UPPER HAWTHORN CONFINING ZONE
						SANDSTONE AQUIFER
						MID-HAWTHORN CONFINING ZONE
			LOWER CARBONATE	PHOSPHATIC POORLY INDURATED LIMESTONE AND DOLOMITE WITH MINIMUM AMOUNTS OF FINE SAND. MINOR SHELL FRAGMENTS. LOW PERMEABILITY THROUGH MIDDLE SEQUENCE. BASAL PHOSPHATIC LIMESTONES ARE INDURATED AND SANDY, FRACTURE PERMEABILITY NEAR BASE WITH GOOD YIELD.		MID-HAWTHORN AQUIFER
						LOWER HAWTHORN CONFINING ZONE
					FLORIDAN AQUIFER SYSTEM	LOWER HAWTHORN / TAMPA PRODUCING ZONE
	OLIGOCENE	SUWANNEE LIMESTONE		LIGHT ORANGE BIOGENIC CALCARENITE LESS THAN 5% SAND. FORAMS AND ECHINOIDS. MOLDIC INTERGRANULAR POROSITY. HIGH YEILD NEAR TOP AND BOTTOM OF UNIT.		SUWANNEE AQUIFER

Figure 2 HYDROSTRATIGRAPHIC FRAMEWORK OF PINE ISLAND

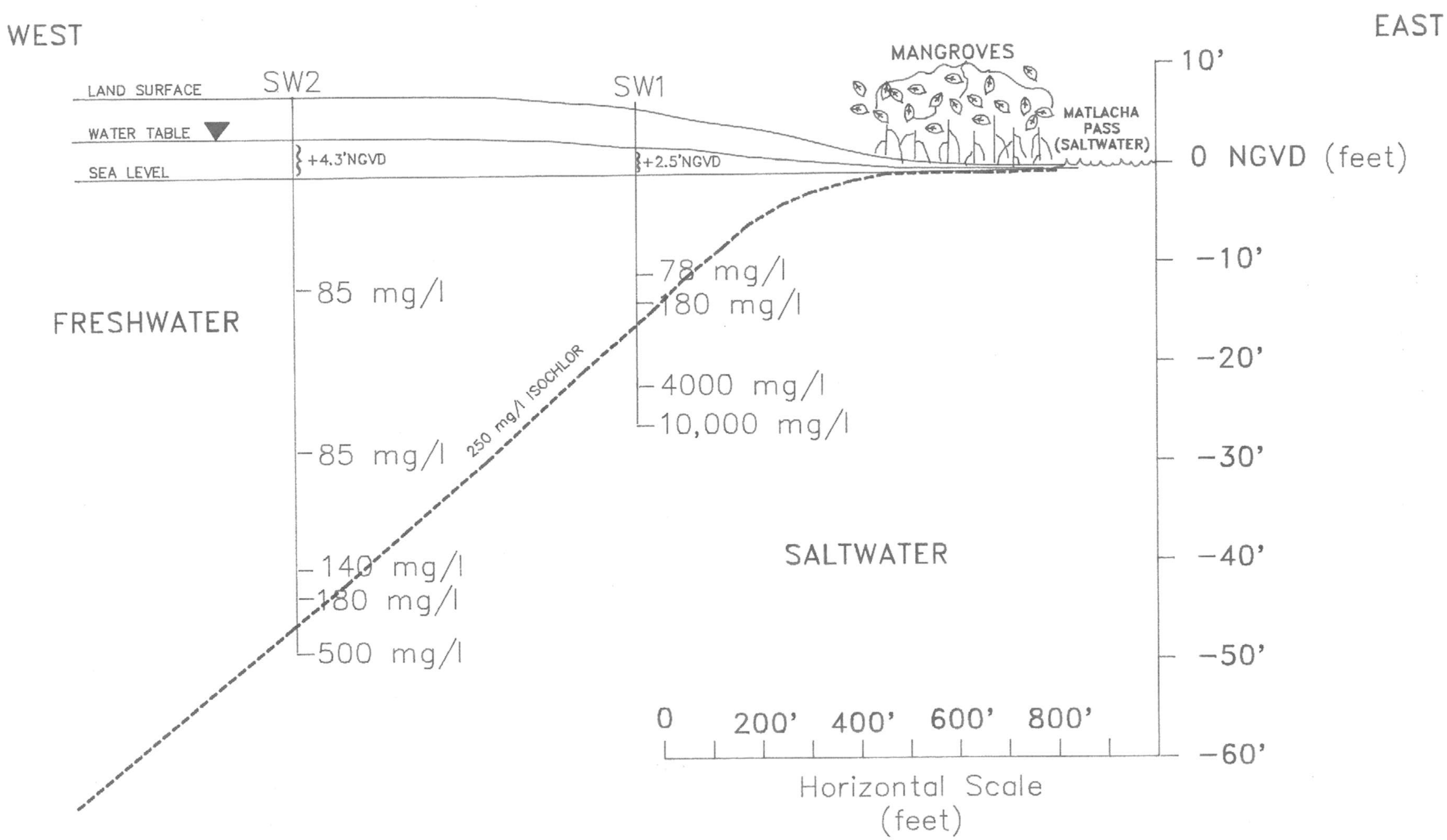


Figure 3 EMPIRICAL RELATIONSHIP BETWEEN FRESH WATER HEAD AND THE 250 mg/l ISOCHLOR ON PINE ISLAND

Intermediate Aquifer System

The Intermediate Aquifer System (IAS) underlies the Surficial System and generally acts to confine the Floridan Aquifer System. The IAS is composed of alternating beds of silts, sandstones, limestone, and micrite with variable permeabilities. Two aquifers, the sandstone and mid-Hawthorn, occur within the Intermediate Aquifer System beneath Pine Island.

The sandstone aquifer occurs at depths between -100 and -200 ft. NGVD and seldom exceeds 50 feet in thickness (Appendix). No aquifer performance tests have been completed on this unit in Pine Island.

The second aquifer in the IAS is the mid-Hawthorn. The mid-Hawthorn is composed of phosphatic limestone which occurs at depths between -200 and -300 ft. NGVD. It is approximately 50 feet thick beneath the Island and contains brackish water which free flows at land surface. Dissolved chlorides range between 560 and 2,620 mg/l in this area. The estimated transmissivity value of the mid-Hawthorn is approximately 10,000 gpd/ft. A few wells on the Island tap this source for irrigation supply.

Beneath the mid-Hawthorn aquifer is a thick sequence of low permeability micrite interbedded with thin permeable limestone stringers. Regionally, these thin beds are included in the lower Hawthorn confining zone. However, in western Lee County, these units are tapped for small uses. These localized units occur at depths between -350 and -450 ft NGVD. Water levels and water quality are generally very similar to the upper portions of the underlying Floridan Aquifer System which is the apparent source of recharge for these unnamed units.

Floridan Aquifer System

The Floridan Aquifer System (FAS) occurs at depths between -400 and -600 ft. NGVD beneath Pine Island. Water quality is considered poor for irrigation but is being extensively used for public supply through reverse osmosis. Chloride data collected on the island range between 600 and 1,800 mg/l. The estimated transmissivity of the upper portion of the System (lower Hawthorn aquifer) is 60,000 gpd/ft. (Missimer, 1981). Water levels for the unit range between 20 to 35 ft. NGVD and wells which tap this unit free-flow at rates between 100 and 300 gpm. Few wells tap the FAS on Pine Island due to the poor quality; however, during the early 1950s, several wells were drilled into this source for free-flowing irrigation water. Over the years many of these wells have been abandoned and have become a source of contamination to the water table aquifer. As a result, these wells are being plugged under the Lee County Well Plugging Program whenever necessary. As of September 1988, 20 abandoned flowing wells have been located on Pine Island – 18 of which have been plugged (written correspondence, Roland Banks, 1988).

WATER USE

Two types of water use permits, Individual and General, are issued by SFWMD. The Individual Water Use Permit is issued on Pine Island for withdrawals which exceed 10,000 gallons per day. These permits usually undergo a detailed review process to determine the possibility of adverse impacts. Users of volumes below 10,000 gallons per day are issued general permits. These permits are for small users with minimal impacts on the resource. Permitted water use on Pine Island is summarized in Table 1.

Water use allocations for agriculture (except citrus) are based on the modified Blaney Criddle formula to determine supplemental crop irrigation requirements (SFWMD, 1985). This formula evaluates climatic conditions – soil type, crop type, and rainfall to determine evapotranspiration rates which are used to estimate supplemental irrigation needs. Citrus allocations are based on a supplemental crop requirement of 5.3 inches per month and 14.4 inches per year.

TABLE 1. WATER USE PERMITS FOR PINE ISLAND

PROJECT NAME	PERMIT #	CROP	ANNUAL ALLOCATION*	ACRES	SOURCE
Sunburst Grove	36-00294	Citrus	254.4 MGY	110	Surficial
Treehouse Nursery	36-00301	Plants	45.6 MGY	15	Surficial
Pine Island Grove	36-00059	Citrus	68.79 MGY	102	Surficial, Floridan
Trop-Ag, Inc.	36-00572-W	Fruits, veg.	19.0 MGM	366	Surficial, onsite lakes
Trop-Ag, Inc.	36-00808-W	Tomatoes	1.8 MGM	32	Surficial
Easterday Nursery	36-00114-W	Plants	8.93 MGY	13	Surficial, Lower Haw.
Quail Run Nursery	36-00060-W	Plants	32.3 MGY	47	Floridan, onsite lakes
GNS Partnership	36-00671-W	Groves	3.6 MGY	42	Surficial
Blind Hog Grove	36-00672-W	Trop. fruits	2.24 MGM	93	Surficial
Singing Bird (North Grove)	36-00773-W	Citrus	6.48 MGM	35	Surficial, Lower Haw.
Singing Bird (Scott Grove)	36-00722-W	Citrus	16.1 MGY	35	Sandstone Aquifer
Brewer's Grove	36-00794-W	Small Veg.	0.33 MGM	10	Surficial
Edward Dean (Pheffer Grove)	36-00779-W	Trop. fruits	0.15 MGM	4	Surficial
Edward Dean (Wetstone Nur.)	36-00780-W	Palm Stock	1.2 MGM	8	Sandstone Aquifer
Samadini Groves	36-00742-W	Mangos	0.15 MGM	18	Surficial
Britton Groves	36-00725-W	Mangos	0.24 MGM	8	Surficial
Blue Crab Key	36-00721-W	Landscaping	16.49 MGY	14.45	Mid-Hawthorn
Wigerts Mango Grove, Nursery	GP-82-300	Nursery Plants	22,000 GPD	10	Surficial
J. Henry Arnt	GP-82-55	Groves	500 GPD	10	Surficial
Treehouse Nursery	GP-85-255W	Citrus, fruit	7000 GPD	3.75	Surficial
Gulf Island Groves	GP-85-177W	Mangos	3500 GPD	20	Surficial
P. Shaw	GP-85-231W	Landscaping	6000 GPD	0.75	Surficial
Lee County School Board	GP-85-153W	Lawn Irrig.	6000 GPD	0.33	Surficial
A.J. Cryder	GP-81-324W	Groves	9000 GPD	3	Surficial
Sunbank	GP-86-317W	Lawn Irrig.	7440 GPD	0.45	Mid-Hawthorn
Perry Brucker	GP-86-268W	Mangos, fruits	7500 GPD	8.0	Surficial
Old Mcgowens Farm	GP-86-1047	Nursery Irrig.	3.28 MGY	--	Surficial

Permit allocations do not necessarily reflect actual water use for a given area. Different types of crops require varying rates of irrigation throughout the year. In addition, since water use allocations are made under the assumption of 2 in 10 year drought conditions, rainfall which occurs during normal years usually provides for the majority of the irrigation needs. Therefore, the allocations shown on Table 1 are based on the amount of water needed to maintain the crop during 2-in-10 year dry season conditions. These allocations may be larger than actually used during normal rainfall years.

Water use on the island is divided into three major categories: agricultural, landscape irrigation, and single family private supply. Water used to supply these needs are derived from the Surficial, Intermediate, and Floridan Aquifer Systems.

The largest category of water use on Pine Island is agriculture with a combined monthly allocation of 59.8 million gallons (mg). A breakdown of irrigated agricultural acreage is summarized as follows: 35.55 million gallons per month (mgm) citrus, 3.12 mgm mangos, and 21.13 mgm vegetables. Of the 59.8 mg allocated, 87% is derived from the water table aquifer. This use, coupled with associated drainage practices, has a net impact of lowering fresh,water head and influencing inland salt,water migration.

The second largest category of water use on the island is for landscape/nursery irrigation. The combined monthly allocation for landscape irrigation is 11.31 mg. These allocations are associated with small properties and individually have minor impact on the resource.

The third category is public water supply. Drinking water is supplied to most residents by the Greater Pine Island Water Association from their reverse osmosis plant located on the mainland. In 1986, the utility estimated that 120 single family homes depended on private wells to supply their potable and irrigation needs. In addition, a large number of additional homes have private wells for lawn irrigation alone. These wells were all assumed to be developed into the water table aquifer. From a quantitative standpoint, this use is negligible; however, the issue of public health makes these wells very important to water management decisions.

MODEL DEVELOPMENT

Hydraulic Parameters

The model used in this study was the U. S. Geological Survey two-dimensional finite difference model developed by Trescott, Pinder, and Larson (1975). Hydrologic data from the study area was discretized into a grid consisting of 1320 rectangular nodes (44 columns and 30 rows). Each grid cell was 1,000 feet along the x-axis and 2,000 feet along the y-axis (Figure 4).

Very little hydrogeologic data was available for Pine Island at the time of the study. Aquifer hydraulic data was available from only three Surficial Aquifer System tests. All three of these tests were located in the northern portion of the island. Long term water level data from the Surficial Aquifer System was available from only two USGS monitor wells. Rainfall data from the north end of the island was collected by a grove owner during 1985, but the data was ambiguous and impossible to verify. More reliable rainfall data was collected from two additional stations, one at the Cape Coral Water Treatment Plant and the other at a USGS station in the center of Pine Island, but these stations were several miles from any of the ground water monitor wells. Actually, very little information regarding the location, orientation, and dynamics of the salt water/fresh water interface was available. As a result, the modeling efforts were somewhat crude and based on the following significant assumptions.

The aquifer was assumed to be homogeneous and isotropic. Lithologic data collected from Pine Island show the Surficial Aquifer System is composed of two different facies with minor clay stringers occurring between the two units. It is likely that the hydraulics of the upper clastic facies differ significantly from the lower carbonate unit and the clay stringers would produce semi-unconfined conditions in the lower portion of the aquifer. As a result, the model should have been treated as a multi-layered system consisting of three different homogeneous isotropic layers. However, there is insufficient data available on the hydraulics or extent of the different facies to justify a multi-layered approach at this time. The results of grouping these layers into one unit are that the model would produce inaccurate values over short time periods (hours to days) but would be accurate for pumping periods longer than several days when delayed drainage effects are achieved.

The second major assumption was that the aquifer was unconfined. Two of the three aquifer performance tests show semi-unconfined conditions occur for wells which are open to the lower carbonate portion. However, delayed drainage effects observed within the first 24 hours of pumpage suggest the aquifer will exhibit unconfined characteristics after one or two days. The pumping periods evaluated in the model were 30 days each; by that time, the assumption that the aquifer is performing as an unconfined system appears valid.

The hydraulic conductivity values calculated from the aquifer tests were intuitively regionalized across the finite difference grid. These values ranged from 1.1 E-3 to 3.1 E-3 ft/sec. based on the transmissivity values divided by aquifer thickness. Transmissivity data were obtained from consultant reports (Missimer, 1986, Murray-Milleson, 1986a. and b.). Aquifer thickness varied between 40 to 75 feet. A single value of 0.2 was used for specific yield.

A constant head boundary was used along the coastal margin of Pine Island to reflect the influence of the Gulf of Mexico on an unconfined aquifer. The head level along this boundary was fixed at zero. The basal boundary of the water table aquifer was treated as a no-flow boundary with no water derived from confining bed storage. Water level data from the underlying sandstone aquifer suggests a slight downward gradient (less than 1 ft.) exists from the water table to the sandstone aquifer under non-stressed conditions. However, during extended pumping from the surficial aquifer, the downward gradient may be reversed and small flows from the underlying aquifers may occur into the areas of stress. Improved understanding of the underlying confining bed hydraulics would be necessary prior to attempting to quantify this flow. The results of treating the base of the aquifer as a no-flow as opposed to a flux boundary are that projected drawdowns may be slightly greater than those which would occur if upward leakage effects were accounted for.

Recharge rates, used to establish initial head conditions, were based on regional long term rainfall trends as described by MacVicar, 1983. For available yield assessments, various seasonal rainfall scenarios were developed from long term trend data derived from MacVicar's report. During calibration, actual rainfall data collected during 1985 in northern Pine Island was used.

Model Calibration

Calibration and validation of the model was difficult due to the lack of rainfall and ground water

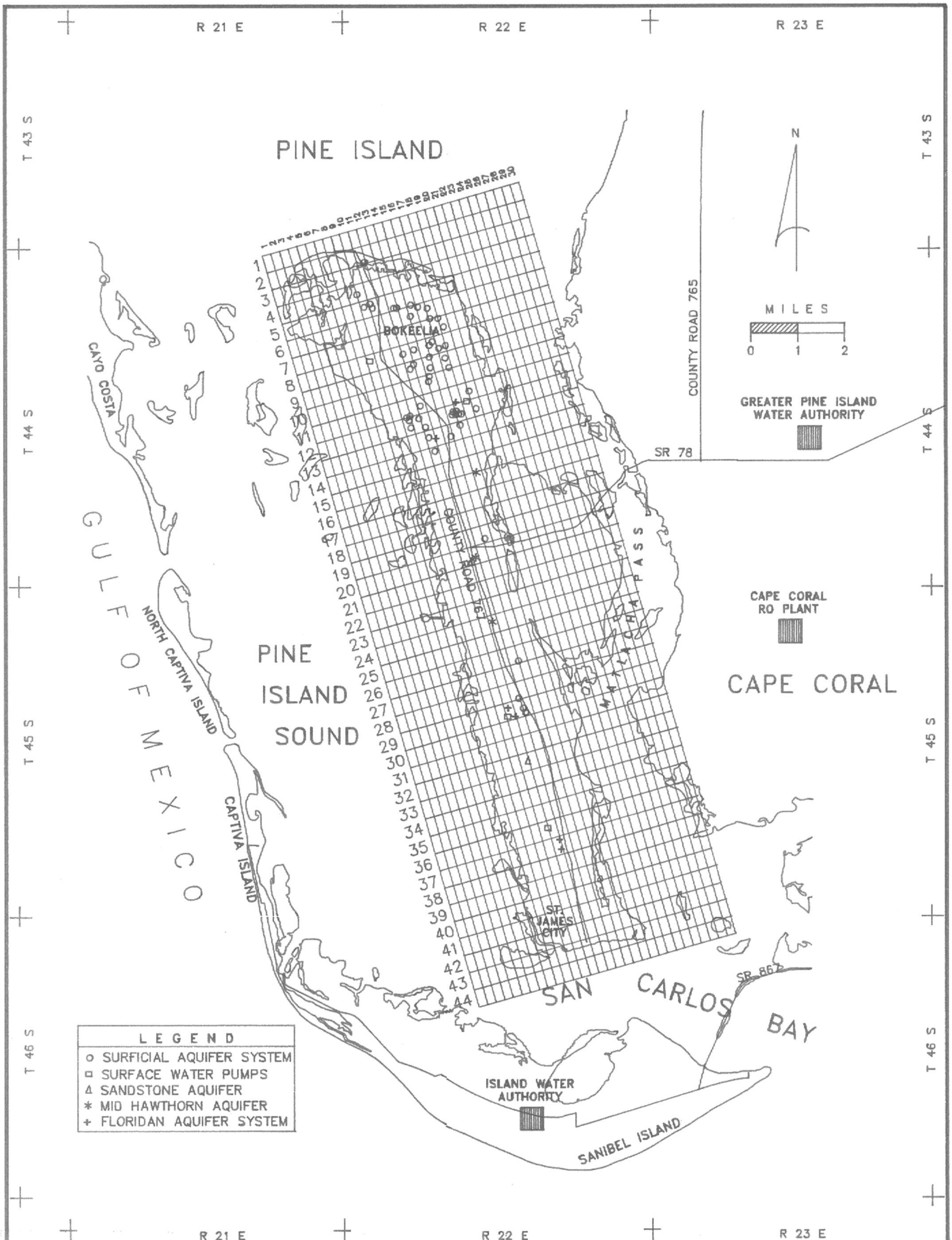


Figure 4 PINE ISLAND MODEL DISCRETIZATION WITH LOCATIONS OF PERMITTED WELLS

monitor data. Period of record data from two long term USGS ground water monitor wells are shown in Figure 5. Several privately owned monitor wells occur in the northwest portion of the island; however, water level data from these private wells was not collected in 1985 when the rainfall data was available. It is impossible to determine the water table configuration of the island with only two wells, but the water level data, combined with the topography of the island, was useful in estimating the general configuration of the water table.

Both hydrographs show water levels generally exceed land surface by approximately one-half foot – at least for one event (end of monthly reading) during the wet season. In addition, seasonal water level fluctuations are generally 2.5 to 3 feet. This information was used along with the hydrograph data from L-3214 and L-3215 to calibrate the model.

The model was calibrated using rainfall and water level data collected during the 1985 calendar year. Rainfall data nearest to monitor well L-3214 was collected at the Sunburst Tropical Fruit Company by the grove owner. Daily events were recorded and summarized in monthly and semi-annual pumpage reports. There were several discrepancies between the monthly and semi-annual reports. In these cases, rainfall data from nearby stations MRF 228 (located at the Cape Coral Reverse Osmosis Plant) and the Frank Watkins gage (on Pine Island Sec. 3, Township 45, Range 22), were used to attempt to resolve the differences. The distance between these stations is several miles, and it was difficult to correlate rainfall data between stations. Rainfall was frequently recorded on the same day, but the magnitude often varied widely. For those months with conflicting rainfall records, modeled recharge rates were varied within the range of values reported until the best water level values were achieved.

During the months of April through June, water levels in the southern portion of the island (L-3215) showed steady declines despite significant rainfall measured at the north end of the island. Applying the rainfall data as collected uniformly across the model grid, calculated water levels for the northern well (L-3214) calibrated well with the actual data, while the calculated water levels for the southern well (L-3215) were significantly higher than the actual levels. It is apparent that rainfall in the southern end of the island must have been much lower than for the northern end during April and June 1985. This is reflected by the June data for well L-3215 where water levels dropped 0.12 ft. despite the 2.7 inch rainfall recorded in the north end of the island. There are no shallow production wells near the southern monitor well which could have caused the drawdown. As a result, the recharge rates were adjusted to produce a better calibration. There were no known rainfall stations on the southern end of the island to substantiate this assumption. An improved rainfall and ground water monitor network for Pine Island would be needed prior to attempting to further improve the accuracy of this model.

No pumpage data was incorporated in the calibration run. Outflow from the system occurred via evapotranspiration and outflow to the constant head boundaries. An annual maximum evapotranspiration rate of 53 inches per year produced the best results. This value was estimated from the modified Blaney-Criddle equation for citrus in sandy soil. The model treats evapotranspiration as a dependent variable based on depth to water with the maximum rate occurring at land surface and decreasing to the evapotranspiration cutoff depth of 10 feet below land surface.

Results of the model calibration are shown in Table 2 and Figure 6. Calculated water levels were generally within 0.5 feet of the measured values for the two USGS wells. Deviation from measured values is attributed primarily to: 1) node averaging, 2) rainfall uncertainty, and 3) impacts from pumpage. The calculated value presented represents the average water level across the 1,000 by 2,000 ft. node. In this case, both observation wells occurred midway between adjacent nodes and, as a result, are impacted by the node averaging.

Uncertainties in the rainfall record have been shown to vary widely over short distances. In addition, the model treats rainfall as a constant rate for each time period. In fact, rainfall typically occurs on just a few days out of a month. During sensitivity analysis, improvements in calculated water levels were achieved by breaking down monthly pumping periods into smaller time increments to simulate one day of rainfall followed by several days of no recharge as reflected by the daily rainfall records.

Considering the generalizations and assumptions associated with the development of this model, the calibration was considered to be acceptable. Improvements to the model could be made by: 1) establishing reliable rainfall stations at the north and south ends of the island, 2) constructing at least one additional Surficial Aquifer System monitor well in the middle of the island, 3) quantifying pumpage in the vicinity of observation wells, 4) developing an improved understanding of aquifer hydraulics through additional field testing, and 5) developing an improved understanding of the dynamics of the coastal saltwater interface.

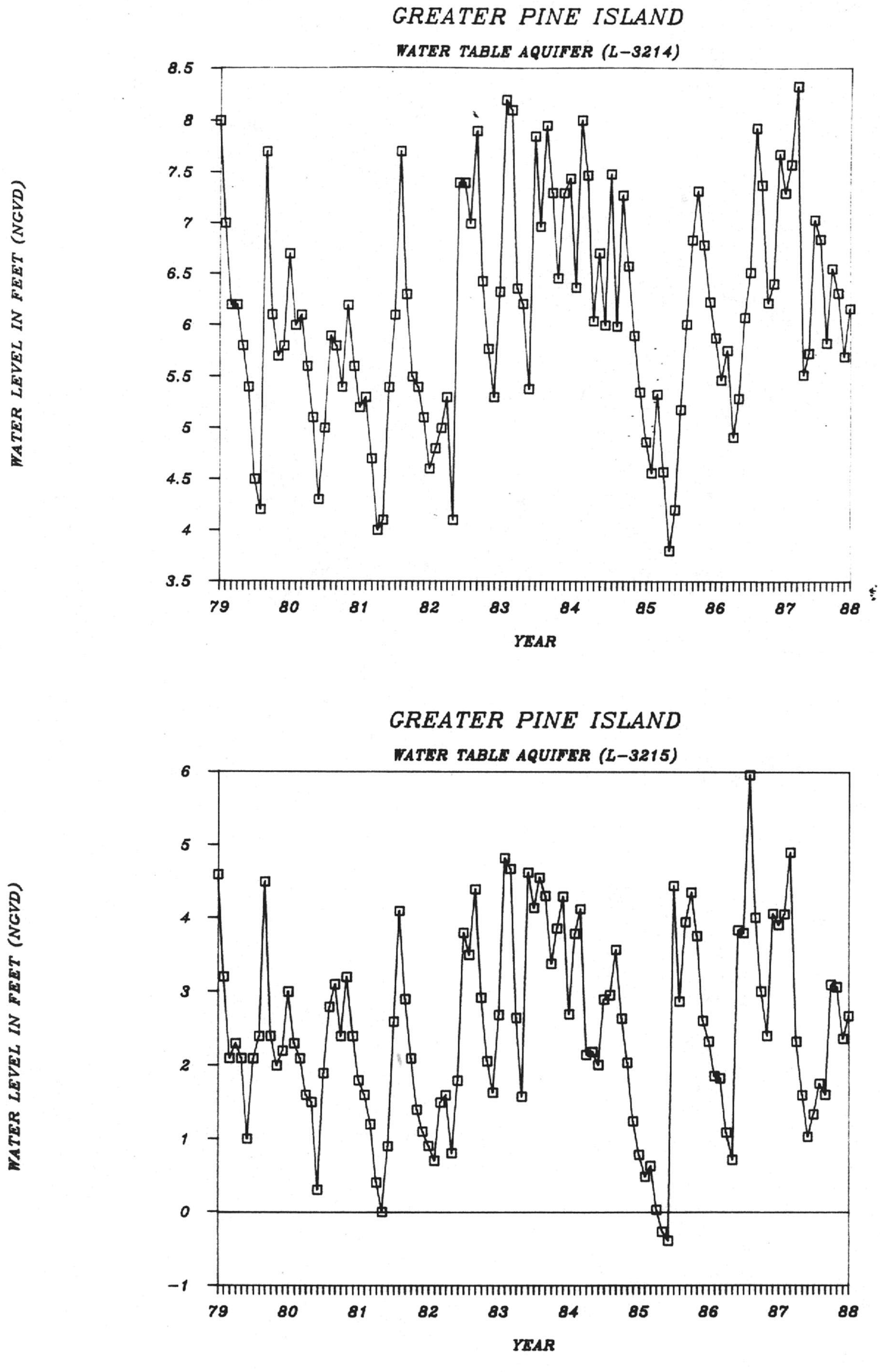


Figure 5 LONG TERM HYDROGRAPHS FOR WELLS L-3214 AND L-3215

TABLE 2. PINE ISLAND PREDEVELOPMENT CALIBRATION DATA

YEAR	MONTH	MEASURED WATER LEVELS		RAIN (INCHES)	RECHARGE (FT3/SEC)	CALCULATED WATER LEVELS	
		L-3214 (FT. NGVD)	L-3215 (FT. NGVD)			L-3214 (FT. NGVD)	L-3215 (FT. NGVD)
1985	1	4.9	0.8	0.65[1.]	2.1E-8	5.4	1.1
1985	2	4.6	0.5	1.00[1.]	3.2E-8	4.6	0.8
1985	3	5.3	0.6	2.55[2.]	7.2E-8	5.5	0.5
1985	4	4.8	0.0	2.00[2.]	6.4E-8	4.6	0.3
1985	5	3.8	-0.3	.75[1.]	2.4E-9	3.4	-0.3
1985	6	4.2	-0.4	3.10[3.]	8.7E-8	3.9	-0.3
1985	7	5.2	4.4	7.50[1.]	2.4E-7	5.4	1.7
1985	8	6.0	2.9	8.90[3.]	2.9E-7	6.4	3.1
1985	9	6.8	4.0	6.84[2.]	5.0E-8	6.8	4.0
1985	10	7.3	4.4	7.03[2.]	3.0E-7	7.2	4.7
1985	11	6.8	3.8	2.55[2.]	5.5E-8	7.0	3.9
1985	12	6.2	2.6	1.18[2.]	6.0E-9	6.2	3.1

1. Rainfall data from Pine Island
2. Rainfall data from Cape Coral
3. Variable recharge rate used

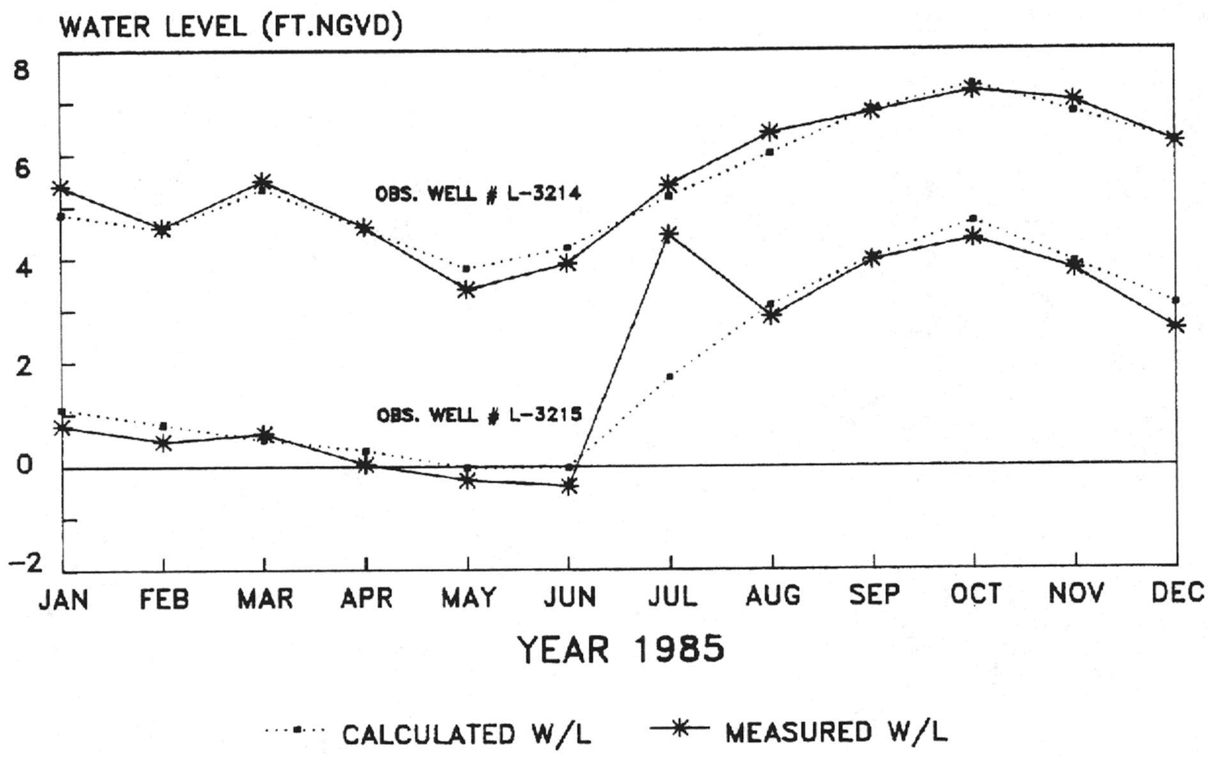


FIGURE 6. COMPARISON OF MEASURED AND CALCULATED WATER LEVEL DATA L-3214 AND L-32-15

ESTIMATION OF AVAILABLE YIELD

Introduction

Estimations of available yield were calculated based on constraints established to minimize movement of the coastal salt water interface. Pumpage was considered to occur only on the inland side of the salt water interface to prevent further inland migration of the salt water front. The estimates were developed by establishing a critical fresh water head elevation which would theoretically result in full saturation of the aquifer with fresh water. Available yield was defined as the amount of water which could be pumped from the aquifer without lowering water levels below this critical head. Because of this, the resulting estimates of available yield are directly related to the estimated critical head elevation. A better understanding of the salt water/fresh water relationship on Pine Island may result in different estimates of available yield; however, the information presented here utilizes all the existing information to produce the best estimate of available yield.

As previously discussed, empirical data collected in the north end of the island was used to estimate the position of the salt water interface. It was estimated that one foot of fresh water head would displace twelve feet of salt water. Therefore, in order to maintain fresh water saturation of the aquifer and assuming an average aquifer thickness of 50 ft., pumpage should not be allowed to reduce head levels below four ft. NGVD on a long term basis.

A second method to estimate available yield would be to establish a maximum allowable drawdown along the coast. Recent District water use permits have been issued on this basis. Pumpage is not allowed to produce greater than 0.1 ft. of drawdown along the coastline under normal conditions and no more than 0.25 ft. of drawdown for dry month withdrawals. A potential problem with this criteria is that it disregards the existing inland extent of the salt water interface. As a result, increased inland flow gradients could occur at the toe of the salt water wedge due to the reduced head levels within the extent of the drawdown cone. Although the gradients would be low, it is possible that the resulting changes in equilibrium between fresh water and salt water could cause inward movement. Presently, there is not enough information to determine the sensitivity of the interface to changes in the gradient.

It was not possible to estimate the water available on Pine Island under the 0.1 foot drawdown criteria using this model due to the infinite number of possible well configurations. In addition, the finite difference model as configured for this project does not calculate head or drawdown at any given point but computes an average node value (1000 x 2000 ft.) which, in this case, is influenced by constant head nodes along the coast. However, for comparative purposes, an analytical model based on the Theis equation was run for two existing permitted allocations using the 0.1 ft. coastal drawdown criteria. The pumpage rates calculated under this criteria were compared to available use estimates under the 4 ft. minimum head criteria as discussed later.

Four Foot Critical Head

The calibrated model was run under specific rainfall conditions to produce calculated wet season water level maps for: a) average wet season conditions, and b) 2 in 10 year rainfall deficient wet season conditions. These surfaces were then used as initial conditions in the transient model runs to determine available yield. Available yield on Pine Island was evaluated for three scenarios: 1) average wet season followed by an average dry season, 2) a 2-in-10 year rainfall deficient wet season followed by an average dry season, and 3) an average wet season followed by a 2-in-10 year rainfall deficient dry season. Rainfall accumulations used for these scenarios were derived from regional rainfall data (MacVicar, 1983) and are shown below in Table 3.

TABLE 3. RECHARGE RATES FOR SELECTED MODEL SCENARIOS

Scenario	Wet Season Recharge	Dry Season Recharge	Number of Available NodeS
1	45 inches	11 inches	82
2	31 inches	11 inches	31
3	45 inches	6.8 inches	17

An iterative algorithm was applied to the available head nodes (nodes with head levels greater than +4 ft.) which calculates pumpage based on excess head above a specified datum (Knapp et al. 1986). The water availability determination began by first estimating an initial withdrawal rate for each of the nodes with a calculated head in excess of +4 ft. NGVD. These nodes were considered the active nodes and were the only ones where withdrawal was simulated. This rate was obtained by multiplying hydraulic conductivity by aquifer thickness, which was then multiplied by the available head in excess of four feet. This product was then multiplied by a constant to accelerate closure. These withdrawal rates were incorporated into a data set and the model was run to develop another set of head levels. The projected heads at the end of the model run were compared to the 4 ft. head criteria, and the withdrawal rate for each active node was adjusted, as necessary, in proportion to the residual head above or below the 4 ft. criteria. The optimum stress was considered to occur when projected heads, under pumping conditions, were within + or - 0.15 ft. of the four foot limit for each node. This iterative process was continued until all active nodes exhibited water levels within the specified criteria.

This approach explicitly addresses water level impacts associated with ground water pumpage. A second factor which also potentially impacts ground water availability is agricultural drainage practices. Surface water drainage systems are constructed to maintain optimum root saturation and prevent flood damage. Due to the areal extent involved, dewatering associated with agricultural development may have a greater impact on coastal salt water migration than irrigation pumpages. Therefore, when considering the potential impacts of agriculture, the combined impacts of drainage and pumpage must be considered.

Results

The results of this procedure, when applied to the three rainfall scenarios evaluated, are shown graphically on Figures 7, 8, and 9. For convenience, the available yield is shown in gallons per day per acre (gpd/acre) for each node.

Under average conditions (Figure 7) fresh ground water is available in quantities between 500 and 3,200 gpd/acre in the north end of the island and from 200 to 1,200 gpd/acre in the southern portion of the island. The unshaded areas are those areas where calculated ground water levels are at or below +4 ft. NGVD. Prolonged pumpage in the unshaded area is considered to result in salt water movement under the critria used here.

Under normal dry season conditions following a 2 in 10 year rainfall deficient wet season (Figure 8) ground water can be safely withdrawn from approximately 1,400 acres in the north central portion of the island at rates between 500 to 2,300 gpd/acre. Withdrawals from the southern portion of the island are assumed to result in undesirable movement of salt water as projected water levels are below +4 ft. NGVD.

The third scenario evaluated available yield under 2 in 10 year dry conditions after a normal wet season (Figure 9). Only fifteen nodes were active under these conditions. Water could be safely withdrawn from a 700 acre area at rates between 300 and 1,500 gpd/acre. A fourth scenario was evaluated using 2-in-10 year dry season following a 2-in-10 wet season. However, under these conditions, there were no nodes with water level greater than +4 ft.

The results of the four foot critical head approach were compared with District criteria for existing water use allocation on Pine Island. Presently, drawdowns resulting from pumpage on the island are limited to 0.1 ft. along the coast. Two permits were evaluated in this exercise, Blind Hog Grove (SFWMD permit #36-00672) and GNS Partnerships (SFWMD permit #36-00671).

As discussed in the Introduction, these properties are located next to each other along the west coast of the island. Under the original application (Murray-Milleson, 1986a) pumpage from two wells at a combined rate of 254,000 gpd was evaluated (using the Theis analytic model) with a resulting drawdown of 0.1 ft. along the coast. Due to potential impacts on other users, the permitted allocation was lower than this. The location of the property corresponds to portions of nodes 11, 12, 12, 12, and 12, 13 (row, column). By weighting the available yield per model node by the number of grove acres which actually occur in each node, the available yield calculated from the +4 ft. model for this property would be 150,000 gpd. However, to minimize impacts on neighboring users the allocation was reduced to 75,000 gpd. For the neighboring GNS property, the permittable yield based on the 0.1 ft. coastal drawdown criteria was 20,000 gpd (excluding impacts of the adjacent property). The corresponding yield for the property using the +4 ft. criteria was calculated at 17,800 gpd. The lower yields estimated using the +4 ft. criteria are the result of the more rigid salt water interface assumption.

It is apparent that under the conditions evaluated in this study, fresh water from the surficial aquifer is safely available from only a small area in north

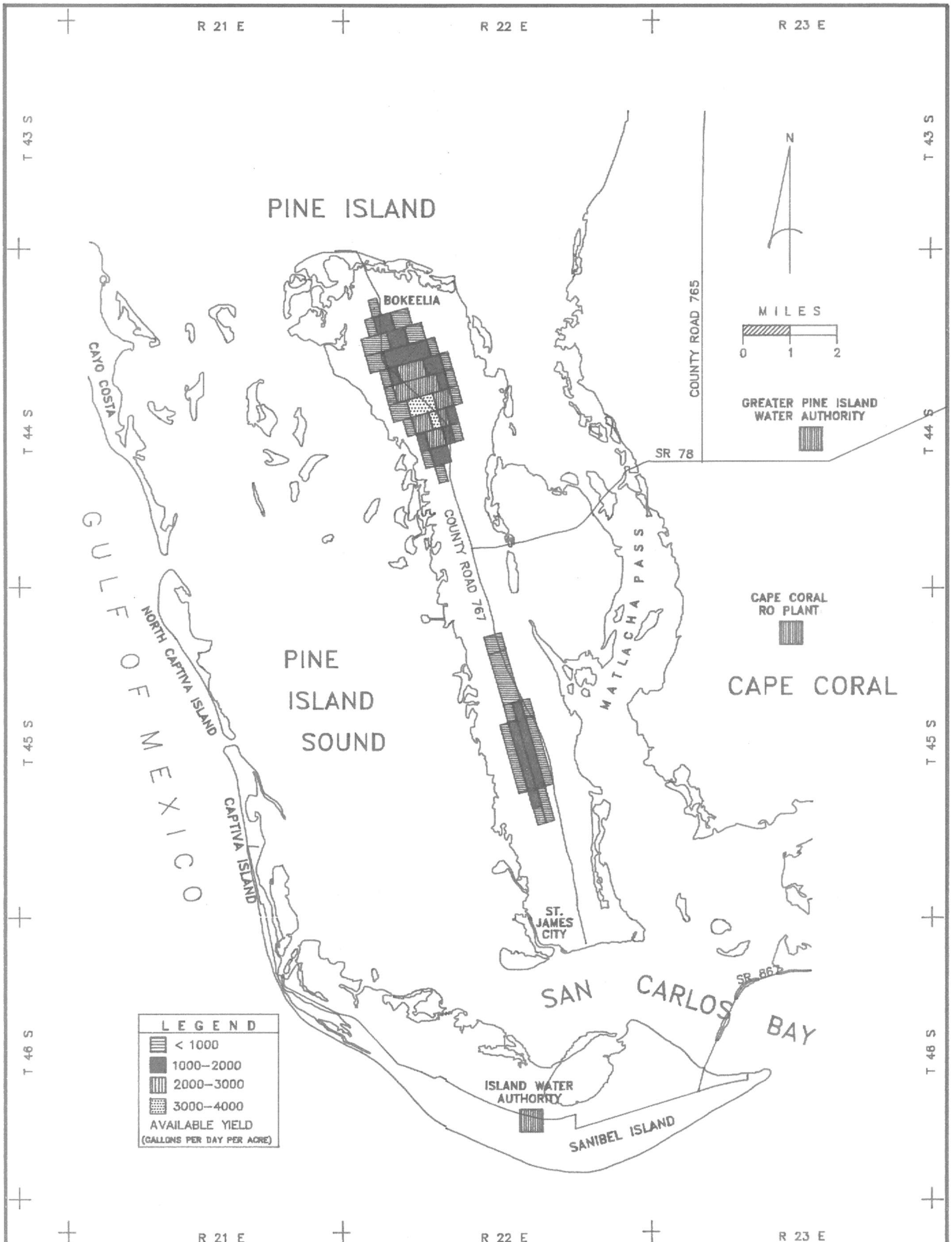


Figure 7 **AVAILABLE YIELD USING + 4 FOOT HEAD CRITERIA: AVERAGE DRY SEASON FOLLOWING AN AVERAGE WET SEASON**

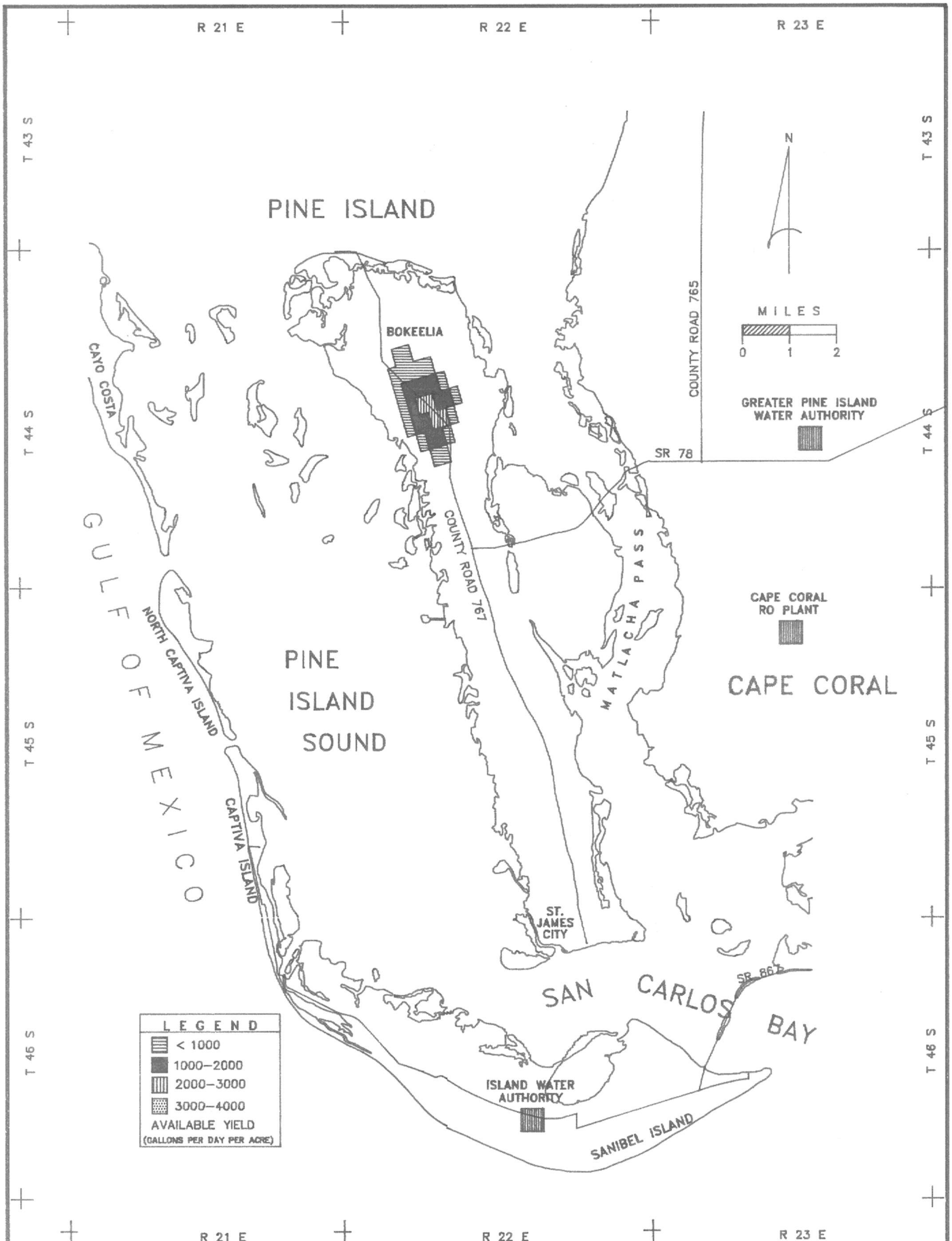


Figure 8 AVAILABLE YIELD USING + 4 FOOT HEAD CRITERIA: AVERAGE DRY SEASON FOLLOWING A 2 IN 10 YEAR DEFICIENT WET SEASON

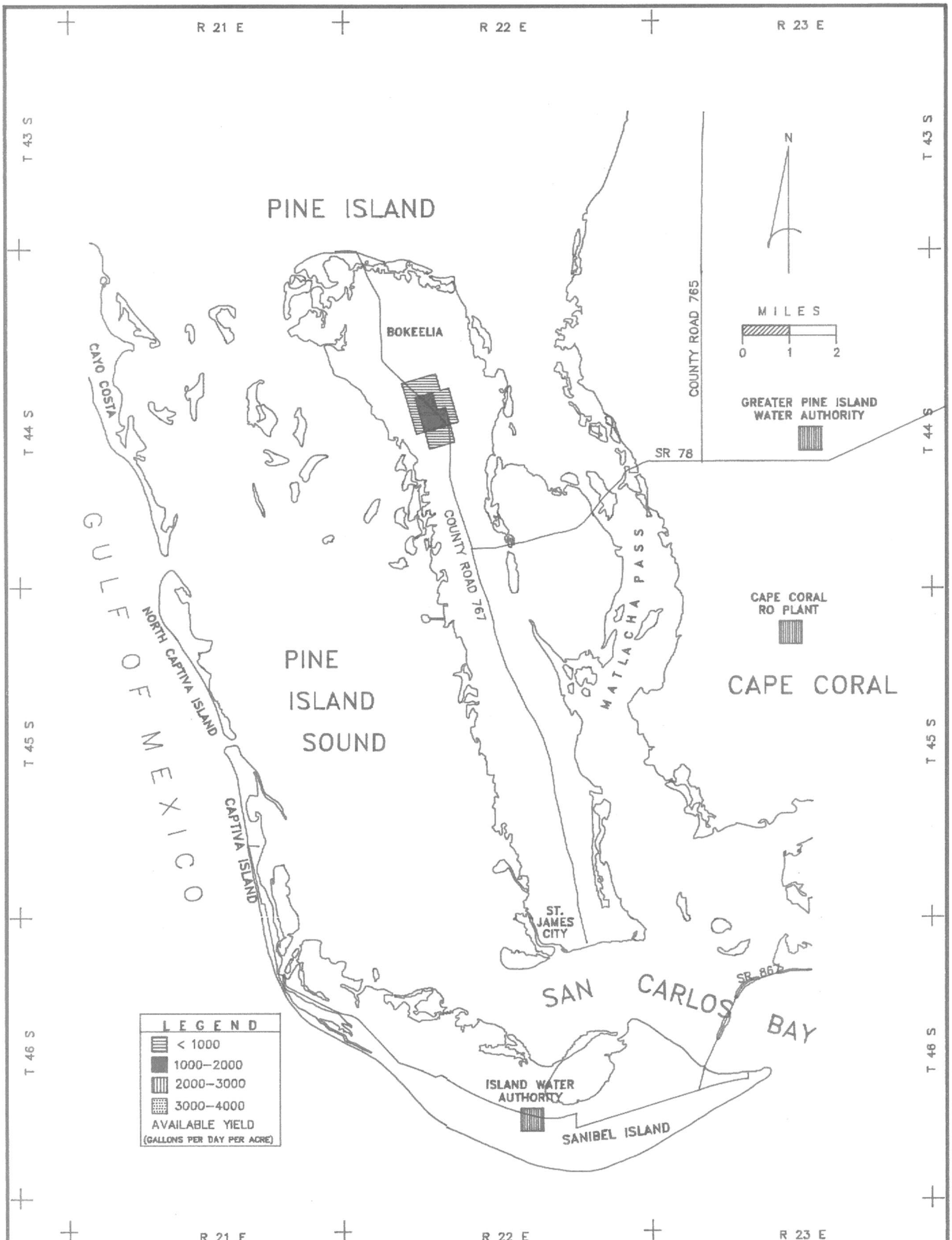


Figure 9 AVAILABLE YIELD USING + 4 FOOT HEAD CRITERIA: 2 IN 10 YEAR DRY SEASON FOLLOWING AN AVERAGE WET SEASON

central Pine Island. Further, under these conditions, only a 700 acre area can be assured of some level of production during 2-in-10 year drought conditions. It is considered that withdrawals in excess of those shown on Figure 8 may result in landward movement of salt water. However, restoration of ground water levels during subsequent wet season rainfall events could flush out salt water which moved inland during prolonged drought and pumpage. There was insufficient data to develop a transport model during this study and, as a result, it is not possible to evaluate temporal changes in the salt water interface. Until such a model can be developed, it is not possible to test the sensitivity of the +4 ft. criteria. Therefore, the results presented here are considered conservative.

Impacts of Existing Users

The model was run under three different scenarios to determine the impacts of 1987 permitted water use. Allocations were adjusted to units of cubic feet per second for input to the model (Table 4). The location of each withdrawal point was determined from the permit file and is shown on Figure 4. For properties with more than one source of ground water, it was assumed that total pumpage was divided equally among each aquifer tapped. Based on these assumptions, the combined withdrawal of permitted users distributed over 32 model node cells was 1.84 MGD.

For Scenario 1, water levels reflecting 30 days of pumpage were compared against the same conditions without pumpage. Initial water levels were set to reflect the end of an average wet season and the model was run for 30 days under normal dry season conditions without pumpage. Pumpage was then added for an additional time period of 30 days. The resulting calculated heads were compared against water levels generated after 60 days (average dry season) with no pumping.

The coastal impacts of pumpage under these conditions appear negligible. Water level drawdowns of 0.1 ft. were calculated along the coastal nodes in the northeastern portion of the island. Impacts on potential coastal salt water intrusion are inferred from the model mass balance. Pumpage resulted in a five percent reduction in outflow (315,000 gpd) of fresh ground water to the coastal constant head boundary. This level of impact under these short conditions are considered to be acceptable.

Scenario 2 evaluated longer pumping conditions. Under this scenario the initial heads were set to equal the end of the average wet season conditions and the model was run for 90 days at average dry season recharge rates without pumpage. Then the pumping nodes were activated for an additional 90 days. This scenario more closely tracks District permit evaluation criteria of 90 days of pumpage with no recharge. Under these conditions impacts along the coast were greater. Water levels along the northeastern portion of the island were approximately 0.3 ft. lower for the pumping scenario as opposed to non-pumping conditions. The calculated water levels under pumping conditions in this area ranged between 0.1 to -1.0 ft. below sea level. The calculated water levels along the coast are presumed to be slightly higher than expected due to the proximity of the coastal constant head nodes. Based on the mass balance calculations, inflow from the constant head boundaries was 304,000 gpd as a direct result of pumpage. This volume represents 16.5 percent of the total water pumped on the island and can be considered a direct indication of the potential for salt water intrusion due to pumpage.

The impacts of pumpage during 180 days of pumpage under 2-in-10 year dry season conditions were evaluated under Scenario 3. Under these conditions, the model was run for 180 days without pumpage using a 2-in-10 year recharge rate followed by 180 days with pumpage. Calculated water levels in the northeastern portion of the island were below sea level from the coast to 3,000 feet inland. Inflow from the constant head boundaries attributed to pumpage was 574,000 gpd or 30% of the amount pumped. Under these conditions, large scale salt water intrusion is considered probable in the northeast portion of the island. Elsewhere on the island salt water intrusion is also considered likely but is not considered to be directly related to pumpage. Specifically, the properties associated with the largest potential coastal drawdowns are Treehouse Nursery, Sunburst Groves, and Trop-Ag, Inc. Ground water monitoring programs should be established in these sensitive areas and owners should consider establishing alternate sources of water.

Alternative Ground Water Supplies

District water use permitting practices on the Lower West Coast allow for the consideration of brackish water as a source of irrigation supply on a case-by-case basis. Generally, three special conditions are evaluated for this type of use: 1) water quality of the source aquifer should not be significantly poorer than that of the receiving aquifer, 2) discharge from the irrigation system must have an ocean outflow, and 3) the use of brackish water must not adversely impact existing legal users.

On Pine Island, the sandstone, mid-Hawthorn, and the upper portion of the Floridan Aquifer System

TABLE 4. SIMULATED PUMPAGE DATA FOR PERMITTED WATER USE

PERMIT #	PERMITTEE	MODEL GRID		Q cfs	Q gpd	# WELLS
		Row i	Col. j			
GP-81-300	Wigerts Nursery	4	10	.034	22,000	1
36-00301	Treehouse Nursery	5	10	.064	41,650	1
		5	11	.129	83,350	2
36-00294	Sunburst Groves	5	13	.308	199,150	2
		5	15	.154	99,550	1
		6	16	.154	99,550	1
		6	17	.462	298,700	3
36-00725	Britton Groves	8	16	.012	8,000	1
36-00575	Trop-Ag, Inc.	7	18	.089	57,550	1P
		8	16	.089	57,550	1P
		8	17	.178	115,100	2S
		9	17	.178	115,100	2S
		9	15	.178	115,100	2P
		8	13	.089	57,550	1P
		8	14	.089	57,550	1P
		9	14	.089	57,550	1P
GP-85-155	Treehouse Nursery	9	13	.011	7,000	1
36-00794	Brewer's Grove	10	15	.017	11,000	2
GP-86-268	Perry Brucker	11	19	.012	7,500	1
36-00779	Pheffer Grove	12	19	.008	5,000	1
36-00114	Easterday Nursery	12	16	.016	10,300	3*
		12	17	.016	10,300	3
		13	17	.005	3,400	1
36-00671	GNS Partnership	12	11	.015	10,000	1
36-00742	Samidini Groves	12	11	.008	5,000	3
36-00672	Blind Hog Grove	11	13	.039	25,000	1
		12	12	.039	25,000	1
		12	13	.039	25,000	1
36-00773	Singing Bird North	13	13	.167	108,000	1*
GP-85-177	Gulf Island Grove	14	13	.005	3,500	1
GP-86-1047	Mcgowers Farm	13	15	.014	9,100	1
GP-85-153	Lee Co. School	19	16	.009	6,000	1
GP-81-324	A. J. Cryder	26	15	.014	9,000	1
36-00059	Pine Island Grove	29	14	.116	75,200	2*
		28	14	.058	37,600	1

*More than one source of water. Allocation presented has been weighted for shallow aquifer only.
P=Primary Well
S=Secondary Well

are three sources of brackish ground water which could be considered for irrigation supply. These sources could be considered for development along the northern coastal margin and throughout most of southern Pine Island. Little information regarding the water quality of these brackish aquifers are available on the island. However, based on the limited data available from the USGS and consultant's reports, chloride levels can be expected to range between 600 and 3,000 mg/l. Well yields should be suitable for the small to moderate size agricultural activities which occur on the island.

CONCLUSIONS

1. Fresh ground water is available from only one source beneath Pine Island, the Surficial Aquifer System. This source is used for irrigation and to a small extent for potable supply. This supply is dependent upon rainfall for recharge and is limited by coastal salt water. Three other sources of ground water are also being developed on the island; the sandstone, the mid-Hawthorn, and the lower Hawthorn aquifers. These aquifers contain brackish water but are considered viable sources in those areas where the surficial is impacted by salt water.

2. Assessments of available yield were made using a two dimensional ground water flow model. The model was developed based on several generalizations due to limitations of existing data. The model was used to simulate ground water levels for the Surficial Aquifer System under various rainfall scenarios. Estimates of available yield were made for those nodes in which calculated water levels exceeded a critical head level. The critical head level was defined as the height of fresh water head needed to saturate approximately 50 ft. of aquifer thickness. Empirical data from the island suggest one ft. of fresh water head displaces 12 ft. of salt water. Therefore, the specified criteria used was +4 ft. NGVD. It should be noted that the estimates of available yield were made for limited available data regarding the orientation of the coastal salt water interface. Changes in the relationship between fresh water head and the salt water interface would result in different estimates of available yield for Pine Island. As a result, the information presented in this study may be subject to revision as new data is generated.

3. It is assumed that the salt water interface is dynamic with respect to fresh water head. Prolonged reduction in fresh water head levels, either through pumpage or drainage especially along the sensitive coastal margin, will result in inland movement of salt water. Until an improved understanding of the dynamics of salt water movement is developed for the study area, conservative allocation criteria should be applied.

4. Estimates of current agricultural water needs from the Surficial Aquifer System during a 2-in-10 year drought are approximately 1.84 MGD. The optimum area to develop this volume of water is in the north central portion of the island; however, the distribution of the existing wells does not correspond to this optimum area. As a result, several existing users may not be protected from salt water intrusion during 2-in-10 year dry season conditions.

5. Existing use of the Surficial Aquifer System is presently near its safe development potential. However, some users located along the coast may be affected by salt water during a 2-in-10 year drought. Small additional allocation can be made in the north central portion of the island. Additional use in the south or along the coastal margin should come from an alternate source.

RECOMMENDATIONS

1. The results developed in this study should be used to augment existing permit evaluation criteria to evaluate future use from the Surficial Aquifer System in Pine Island.

2. Issuance of additional water use permits for the Surficial Aquifer System on Pine Island should be curtailed for all but the north central portion of the island. Policy should be developed for the use of brackish water sources for additional users along the coastal area and in the southern half of the island.

3. Permitted users along the coast should be required to construct monitor wells on their properties and collect chloride data and water level data. These wells should be constructed to monitor a narrow interval near the base of the aquifer or along the 250 mg/l isochlor. Data should be referenced to sea level and submitted monthly.

4. Impacts resulting from drainage practices and the construction of canals can be greater than those from wells. During evaluation of coastal permits, consideration should be given to: a) prohibiting drainage along the coastal margin of the Island, and b) high efficiency irrigation practices should be emphasized for agricultural properties with supplemental irrigation requirements above 10,000 gpd.

5. If additional work efforts are sought to improve the reliability of this resource assessment, efforts should be directed in the following areas:

   a. Rainfall stations should be established in the north central and southern portions of the island.

   b. Ground water monitor stations should be added to the central portion of the island. In addition, at least three salt water interface monitoring stations should be established; one on each coast of the north end of the island and one station on the south end. Each station should be constructed to monitor fresh water head and the position of the interface independently. Monitor data should be collected for at least one year.

   c. A detailed well and water use inventory should be developed for existing agricultural and private irrigation users.

   d. Existing pump test data should be reevaluated and new hydraulic data should be collected to determine the characteristics of the aquifer systems. This would consist of one duration pump test with multiple piezometers in the central portion of the island.

   e. This information should be incorporated into a calibrated solute transport model capable of assessing temporal salt water dynamics.

The estimated cost to collect and evaluate this additional data is approximately $350,000.

REFERENCES

Florida Geological Survey, 1986. Hydrogeological Units of Florida: Florida Geologic Survey Special Publication No. 28.

Knapp, M. S. W. S. Burns, and T. S. Sharp, 1986. Preliminary Assessment of the Ground Water Resources of Western Collier County, Florida. Technical Publication 86-1, South Florida Water Management District, Hydrogeology Division, Resource Planning Department.

MacVicar, 1983. Rainfall Averages and Selected Extremes for Central and South Florida. Technical Publication 83-2, South Florida Water Management District, Rsource Planning Department.

Missimer and Associates, Inc., 1981. Groundwater Resources of the Alden Pines Country Club Development, Lee County, Florida, Report to Alden Pines Country Club.

Missimer and Associates, Inc., 1986. GNS Partnership Application #09035-D, Report to Water Use Division, Resource Control Department, South Florida Water Management District.

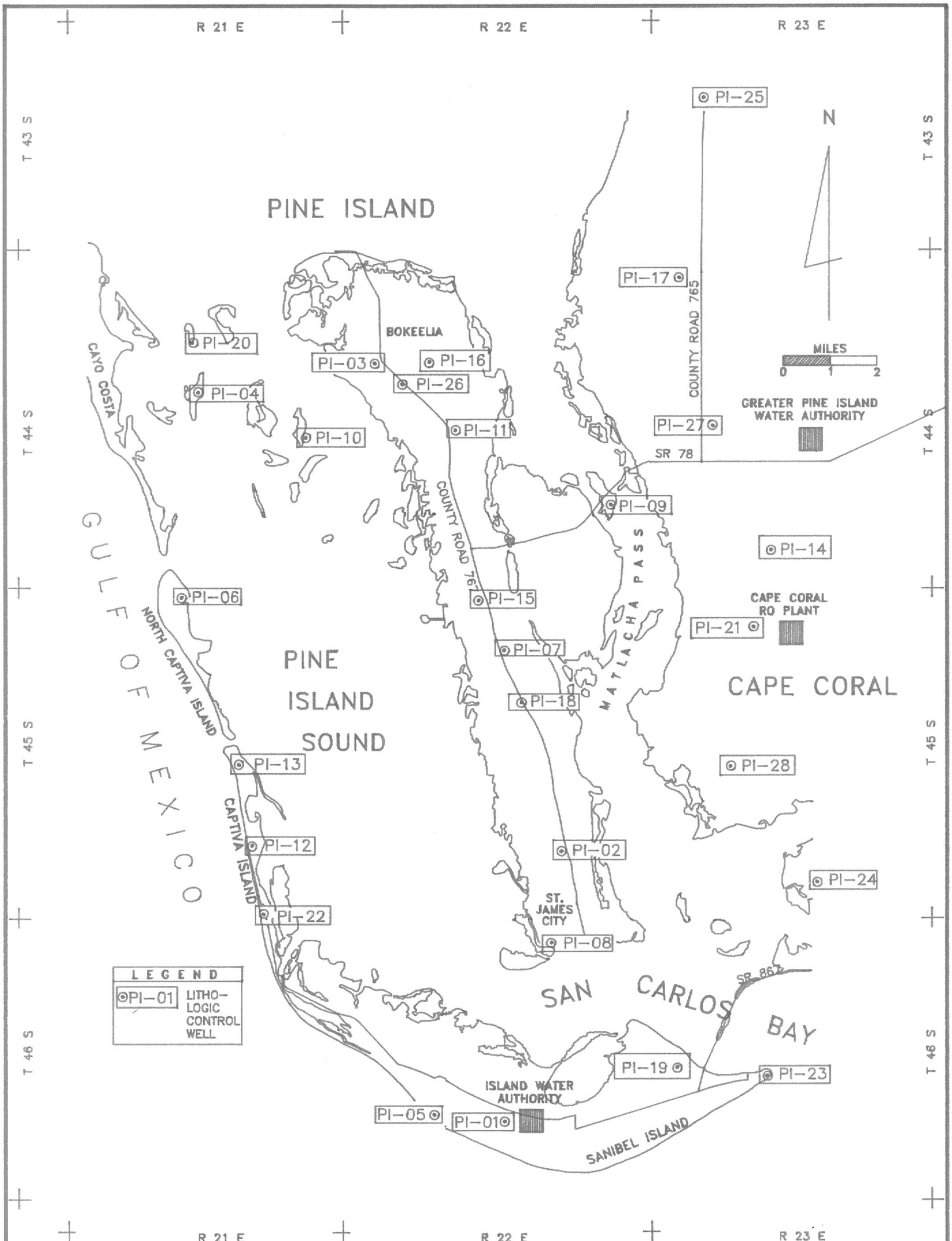
Murray-Milleson, Inc., 1986a. Hydrogeologic Study for Murrah Grove, Report to Water Use Division, Resource Control Department, South Florida Water Management District.

Murray-Milleson, Inc., 1986b. Hydrogeologic Study for Pine Island Agricultural Water Management District Association, Inc., Report to Water Use Division, Resource Control Department, South Florida Water Management District.

South Florida Water Management District, 1985. Management of Water Use: Permit Information Manual, Volume III, Resource Control Department.

Trescott, P. E., G. F. Pinder, and S. F. Larson, 1976. Finite-Difference Model for Aquifer Simulation in Two Dimensions with Results of Numerical Experiments, Techniques of Water Resources Investigation of the U. S. Geological Survey, Book 7.

APPENDIX



LOCATION OF LITHOLOGIC CONTROL WELLS

(page 1 of 2)

PINE ISLAND LITHOLOGIC DATA

MAP ID #	T/R	LITHO. WELL NUMBER USGS	LITHO. WELL NUMBER SFWMD	LATITUDE DEG	LATITUDE MIN	LATITUDE SEC	LONGITUDE DEG	LONGITUDE MIN	LONGITUDE SEC	ELEV. (FT.)	THICKNESS OF SURFICIAL AQUIFER (FT.)	THICKNESS OF WATER TABLE (FT.)	TOP OF LOWER TAMIAMI CONFINING BED (FT.)	THICKNESS OF LOWER TAMIAMI CONFINING BED (FT.)	TOP OF LOWER TAMIAMI AQUIFER (FT.)
PI-01	46/22		W-4	26	26	15	82	6	17	4.0	64.0	64.0	NP	NP	NP
PI-02	45/22		W-6	26	31	17	82	5	10	8.0	50.0	50.0	NP	NP	NP
PI-03	44/22		W-14	26	40	18	82	9	5	3.0	75.0	75.0	NP	NP	NP
PI-04	44/21		W-15	26	39	44	82	12	43	5.0	80.0	80.0	NP	NP	NP
PI-05	46/21		W-16	26	26	22	82	7	44	5.0	55.0	15.0	-10.0	15.0	-25.0
PI-06	44/21		W-21	26	35	55	82	13	2	5.0	60.0	60.0	NP	NP	NP
PI-07	46/22		W-31	26	35	0	82	6	23	5.0	M	M	M	M	M
PI-08	46/22		W-35	26	29	35	82	5	21	5.0	40.0	40.0	NP	NP	NP
PI-09	44/22		W-37	26	37	43	82	4	12	6.0	55.0	55.0	NP	NP	NP
PI-10	44/23		W-7456	26	38	55	82	10	30	7.0	40.0	40.0	NP	NP	NP
PI-11	44/22		WA-578	26	39	5	82	7	25	11.0	50.0	50.0	NP	NP	NP
PI-12	45/21	L-406		26	31	20	82	11	32	5.0	M	M	M	M	NP
PI-13	45/21	L-587		26	32	50	82	11	49	3.0	43.0	43.0	NP	NP	NP
PI-14	44/23	L-648	W-13	26	36	54	82	0	54	10.0	48.0	48.0	NP	NP	NP
PI-15	44/22	L-665		26	35	55	82	6	55	8.0	75.0	75.0	NP	NP	NP
PI-16	44/22	L-666		26	40	20	82	7	58	8.0	72.0	72.0	NP	NP	NP
PI-17	43/23	L-675		26	41	57	82	2	50	6.0	15.0	15.0	NP	NP	NP
PI-18	45/22	L-1021		26	34	2	82	6	1	5.0	55.0	55.0	NP	NP	NP
PI-19	44/22	L-1740		26	27	17	82	2	45	5.0	120.0	39.0	-34.0	10.0	-44.0
PI-20	44/21	L-2117		26	40	39	82	12	51	2.0	70.0	70.0	NP	NP	NP
PI-21	45/23	L-2272		26	35	28	82	1	15	8.0	50.0	50.0	NP	NP	NP
PI-22	46/21	L-2315		26	30	4	82	11	17	5.0	100.0	30.0	-25.0	50.0	-75.0
PI-23	46/23	L-2401		26	27	8	82	0	54	5.0	130.0	20.0	-15.0	20.0	-35.0
PI-24	45/23	L-2446		26	30	45	81	59	54	6.0	60.0	60.0	NP	NP	NP
PI-25	43/23	L-2526		26	45	17	82	2	21	12.0	35.0	35.0	NP	NP	NP
PI-26	44/22	L-2527		26	39	55	82	8	31	8.0	75.0	75.0	NP	NP	NP
PI-27	44/23	L-2609		26	39	12	82	2	7	7.0	30.0	30.0	NP	NP	NP
PI-28	45/23	L-2643	W-34	26	32	53	82	1	42	7.0	40.0	40.0	NP	NP	NP

PINE ISLAND LITHOLOGIC DATA

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MAP ID #	THICKNESS OF LOWER TAMIAMI AQUIFER (FT.)	ELEV. TOP OF UPPER HAWTHORN CONFINING BED (FT.)	THICKNESS TOP OF UPPER HAWTHORN CONFINING BED (FT.)	ELEV. TOP OF SANDSTONE AQUIFER (FT.)	THICKNESS OF SANDSTONE AQUIFER (FT.)	ELEV. TOP OF MIDDLE HAWTHORN CONFINING BED (FT.)	THICKNESS OF MIDDLE HAWTHORN CONFINING BED (FT.)	ELEV. TOP OF MIDDLE HAWTHORN AQUIFER (FT.)	THICKNESS OF MIDDLE HAWTHORN AQUIFER (FT.)	ELEV. TOP OF LOWER HAWTHORN CONFINING BED (FT.)
PI-01	NP	-60-0	87.0	-147.0	73.0	-220.0	66.0	-286.0	68.0	-354.0
PI-02	NP	-42.0	80.0	-122.0	20.0	-142.0	90.0	-232.0	90.0	-322.0
PI-03	NP	-72.0	78.0	-150.0	45.0	-195.0	70.0	-265.0	40.0	-305.0
PI-04	NP	-75.0	12.0	-87.0	68.0	-155.0	10.0	-165.0	28.0	-193.0
PI-05	25.0	-50.0	115.0	-165.0	45.0	-210.0	20.0	-230.0	20.0	-250.0
PI-06	NP	-55.0	110.0	-165.0	10.0	-175.0	50.0	-225.0		
PI-07	M	M	M	M	M	M	M	M	M	M
PI-08	NP	-35.0	95.0	-130.0	15.0	-145.0	115.0	-260.0	60.0	-320.0
PI-09	NP	-49.0	105.0	NP	NP	NP	NP	-154.0		
PI-10	NP	-33.0	100.0	NP	NP	NP	NP	-133.0		
PI-11	NP	-39.0	97.0	-136.0	20.0	-156.0	38.0	-194.0	90.0	-284.0
PI-12	M	M	M	M	M	M	M	-310.0		
PI-13	NP	-40.0	80.0	-120.0	M	M	M	-317.0	117.0	-434.0
PI-14	NP	-38-0	87.0	NP	NP	NP	NP	-125.0		
PI-15	NP	-67.0	60.0	-127.0	20.0	-147.0	70.0	-217.0		
PI-16	NP	-64.0	94.0	-158.0						
PI-17	NP	-9.0	130.0	NP	NP	NP	NP	-139.0	115.0	-254.0
PI-18	NP	-50.0	119.0	-169.0	18.0	-187.0	107.0	-294.0	136.0	-430.0
PI-19	71.0	-115.0	100.0	-215.0	62.0	-277.0	36.0	-313.0	59.0	-372.0
PI-20	NP	-68.0	40.0	-108.0	20.0	-128.0	85.0	-213.0	35.0	-248.0
PI-21	NP	-42.0	65.0	NP	NP	NP	NP	-107.0	95.0	-202.0
PI-22	20.0	-95.0	10.0	-105.0	70.0	-175.0	105.0	-128.0	35.0	-315.0
PI-23	90.0	-125.0	80.0	NP	NP	NP	NP	-205.0		
PI-24	NP	-54.0	105.0	NP	NP	NP	NP	-159.0		
PI-25	NP	-23.0	25.0	-48.0	15.0	-63.0	70.0	-133.0	120.0	-253.0
PI-26	NP	-67.0	75.0	-142.0	50.0	-192.0	90.0	-282.0	70.0	-352.0
PI-27	NP	-23.0	110.0	NP	NP	NP	NP	-133.0	80.0	-212.0
PI-28	NP	-33.0	100.0	NP	NP	NP	NP	-133.0		