MARTIN COUNTY
WATER RESOURCE ASSESSMENT

May 1987

DRE-229

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EXECUTIVE SUMMARY

The South Florida Water Management District (SFWMD) and the Martin County Board of County Commissioners agreed in June 1984 to perform a cooperative study to assess the water resources of the county. The purpose of the study was to provide the county with a regional analysis of water availability and subsequent water resource planning recommendations that could be used for future growth management strategies. To achieve this goal, a series of tasks were delineated by SFWMD and Martin County.

A time frame of one year was allotted for the collection and interpretation of data required to complete each task. The second phase of the program consisted of a three month period during which the data was compiled in report form for review and acceptance by Martin County.

A general overview of the major findings of this study is presented in the following paragraphs. Surface water availability from both C-44 (St. Lucie Canal) and Lake Okeechobee was evaluated through the use of regression equations and computer models. The potential use of these surface water sources is limited in times of drought, therefore, these sources are not considered to be a reliable water supply on a continuous basis.

The Martin County Planning Department provided estimates of future population growth and land use types. This information was utilized to construct water demand estimates at various population centers throughout the country. These estimates were then used as input into a series of computer models to evaluate the ground water development potential versus future demands.

A series of hydrogeologic analyses and computer modeling efforts were completed to assess the availability of ground water from the Surficial and Floridan Aquifer Systems. The Surficial Aquifer System is the primary source of fresh drinking water to the county. The Floridan Aquifer System can be used as a secondary source of ground water, but desalination will be required to obtain potable standards. Abandoned flowing wells which penetrate the Floridan Aquifer System should be plugged to avoid unnecessary contamination of the Surficial Aquifer System.

The county-wide modeling endeavor indicates that with prudent aquifer management, the Surficial Aquifer System can meet the future water demands of the county. To avoid detrimental impacts on the aquifer system due to large concentrated withdrawals, an engineer's site-specific study should be undertaken. Such a study should address the potential contamination of the Surficial Aquifer System from landfills, septic tanks, agricultural, industrial, and commercial land uses.

Two areas of concentrated future withdrawals are the city of Stuart and the north Martin County wellfields. It may be necessary to enlarge these wellfields to meet these demands. To avoid salt water intrusion, withdrawals should be concentrated in the southern portion of the Stuart wellfield. Additional wells should be placed in the southern portion of the peninsula. In order to maximize water availability at the north Martin County wellfield, an engineer's site-specific study should determine the optimal wellfield configuration and address potential detrimental impacts such as salt water intrusion. In addition, the evaluation of wellfield impacts on wetlands in the north Martin County peninsula will require the collection of site-specific data and the use of a three-dimensional ground water flow model to accurately simulate this multi-layered system.

The SFWMD, through the local government planning and assistance program, can offer assistance to the county in the analysis and design of a comprehensive water conservation and demand reduction program to suit the needs of Martin County and its municipalities.

ADDENDUM

The draft "Martin County Water Resource Assessment" was presented to the Martin County Board of County Commissioners in December 1985.

At that meeting the Board appointed a committee to review the report and make recommendations back to the Board. The members of that committee are listed below. The Committee met several times, discussing the text, conclusions, and recommendations.

In April 1986, the Committee concluded its discussions and recommended to the County Commission that the report be received and that the conclusions and recommendations be accepted and incorporated into the County's planning process.

At the May 6, 1986, meeting of the Martin County Board of County Commissioners, the "Martin County Water Resource Assessment" was received and the conclusions and recommendations were accepted.

There were three principal areas of disagreement between the members of that committee and the assumptions made in the report:

1. Percent buildout-based on discussions with the County's Office of Community Development, it was agreed to base the report on 100% buildout. The review committee disagreed, contending that the modeling runs should be based on 90%, a more historic build-out figure.

2. Percent occupancy rate-again based on discussions with the County's Office of Community Development, 100% occupancy was selected for the initial modeling runs. The combination of a maximum buildout, combined with the maximum occupancy rate, resulted in a 'worst case' scenario, therefore creating a conservative assessment. As a result of some early comments, the final draft also included modeling runs based on an 85% occupancy rate. The results were not appreciably different from those obtained with the 100% occupancy rate. The committee felt that the runs assuming 85% were more historically accurate.

3. Per capita consumption - the report utilizes a figure of 150 gallons per person, per day for residential demand. That figure splits between approximately 100 gallons utility provided and 50 gallons from non-utility sources. This information is based on historic, permitted water use in Martin County and is correlated with other counties within our 16 county jurisdiction as well as with state standards. Based on data provided by the County's engineering consultants, the committee felt that a figure of 80 gpd/capita total water use was more accurate.

The Committee was comprised of the following:

Tom Kenny, Chairman, Martin County Commission

Oren S. Hillman, Utilities Director, Martin County

Jim Winn, Public Works Director, Martin County

Joe Banfi, Community Dev. Dir., Martin County

Les Scherer, Environmental Services Dir., Martin County

Vaughan Weaver, City Engineer, Stuart, Florida

Paul Millar, Project Administrator, South Florida Water Management District

Thomas Babcock, Vice President, Martin Downs, Stuart

Terry Keathley, General Mgr., Intracoastal Utilities, Stuart

Jack Robinson, General Mgr., Indiantown Company, Indiantown

Kenneth L. Ferguson, Chairman, UAC, Palm City

Joe J. Celli, Chairman, LPA, Jensen Beach

Mike Hermesmeyer, Vice President, William M. Bishop Consulting Engineers, Inc., Jensen Beach

ACKNOWLEDGEMENTS

This study has been a joint effort of the Resource Planning Department, completed under the direction of Peter B. Rhoads and C. Alan Hall. The authors would like to acknowledge several individuals for their contributions to this report. Appreciation is extended to Joan Stockum for her outstanding and timely assistance in providing maps and illustrations; to Barbara Dickey for modifying various computer programs to facilitate the modeling endeavor; and to Hedy Marshall for the efficiency and patience she demonstrated while typing and assembling the text. A special acknowledgement is extended to Karin Nelms for her excellent editorial contributions to the final report. Appreciation is also extended to Harold Nelson for his assistance in graphics preparation, and to Odile Grosser for editorial review and assistance throughout the publication process.

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INTRODUCTION

Purpose and Scope

As a result of a meeting held on February 15, 1984 between the South Florida Water Management District (SFWMD) and Martin County, the SFWMD outlined the scope of a study designed to assist public officials of Martin County in water resource planning. The major goal of this study is stated in the documentation of "Martin County: SFWMD Water Resources Planning Assistance Program" as:

> " The study will provide the Martin County Board of County Commissioners with an analysis of water availability and will provide water resource planning recommendations to be used for the county's future growth management strategies."

In order to achieve this goal, a set of tasks were outlined by the SFWMD and the Martin County Board of County Commissioners. The responsibility for completion of each task was assigned to either the SFWMD or Martin County. Tasks for which the SFWMD was assigned the lead responsibility included performing hydrologic, hydrogeologic, water demand, water availability, and availability versus demand analyses.

In light of these efforts, the availability, quality, and potential use of surface water and ground water for public water supply are examined in this report. The major source of surface water in Martin County is from C-44, the St. Lucie Canal. The major source of ground water is the Surficial Aquifer System. A secondary source of ground water is the Floridan Aquifer System. Overall water availability from the above sources and future water demands are investigated with respect to the needs of Martin County.

Martin County assumed the responsibility of performing a land use and population study and obtaining engineering cost estimates of the possible raw water sources available to the county. This engineering cost analysis is presented in Appendix 4.

This report presents the results of each of the tasks performed by the SFWMD. The general framework of the report is described in the following paragraphs. A brief summary of the availability and quality of surface water as a potential water supply source is followed by a brief hydrogeologic analysis of the potential ground water sources. The methodology utilized to obtain water demand estimates is described. The water demand estimates are then used as input to a series of computer models which simulate the hydrogeologic conditions in Martin County. The computer models are used to assess the availability of ground water on both a county-wide and site-specific basis at the north Martin County and city of Stuart well fields. The feasibility of utilizing reclaimed waste water as a potential water supply source is also examined.

An assessment of ground water development potential based on various limiting criteria such as salt water intrusion, environmental impacts, and potential land use impacts is performed. Recommendations and conclusions are then provided to assist the county in making future water management decisions.

Location and Extent of Area

Martin County is located in southeastern peninsular Florida and comprises an area of approximately 560 square miles (Figure 1). The county is 35 miles from east to west and 16 miles from north to south; it lies between 26° 57' 24" and 27° 15' 46" north latitude and 80° 04' 49" and 80° 40' 40" west longitude. It is bounded on the east by the Atlantic Ocean and to the west by Lake Okeechobee and Okeechobee County. To the north and south, it is bordered by St. Lucie and Palm Beach Counties, respectively.

Previous Investigations

The hydrogeology of southeastern Florida was generally examined by Parker (1955). A detailed investigation on the water resources of Martin County was performed by Lichtler (1960). The water resources of the county were revisited by Earle (1975) and Miller (1978). Within the Upper East Coast Planning Area, Miller (1979) has provided data on the Surficial Aquifer System and has also evaluated the major lithologies of the aquifer (1980). Brown and Reece (1979) examined the Floridan Aquifer System within this same area. The ground water flow of the Floridan Aquifer System was investigated by Trost (1987, in press) in a recent modeling effort for the upper east coast. MacVicar and others (1984) examined the ground water flow of the Surficial Aquifer System also within this same planning area. Stodghill and Stewart (1984) reviewed the electrical properties of the Surficial Aquifer System in Martin County. The soil characteristics of the county have been provided by McCollum and Cruz (1981). A number of authors have also provided information on the county aquifers, but on a site-specific basis.

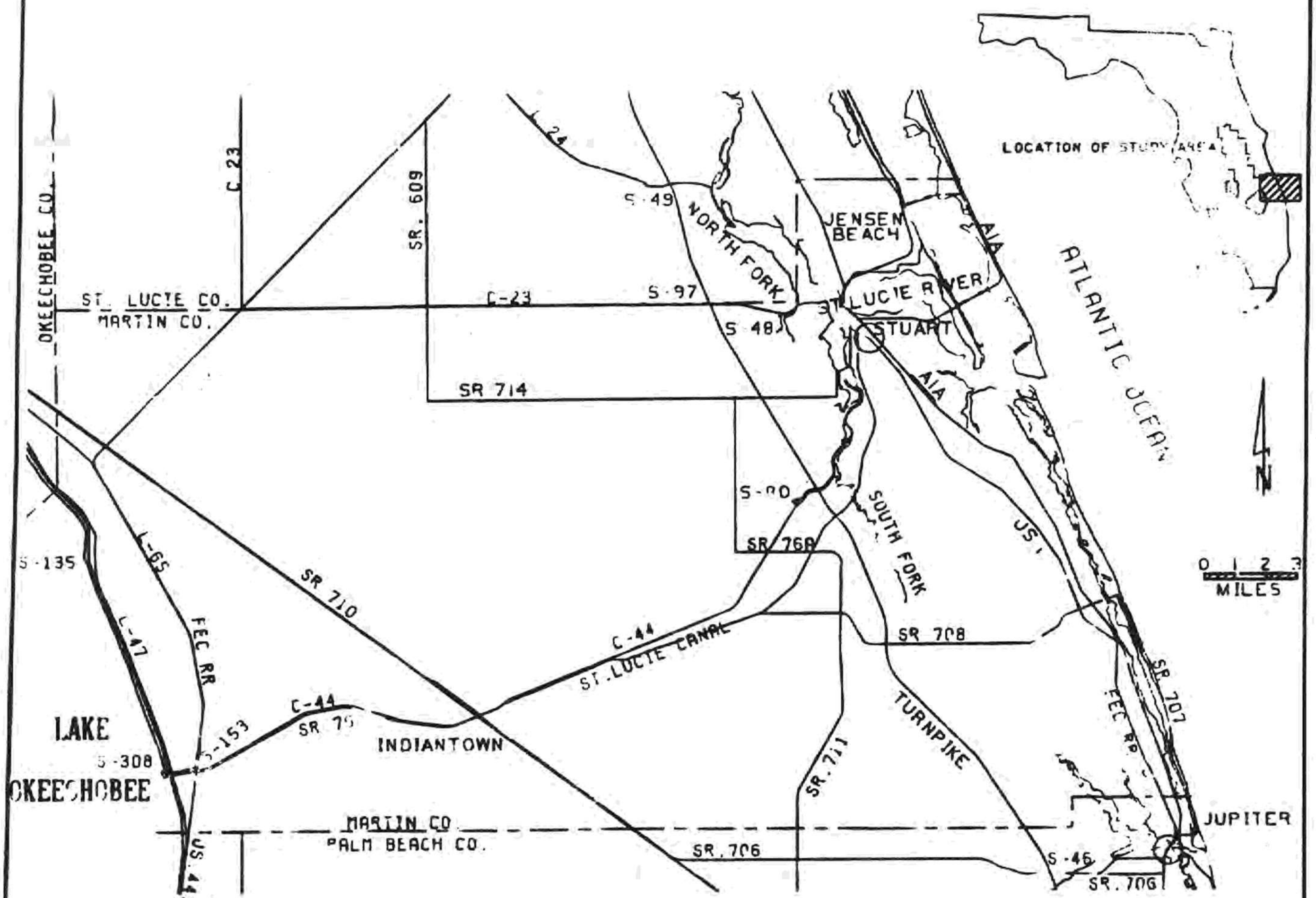


Figure 1 LOCATION MAP OF MARTIN COUNTY

Climate

The climate of Martin County is subtropical with an average annual temperature of 75°F. It is characterized by long, warm, humid summers and mild winters. The major controlling factors upon the temperature are the Atlantic Ocean and the Gulf Stream. High summer temperatures are depressed, while winter lows are enhanced by the ocean breeze.

The average annual rainfall is approximately 57 inches a year, but annual rainfall ranges between 35 to 80 inches. Due to seasonal variations, about 60% of the rainfall occurs from June to October, while the remaining 40% takes place from November through May.

Evapotranspiration is similar to rainfall in that it is also unevenly distributed throughout the year. From March to October evapotranspiration rates are highest, and lowest from November to February. Measurements of rainfall and evapotranspiration obtained in two areas of Martin County are shown in Figures 2 and 3.

Physiography

Martin County lies within the Atlantic Coastal Province which includes three physiographic regions. These regions are the Atlantic Coastal Ridge, Eastern Flatlands, and the Everglades (Figure 4). The Atlantic Coastal Ridge parallels the coast and is 3 to 6 miles in width. The region contains the dunes of both the Jensen Beach and Dickinson Park sandhills. The Eastern Flatlands contain the Allapattah Flats, Orlando Ridge, and the Green Ridge. East of the Orlando Ridge, the Allapattah Flats are characterized by a wide, poorly defined drainageway which remains marshy during most of the year. Located adjacent to Lake Okeechobee are the Everglades. The Everglades are approximately 1.5 miles wide and are almost indistinguishable from the Eastern Flatlands (Lichtler, 1960).

Topography

The topography of Martin County can be correlated with each physiographic region (Figure 5). Within the Atlantic Coastal Ridge, land surface elevations are generally between 25 and 35 feet above mean sea level. The highest elevations occur in Jonathan Dickinson Park where the dunes rise to 85 feet above sea level. North of these dunes and parallel to the Intracoastal, the elevation of the ridge is commonly below 35 feet mean sea level. The St. Lucie River breaches the coastal ridge, but it continues north into Jensen Beach where the sandhills are elevated to 80 feet above sea level.

The Eastern Flatlands comprise most of the area in the county. The area is between 15 to 30 feet above sea level with the exception of both the Orlando and Green Ridges. These ridges are parallel to one another and are separated by the Allapattah Flats. The Orlando Ridge is approximately two miles wide and has an elevation between 30 to 50 feet above mean sea level. The Green Ridge is a very narrow strip and has an elevation of 30 to 35 feet above sea level.

To the west of the Flatlands and adjacent to Lake Okeechobee are the Everglades. This area is an extremely flat marsh environment. Elevations in the Everglades range between 15 and 20 feet above sea level.

Soils

The soils within Martin County may be grouped into five broad categories. They include: 1) the sand ridges and coastal islands; 2) low ridges and knolls; 3) flatwoods; 4) sloughs and fresh water marshes; and 5) the tidal swamps. In each broad category the soils may include one or more soil types although a distinctive pattern is present in each. Figure 6 illustrates the general soil types in Martin County.

Sand and shell fragments are the major components in the soils of the sand ridges and coastal islands. They are nearly level to moderately steep, excessively drained to poorly drained, and occur within the Coastal Ridge and adjacent to the Atlantic Ocean (McCollum, et al., 1981). Shallow depressions in the sandy ridge are occupied by intermittent ponds which flood during the rainy seasons (Lichtler, 1960).

Low ridges and knolls occur along the coast and within the Eastern Flatlands, the soils of which consist of sand that is excessively to poorly drained. These soils exist in scattered depressions, elevated knolls, and long narrow ridges (McCollum, 1981).

A portion of the north Martin County peninsula and a substantial section of the Eastern Flatlands consist of soils of the flatwoods. The flatwoods are nearly level and poorly drained. The soil is either sandy throughout or sandy with a loamy subsoil (McCollum, et al., 1981).

Soils of the sloughs and fresh water marshes occupy a significant portion of the Eastern Flatlands and all of the area within the Everglades. The soils are varied - some are sandy throughout or may have a

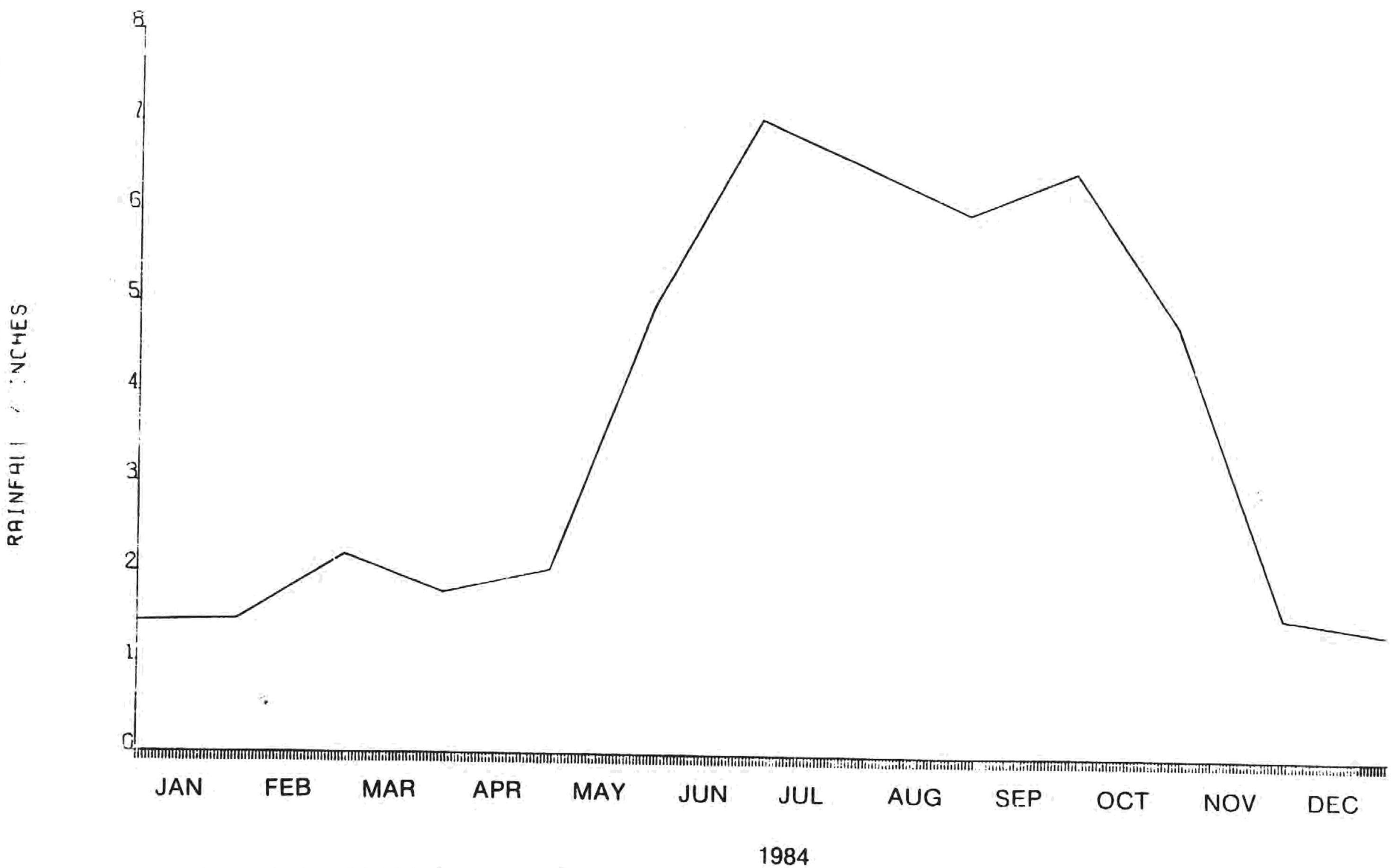


Figure 2 MEAN MONTHLY RAINFALL IN SOUTHEASTERN MARTIN COUNTY (MODIFIED FROM FAN 1952-1983)

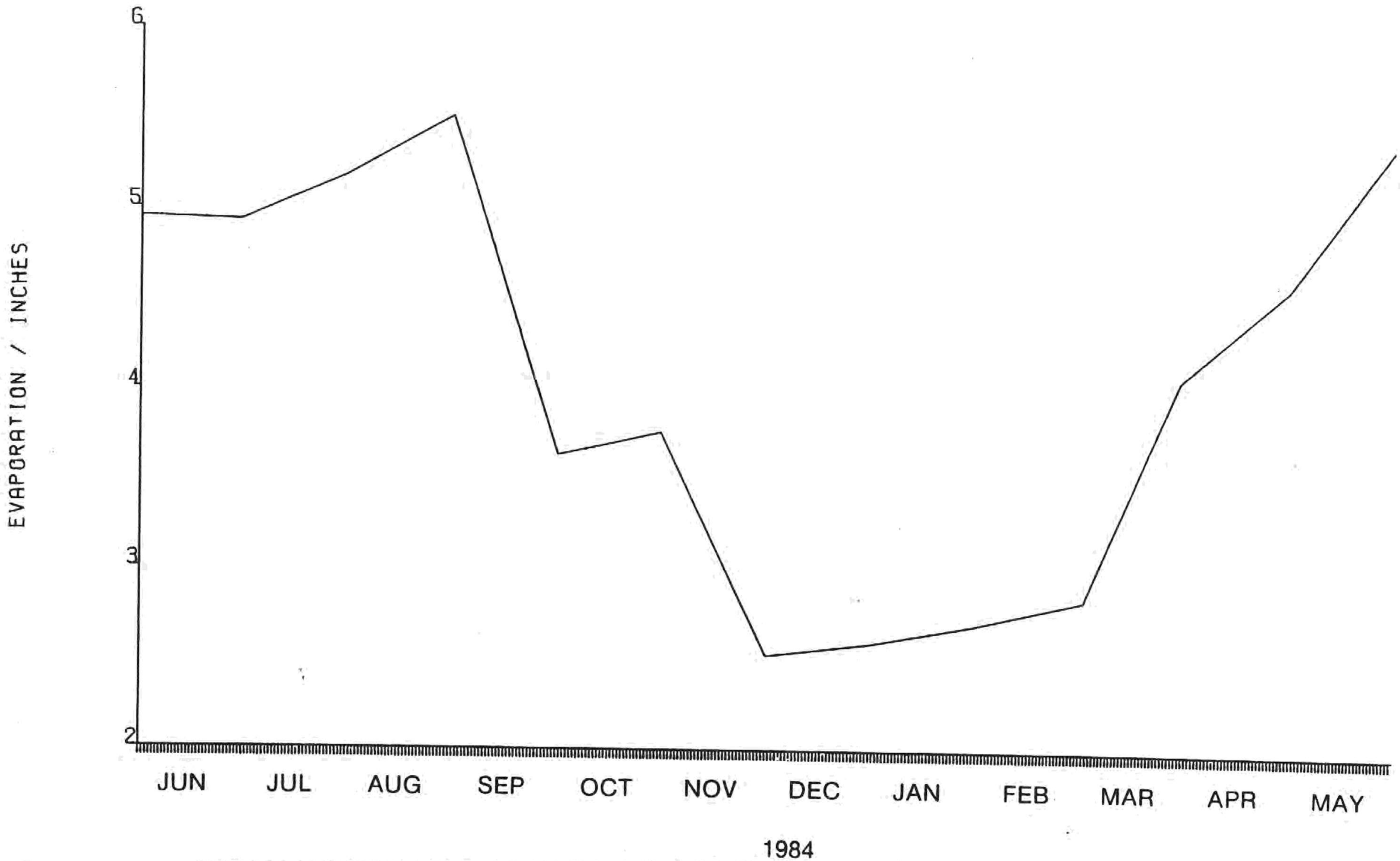


Figure 3 **MEAN MONTHLY EVAPORATION SUMMARY, CAULKINS CITRUS GROVE, MARTIN COUNTY (1984)**

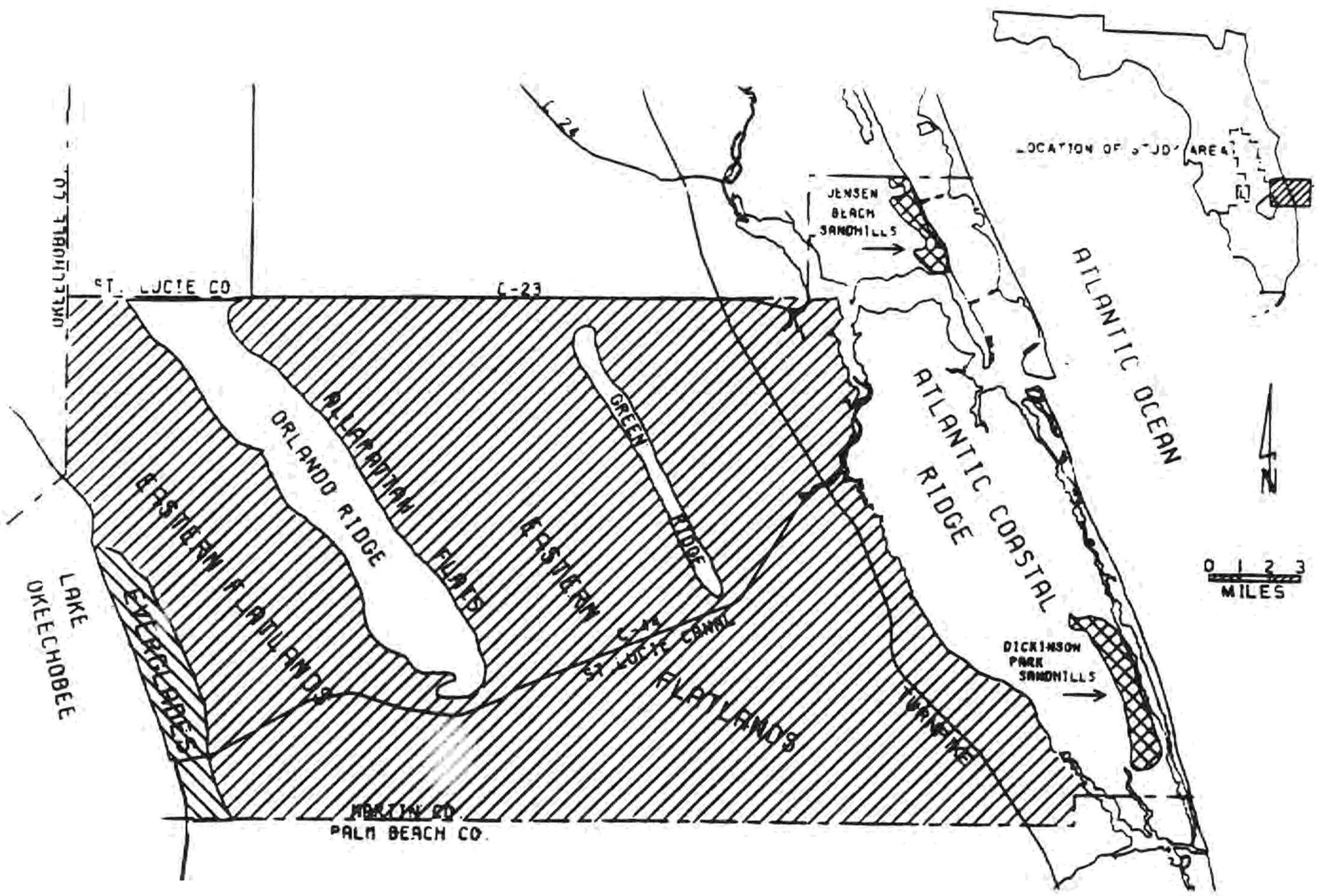


Figure 4 PHYSIOGRAPHIC REGIONS OF MARTIN COUNTY (LICHTLER,1960)

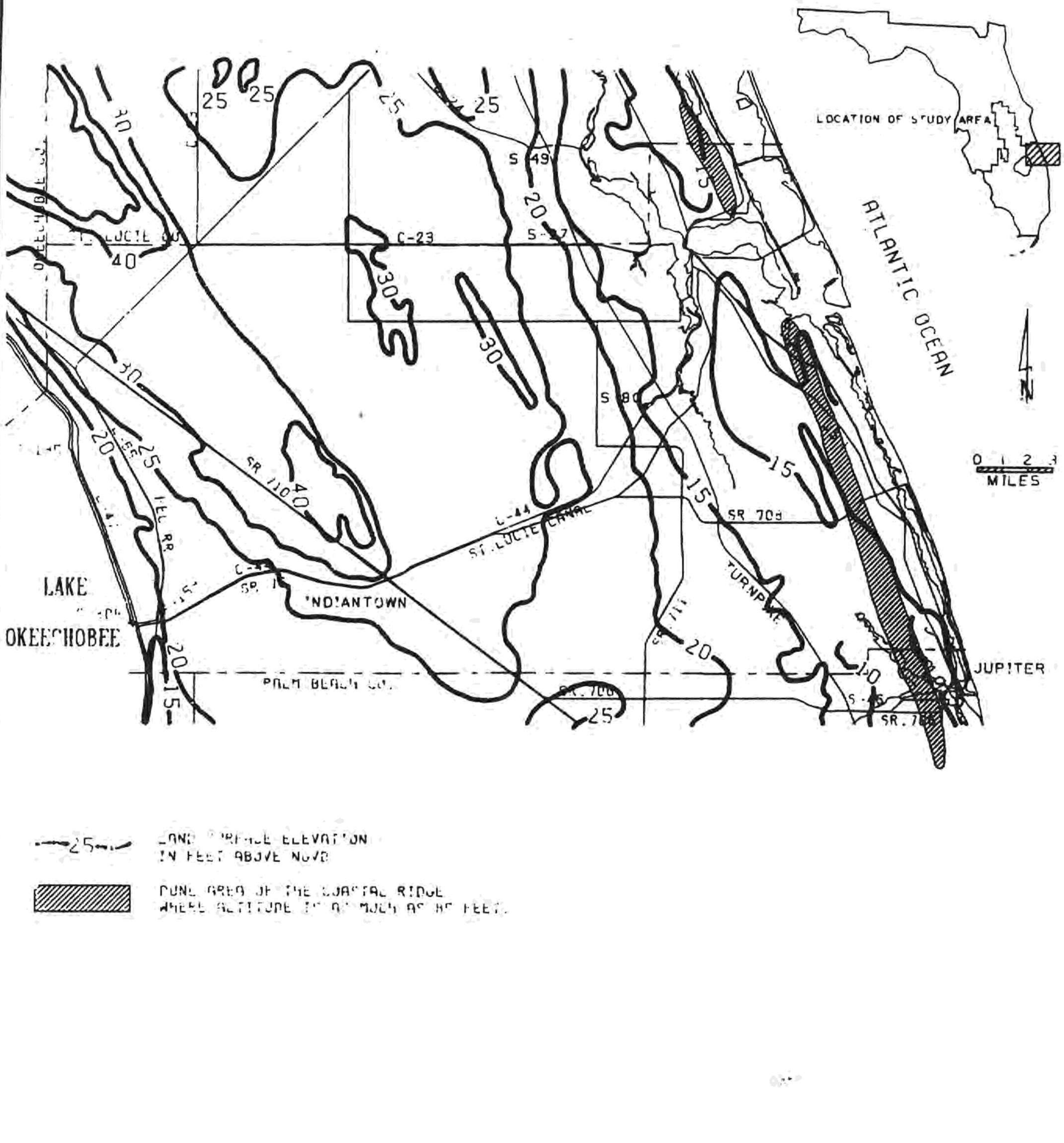


Figure 5 TOPOGRAPHY OF MARTIN COUNTY

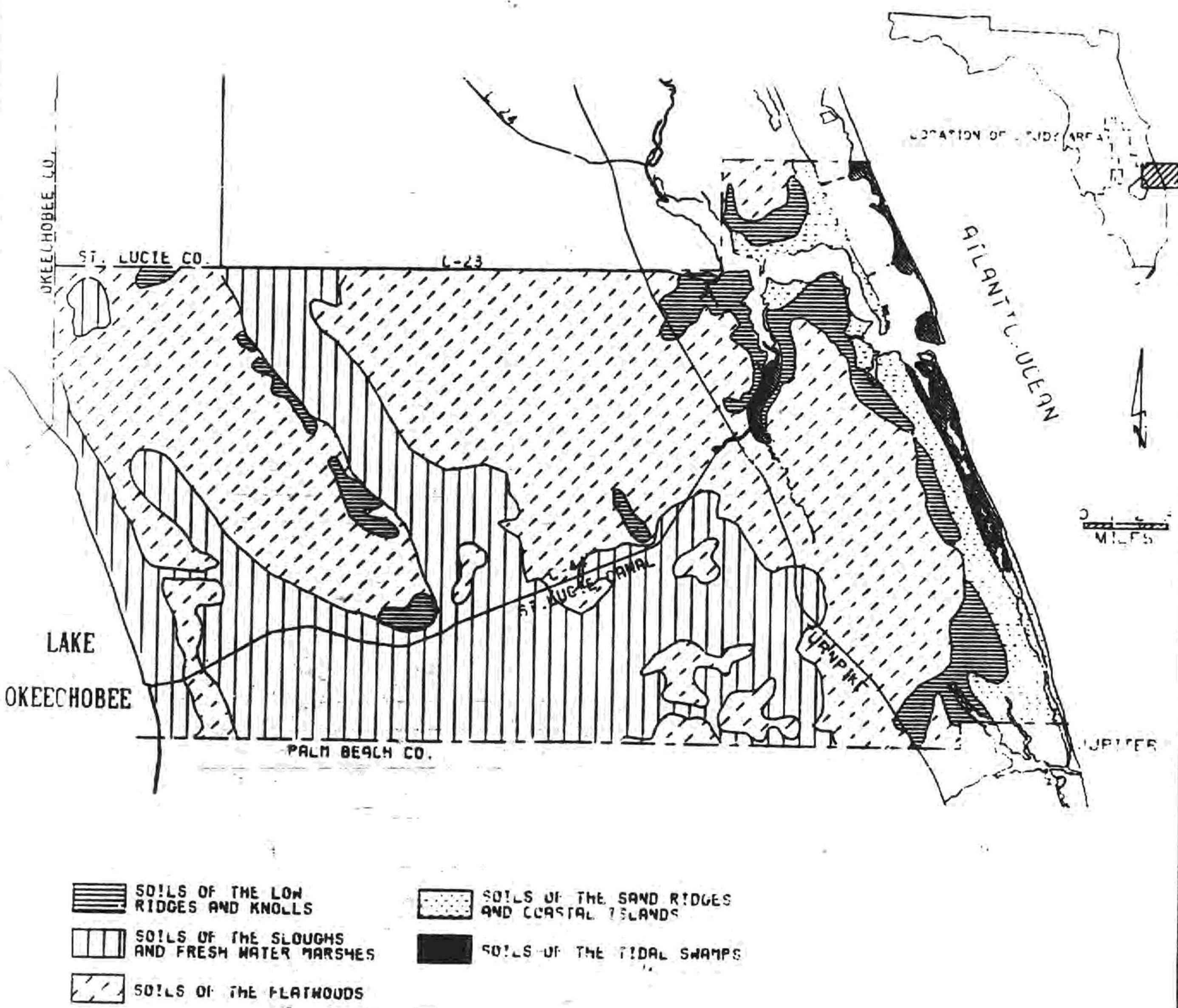


Figure 6 GENERAL SOIL MAP OF MARTIN COUNTY. (AFTER McCOLLUM, 1981)

loamy subsoil while others are organic or hard limestone. They are present within broad sloughs, depressions, and marshes. Drainage is typically poor to very poor (McCollum, 1981).

Tidal swamp soils occur along the Intracoastal Waterway and the St. Lucie River, and may be clay or sand which is very poorly drained (McCollum, et al., 1981).

HYDROLOGIC ANALYSIS

As part of this study, the Water Resources Division of the SFWMD provided an analysis of rainfall/drought frequency and the availability of surface water in Martin County. A brief summary of that analysis is presented here. For more detailed information, the reader is referred to Appendix 1.

The major source of surface water in Martin County is from C-44 (St. Lucie Canal). A minor source of water can also be obtained from C-23, which lies on the boundary of St. Lucie and Martin Counties. A decision has been made, however, to exclude C-23 from the study because the major portion of the drainage area of C-23 is within St. Lucie County, and the availability of canal water in C-23 has been known to be limited.

Surface water can be obtained from C-44 by direct withdrawal or by interception and diversion of secondary canal inflows to the canal. An analysis of surface water availability in Martin County is equivalent to analyzing the availability of C-44 inflow. In this report, C-44 inflow refers to the portion generated within the canal basin. The portion contributed by Lake Okeechobee is excluded in this analysis. A SFWMD water supply (computer) model is used to address the potential water availability contributed by Lake Okeechobee in a following section.

The C-44 inflow was calculated as the difference between the discharges at S-80, located at the South Fork of the St. Lucie River (Figure 1), and S-308, located on the western edge of Lake Okeechobee. The C-44 inflow included the effects of the 1978 to 1983 canal water usage. The calculated inflow represents the amount of water available for additional usage.

The rainfall data were based on the average of two long term rainfall stations within the C-44 basin, one located at S-80 and the other at S-308. A total of 31 years of data covering the period of 1952 to 1983 was used in the rainfall/drought frequency analysis.

Relatively long records are available for the rainfall data, but only six years of data are available for the C-44 inflow. The C-44 inflow record was extended by regression with rainfall. A statistical test was used to determine that the variance was not significantly reduced by the extension, thereby assuring that the extension was worthwhile.

Rainfall/Drought Frequency

Estimates of rainfall/drought frequencies were computed for this study. The reliability of the frequency estimates is related to the length of the data record available. According to Fan (1984), with the current data it is permissible within reasonable confidence limits, to project rainfall return frequencies of up to 1 in 60 years and C-44 inflow frequencies of up to 1 in 20 years. Table 1 depicts the estimates of annual rainfall for various drought frequencies up to a 1 in 100 year return interval. The average annual rainfall for a drought with a return interval of 1 in 100 years was extrapolated from data provided by Fan (1984).

TABLE 1. DROUGHT FREQUENCIES

RETURN INTERVAL (Years)	ANNUAL RAINFALL (Inches)
Average Year	57
1 in 10	41
1 in 20	39
1 in 50	37
1 in 100	36

In summary, the dry season in the C-44 basin begins in November and usually ends in April. There is a sharp decrease in rainfall after October. The rainfall remains at about the same low level between November and April and rebounds sometime in May or June. The amount of rainfall in May is most variable.

Surface Water Availability

The seasonal trend of the C-44 inflow generally follows that of rainfall with one exception. In a normal year, the flow reaches a minimum in April, and in a drier year it reaches a minimum in May. For rainfall, there is no sharp month to month variation during the dry season. The inflow, however, follows a slow recession curve which responds to the cumulative effect of dry season rainfall with a lag time of two to three months. The flow in May, similar to rainfall, is most variable and unpredictable as it is dependent on the arrival of wet season rainfall. Similar responses have been observed in C-43 (Caloosahatchee River Basin) which is hydrologically analogous to C-44.

A deficit condition occurs when there is greater withdrawal from the canal than inflow. The situation in the C-44 basin is similar to that of the C-43 basin; the canal flow is plentiful during the wet months and is inadequate to meet demand during some of the dry months. Hence, supplemental water from Lake Okeechobee is needed. Under the current conditions, supplemental releases from Lake Okeechobee are needed for an approximate duration of one month in a normal year and three months in a 1 in 10 year drought. Additional withdrawals from C-44 will inevitably impose greater stresses on Lake Okeechobee, unless an alternate source of water is developed or a plan to store the wet season surplus for use at a time of shortage is implemented.

Storing the surplus runoff in surface impoundments is generally inefficient in south Florida. If a reservoir were created it would have to be very large and shallow, and the evapotranspiration loss per unit depth of storage would be excessive. Storing the water in the Surficial Aquifer System is equally difficult because of the lack of storage capacity during the wet months.

Water Availability in Lake Okeechobee

Martin County will have a substantial increase in future water use requirements due to its rapid development. Presently, Martin County's permitted utility water usage averages about 15 million gallons a day (MGD). Existing and committed demands are estimated to be 21 MGD. Furthermore, if projected buildout conditions are met in the future, up to 55 million gallons of water a day will be needed by the public municipalities.

The purpose of this analysis is to quantify the availability of water in Lake Okeechobee to meet the future demands of Martin County municipalities. To do this, a series of computer simulations have been performed with a regional hydrological model (Inflow-Outflow Management Model) which simulates stages for Lake Okeechobee under historical rainfall conditions. Five computer simulations have been analyzed to quantify the ability of Lake Okeechobee to meet the additional future Martin County water use requirements.

The first model simulation is the base run. This model run simulates the hydrological conditions with present water use requirements, conveyance capacities, and management policies in effect; based on the repetition of historical rainfall patterns from 1963 through June 1983. Runs two through five simulate the conditions and the amount of water available from the lake when various amounts of additional water is supplied to Martin County from the lake. Run two simulates what the stages would be if all the municipal water use presently supplied or committed by the municipalities (21 MGD) was supplied by Lake Okeechobee. The third model run supplies the Martin County buildout municipal water requirements (55 MGD) from Lake Okeechobee. Model runs four and five repeat runs two and three respectively, except that they assume that current usage levels (15 MGD) are still obtained from local storage. Therefore, run four supplies 6 MGD from Lake Okeechobee and run five supplies 40 MGD from Lake Okeechobee.

In all cases, it is assumed that existing private wells will continue to obtain water from local aquifer storage. From these model runs, it is possible to calculate how many days a year water demands are not met, as well as the percentage of cutbacks that will be required by the current users during these periods. Whether potential Martin County users will need to cutback completely or just to the same degree as other users is still in question. Tables 2 and 3 illustrate the number of days cutbacks are required each year and the percentage of cutbacks that would be required of present users under each level of supply.

TABLE 2. NUMBER OF DAYS DEMAND NOT MET--LAKE OKEECHOBEE

Year	Base Run	21 MGD	55 MGD	6 MGD	40 MGD
1963	163	165	169	163	166
1964	58	62	73	58	71
1965	10	12	13	10	12
1966	--	--	--	--	--
1967	--	--	--	--	--
1968	--	--	--	--	--
1969	--	--	--	--	--
1970	--	--	--	--	--
1971	90	105	112	95	111
1972	81	84	93	82	88
1973	94	109	127	96	125
1974	108	111	116	109	114
1975	--	--	--	--	--
1976	21	60	101	27	76
1977	155	161	183	155	169
1978	--	--	--	--	--
1979	--	--	--	--	--
1980	--	--	--	--	--
1981	268	268	271	268	268
1982	169	169	169	169	169
1983	--	--	--	--	--

TABLE 3. PERCENTAGE OF DEMAND UNAVAILABLE LAKE OKEECHOBEE SERVICE AREAS

	Base Run	21 MGD	55 MGD	6 MGD	40 MGD
Wet 63	34.8	35.5	37.3	35.3	36.4
Dry 64	7.3	9.6	12.3	7.3	11.0
Wet 64	--	--	0.4	--	0.2
Dry 65	--	--	0.7	--	--
Wet 65	17.4	21.0	21.0	17.4	21.0
Dry 71	3.8	3.8	4.4	3.8	4.1
Wet 71	11.9	14.9	15.9	12.9	15.9
Wet 72	25.4	25.5	25.8	25.4	25.6
Dry 73	2.9	5.3	10.3	2.9	8.1
Wet 73	8.8	9.9	10.5	9.2	10.5
Dry 74	26.0	27.4	30.5	26.8	29.3
Wet 74	14.8	14.8	14.8	14.8	15.1
Dry 76	3.8	6.4	12.8	4.5	9.6
Dry 77	--	1.6	4.1	0.5	4.0
Wet 77	21.7	23.1	29.6	21.7	26.2
Dry 78	1.0	1.1	1.1	1.0	1.0
Wet 78	--	1.1	--	--	--
Dry 81	17.7	18.5	19.8	17.7	19.5
Wet 81	81.5	82.0	82.0	81.5	82.0
Dry 82	74.9	74.9	74.9	74.9	74.9
Wet 82	3.7	3.7	3.7	3.7	3.7

The results indicate that under the present operational policies, cutbacks would be needed 16.2% of the time without any additional deliveries being made to Martin County. Increases of 6, 21, 40 and 55 MGD would cause increases in the number of days of cutbacks for present users to 16.4, 17.5, and 18.2%, respectively. These additional deliveries would cause up to a 5% increase in the water demand unsatisfied by other Lake Okeechobee service areas and may cause the lake stage to be two tenths of a foot lower during critical dry periods.

Lake Okeechobee appears capable of supplying Martin County with its increased water demands the majority of the time. However, during periods when water needs are the greatest, cutbacks may be required by Martin County municipalities. Also, some additional reductions in water supplied to other users around the lake may occur.

Surface Water Quality

Water quality in the St. Lucie River, as measured at S-80 over the period of record January 1, 1979 through December 31, 1984, remained fairly constant as measured by concentrations of nutrients, major anions, major cations, and other parameters. In general, the water is usually hard to very hard, highly alkaline, highly variable with respect to color, nitrogen, and phosphorus species, and high in dissolved solids (Table 4).

TABLE 4. SUMMARY OF SELECTED WATER QUALITY PARAMETERS IN THE ST. LUCIE RIVER AT S-80 FROM 1/01/79-12/31/84 (Means and Ranges (mg/L unless otherwise specified)

	Monthly Sampling Frequency		
	MEAN	MIN	MAX
D.O.	6.3	2.2	9.2
Spec. Cond (µmhos/cm)	676	372	1700
pH	7.53	5.92	8.53
Turbidity (NTUs)	10.1	1.3	95.0
Color	75	5	220
TDS	15.5	1.0	110.0
No_x	.211	.004	.684
No_2	.019	.004	.147
No_3	.197	.004	.680
NH_4	.05	.01	.26
TKN	1.73	0.25	5.87
Total N	1.94	0.66	6.16
Ortho P	.076	.005	.286
Total Hardness	.133	.048	.351
Na	50.7	29.0	80.5
K	4.7	4.2	5.5
Ca.	59.3	38.4	79.3
Mg	12,4	07.2	15.8
Cl	84.5	14.8	161.2
SO_4	40.9	24.8	55.0
Alk $CaCo_3$	141.5	33.8	220.5
Hardness ($CaCO_3$)	199.3	143.2	243.7

Data collected upstream of S-80

Dissolved oxygen levels during this period were rarely below 5.0 mg/l. Mean specific conductance, sodium and potassium, chloride, pH, turbidity, nitrogen species, phosphorus species, and color were approximately equivalent to mean values for these parameters in Lake Okeechobee at the Port Mayaca locks (Table 5). Total suspended solids, total iron, magnesium, and sulfates were slightly lower at S-80 than at the Lake Okeechobee station. Mean calcium concentrations were slightly higher at S-80 than at Port Mayaca.

In summary, water quality as measured in the St. Lucie River at S-80 was not appreciably different from that of Lake Okeechobee at Port Mayaca. With the exception of the few occasions when dissolved oxygen levels were less than 5.0 mg/l at S-80, quality at both locations met criteria for both FAC 17-3 Class IA and Class III surface waters for those parameters measured.

TABLE 5. SELECTED WATER QUALITY PARAMETERS, LAKE OKEECHOBEE AT PORT MAYACA FROM 1/01/79-12/31/84
(Means and Ranges (mg/L unless otherwise specified)

	Monthly Sampling Frequency		
	MEAN	MIN	MAX
D.O.	7.4	2.9	12.1
Spec. Cond (μmhos/cm)	606	330	926
pH	7.94	6.95	9.09
Turbidity (NTUs)	26.5	1.5	138.0
Color	70	5	213
TDS	27.9	1.0	190.0
No_x	.224	.004	1.719
No_2	.014	.002	.131
No_3	.211	.004	1.659
NH_4	.06	.01	.33
TKN	1.79	0.85	3.40
Total N	2.02	0.90	3.72
Ortho P	.068	.003	.311
Total Hardness	.158	.050	.420
Na	51.8	29.1	77.6
K	4.7	3.4	5.8
Ca.	43.5	24.6	79.4
Mg	15.2	8.8	19.7
Cl	80.8	36.5	137.4
SO_4	50.8	26.2	72.7
Alk $CaCo_3$	2.4	1.1	3.8
Hardness ($CaCO_3$)	171.3	97.8	276.5

Data collected upstream of S-80

HYDROGEOLOGIC ANALYSIS

Three major hydrostratigraphic units which extend from land surface to depths of over 1,000 feet are encountered throughout Martin County. These units are the Surficial Aquifer System, the Hawthorn confining beds, and the Floridan Aquifer System. A schematic representation of these hydrostratigraphic units is shown in Figure 7.

The predominant lithologies underlying Martin County are sand, sandstone, limestone, silt, and clay. At a depth of almost 13,000 feet these sedimentary rocks are underlain by the igneous and metamorphic rocks of the basement complex (Lichtler, 1960).

FIGURE 7. SCHEMATIC REPRESENTATION OF THE MAJOR STRATIGRAPHIC UNITS ENCOUNTERED IN MARTIN COUNTY

Hydrostratigraphic Unit	Hydrogeologic Properties
Surficial Aquifer System 90-200 Feet Thick	**Moderate Transmissivity Water Quality: Fair to Good**
HAWTHORN CONFINING BEDS 400-650 Feet Thick	**Poor Transmissivity Yields Little Water**
FLORIDAN AQUIFER SYSTEM 2800-3400 Feet Thick	**High Transmissivity Water Quality: Poor**

The Floridan Aquifer System consists of a sequence of limestone, and the deepest unit encountered is the Avon Park of Eocene Age. The Avon Park is a chalky to finely crystalline limestone and differs from the overlying Ocala limestone of Late Eocene age only in fossil content. Above the Ocala is a soft, granular limestone of Oligocene age known as the Suwannee limestone. The Tampa Formation is the uppermost unit in this series of limestones and is a dense, sandy limestone of Miocene age.

Separating the Floridan Aquifer System from the Surficial aquifer is a 450 to 650 foot thickness of phosphatic clay, dolosilts, and quartz sand which compose the Hawthorn Formation of Miocene age (Lichtler, 1960). The sediments of the Hawthorn Formation act as a confining bed for the Floridan Aquifer System. The great thickness and low permeability of this confining unit effectively separates the Floridan Aquifer System from the Surficial Aquifer System, and retards the vertical movement of water between these systems.

Geology of the Surficial Aquifer System

The base of the Surficial Aquifer System is formed by the permeable sands of the Tamiami Formation. This Miocene age formation also includes semi-permeable lithologies similar to those of the Hawthorn mentioned above. Figure 8 depicts contour lines which show the elevation of the base of the aquifer or Tamiami Formation (relative to the NGVD of 1929) (Miller, 1980).

The Caloosahatchee Marl overlies the Tamiami Formation; however, its thickness and continuity have not been thoroughly determined throughout the county. Sand and shell are the main components of the Caloosahatchee Marl, and it is thought to be of Pliocene age. Overlying the Caloosahatchee Marl is the Fort Thompson Formation which is of Pleistocene age. The Fort Thompson Formation consists of shell marl and limestone. This formation may extend as far east as the Atlantic Ridge where it merges with the Anastasia Formation. The Anastasia is also of Pleistocene age and consists of sand, shell beds, and discontinuous layers of sandy limestone or sandstone (Lichtler, 1960). The formation is wedge-shaped and thins to the west. Both the Fort Thompson and the Anastasia are overlain by the Pamlico Sand. The Pamlico Sand is only a few feet thick and covers most of the county (Lichtler, 1960).

As mentioned, the elevation of the base of the Surficial Aquifer System is shown in Figure 8. The aquifer is thickest in the eastern portion of the county and along its southern boundary. A sinuous structural high exists within the aquifer which emanatesfrom the north central portion of the county and meanders to the east and then westward. In northwestern Martin County the aquifer thickens and forms a pocket shaped depression. Figure 8 also indicates the locations of geologic cross sections. These cross sections illustrate the major lithologies of the Surficial aquifer in Figures 9 and 10.

The geoelectric properties of the Surficial aquifer were investigated by Stodghill (1984) with surface resistivity equipment. The surface resistivity surveys measure the potential of an electric current which can flow through the ground. The intensity of the current is determined by the characteristics of the earth materials encountered, such as mineralogy, pore surface, effective porosity, and the interstitial fluids. The investigation determined that three unique geoelectric layers exist within the Surficial aquifer. First, a high resistivity response is located at or near land surface. This response may be indicative of medium to fine grained siliceous sand. A low resistivity response represents the second geoelectric response. This layer is composed of quartz sand along with shell material, silts, and clays, with a significant amount of fine grained sediments. The third layer has a relatively low resistivity response. This layer is primarily composed of calcarenite and shell beds intermixed with quartz sand (Stodghill, 1984). For a detailed understanding of surface resistivity in Martin County, the reader is referred to Stodghill, 1984.

Hydrogeology of the Surficial Aquifer System

The Surficial Aquifer System is the principal source of fresh water within Martin County. In general, three zones compose the aquifer: the surficial sands, the primary water producing zone, and the base which forms the confining bed. The surficial sands are shallow and may not be completely saturated throughout the year. The primary water producing zone consists of shell, sandstone, limestone, and sand of the Anastasia, Caloosahatchee Marl, and the Fort Thompson Formation. The confining bed is delineated as the sandy clay of the Tamiami Formation and the clay of the Hawthorn Formation (Miller, 1979).

Generally, the surficial sands range between 20-40 feet in thickness. These sands have low to medium permeability and may produce small quantities of water (Lichtler, 1960).

The major producing zone has an approximate thickness of 130-150 ft. (Miller, 1979), although the thickness does vary. The producing zone is capable of providing relatively large quantities of water; this yield to wells is determined by the aquifer characteristics. The parameters which are most valuable for the quantification of the water resources are the saturated thickness and permeability of the aquifer. The saturated thickness of the aquifer is the zone within the subsurface in which the openings are full of water. The permeability of the aquifer, which is defined as the capacity of a unit volume of porous medium to transmit water, is contingent on the lithology of the aquifer. As the lithology of the aquifer varies both vertically and horizontally, so does the permeability. Since permeability values are highly variable, an average permeability value is most often assigned to the lithologies which compose the aquifer at a given site. A single term which represents the water transmitting capacity of the entire aquifer at a site is known as transmissivity. Transmissivity is the product of permeability and saturated aquifer thickness; it may be defined as the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient (Lohman, 1972).

Values of transmissivity were collected from the United States Geological Survey and a variety of engineering consulting firm reports. A total of 29 values were obtained from these sources for the Martin County area. Transmissivity values were mapped and statistically analyzed to determine data

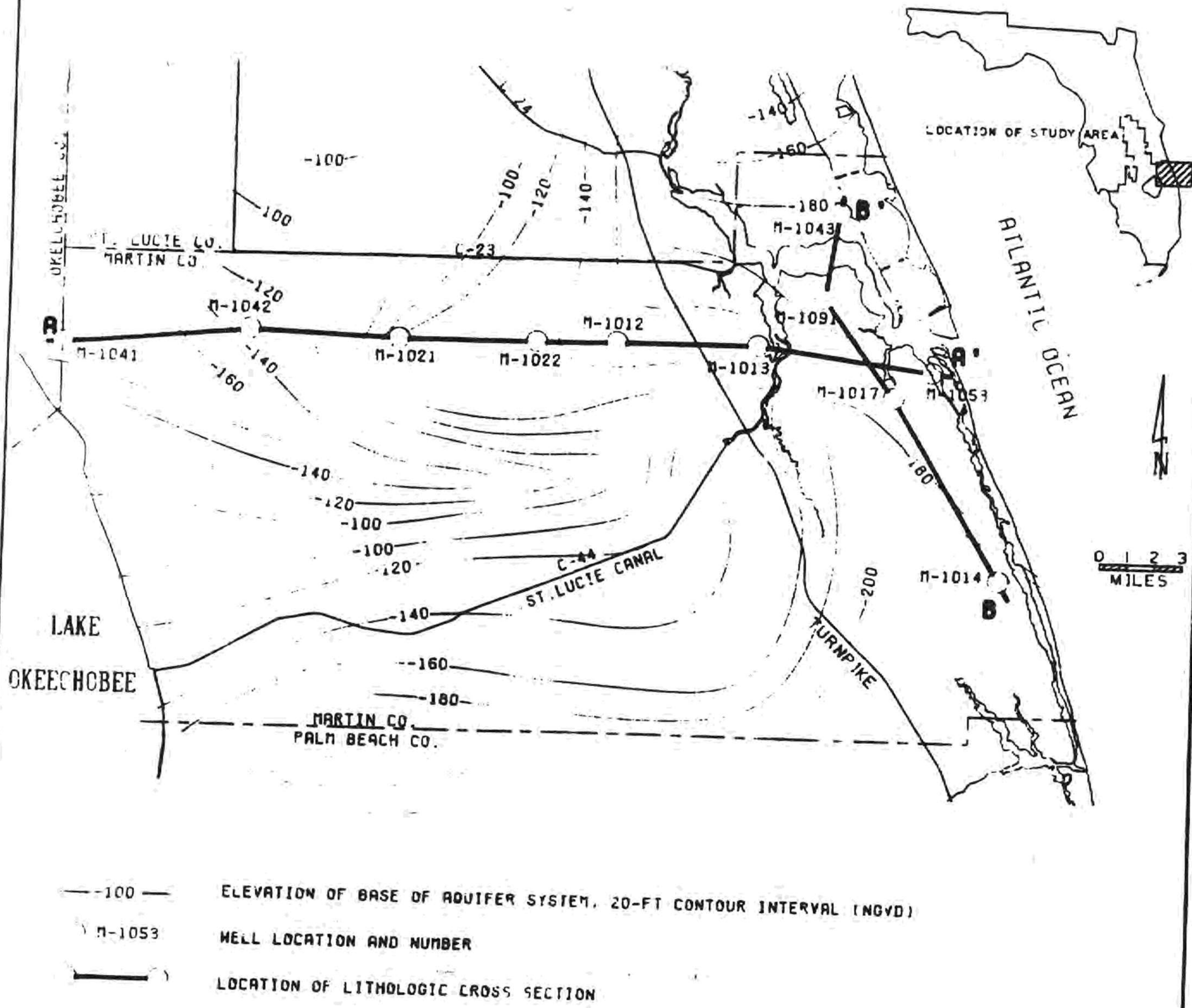


Figure 8 ALTITUDE OF THE BASE OF THE SURFICIAL AQUIFER, MARTIN COUNTY. (MODIFIED FROM MILLER, 1980)

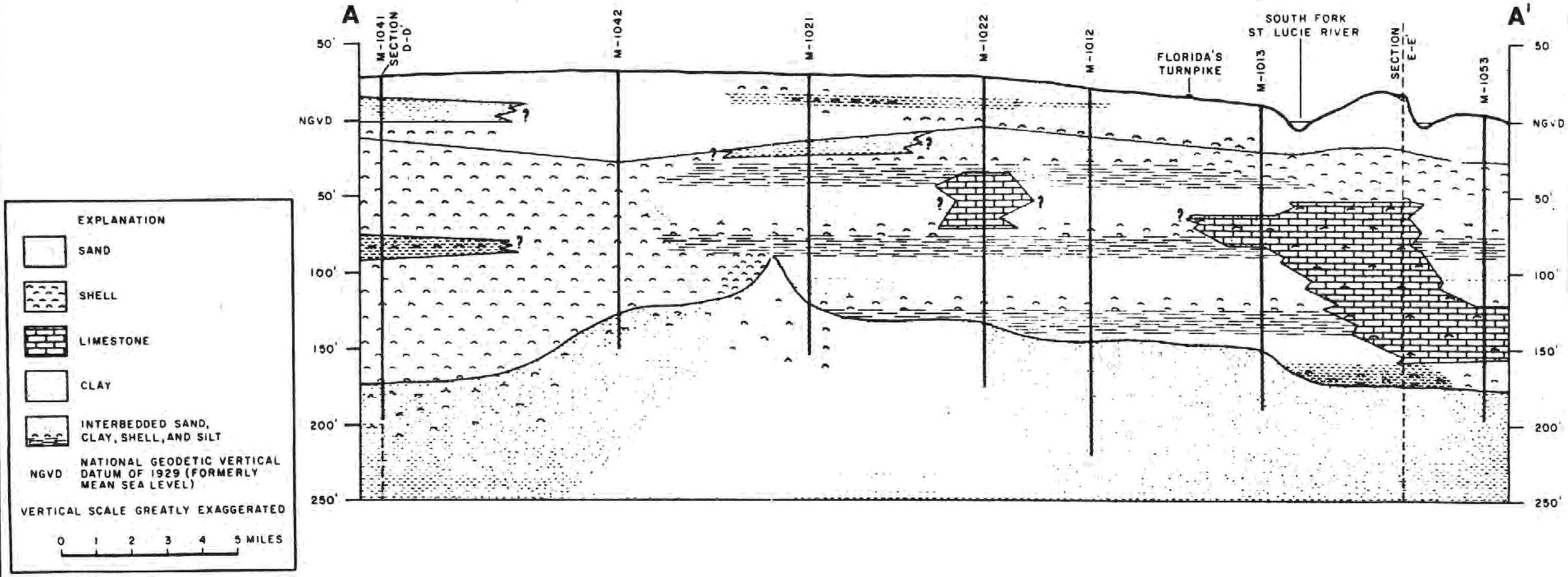


Figure 9 EAST-WEST GEOLOGIC CROSS SECTION (AFTER MILLER, 1980)

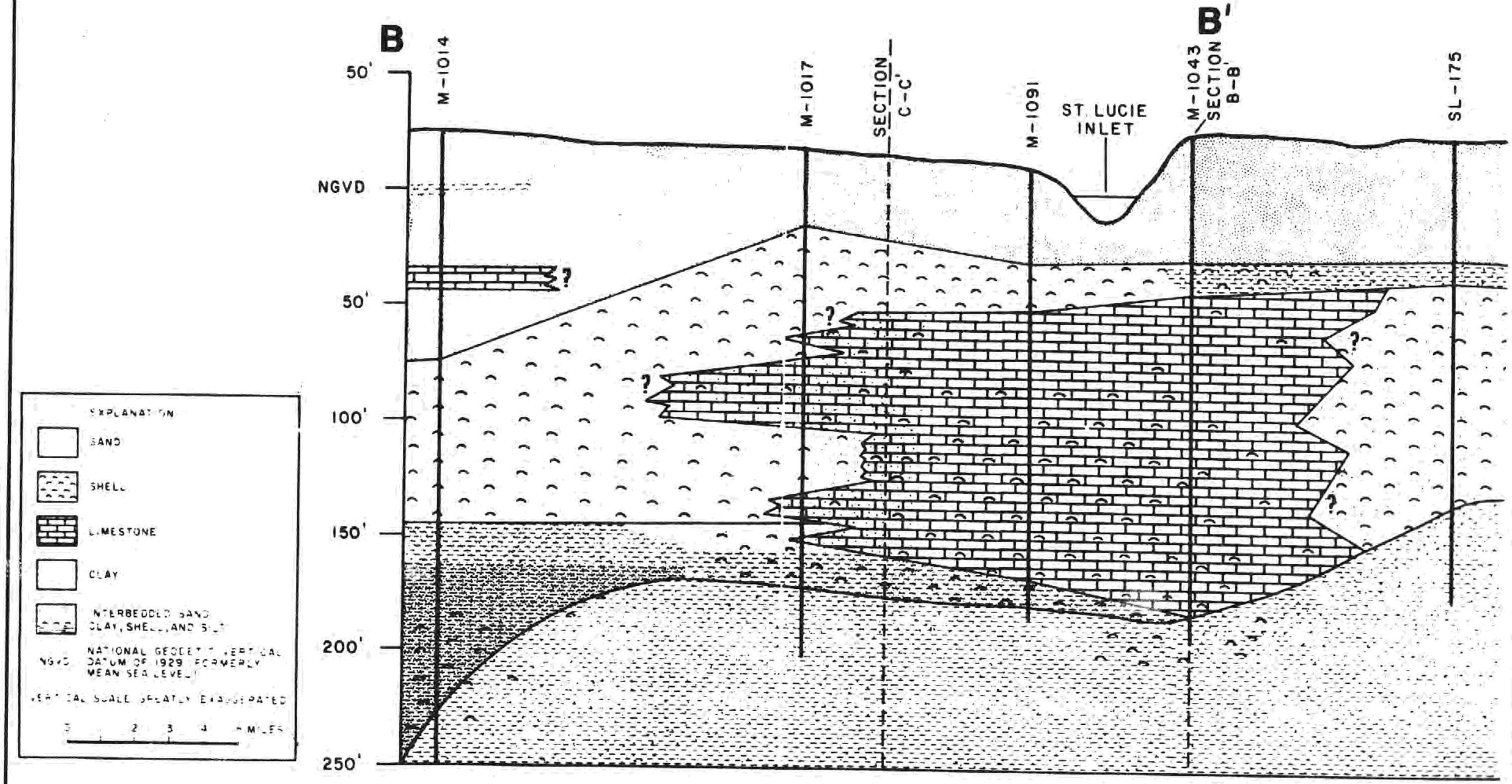


Figure 10 NORTH-SOUTH GEOLOGIC CROSS SECTION (AFTER MILLER, 1980)

deficient areas within the county. Data gaps were identified at five locations and transmissivity values were subsequently determined at sites within each area (see Figure 11).

To determine a transmissivity value at a site, an aquifer test must be performed. An aquifer test involves analyzing the change with time, of water levels or head in an aquifer, caused by withdrawals of water through wells. Pumping wells of six inch diameter were drilled at the five sites along with a corresponding observation well. The observation wells were drilled to the base of the aquifer at each site. The pumping wells were drilled to a depth of two-thirds the thickness of the aquifer, and the well screen was centralized within the aquifer. The pumping wells were discharged at a constant rate, and the drawdown or water decline was measured in both the pumping wells and the observation wells. Measurements were observed until the aquifer reached steady-state or until there was no measurable change in head with time. The steady-state drawdowns in the pumping wells and observation wells were plotted for the corresponding distance from the pumping well, and the transmissivity values were obtained for each site.

Figure 12 illustrates a regional contour map of the transmissivity of the Surficial Aquifer System. The map was generated by statistically analyzing the transmissivity values shown in Figure 11. In general, the transmissivity is greater in the southern and southeastern portions of the county. The permeable limestone, sandstone, and shell strata are more prevalent towards the east (Lichtler, 1960). Highly permeable, cavity riddled beds occur within the Surficial Aquifer System in northeastern Palm Beach County (Fischer, 1978) and probably occur within southeastern Martin County. In addition, the aquifer thickness is greater in this area. The combination of highly permeable beds and large saturated aquifer thickness results in high transmissivity values. Transmissivity values for the southern half of the county range between 70,000 to 150,000 gpd/ft. To the northwest, the transmissivity values decline as does the saturated aquifer thickness. Furthermore, permeable beds may be missing entirely in some areas (Lichtler, 1960). Within the north Martin County peninsula and the city of Stuart area, transmissivity values range between 30,000 to 50,000 gpd/ft. These values are smaller in comparison to the values found in the southeast and may be due to the high percentage of clay within the aquifer in this area (Miller, 1979).

Variations in transmissivity within the aquifer values are dependent on saturated aquifer thickness and permeability of the lithology. Hence, additional transmissivity values may deviate from those values obtained in this study. Values shown in Figure 12 are employed in the following ground water modeling section for the Surficial Aquifer System.

An additional parameter which can also be determined by an aquifer pumping test is the specific yield. Specific yield is known as the storage term for unconfined aquifers. It is defined as the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table. The specific yields of unconfined aquifers usually range from 0.01 to 0.30 (Freeze, 1979). However, values reported for the Surficial Aquifer System are often lower than those of the usual range. Within Martin County specific yield values have been reported to be as low as 0.0001. Underestimating the specific yield value may be due to short duration pumping tests. It is anticipated that specific yield values for the Surficial Aquifer System are within the normal range. In the following ground water modeling section a specific yield value of 0.2 was employed.

Water Levels

The ground water which occurs within the Surficial aquifer is under water table conditions; the aquifer can be referred to as a water table or unconfined aquifer. Water within a well completed under these circumstances will stand at the same level as the water table. The water table is the level in the saturated zone at which hydraulic pressure is equal to atmospheric pressure.

The water table is an undulating surface which generally follows the topography of the land. Figure 13 depicts the wet season water table elevations in October of 1974. The highest water levels occur in the northwest portion of the county underlying the topographic high of the Orlando Ridge. Water levels as high as 32 feet above NGVD occur in this area, and the water table contours or equipotential lines parallel the configuration of the ridge (see Figure 13). The water flows perpendicular to the equipotential lines, such that the flow radiates outward southeast from the Orlando Ridge. West of the ridge, water flows southwest to Lake Okeechobee where water levels are generally 14 to 16 feet above NGVD. Water levels in this area are influenced by the lake and respond to its regulation stage. The equipotential lines east of the Orlando Ridge are contained within the C-44, C-23, and St. Lucie River Basins. Water flows northeastward to the St. Lucie River and southeast to C-44 with a hydraulic gradient or slope of approximately one foot per mile. South of C-44 and the St. Lucie River, the ground water

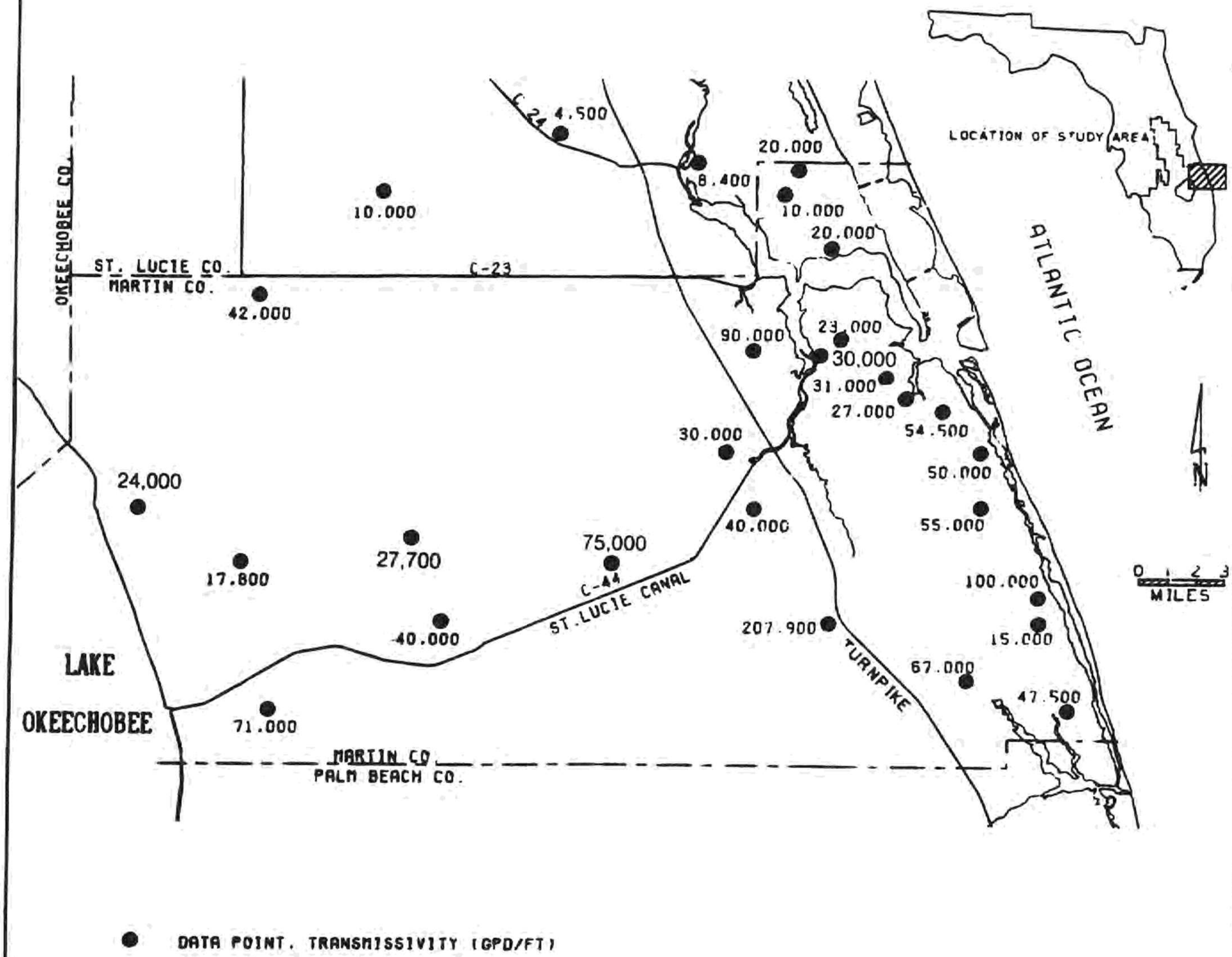


Figure 11 LOCATIONS OF THE TRANSMISSIVITY VALUES OF THE SURFICIAL AQUIFER SYSTEM, MARTIN COUNTY

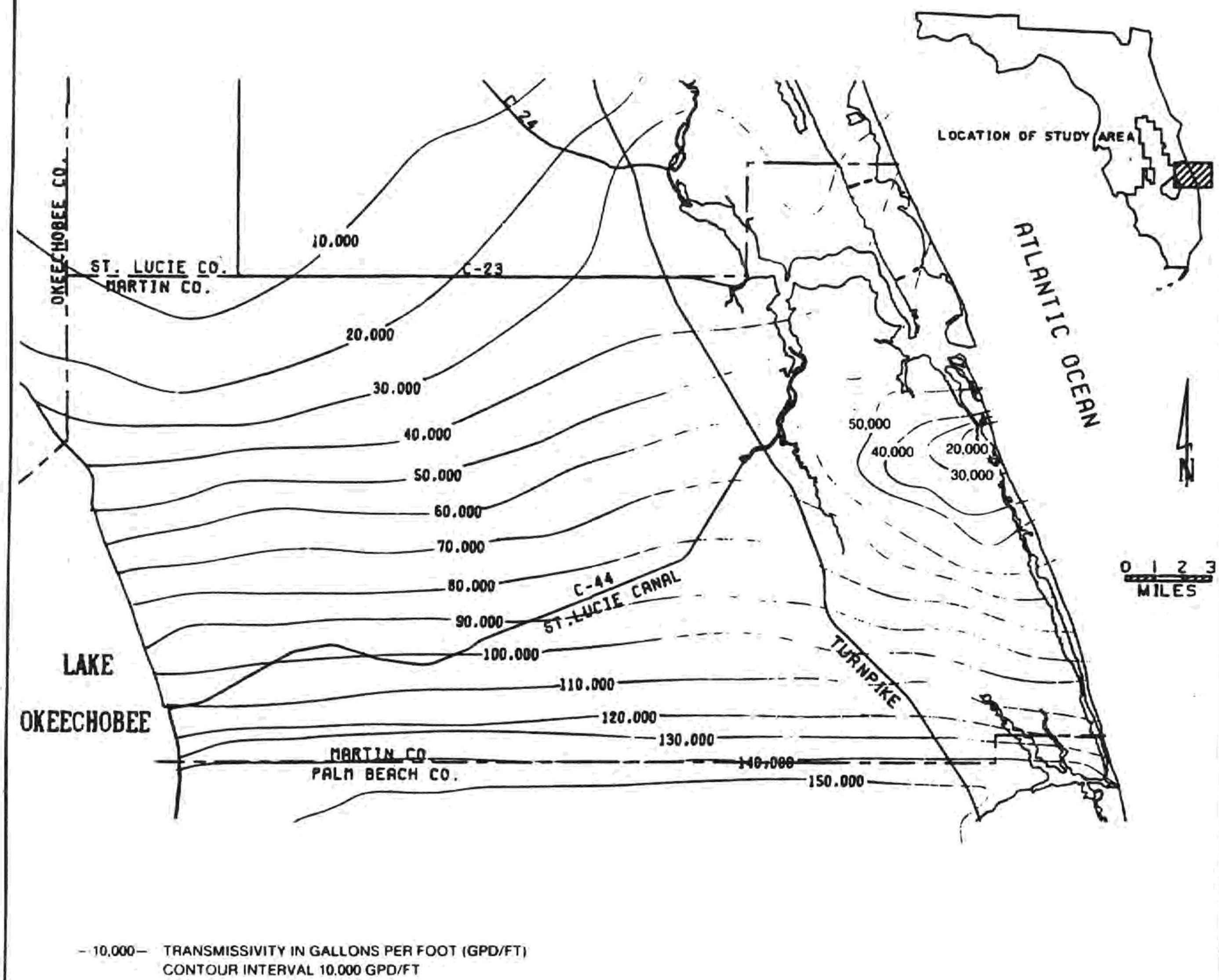


Figure 12 STATISTICAL TRENDS OF THE TRANSMISSIVITY OF THE SURFICIAL AQUIFER SYSTEM, MARTIN COUNTY

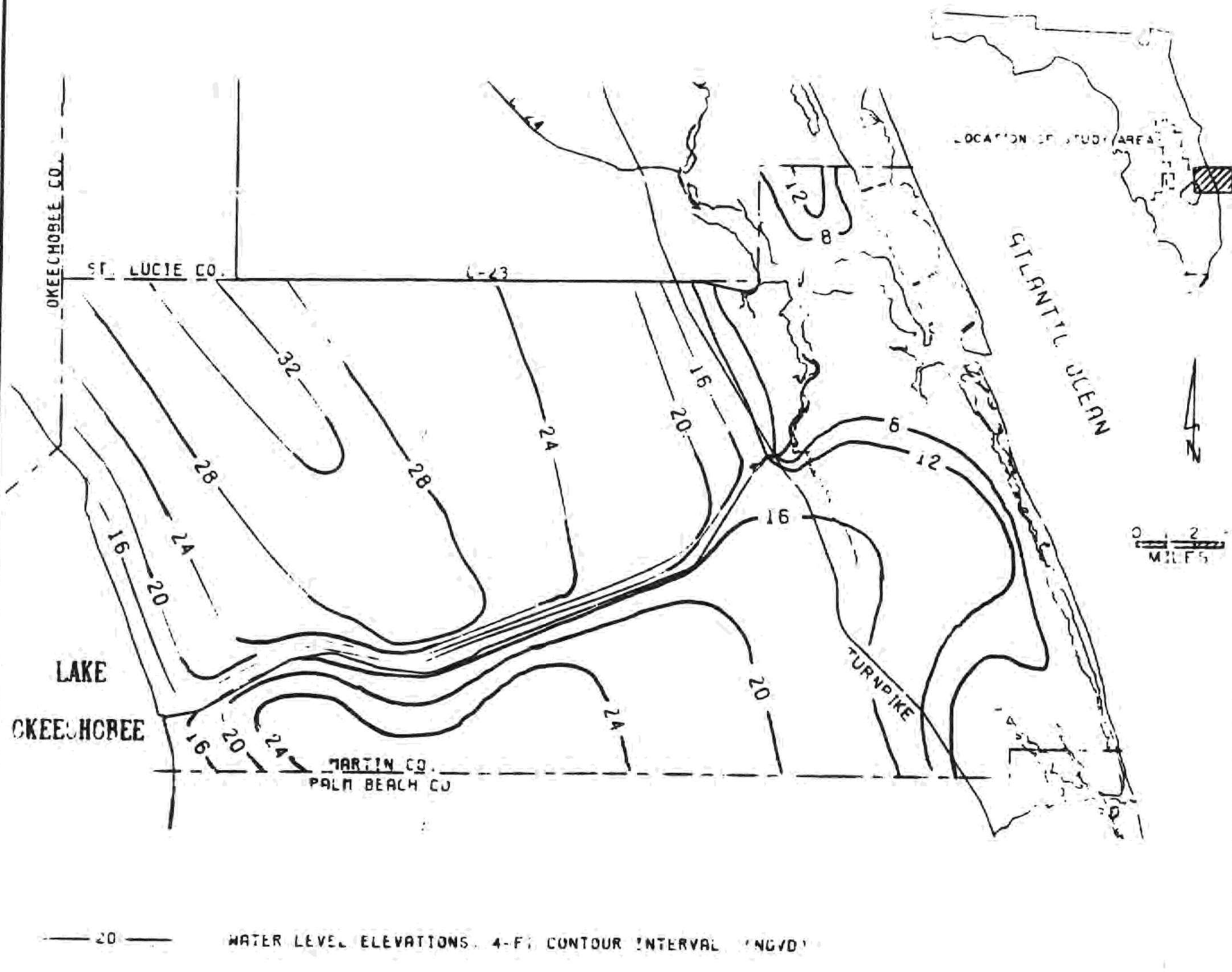


Figure 13 WET SEASON WATER TABLE CONTOURS, (OCT. 1974) MARTIN COUNTY (FROM MILLER, 1978)

generally flows northward but radiates outward towards both the Atlantic Ocean and Lake Okeechobee. In the south central portion of the county the highest water levels are approximately 24 feet above NGVD. In the peninsulas of north Martin County and the city of Stuart, the equipotential lines generally mimic the shape of each peninsula (see Figure 13). Water levels are highest in the south central portion of peninsular Stuart, and flow is to the north, east, and west. The north Martin County peninsula mirrors the water levels of the Stuart area. Flow also radiates outward, but the water table is highest in the north central portion of the peninsula.

The water table is not a stationary surface, but fluctuates in response to recharge and discharge from the aquifer. Rainfall contributes the majority of recharge to the aquifer. Differences in the wet and dry season water table elevations range between 2 to 4 feet. The water table is higher during the wet season since 60% of the rainfall occurs at this time. Fluctuations in the water table also occur due to discharges such as evapotranspiration, well withdrawals, and natural flow to the ocean, canals, and Lake Okeechobee. Evapotranspiration is the major discharge source other than natural flow discharges, and may vary between 35 to 58 inches per year for the county area (Allen, 1982). Several factors which influence evapotranspiration rates are climatic conditions, elevation of the water table, and vegetation cover.

Hydrographs for wells M-140, M-933, M-1048, and M-147 (see Figures 14 through 17) illustrate the fluctuations in the water table for the years 1974 through 1982. A bargraph depicting the mean rainfall at Port Mayaca Locks is also shown for this period (Figure 18). A correlation between heavy rainfall and high water levels is evident in these figures. However, well M-147 is principally affected by the city of Stuart's well field; water levels are consistently below sea level (NGVD). The historic record indicates that prior to the well field's influence, water levels in well M-147 were as high as 13 feet above NGVD (Lichtler, 1960).

Vertical differences in water level elevations occur if significant differences in lithology exist within the aquifer. When impermeable or semi-impermeable materials occur within the upper zone of the aquifer, the percolation of water is impeded. The water accumulation within the upper, less permeable zone results in a condition known as a perched water table. Thus, the water level is higher in the perched water table than within the main aquifer. This may be a common hydrogeologic condition throughout the county but has only been determined locally. Wells W-4A and W-4B located near the north Martin County well field are adjacent to one another and are indicative of this condition. Well W-4A penetrates the main aquifer at a depth of approximately 140 feet and could be immediately affected by the production wells. Well W-4B is shallow, about 50 feet deep, and does not appear to be immediately impacted by the well field. Hydrographs for these wells illustrate (Figure 19) that the shallow well (W-4B) maintains a higher water level than the deep well (W-4A). However, at the end of the hydrograph, the water levels in both wells are converging which may be due to a combination of factors. Rainfall and monitor well data supplied by Martin County Public Utilities (Written communication, October 25, 1985) indicate that the water levels in the two zones appear to converge during a dry period. Withdrawals from the deeper zone lower the water levels within the aquifer and may have subsequently forced the downward percolation of water from the shallow zone.

Water Quality

The ground water quality within the Surficial aquifer is determined chiefly by its lithology. Generally, the ground water is high in calcium and bicarbonate from the dissolution of limestone and shell beds. Concentrations of magnesium can be attributed to the presence of limestone within the aquifer. Iron, which is found in most soils and rocks, exceeds the recommended standard in portions of the county. Sodium and potassium, along with sulfate, are associated with connate water or ancient sea water which is geologically trapped within the sediments of the aquifer. In addition, high chloride concentrations can also result from the occurrence of connate water. Table 6 lists the natural inorganic constituents which are commonly found in the Surficial Aquifer System. The well locations for which water quality samples were obtained are illustrated in Figure 20.

Concentrations of calcium (Ca) range between 1.8 and 178 mg/l within the aquifer. Typical values of calcium content often surpass the recommended maximum standard of 25 mg/l. Associated with calcium, due to the dissolution of limestone, is magnesium (Mg). Within the aquifer, magnesium concentrations are usually below 50 mg/l, a level which is not considered significant. Both calcium and magnesium are the principal causes of hardness. The hardness of water can be demonstrated by the amounts of soap needed to produce suds. The calcium and magnesium concentrations of water commonly leave deposits in hot water heaters. This incrustation develops when water undergoes a change in temperature.

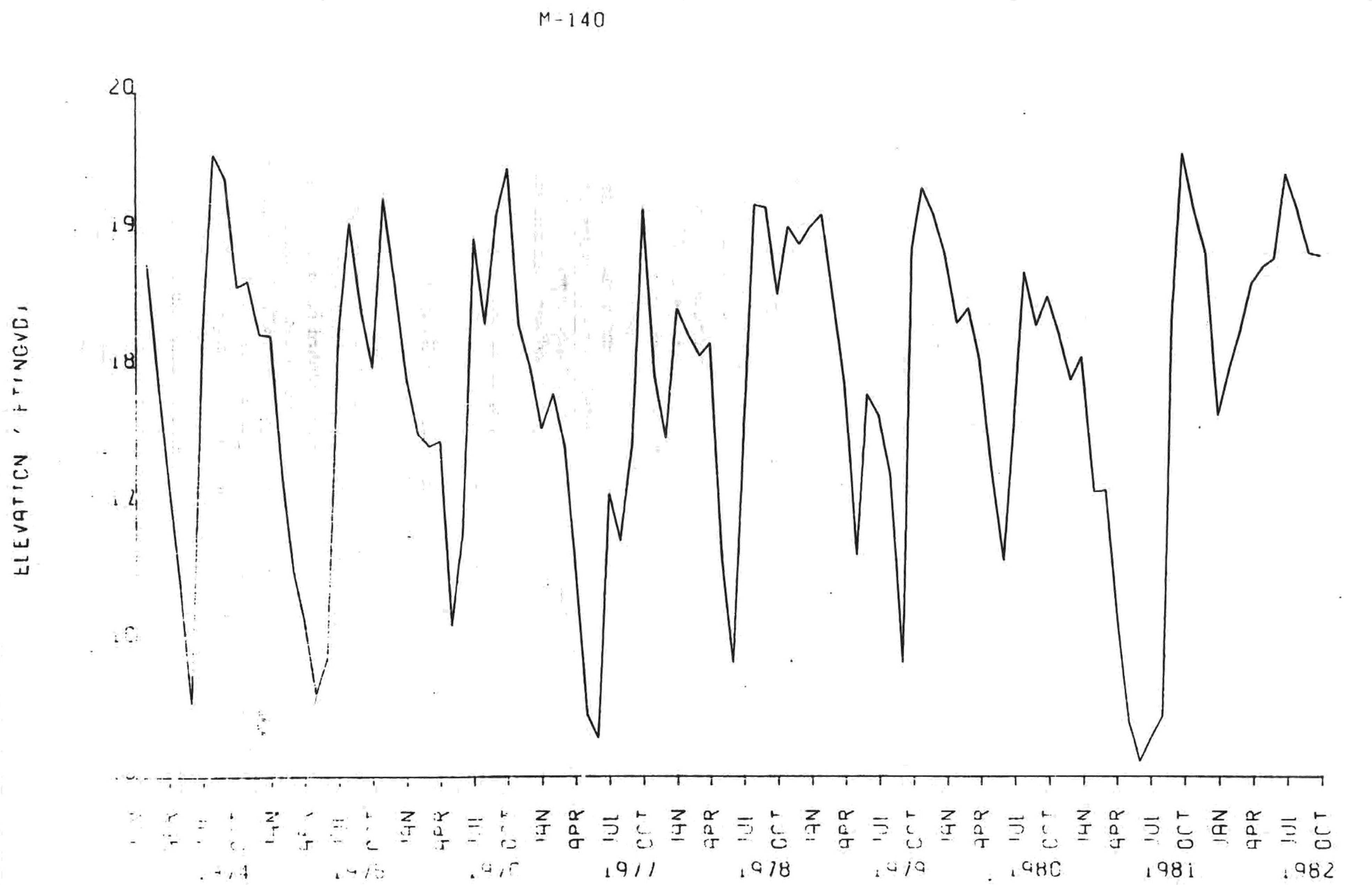


Figure 14 **HYDROGRAPH OF WELL M-140, (JANUARY 1974 — OCTOBER 1982)**

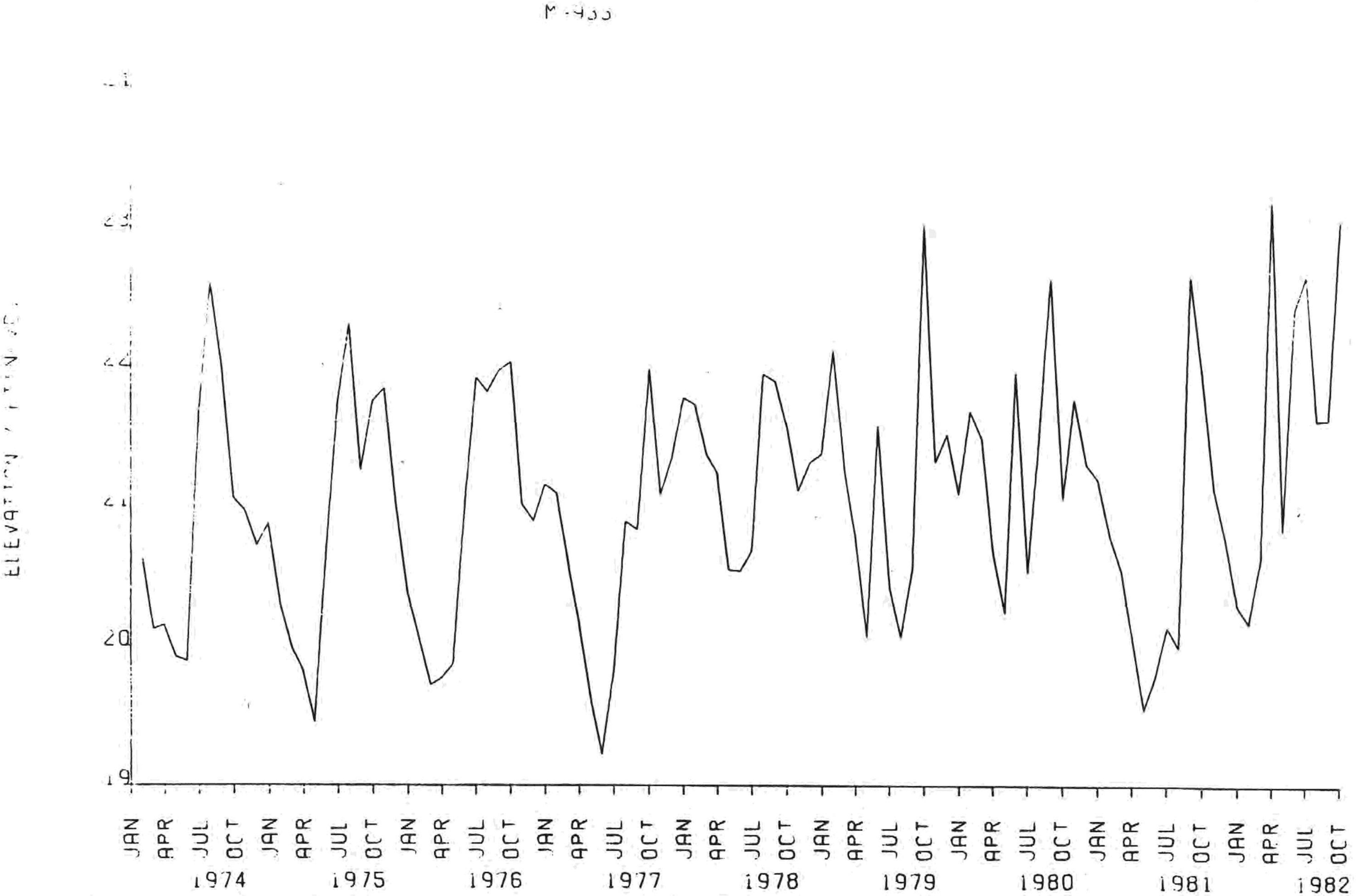


Figure 15 HYDROGRAPH OF WELL M-933, (JANUARY 1974 — OCTOBER 1982)

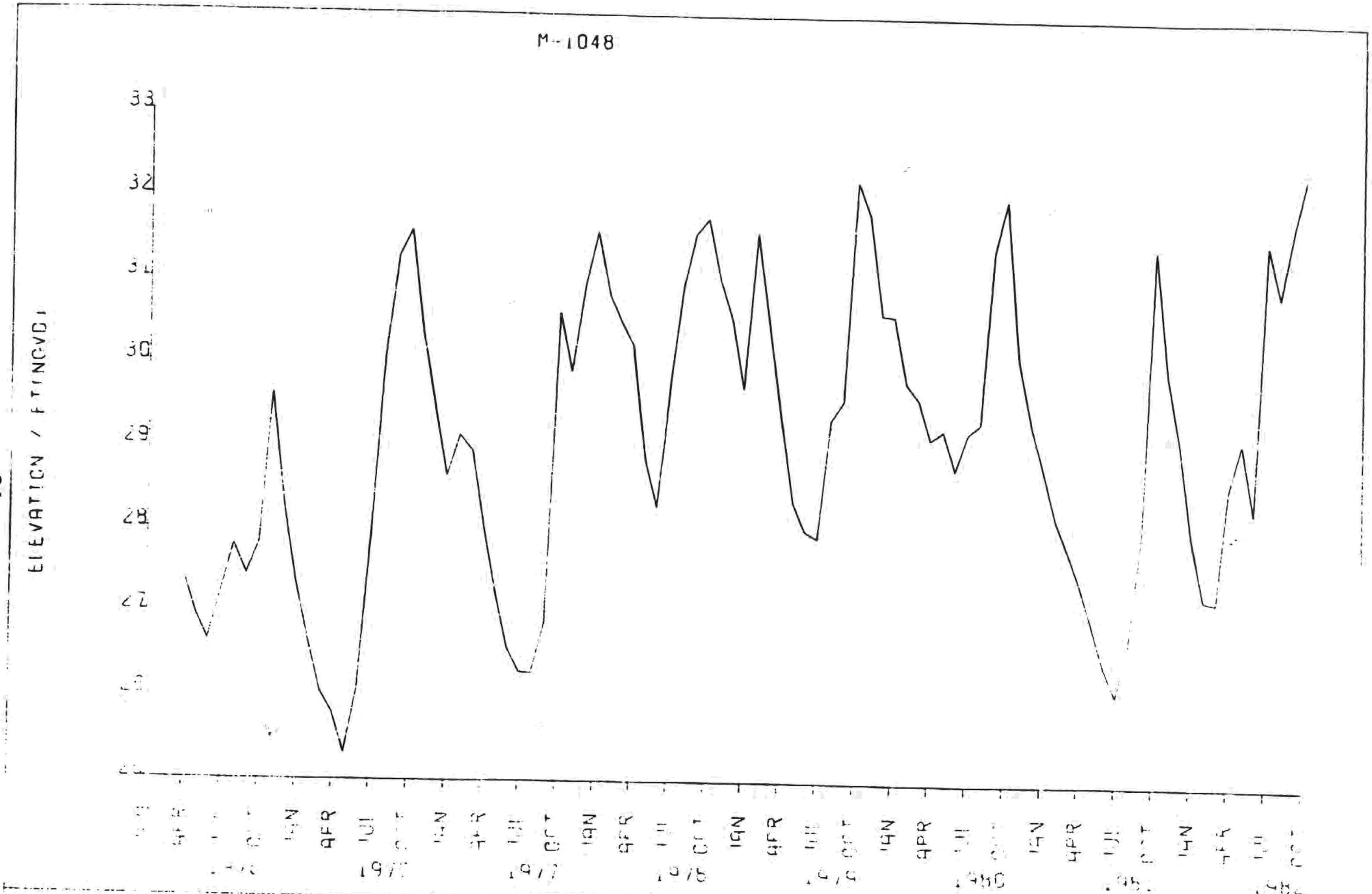


Figure 16 HYDROGRAPH OF WELL M-1048, (APRIL 1975 — OCTOBER 1982)

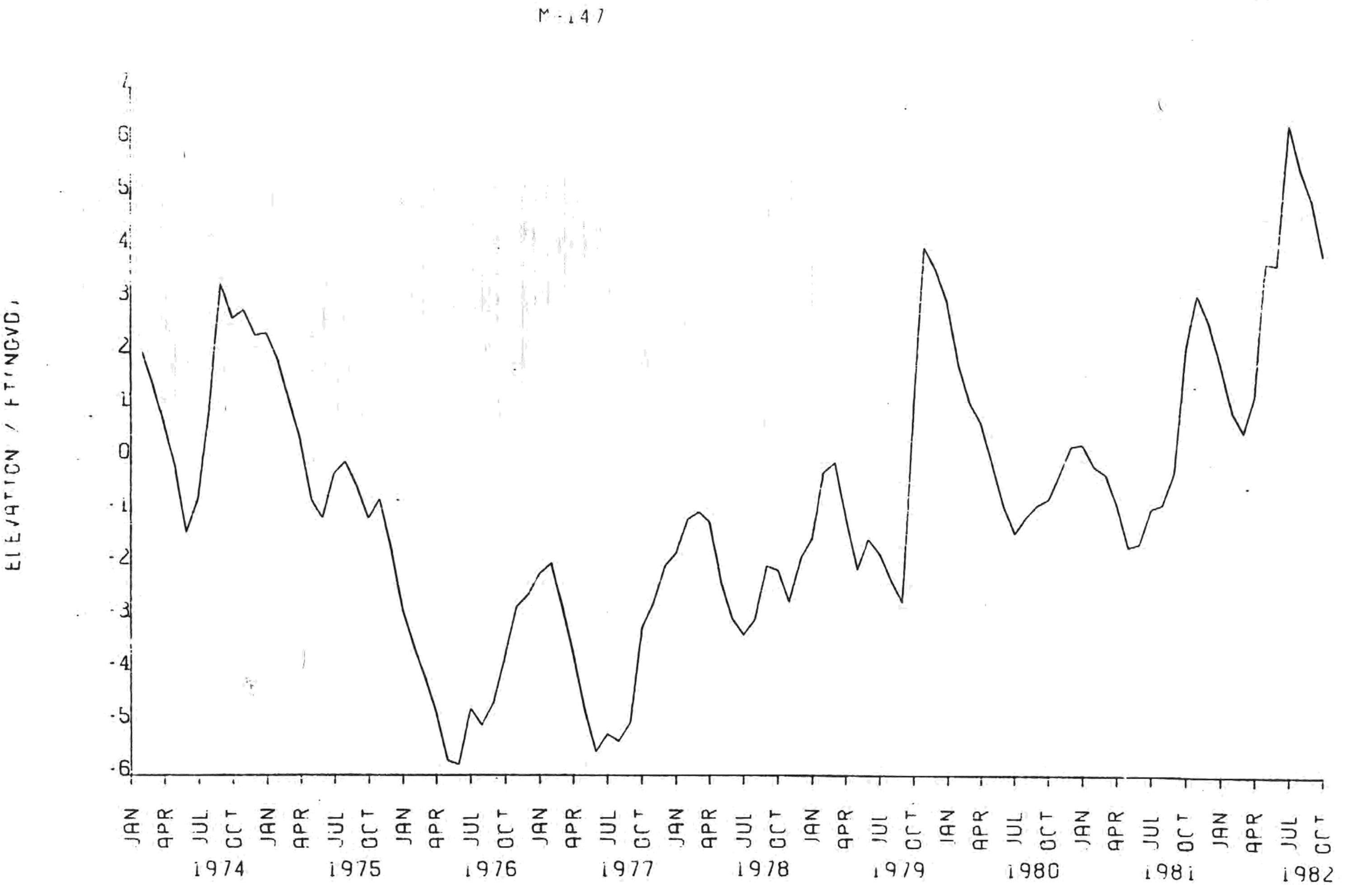


Figure 17 HYDROGRAPH OF WELL M-147, (JANUARY 1974 — OCTOBER 1982)

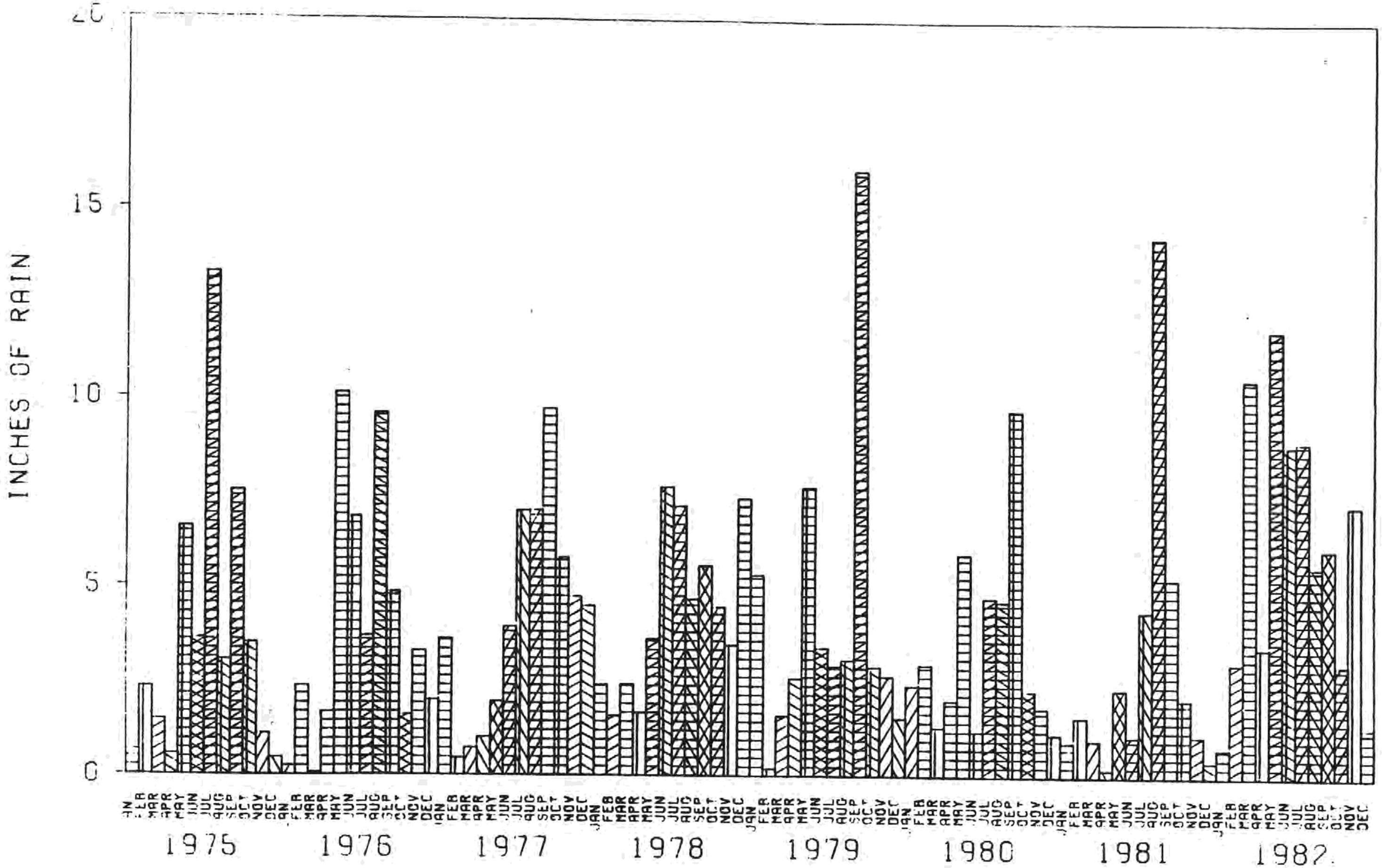


Figure 18 MEAN RAINFALL AT PORT MAYACA LOCKS, MARTIN COUNTY (JANUARY 1975 —DECEMBER 1982)

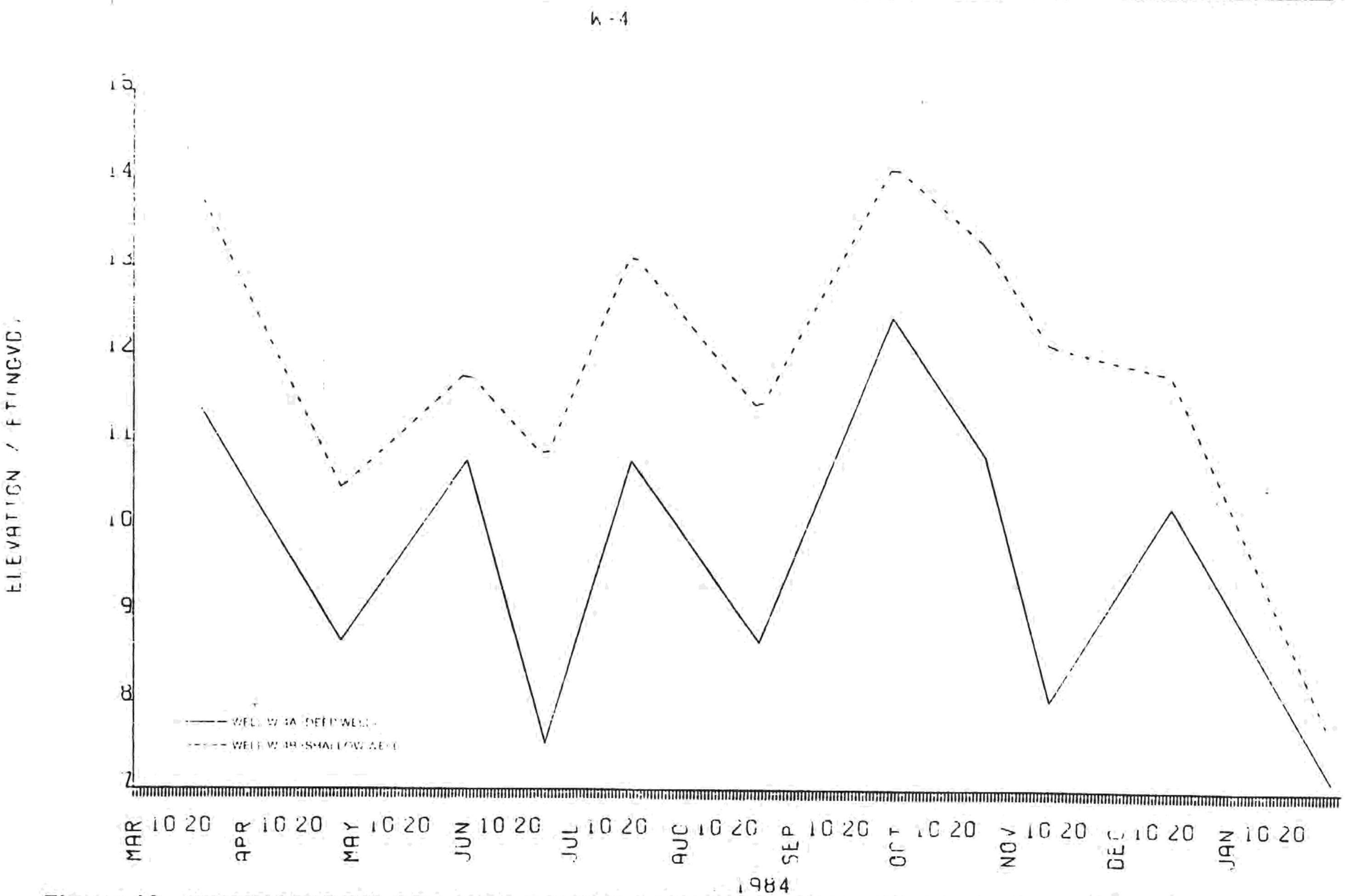


Figure 19 COMPARISON OF WATER LEVELS IN SHALLOW WELL W-4B AND DEEPER WELL W-4A, (MARCH 1984 — JANUARY 1985)

TABLE 6. WATER QUALITY WITHIN THE SURFICIAL AQUIFER

Well Number	Cl (mg/l)	MG (mg/l)	SO_4 (mg/l)	Ca+ (mg/l)	Na+ & K+ (mg/l	HCO_3 (mg/l)	Fe (mg/l)
M-12	183.0	14.25	92.6	69.20	170.43	--	.28
M-52	11.3	2.74	4.6	85.60	16.47	--	.21
M-1030	20.0	2.40	27.0	93.00	17.90	264	.02
M-1031	8.3	1.40	38.0	35.00	16.40	96	9.60
M-1037	54.2	4.25	5.1	120.60	44.15	--	9.34
M-1041	46.0	9.20	1.6	92.00	34.40	380	2.00
M-1042	8.6	4.20	11.0	92.00	12.30	288	9.40
M-1045	82.0	6.30	1.4	60.00	46.40	352	.02
M-1046	44.9	7.38	25.0	116.30	50.64	--	8.53
M-1047	15.5	1.10	18.9	1.80	15.79	--	9.00
M-1049	36.0	3.40	3.4	110.00	30.10	584	.16
M-1050	75.0	8.50	3.4	110.00	52.60	624	.10
M-1051	43.0	4.40	4.8	97.00	31.60	308	1.10
M-1052	91.0	9.90	11.0	130.00	57.00	416	.56
M-1053	1,600.0	89.00	85.0	170.00	8,330.00	360	1.70
M-1054	11,000.0	730.00	1500.0	330.00	6,430.00	268	.99
M-1055	29.0	3.30	17.0	82.00	56.40	349	.13
M-1058	15.0	1.00	3.3	6.90	13.40	32	1.80
M-1071	28.0	1.50	11.0	58.00	18.20	180	.03
M-1073	24.0	2.70	0.3	78.00	18.10	280	.28
M-1081	22.8	8.70	16.8	108.00	19.22	--	1.77
M-1084	220.0	16.00	130.0	160.00	134.60	415	.92
M-1093	17.8	1.90	10.3	73.70	11.70	--	.26
M-1096	90.0	9.00	0.0	110.00	47.00	360	8.80
M-1100	64.0	7.20	2.2	100.00	40.30	320	.02
L-01	13.0	7.40	17.0	64.00	16.00	231	--
L-09	10.0	19.00	39.0	148.00	6.70	489	.40
L-13	16.0	2.10	5.1	39.00	9.70	120	.01
L-15	79.0	10.00	24.0	124.00	51.00	396	.91
L-22	161.0	30.00	34.0	128.00	124.00	548	.08
L-98	108.0	4.60	12.0	102.00	35.00	224	.04
L-655	16.0	0.90	0.5	70.00	9.50	220	.02
L-657	15.0	2.30	0.0	86.00	10.20	272	.73
L-936	626.0	35.00	128.0	134.00	--	492	.28
L-939	16.0	3.40	1.8	109.00	8.80	362	.03
GS-23	238.0	26.00	139.0	128.00	182.00	418	.03
WW43-42983	18.0	7.30	10.0	77.00	15.00	234	--
WW43-51320	784.0	48.00	115.0	88.00	474.00	181	--

*Data were collected from the following sources:

Well No.	Source
M-0000	(Miller, 1980)
WW00-00000	(South Florida Water Management, unpublished)
GS-00	(Lichtler, 1960)
L-000	(Lichtler, 1960)

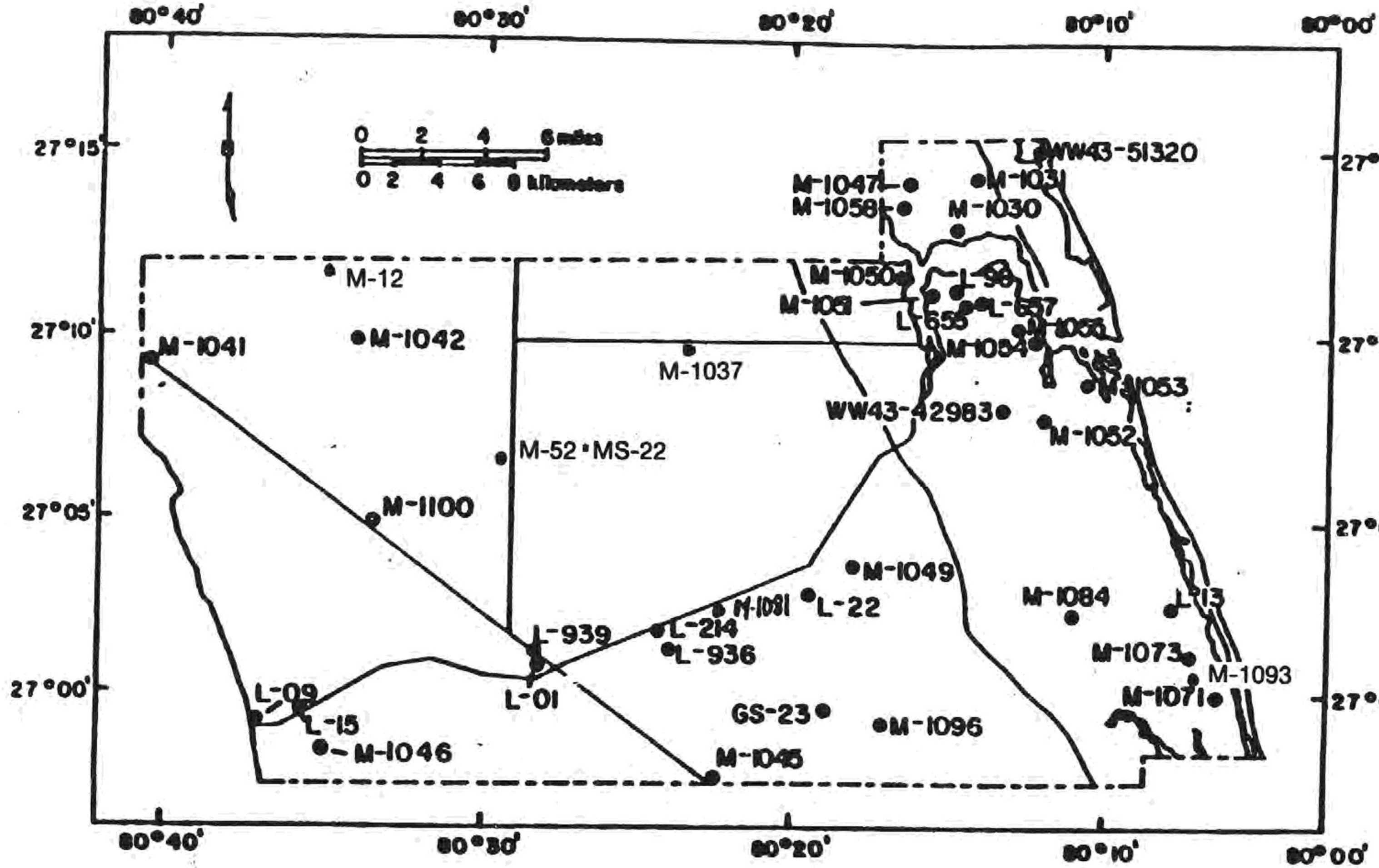


Figure 20 LOCATIONS OF WATER SAMPLES FROM THE SURFICIAL AQUIFER SYSTEM, MARTIN COUNTY. (MODIFIED FROM STODGHILL, 1984)

Bicarbonate (HCO_3) exists in ground water as a result of dissolved carbon dioxide. The carbon dioxide which assists the water in dissolving limestone and shell produces dissolved calcium and magnesium. Bicarbonate reacts with the calcium and magnesium, and the carbon dioxide is released as a gas. Bicarbonate also has the capacity to neutralize strong acids. Therefore, corrosive water which tends to dissolve metals and other material can be rendered neutral or alkaline due to the bicarbonate concentration of the water. The content of bicarbonate is commonly above 200 mg/l (which exceeds the recommended standard of 150 mg/l) within the Surficial Aquifer System.

High concentrations of iron (Fe) can be found within the water of the Surficial aquifer throughout Martin County. Health standards recommend that the iron concentration of water be limited to 0.3 mg/l; however, within the aquifer, concentrations usually border or exceed this standard. In water, iron is in the ferrous state which precipitates out of solution upon contact with air and changes to the ferric state. The precipitation of iron is responsible for staining various materials like plumbing fixtures and clothes. Iron bearing water is also responsible for the growth of iron bacteria which can clog wells and plumbing.

Sodium and potassium generally occur in all natural water. In sedimentary rocks, a few hundred milligrams per liter can occur in fresh water as a result of exchange of dissolved calcium and magnesium for sodium and potassium in the aquifer material. In large concentrations, sodium may adversely affect persons with cardiac conditions and may be detrimental to certain irrigated crops. The potassium concentration is usually much less than that of sodium. Very high concentrations of sodium are associated with salt water. Ground water from wells M-1053 and M-1054, located near the coast (see Figure 20), have high sodium concentrations. These wells are located in low lying areas which are affected by tidal fluctuations rather than salt water intrusion.

The recommended standard for sulfate (SO_4) is 250 mg/l, which is usually higher than the concentrations found within the aquifer. Ground water having a sulfate concentration greater than 600 mg/l may have a laxative effect and give the water a bitter taste. High sulfate concentrations are associated with high chloride content which is correlated with saline water either from connate water or salt water intrusion.

The chloride (Cl) content of water within the Surficial Aquifer System is typically below the 250 mg/l recommendedstandard. Waters of high chloride content can be corrosive, and, in conjunction with sodium, can give water a salty taste. Concentrations of 750 mg/l or above will damage plants and may be detrimental to livestock. Chloride concentrations which exceed 100 mg/l were obtained from wells M-12, L-22, L-936, and GS-23 in west central Martin County. This relatively high concentration is associated with connate water which is ancient sea water that has been trapped in sedi-ments of low permeability. In addition, the artesian wells of the Floridan Aquifer System may also con-taminate the Surficial Aquifer System with excessive chloride concentrations. Lichtler (1960) reported that well L-936 had a chloride concentration of 626 mg/l, however, this is not common in inland areas of Martin County. High chloride concentrations are also associated with the sea water within coastal areas as illustrated by wells WW-43, M-1053, and M-1054. The maximum chloride concentration within these wells was 11,000 mg/l (see Table 6).

The quality of ground water is dependent upon the characteristics of the aquifer. Most ground water contains suspended solids and minerals which determine its usefulness for various purposes. The ground water of the Surficial Aquifer System, however, is generally of good quality. Where minerals are in excess of the recommended standards, common methods of treatment can be applied to render the water suitable.

<u>Salt Water Intrusion</u>: Along coastal Martin County the Surficial Aquifer System is hydrogeologically in contact with the saline water of the ocean and the St. Lucie Estuary. The migration of sea water into the fresh water aquifer can occur if the water table elevation is lowered beyond a certain point. The Ghyben-Herzberg equation can approximate the required elevation necessary for the maintenance of a satisfactory salt water-fresh water interface. The equation assumes that the aquifer is both homogeneous and unconfined. An additional assumption in the analysis is that the interface which separates the sea water from the fresh water is perpendicular to the aquifer. A column of fresh water required to balance or be hydrostatically in equilibrium with that of salt water is determined by the density of the two liquids. The density of fresh water is 1.00 g/cm^3 and that of salt water is 1.025 g/cm^3. The required water table elevation can be calculated with the following equation:

$$H_s = (P_f / P_s - P_f) H_f \qquad (1)$$

where,

H_s = elevation of sea water
H_f = elevation of fresh water
P_s = density of sea water
P_f = density of fresh water

Since the densities of both liquids are given, the equation can be stated simply as:

$$H_s = 40\, H_f \quad (2)$$

Assuming that the Surficial Aquifer System is approximately 180 feet thick along the coast, and employing the equation above, would indicate that the water table should be maintained at 4.5 feet above mean sea level. This water level elevation would maintain the saline water below the base of the aquifer according to the Ghyben-Herzberg equation.

Typically, lowering the elevation of the water table is due to well field withdrawals. An example of this is the city of Stuart well field which is bordered by saline water of the ocean and the St. Lucie Estuary. Monitoring wells in the vicinity of the well field have chloride concentrations which range between 35 and 45 mg/l. These concentrations do not suggest salt water intrusion which can be indicated by chloride concentrations as high as that of sea water (which is 19,000 mg/l). Lichtler (1960) indicates that heavy withdrawals from the city of Stuart well field may have caused salt water intrusion. A monitoring well located between the St. Lucie Estuary and the well field, for example, had a chloride content of 9,180 mg/l. More recent data does not reflect any detrimental impact on the aquifer. A possible explanation may be due to the enlargement of the well field which now obtains water from wells in the south, leaving a greater distance between the well field and thesaline water.

The north Martin County well field is a well field which is bordered on three sides by salt water. Chloride concentrations found in ground water from nearby monitoring wells were normally below 70 mg/l.

High chloride concentrations indicate sea water in wells WW-43, M-1053, and M-1054 (Figure 20). These wells are in low lying areas paralleling streams which are affected by tidal fluctuations.

Monitoring wells installed throughout Martin County provide the best possible indicators of salt water intrusion. Records of chloride concentrations are maintained by the SFWMD and are evaluated to determine any changes in the landward extent of salt water. Monitoring wells should be installed wherever salt water intrusion poses a significant threat. Although the Ghyben-Herzberg equation indicates the required water table elevation necessary to prevent salt water intrusion, it does not always reflect actual conditions due to the assumptions inherent in the equation; therefore, the equation should be used only as an approximation.

Flowing Wells: A prevalent source of pollution throughout south Florida is the uncontrolled discharge of flowing wells drilled into the Floridan Aquifer System. Chloride concentrations within the Floridan Aquifer System in Martin County range between 400 and 1400 mg/l, whereas typical values within the Surficial Aquifer System are below 50 mg/l with the exception of anomolous areas or those impacted by salt water intrusion. These abandoned flowing wells contribute to the deterioration of the water quality of the Surficial Aquifer System, and result in the loss of potable water.

Currently, the SFWMD has a cooperative program with local counties, municipalities, and the Agricultural Stabilization and Conservation Service to plug abandoned free-flowing wells.

Hydrogeology of the Floridan Aquifer System

The Floridan Aquifer System is composed of a thick sequence of interbedded limestones and dolomites. Miller (1982c) indicates that this aquifer system is areally extensive throughout south Florida and ranges in thickness between 2,800 and 3,400 feet in Martin County.

The top of the Floridan Aquifer System is encountered between 600 to over 800 feet below sea level in Martin County, as shown in Figure 21.

According to Shaw and Trost (1984), the Floridan Aquifer System is highly permeable due to the fractured nature of the limestone units as well as the high degree of secondary porosity derived from dolomitization and dissolution. Water-producing zones often occur along formational contacts within the aquifer system which can be traced laterally.

The transmissivity or ability of the Floridan Aquifer System to transport water is relatively high. Trost (1987, in press), reports a transmissivity range of less than 50,000 to over 150,000 gallons per day per foot in Martin County. The transmissivity of the Floridan Aquifer System in Martin County is depicted in Figure 22.

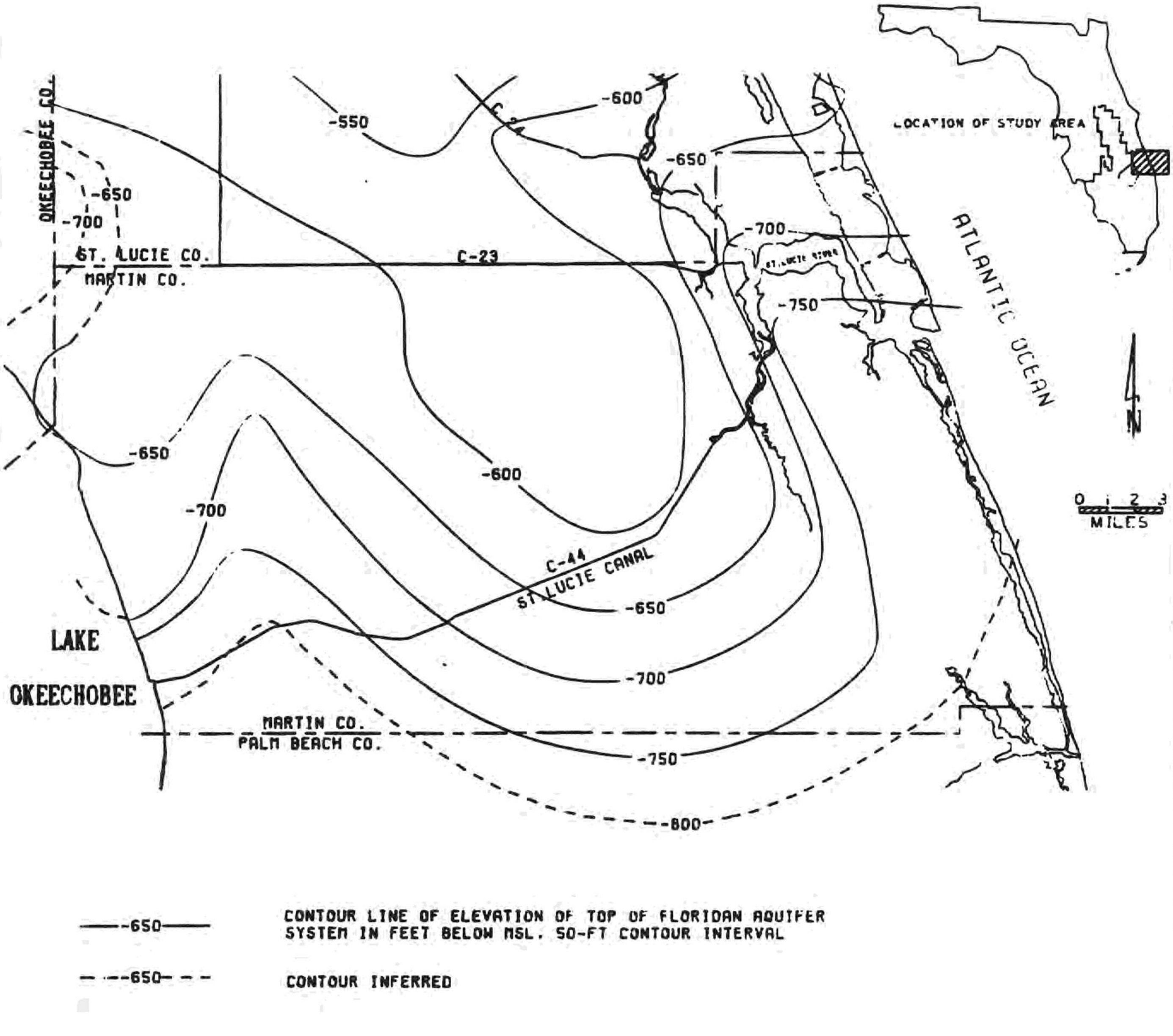


Figure 21 ELEVATION OF THE TOP OF FLORIDAN AQUIFER SYSTEM, MARTIN COUNTY (FROM BROWN AND REECE, 1979)

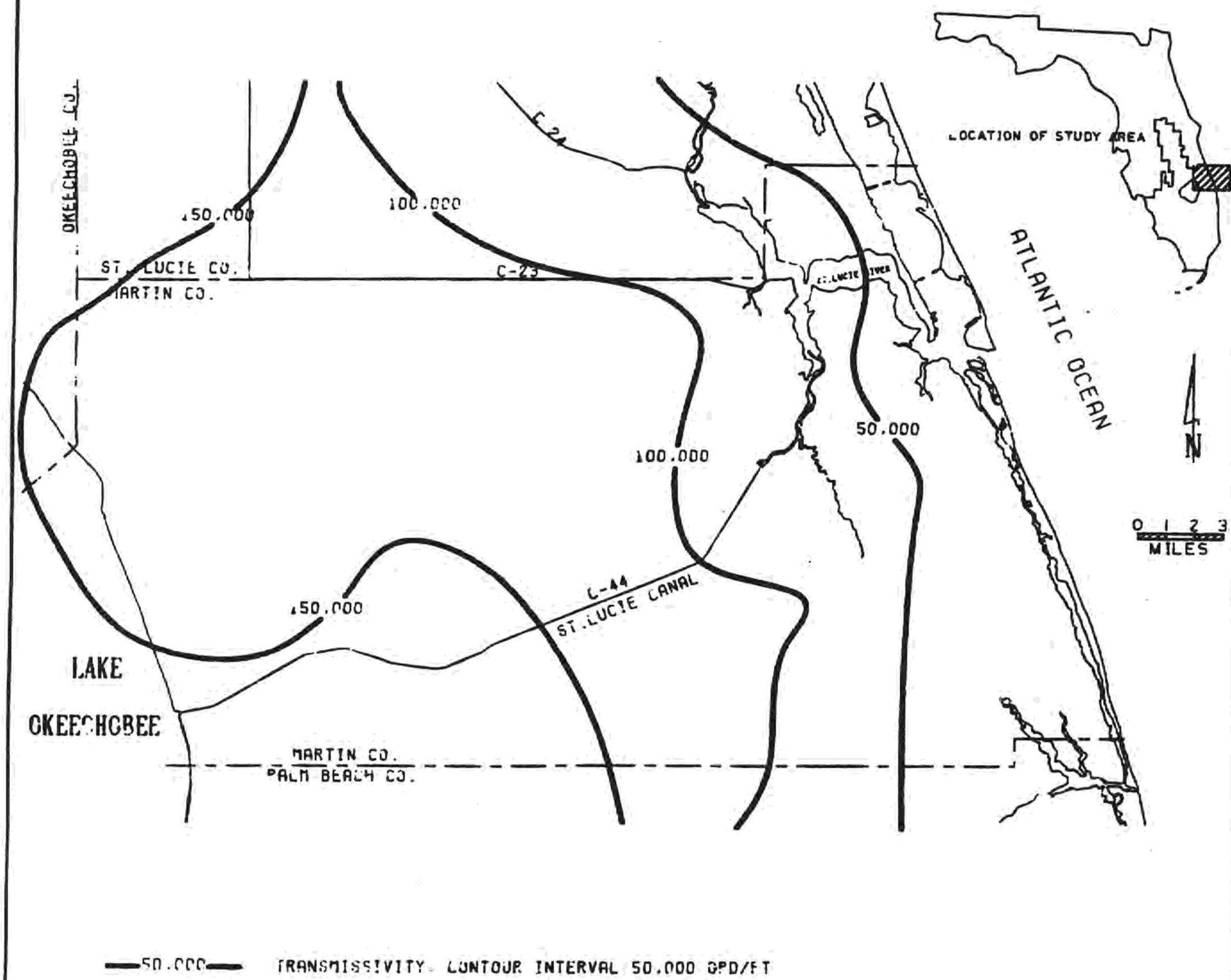


Figure 22 TRANSMISSITY OF THE UPPER FLORIDAN AQUIFER, MARTIN COUNTY

Water Levels

The Floridan Aquifer System is classified as a confined aquifer, because the water within this aquifer system is separated from the atmosphere by the thick, relatively impermeable Hawthorn confining beds and the sediments of the Surficial Aquifer System. The hydrostatic pressure of the water in the Floridan Aquifer System is greater than atmospheric pressure; therefore, it can also be referred to as an artesian aquifer. For this reason, water levels in wells penetrating the Floridan Aquifer System in Martin County will rise above the top of the aquifer. Wells tapping the Floridan Aquifer System will flow in all parts of Martin County, except in localized topographic highs encountered in some of the coastal sand dunes. These wells are referred to as flowing artesian wells.

The water levels measured in individual wells which penetrate the Floridan Aquifer System can be used to construct potentiometric maps. The potentiometric maps presented here are water-level contour maps which depict the elevations in feet above mean sea level in which water levels rose in tightly cased wells.

A potentiometric map of the Floridan Aquifer System in April 1957 presented by Lichtler (1960) is shown in Figure 23. At the time this map was prepared, the water levels ranged from 53 in the southeastern part to 48 feet above mean sea level in the northeastern part of Martin County. In April of 1957 the potentiometric surface sloped gently in an east-southeasterly direction. According to Lichtler (1960), this regional pattern was distorted by cones of depression due to localized heavy withdrawals in the vicinities of Palm City and Indiantown.

A map of the potentiometric surface of the Floridan Aquifer System in May of 1984 is shown in Figure 24. In May of 1984, the potentiometric surface ranged from about 48 feet above mean sea level in the southwestern part of the county to about 41 feet in the northeastern part, indicating a general north-northeast gradient. In the 27-year span, the potentiometric surface in the northeast part of the county declined about 7 feet, and in the southwest part about 5 feet. This gradual lowering of the potentiometric surface is probably due to an increase in irrigation withdrawals from the aquifer system. The difference in ground water flow patterns, as indicated by the potentiometric surfaces of 1957 and 1984, may also be due to withdrawals from the aquifer.

Water levels in the Floridan Aquifer System tend to be highest at the end of the wet season, during September and October. Water levels in this aquifer system are usually lowest at the end of the dry season, in April and May. Rainfall in Martin County does not directly influence the potentiometric surface of the aquifer system; rather, Martin County is a discharge area for the Floridan Aquifer System. Water levels tend to be higher during the wet season because the wells are not used heavily. Conversely, water levels tend to drop in the dry season due to the increased irrigation demand. Water levels in wells tapping the Floridan Aquifer System tend to be 1-3 feet higher in September than in May.

In nearly all of Martin County (with the exception of an area of topographic highs near coastal sand dunes), the potentiometric surface of the Floridan Aquifer System ranged from 10 feet to nearly 35 feet above land surface in September of 1983 (Figure 25). All tightly cased wells which penetrate the Floridan Aquifer System in these areas will flow freely at land surface.

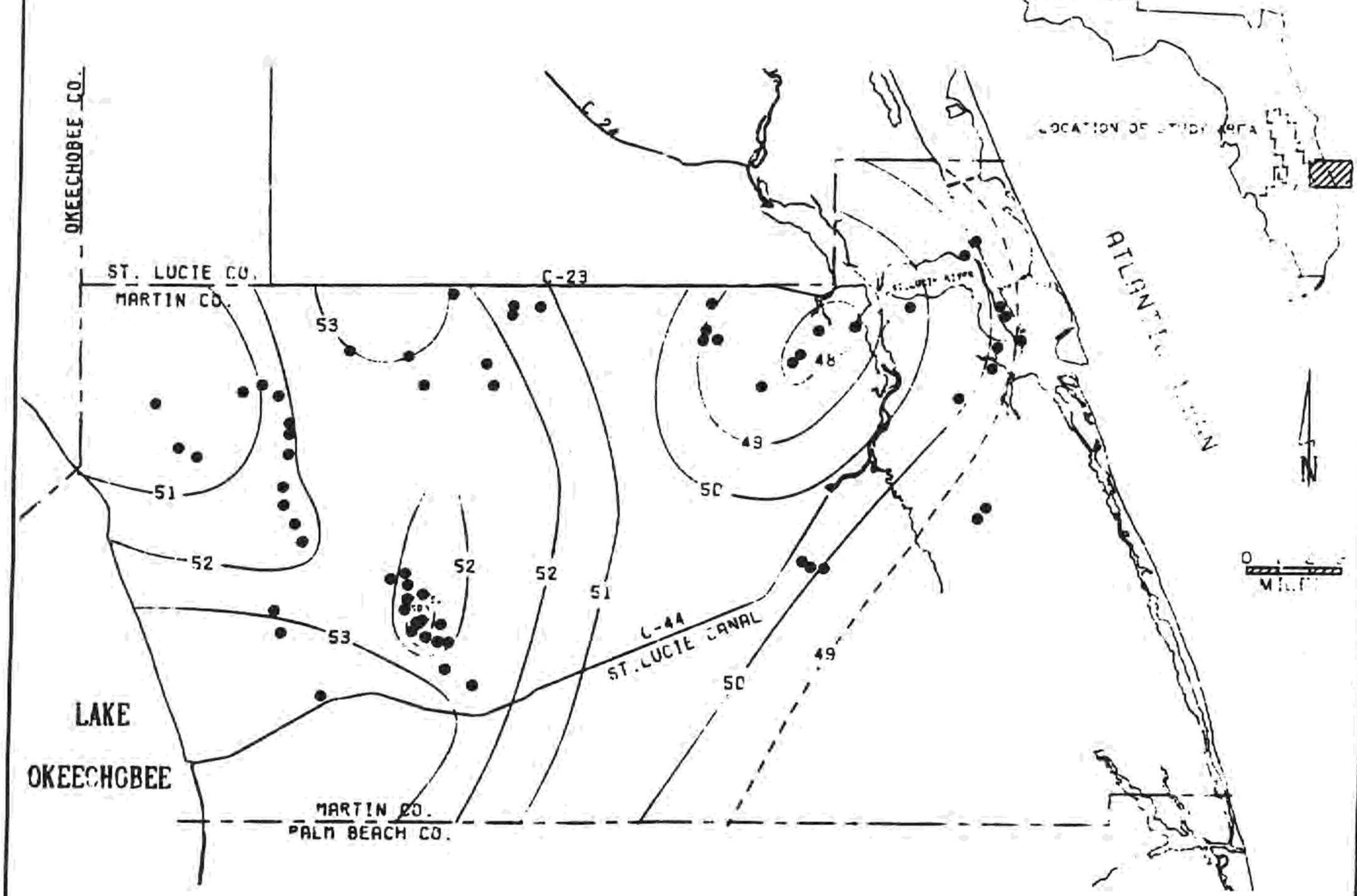
Water Quality

Throughout Martin County, ground water from the Floridan Aquifer System is of poor quality and is generally non-potable. According to Brown and Reece (1979), chloride concentrations (Figure 26) of Floridan Aquifer System ground water in September of 1977 ranged from over 200 to over 1,400 mg/l. Chloride concentrations shown on Figure 26 may be artificially low in western Martin County due to a lack of data availability at the time the wells were sampled. Work performed by Lichtler (1960) and Miller (1978) indicates that chloride concentrations are higher than those shown for western Martin County.

Brown and Reece (1979) also published a contour map of total dissolved solids of Floridan Aquifer System waters for September 1977, which is presented as Figure 27. Total dissolved solids ranged from about 500 to over 3,000 mg/l.

The maximum potable limits of chloride concentrations and total dissolved solids recommended by the U. S. Public Health Service are 250 mg/l and 500 mg/l, respectively.

Due to the high salinity of the water from the Floridan Aquifer System, most of the wells that tap this aquifer in Martin County are used as irrigation wells. Grove owners and ranchers tend to discharge water from these flowing wells into ditches, where it mixes with surface water and ground water from the



—50— CONTOUR LINE SHOWING APPROXIMATE ALTITUDE OF THE POTENTIOMETRIC SURFACE IN FEET ABOVE MSL, 1-FT CONTOUR INTERVAL

- - -49- - - CONTOUR INFERRED

● WELL LOCATION IN WHICH WATER LEVEL WAS MEASURED

Figure 23 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER, APRIL 1957, MARTIN COUNTY (FROM LICHTLER, 1960)

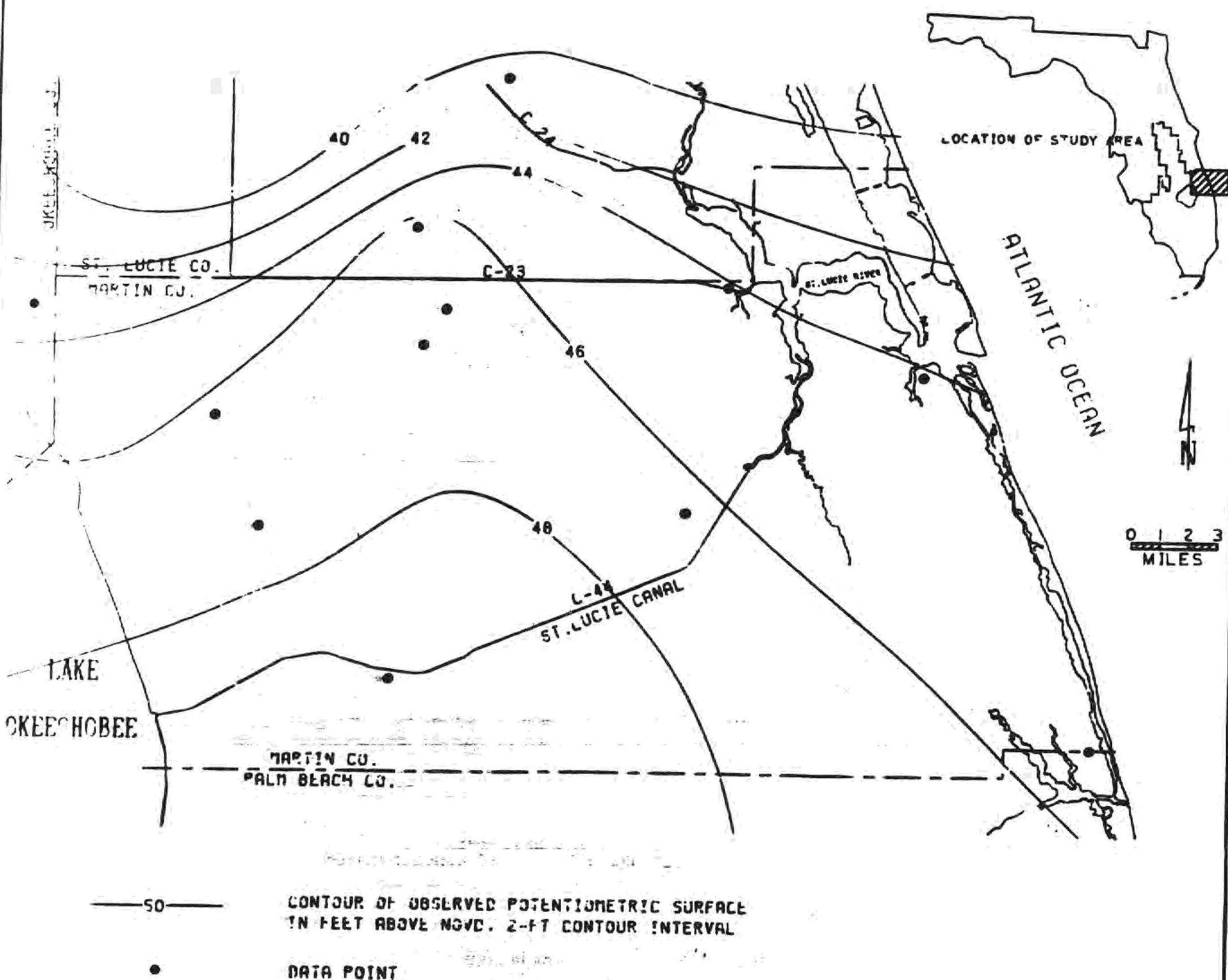


Figure 24 POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM, MAY 1984, MARTIN COUNTY

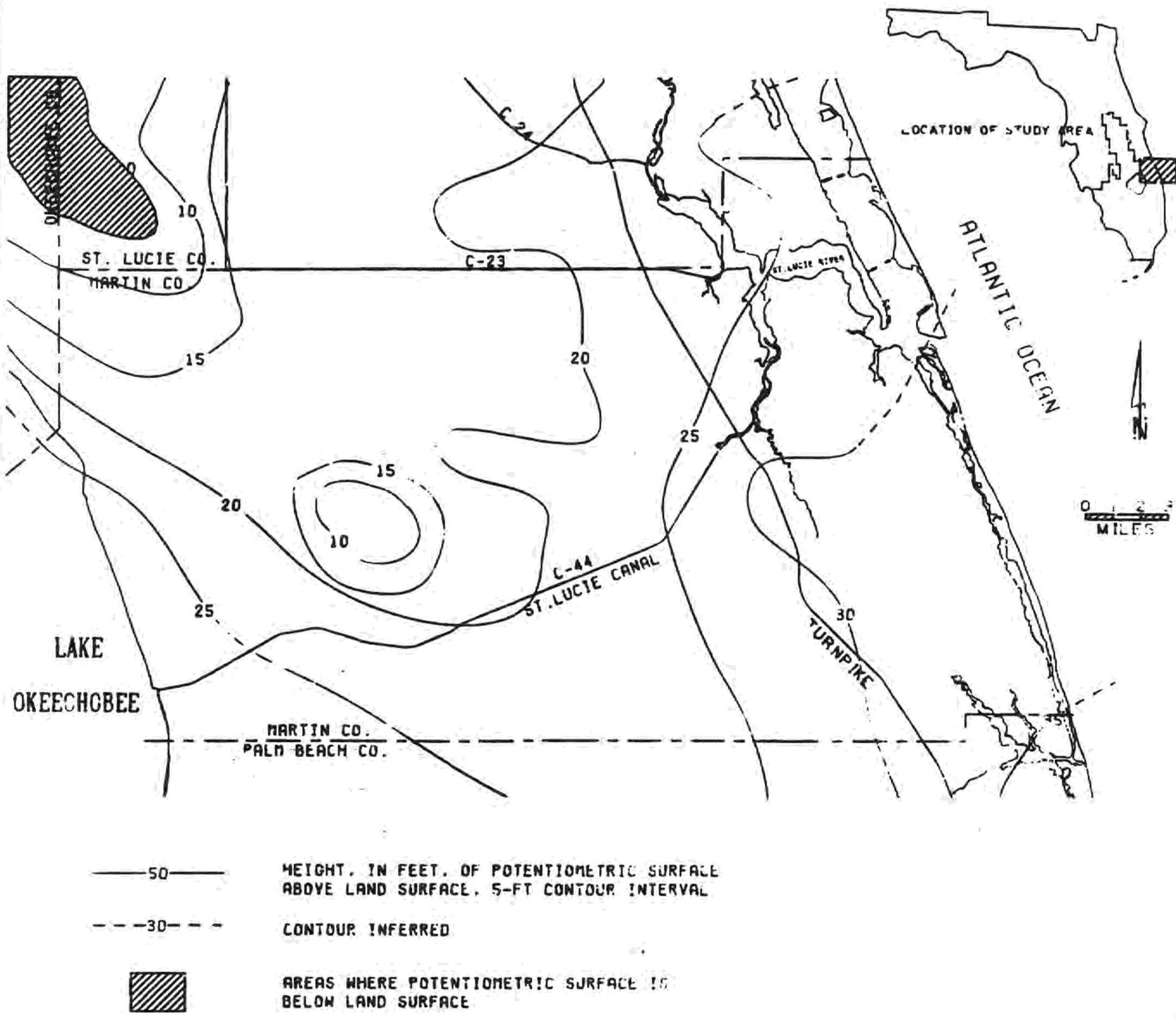


Figure 25 APPROXIMATE HEIGHT OF THE POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER SYSTEM ABOVE LAND SURFACE, SEPTEMBER 1983. MARTIN COUNTY

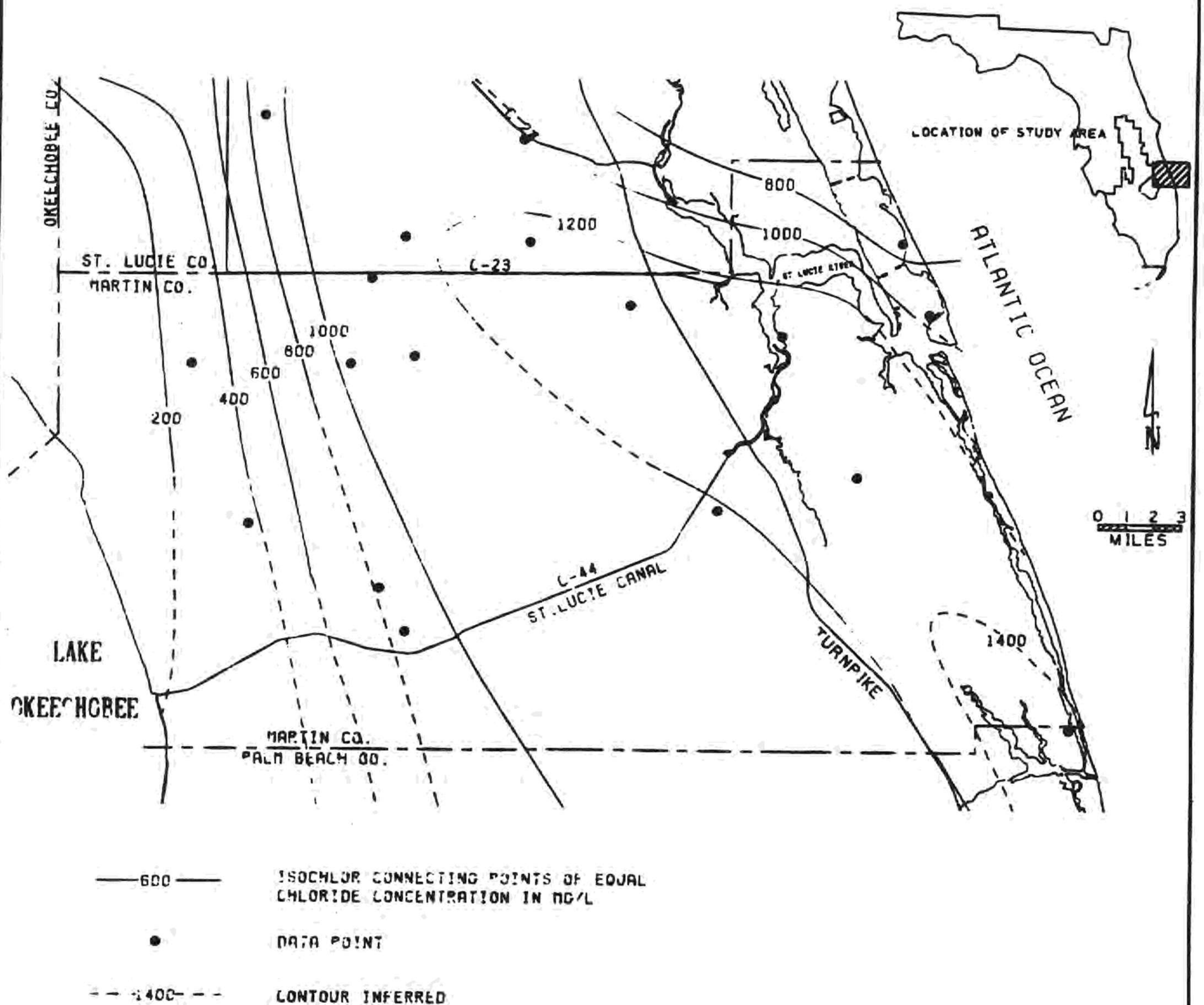


Figure 26 CHLORIDE CONCENTRATION OF FLORIDAN AQUIFER SYSTEM WATERS FOR SEPTEMBER 1977, MARTIN COUNTY (REPLOTTED FROM BROWN AND REECE, 1979)

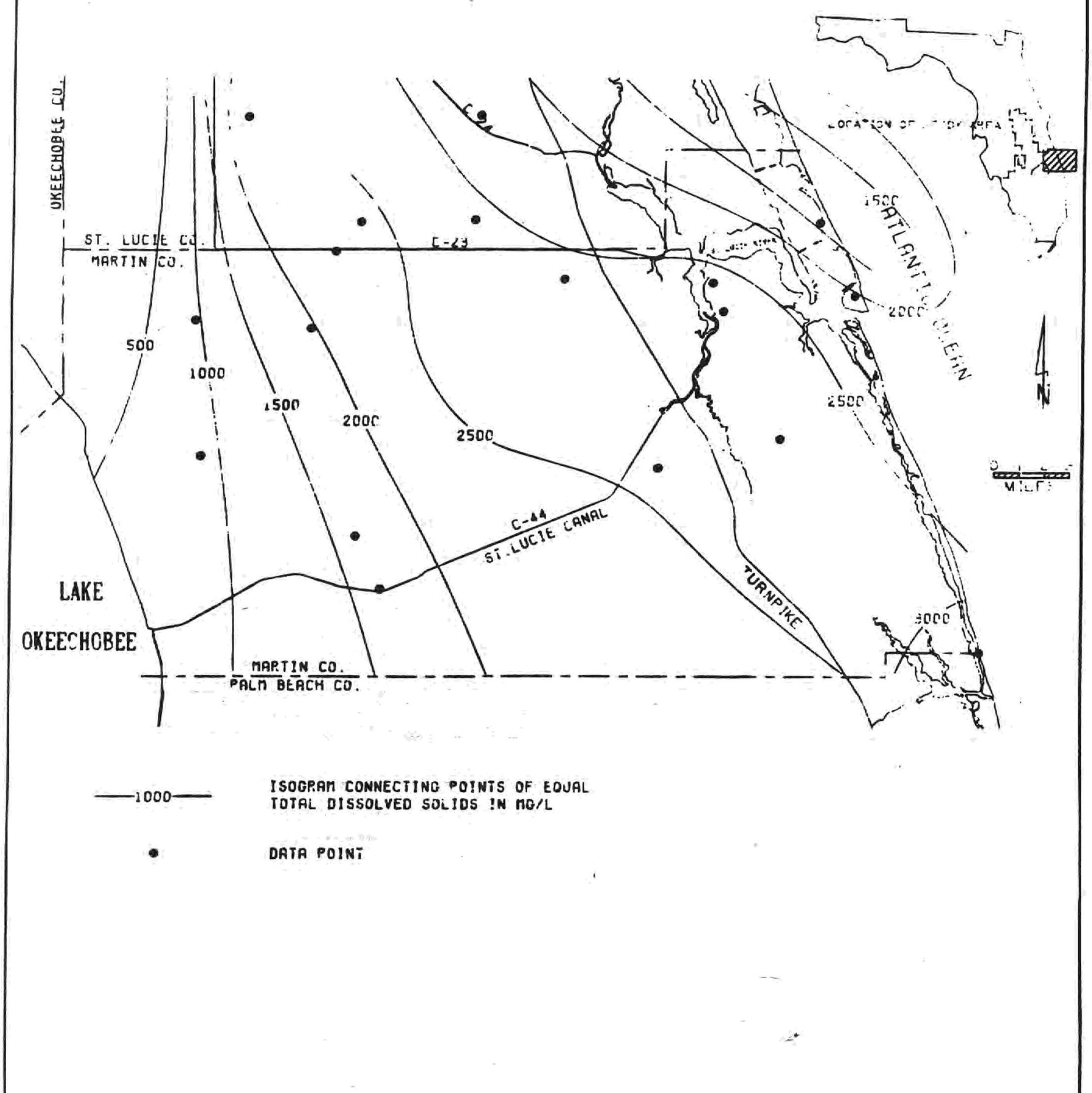


Figure 27 TOTAL DISSOLVED SOLIDS OF FLORIDA AQUIFER SYSTEM WATERS FOR SEPTEMBER 1977, MARTIN COUNTY (FROM BROWN AND REECE. 1979)

better quality Surficial Aquifer System. This practice enables water users to augment surface water supplies when canal stages are low, and it also minimizes the effects of the saline Floridan Aquifer System waters through dilution.

There are a few wells which penetrate the Floridan Aquifer System that provide public water supplies for a limited number of condominiums on the barrier island, where fresh water is not available. Reverse osmosis plants are used at these locations in order to de-salinate the water for potable use. Table 7 lists the existing desalination plants in Martin County.

TABLE 7. REVERSE OSMOSIS PLANTS IN MARTIN COUNTY*

Plant Name	Current Usage	Plant Capacity
Joe's Point	0.04 MGD	0.12 MGD
River Club	0.015 MGD	0.06 MGD
Sailfish Point	0.05 MGD	0.15 MGD
Indian River Plantation	0.07 MGD	0.20 MGD

*Source: Port St. Lucie Office, Florida Dept. of Environmental Regulation

Well Abandonment:

Flowing wells which penetrate the Floridan Aquifer System represent a potential source of contamination to the potable ground water of the Surficial Aquifer System. The water of the Floridan Aquifer System may migrate into the Surficial Aquifer System through corroded or improperly cased wells or by downward percolation where wells do flow at the surface. Uncontrolled flow of these artesian wells at land surface is usually due to broken or non-existent valves.

Healey (1978) has confirmed that there are 26 continuously flowing wells in Martin County, and the total number of these abandoned, free flowing wells is estimated to be 100. The total flow from these wells is thought to be approximately 10 million gallons per day. In a recent investigation, a flowing well located in the county had a discharge of 15 gallons per minute. At the time it was drilled, however, the withdrawal rate was over 300 gallons per minute. Over the years the continuous flow has resulted in a depletion of water quantity within the aquifer which is reflected in the reduced flow rate.

Abandoned or uncontrolled flowing wells should be properly sealed in order to abate this source of contamination. Two effective well plugging methods are: 1) packer installations, and 2) grouting. A packer is an impermeable device and is set at a depth which isolates the artesian aquifer from the water table aquifer. A grout plug may be placed within the borehole to stop the upward flow of water. Most often a fast hardening cement is used to plug the well. While grouting is the most effective and reliable method for controlling flow, it is also the most expensive. This method of stage grouting is utilized in the SFWMD cooperative well plugging program.

WATER DEMAND ESTIMATES

As part of this study it was necessary to construct water use factors by land use type so that future water demands could be estimated. Included in this process was an analysis of population, housing unit, and land use data. The following is a summary of that analysis and a review of the methodology used to construct the water use factors.

Martin County Planning Framework

The Martin County Planning Department was responsible for providing land use and population data for the study area. This information was provided for two distinct development phases, 1983 existing and committed, and buildout. "Existing and committed" refers to development that actually exists or has received preliminary approval from the County Commission, and "buildout" refers to the maximum amount of development expected under the current Comprehensive Plan. Estimates of existing and committed and buildout water demands must be made so that the potential impacts of these development phases upon the ground water resources of Martin County can be evaluated.

For each of the two development phases mentioned above, land acreage for 14 land use types (i.e. rural ranchette, rural, estate, low, medium, high, and mobile residential uses, general, limited, commercial office residential, and waterfront commercial uses, industrial, institutional, and agriculture) by traffic analysis zone (TAZ) were provided. Figure 28 is a map of the traffic analysis zones examined in this study. These acreage figures were further classified as vacant, wetland, or developed. The land was considered "developed" if actual development existed or if there was committed development approved by the County Commission; thus the "developed" acres

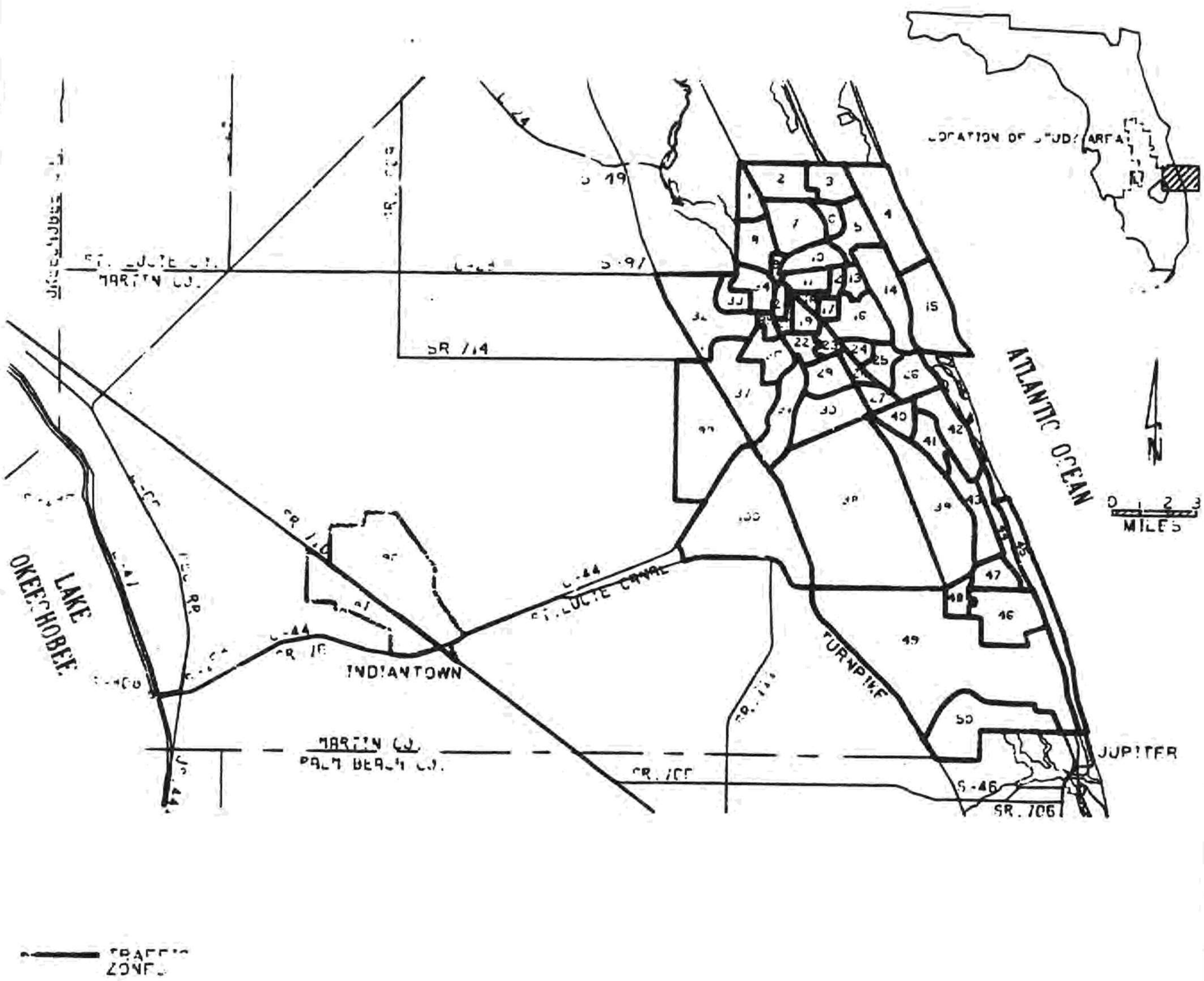


Figure 28 LOCATION OF TRAFFIC ANALYSIS ZONES IN MARTIN COUNTY (1984)

represent 1983 existing and committed, and "developed" plus "vacant" acres represent buildout, with no vacant acres existing at buildout. The acres classified as agriculture were not included in this analysis because water use for this category is handled directly by the ground water model.

Along with these land use data, housing unit data were provided by unit type (i.e. single-family, multi-family) by TAZ. From these data, population estimates were calculated by using a persons per unit factor of 2.9 for single-family units and 2.0 for multi-family units. These factors were provided by Martin County, as well as the assumption of 100% occupancy. Historically the occupancy rate for Martin County has been 76% (1980 census). Another assumption made by Martin County was that all future development would occur at maximum density and make full use of the density transfer provision in the Comprehensive Plan. These assumptions about occupancy and development density lead to the housing unit and population data representing the maximums, causing the water demand projections to be maximum demand.

Due to the nature of the water demand estimation process used in this study, it was necessary to combine the housing unit data with the land use data so that the housing units could be distributed by land use type by TAZ (Table 8). Future units were quite easily distributed based on the assumption made by Martin County that single-family units were to be allocated to land use categories with a density less than 5 units per acre (upa) and multi-family units were to be allocated to land use categories with a density equal to or greater than 5 upa. This assumption, combined with the assumption that vacant acreage would be developed to maximum density, made it possible to distribute these future units. Also used in this distri-bution process was a provision of the Martin County Comprehensive Plan known as density transfer. This provision allows developers to use some of their wetland acres, which are protected from development, in calculating the density of their development. In allowing this, the density of the development's upland acres may be greater than the land use categories allow, but the gross density of the entire development still conforms

TABLE 8. POPULATION AND HOUSING UNIT SUMMARY

	1983 Existing & Committed			Buildout		
Planning Area	SF Units	MF Units	Population	SF Units	MF Units	Population
Hutchinson Island[1]	991	3,369	9,612	1,650	3,999	12,783
North County[2]	4,833	3,796	21,608	7,050	14,441	49,327
Palm City[3]	6,117	2,240	22,219	9,175	5,741	38,090
Port Salerno[4]	2,780	1,496	11,054	3,499	2,740	15,627
Mid County[5]	2,606	3,132	13,821	8,156	11,253	46,158
South County[6]	5,171	4,779	24,554	20,190	22,364	103,279
West County[7]	892	230	3,047	8,999	3,733	33,563
Stuart[8]	4,297	5,652	23,765	5,122	7,957	30,768
Study Area Totals	27,687	24,694	129,680	63,841	72,228	329,595

[1]Includes TAZs 4, 14, and 15
[2]Includes TAZs 1-3, 5-8, and 10
[3]Includes TAZs 32-37
[4]Includes TAZs 24-28
[5]Includes TAZs 29-31 and ED's 98-100
[6]Includes TAZs 38-50
[7]Includes EDs 96 and 97 (Indiantown)
[8]Includes TAZs 9, 11-13, and 16-23. TAZs 16 and 22 were included in this area

to the land use code. The effect of density transfer, put simply, is that it allows more units to exist per development and causes lot sizes to decrease.

The units in the category of "existing and committed" had to be distributed in a slightly more complicated fashion. The first step in distributing these units was to calculate the maximum number of units which could exist in each TAZ given the land use acreage data and the maximum upa for each land use category, the latter being in accordance with the Comprehensive Plan. Using these estimates, existing and committed units were distributed in proportion to the potential maximum number of units for each land use type within each TAZ. The housing unit and population data are summarized in Table 8 by planning areas.

Water Use Factors

After reviewing the land use and population data, and completing the housing unit allocation, the next step was to construct water use factors by land use type so that future water demands could be estimated. Historical water use in the region was reviewed in order to gain some insight into future water use.

It was discovered that recent and proposed development in Martin County seems to be quite different from that of the past. Because there was this weak link between historical water use and future water use, the analysis concentrated on the characteristics of future development in Martin County, making extensive use of material contained in the Martin County Comprehensive Plan regarding such things as maximum density, open space requirements, and density transfer.

There were four areas for which water use factors had to be constructed; residential potable and nonpotable, and nonresidential potable and nonpotable. For each type of use it was necessary to develop these factors so that they would reflect the different water use characteristics associated with the various land use categories.

Residential potable demand was determined to be independent of land use type and instead was directly tied to population. A factor of 100 gallons per capita day (gpcd) was applied to the population data in order to estimate the residential potable component of urban water demand.

Residential nonpotable water use was determined to be strongly dependent upon land use type, mainly because the area of irrigation per unit varies considerably across land use categories. These range from an estimated 23,500 square feet per unit for rural ranchette, down to 800 square feet per unit for high density development. Since outdoor water use is dependent upon area of irrigation, which is dependent upon land use type, outdoor water use is therefore dependent upon land use.

The procedure followed to construct water use factors for residential nonpotable use was to determine the area of irrigation per unit by land use type, determine irrigation system characteristics by land use type, and finally develop application rate and frequency factors which together could be used to estimate the nonresidential nonpotable component of urban water demand. See Memorandum Report "Urban Water Demand Estimates for Martin County: 1983 Existing and Committed, and Buildout" for a more detailed description of the water use factors for residential nonpotable use.

Nonresidential potable water demand was linked to land use due to the variability of development across nonresidential land use categories. The procedure used to construct water use factors for nonresidential potable demand was designed to take nonresidential developed acres and convert them into building area. This was accomplished by making use of the open space requirements and maximum building coverage factors described in the Comprehensive Plan. After calculating the total area of building space for each land use, it was simply a matter of applying standard water consumption factors for nonresidential use (which are based on typical wastewater flows) and combining them with the building area data in order to estimate the nonresidential potable component or urban water demand. (See Memorandum Report "Urban Water Demand Estimates for Martin County: 1983 Existing and Committed, and Buildout" for more detail).

Finally, nonresidential nonpotable water demand was tied to land use via the open space requirement. Developed nonresidential acres were first converted to irrigation area based on the open space requirement for each land use. Application rate and frequency factors, similar to those for residential nonpotable demand, were then used in order to estimate the nonresidential nonpotable component of urban water demands. (see "Urban Water Demand Estimates for Martin County: 1983 Existing and Committed, and Buildout" for more detail).

Total urban water demand was obtained by adding each of the four components described above. Total urban water demand for 1983 existing and committed, and buildout are summarized in Table 9 by planning areas.

TABLE 9. TOTAL URBAN WATER DEMAND
(million gallons per day)

Planning Area	1983 Existing and Committed	Buildout
Hutchinson Island[1]	3.62	4.94
North County[2]	7.48	18.94
Palm City[3]	9.07	17.17
Port Salerno[4]	4.93	6.79
Mid County[5]	5.07	21.48
South County[6]	8.15	42.22
West County[7]	2.11	15.96
Stuart[8]	7.34	10.01
Study Area Totals	47.80	137.50

[1]Includes TAZs 4, 14, and 15
[2]Includes TAZs 1-3, 5-8, and 10
[3]Includes TAZs 32-37
[4]Includes TAZs 24-28
[5]Includes TAZs 29-31 and EDs 98-100
[6]Includes TAZs 38-50
[7]Includes EDs 96 and 97 (Indiantown)
[8]Includes TAZs 9, 11-13, and 16-23. TAZs 16 and 22 were included in this area because the Stuart Utility services these areas.

Water Sources and Utility Demand

The results of this water demand estimation procedure are analyzed by a ground water flow model which evaluates various scenarios regarding the location of well fields and their impacts on water levels. The structure of this model was such that it specifically inputs only utility supplied water from central well fields. Thus, it was necessary to adjust the urban water demands shown in Table 9 so that they reflected only utility urban water demands.

Residential potable water demand could be adjusted for self-supplied and small system sources by making use of private well data from the 1980 census and small system data from the Department of Environmental Regulation; small systems referring to those public systems which pump less than 100,000 gallons per day. It was assumed by Martin County that these small systems would eventually be replaced by more efficient large utility systems. It was also assumed that the majority of private wells would be replaced by utility service, except for units within the land use categories of rural ranchette, rural, and some estate. These assumptions lead to the majority of residential potable demand being utility supplied by buildout.

Residential nonpotable water demand was also adjusted for self-supplied, basing these adjustments on sample observations of existing units, as well as information provided by the Florida Irrigation Society. Approximately 15% of the mid to high density outdoor water use was attributed to utility sources, with the remaining 85%, and the majority of the lower density demands, being self-supplied.

The nonresidential demands were more difficult to adjust due to the lack of data about alternative nonresidential water supplies. Because of this, it was necessary to make the assumption that 100% of the potable demand and 15% of the nonpotable demand would be utility supplied.

After incorporating these various source factors into the demand estimates a set of utility demands was derived. These demands were then increased by 10% so as to reflect the unaccounted for water that is lost during the operation of a utility system. These adjusted demands are summarized in Table 10 by planning areas. In the following section, these utility demands are incorporated into a ground water flow model.

TABLE 10. UTILITY URBAN WATER DEMAND
(million gallons per day)

Planning Area	1983 Existing and Committed	Buildout
Hutchinson Island[1]	1.50	2.16
North County[2]	3.22	9.48
Palm City[3]	2.90	5.66
Port Salerno[4]	2.22	3.92
Mid County[5]	1.28	6.54
South County[6]	3.25	14.05
West County[7]	1.41	7.20
Stuart[8]	5.20	6.90
Study Area Total	20.93	55.90

[1]Includes TAZs 4, 14, and 15
[2]Includes TAZs 1-3, 5-8, and 10
[3]Includes TAZs 32-37
[4]Includes TAZs 24-28
[5]Includes TAZx 29-31 and EDs 98-100
[6]Includes TAZs 38-50
[7]Includes EDs 96 and 97 (Indiantown)
[8]Includes TAZs 9, 11-13, and 16-23. TAZs 16 and 22 were included in this area because the Stuart Utility services these areas

GROUND WATER AVAILABILITY ANALYSIS

Surficial Aquifer System

The South Florida Water Management Model

The South Florida Water Management Model was developed to simulate the regional and integrated system of surface and ground water. The physical system to be modeled is defined by setting the appropriate value for all relevant variables at each node within the grid matrix or modeled area (see Figure 29). A series of parameters must also be determined for each canal in the model area. The following variables are defined at each node: land surface elevation, initial ground water level, aquifer thickness, aquifer permeability, land use type, surface water flow, basin identifier, and rainfall basin identifier. Each canal requires the following variables: width, regulation stages, hydraulic conductivity coefficient, gate width of outflow structure, canal number receiving outflow, overland flow basin identifier, and the location of each node through which the canal passes. Definition data also includes: the starting year, number of years to be simulated, number of rows and columns, the nodal spacing, number and location of well fields, number of structure flow points, aquifer storage coefficients, soil infiltration rates, surface water detention depth, Manning coefficient, and evapotranspiration parameters (MacVicar, 1984).

The model is driven by such hydrologic activity as rainfall, evapotranspiration, open channel flow through major structures, and ground water withdrawals at well fields. Whenever possible, historical data was used to represent the actual hydrologic parameters listed above. For a detailed documentation of the South Florida Water Management Model, the reader is referred to MacVicar (1984).

In this study, the South Florida Water Management Model was modified to simulate the Martin County area. The modeled area is bordered by the Atlantic Ocean on the east and to the west by Lake Okeechobee and the southeastern portion of Okeechobee County. The southern and northern model boundaries extend several miles into Palm Beach and St. Lucie counties, respectively (see Figure 29). A 1 by 1 square mile grid matrix was employed in the model area which consists of 847 nodes. The grid matrix consists of 26 rows in the north-south or y direction and 41 columns in the east-west, or x direction. The ground water boundary conditions consist of a constant head of 0.0 ft. msl along the coast, while the northern, southern, and western boundaries are modeled as no flow boundaries. Since the no flow boundaries are outside of Martin County itself, the impact on adjacent nodes within the county is assumed to be insignificant. The principal driving forces of the model are rainfall, evapotranspiration, canal flow, ground water flow, and well field withdrawal.

The rainfall data were obtained from rainfall stations in the Martin County area shown on Figure 30. Each available rainfall station was weighted with respect to location in each of the four sub-basins in which they occur. The estimated daily rainfall values were uniformly distributed in the respective sub-basins. The average rainfall for the years 1977-78 was approximately 54 inches per year which is considered well within the normal range. The evapotranspiration used in the model is listed per month and by land use type in Table 11.

TABLE 11. EVAPOTRANSPIRATION RATES FOR VARIOUS LAND USE TYPES

MONTH	1	2	3	4
Jan	.060	.078	.096	.078
Feb	.066	.096	.132	.096
Mar	.072	.132	.162	.132
Apr	.078	.162	.180	.144
May	.084	.180	.192	.150
June	.072	.156	.180	.150
July	.072	.168	.180	.132
Aug	.072	.162	.180	.132
Sept	.060	.144	.162	.120
Oct	.060	.132	.144	.108
Nov	.048	.096	.132	.084
Dec	.042	.084	.108	.072
Annual Total (Inches)	23.91	48.44	56.24	42.55

	SRZ	DRZ
1 Urban	3.00	12.00
2 Agricultural	3.00	12.00
3 Swamp	1.00	12.00
4 Vacant Land	1.50	12.00

SRZ - Shallow root zone
DRZ - Deep root zone

Evapotranspiration rates vary with the time of year and land use type. Since evapotranspiration is a highly variable parameter, it was used as the calibrating tool to adjust the computed hydrologic condition to the actual. The evapotranspiration values employed in the model are well within those historically measured.

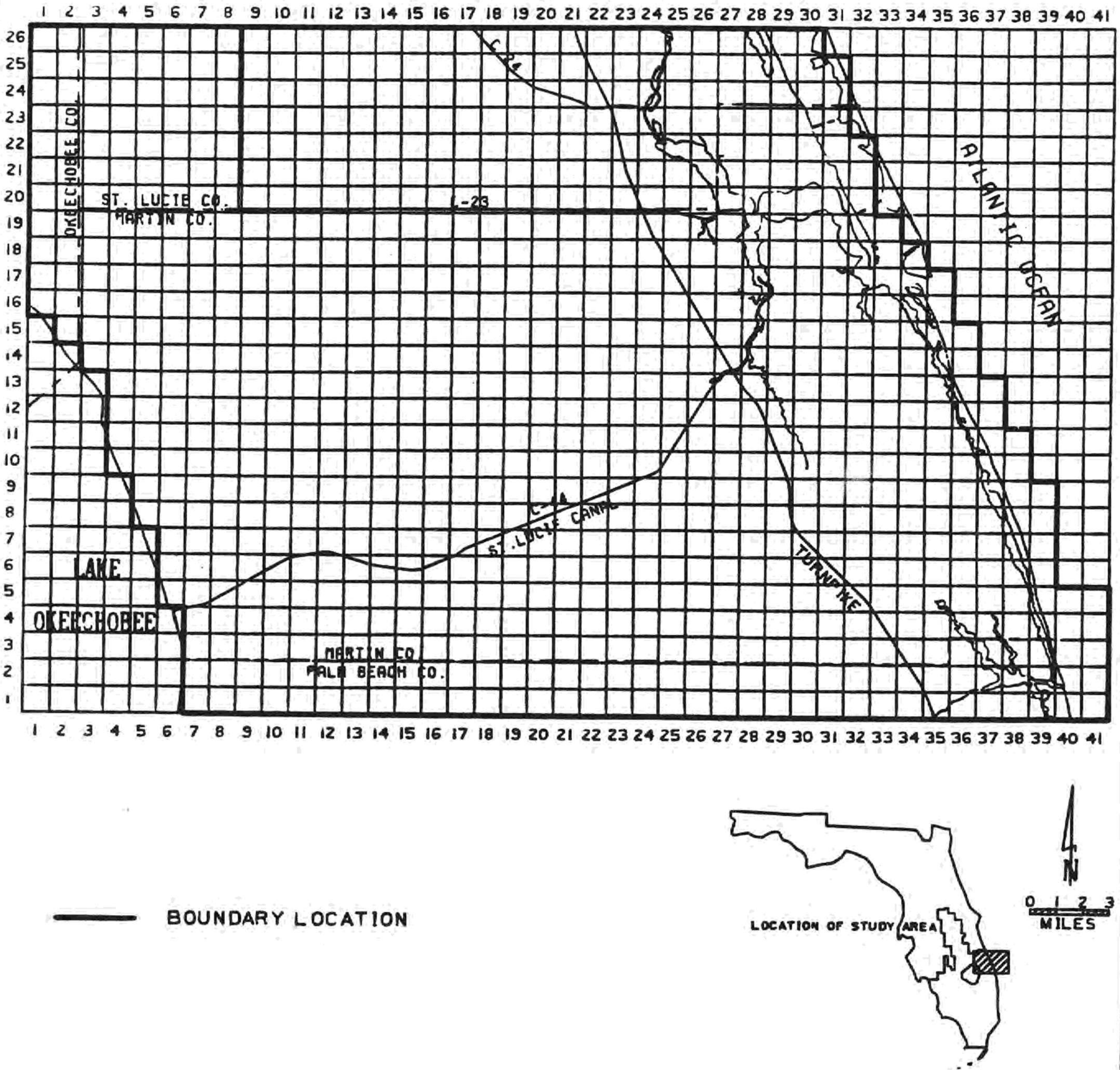


Figure 29 GRID MATRIX OF MODELED AREA OF THE SURFICIAL AQUIFER SYSTEM, MARTIN COUNTY

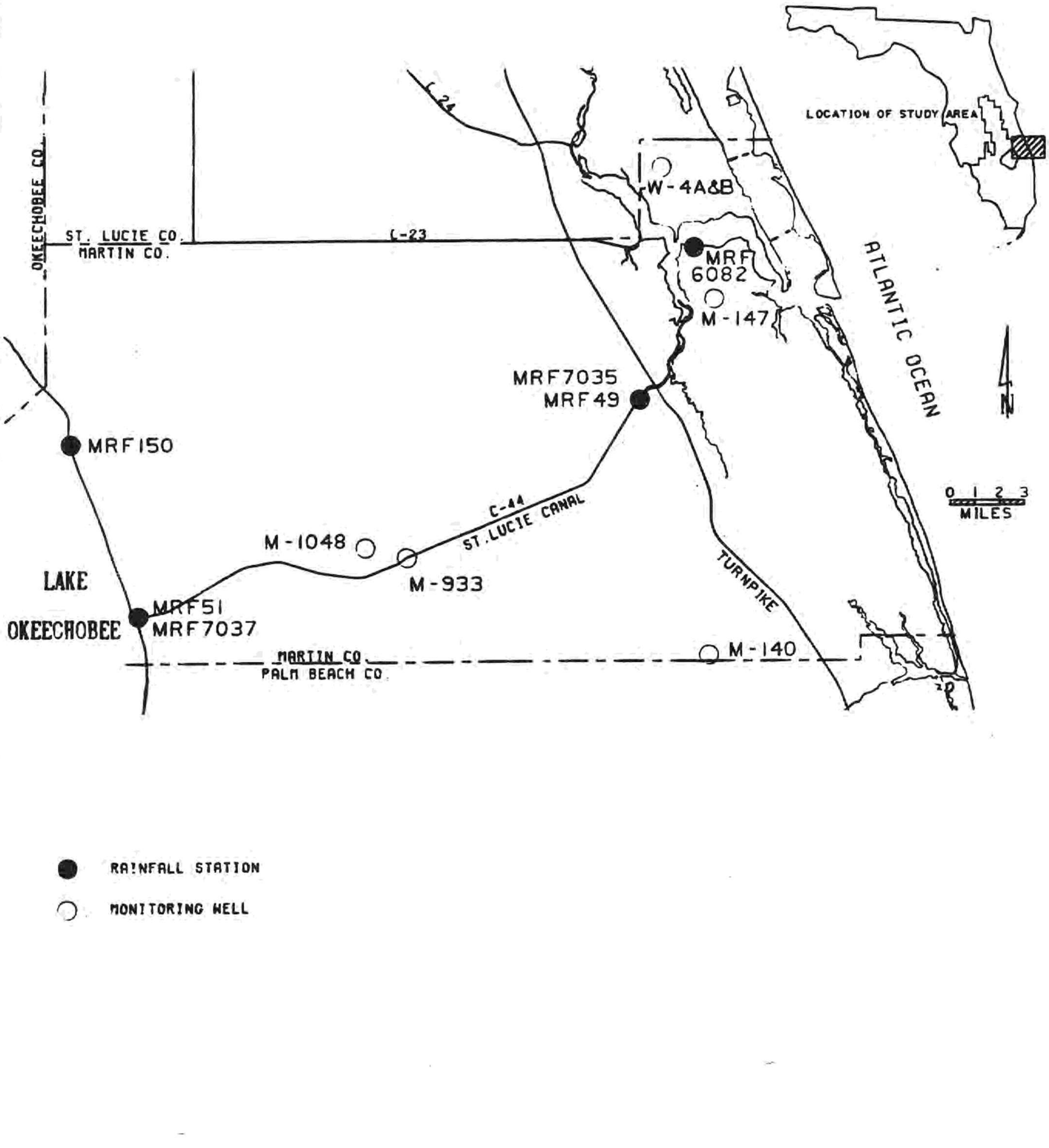


Figure 30 RAINFALL STATIONS AND MONITORING WELL LOCATIONS, MARTIN COUNTY

Model Calibration and Verification

The South Florida Water Management Model was employed to simulate the hydrogeologic conditions in Martin County. The model was calibrated for the years 1977-78 along with the corresponding well field withdrawals for this period. Land use types employed in the model which included urban, agricultural, swamp, and vacant were those observed in 1980. Although a difference of several years exists between the land use and the hydrogeological data used, a sensitivity analysis indicates that the difference is insignificant. In addition, the well field withdrawals for the 1983 existing and committed, and future buildout pumpages were simulated. A series of drought conditions wer also included in the model. Although routines are a ilable within the model to simulate channel flow, emphasis was placed upon the Surficial Aquifer System's ground water regime. The majority of data in this modeling effort was supplied by the District's Water Resources Division. These data were derived from the 1977-78 simulation of the Upper East Coast Planning Area. Adjustment and extrapolation of these data were necessary for the simulation of Martin County and its immediate vicinity. However, these data are essentially the same with the exception of transmissivity values and future well field pumpages and land use types. As mentioned previously, transmissivity values were obtained from a variety of sources along with an additional five values obtained in recent field tests. These values were then subject to a statistical evaluation and used throughout all of the simulations (values employed here are consistently lower than those used in past studies) (see Figure 12). In addition, a specific yield value of 0.2 was used in all ground water simulations of the Surficial Aquifer System. Future land use and well field withdrawals were obtained from the District's Water Use Planning Division. Scenarios reflecting future conditions are discussed in greater detail in a following section.

The major surface water channels within Martin County, as well as the model, are the southern leg of C-24 (Diversion Canal), C-23 (County-Line Canal), C-44 (St. Lucie Canal), the St. Lucie River, and the Jupiter Inlet. The actual versus computed canal stages for C-44 are shown in Figure 31. The water levels represent the downstream canal stage on the upstream face of structure S-80 (see Figure 1). The locations of modeled canals are shown in Figure 32. In addition, secondary canals were included in the model. These canals are prefaced with either CL or text with the exception of the St. Lucie Canal and Jupiter Inlet, and are also shown in Figure 32. The secondary canals are linked to major canals or natural water bodies to receive or discharge water as the need arises. The canal locations as shown are consistently used in all the county-wide simulations.

Ground water flow is dependent on numerous factors, however. Initially, the model requires a starting water level. These data were obtained from the U. S. Geological Survey and water levels were designated for each node within the grid matrix. The initial water levels define the hydraulic gradient at the onset of the model simulation. In order for ground water flow to occur, the aquifer medium must also be defined. The transmitting capacity of the aquifer is determined by its transmissivity. The values of transmissivity analyzed in a previous section were used consistently throughout the modeling endeavor. Since the transmissivity of the aquifer determines the aquifer's capacity to supply water to wells, the wellfields and their corresponding withdrawal rates were modeled to evaluate their impact on the aquifer. The wellfields and their pumpages for 1977-78 are listed in Table 12. The wellfield withdrawals were obtained from monthly pumpage reports supplied by the utilities. Pumpages were adjusted for seasonal fluctuations. The withdrawal rates in Table 12 are presented as average daily withdrawal rates for each month. The locations of these wellfields are shown in Figure 33.

As mentioned, the evapotranspiration rates were adjusted within the model until the actual and computed ground water levels achieved a reasonable similarity or calibration. Comparisons of actual versus computed ground water levels for wells M-140, M-933, and M-1048 are shown in Figures 34 through 36, and their locations are illustrated in Figure 30. The actual versus computed water levels vary by no more than 35 percent and in some instances correspond directly with one another. Hydrographs for wells M-140 and M-933 also indicate a similar trend. Errors in calibration of the water levels in these wells are probably due to the large grid size and the comparatively small well. Figure 37 illustrates the hydrograph of computed versus actual water levels for M-147, located in Stuart. Calibration results for water levels in observation well M-147 were the poorest of all the monitoring wells. The calibrated water levels are consistently higher than the actual measured value and differences of approximately 10 feet occurred. The difficulty in calibrating well M-147 is probably due to its proximity to the St. Lucie River and more importantly, because of the influence of the city of Stuart's wellfield. Although well M-147 shares the same model location as the wellfield, the one square mile grid block area may not provide the necessary resolution for calibration of water levels in this well.

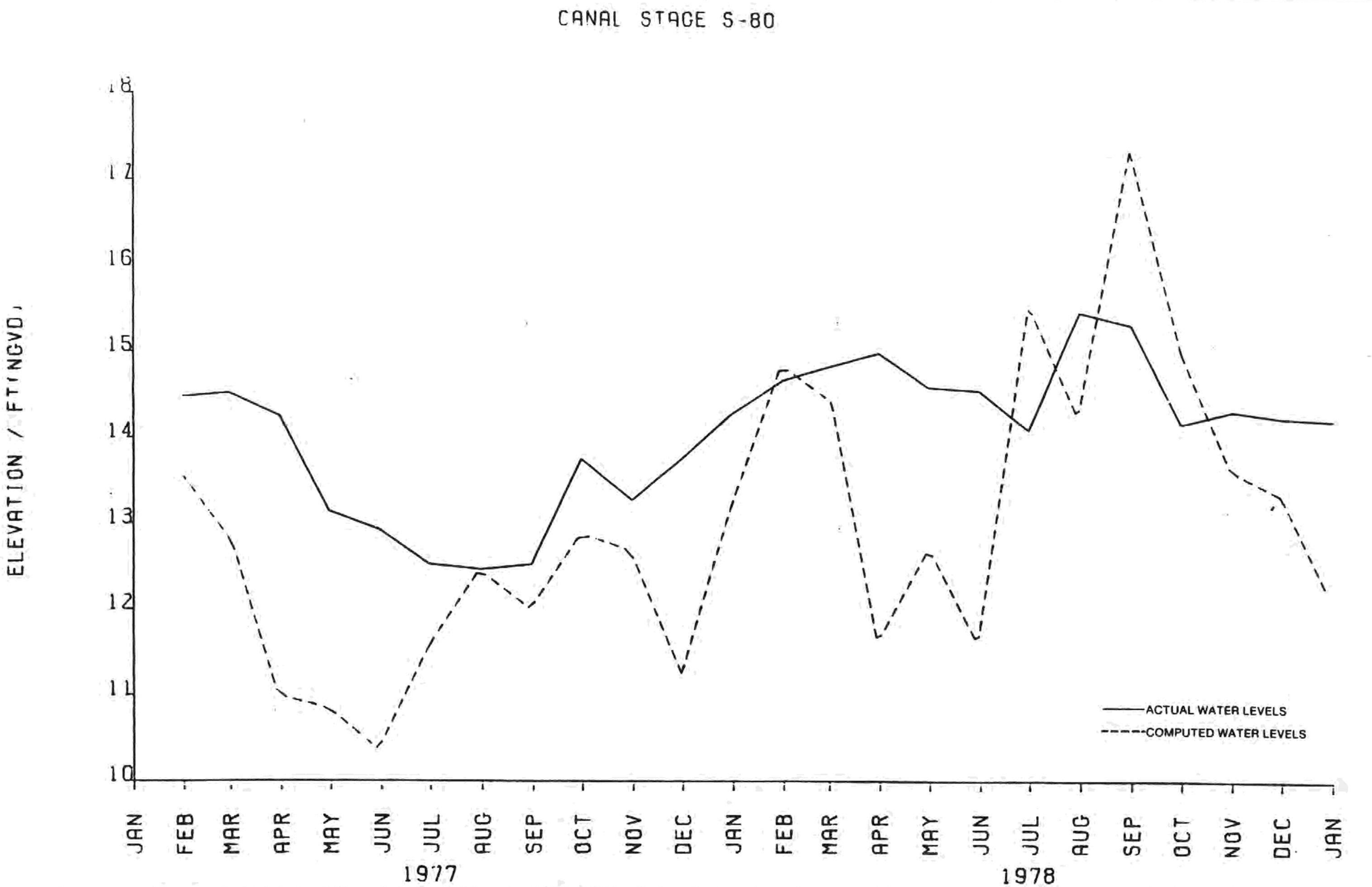


Figure 31 **ACTUAL VS. MODEL COMPUTED STAGES IN THE ST. LUCIE CANAL (C-44) AT STRUCTURE S-80**

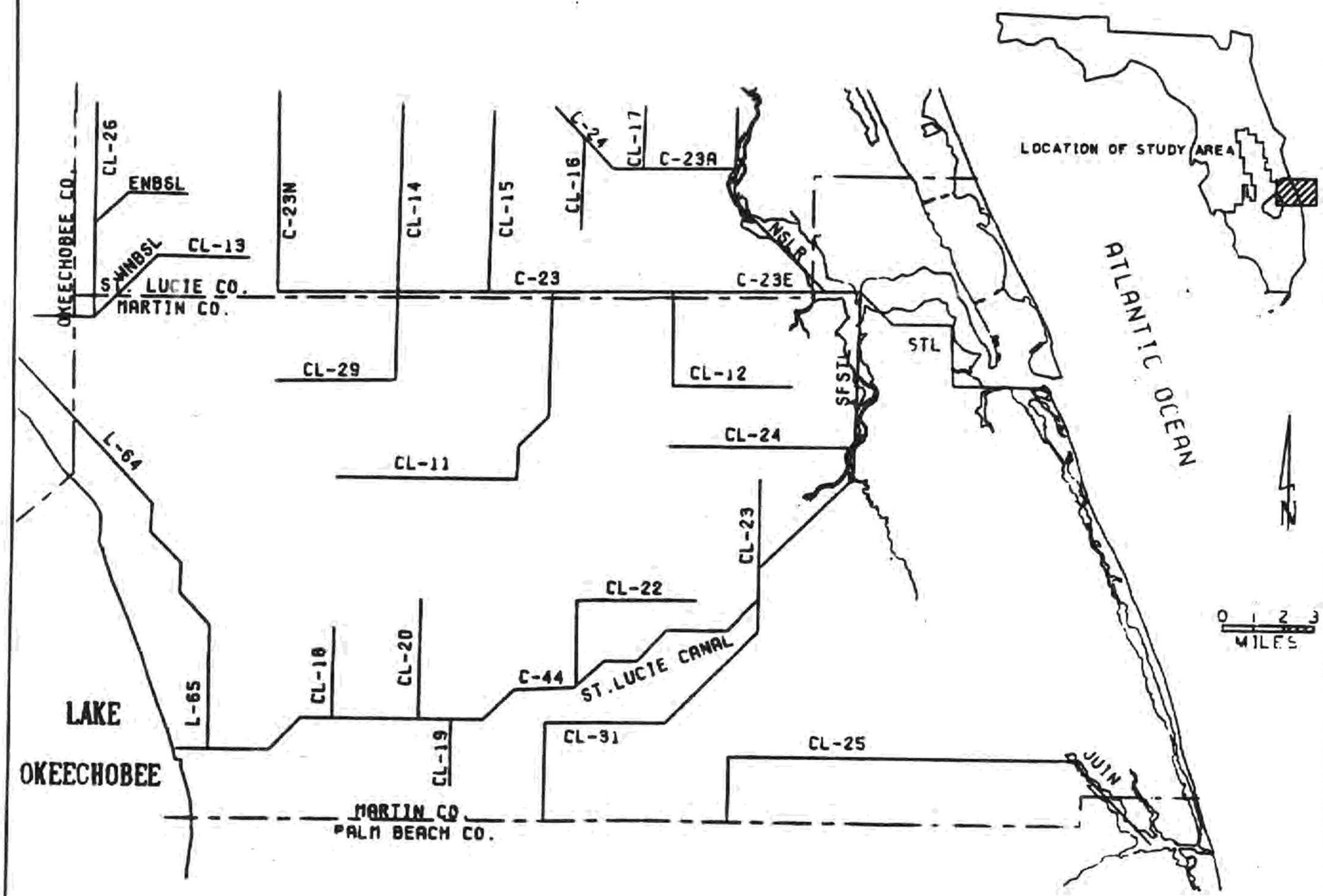


Figure 32 LOCATIONS OF MODELED CANALS, MARTIN COUNTY

TABLE 12. WATER DEMANDS UNDER VARIOUS DEVELOPMENT CONDITIONS

1977-78 WITHDRAWALS (Seasonally Adjusted)

Wellfield	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Stuart	2.6	2.8	3.1	3.4	2.9	2.6	2.5	2.7	2.5	2.4	2.6	2.7
Hobe Sound	0.7	0.8	1.1	1.5	0.9	1.0	1.1	1.1	0.9	1.2	1.1	0.8
Indiantown	0.3	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
FM Water Co.[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.1	0.1	0.1
Hydratech	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.0	0.0	0.0
Intracoastal	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1
Miles Grant[2]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Oz Development[3]	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinelakes Village	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Southern States	0.6	0.7	0.0	0.9	0.8	0.6	0.9	0.4	0.0	0.6	0.6	0.5

FUTURE WATER DEMANDS (Million Gallons Per Day)

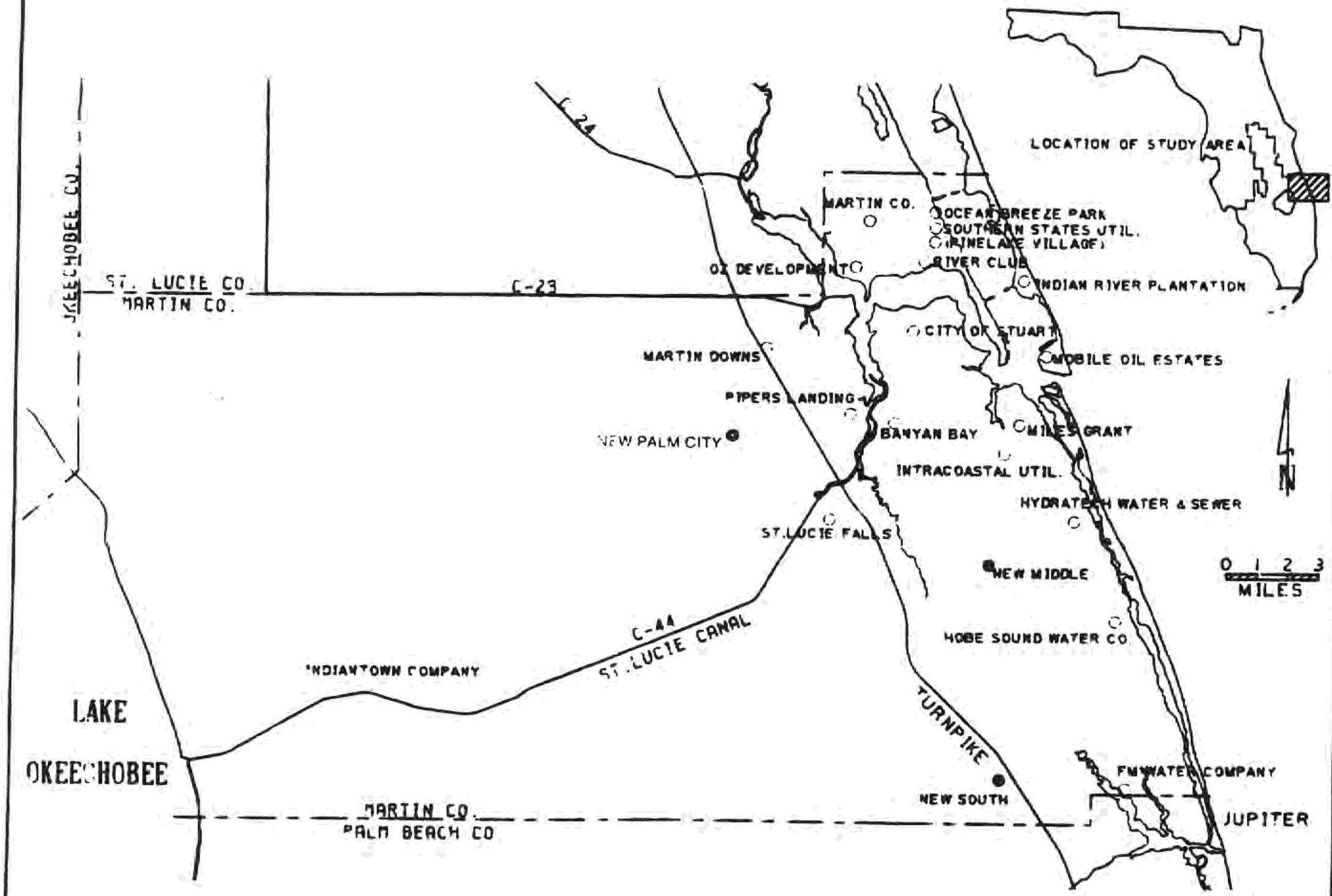
Wellfield	Existing & Committed Withdrawals	Buildout Withdrawals	Wellfield	Existing & Committed Withdrawals	Buildout Withdrawals
Stuart	5.1	6.9	Southern States	0.9	0.9
St. Lucie Falls	0.5	2.1	Pipers Landing	0.1	0.1
Hobe Sound	0.2	1.1	Banyan Bay	0.4	0.4
Indiantown	1.4	7.2	North Martin Co.	4.7	11.6
FM Water Co.[1]	0.2	0.2	Martin Downs	2.0	2.7
Hydratech	2.1	4.9	River Club	0.1	0.1
Intracoastal	2.1	4.9	Ocean Breeze[1]	0.1	0.1
Miles Grant[2]	0.3	0.3	New Palm City	1.6	7.8
Oz Development[3]	0.1	0.1	New South	0.6	1.5
Pinelake Village	0.2	0.2	New Middle	0.1	5.0

1. No longer active
2. Re-named Utilities, Inc.
3. Re-named Beacon 21

FUTURE WATER DEMANDS (Million Gallons Per Day)

Wellfield	Existing & Committed Withdrawals	Buildout Withdrawals	Wellfield	Existing & Committed Withdrawals	Buildout Withdrawals
Stuart	5.1	6.9	Southern States	0.9	0.9
St. Lucie Falls	0.5	2.1	Pipers Landing	0.1	0.1
Hobe Sound	0.2	1.1	Banyan Bay	0.4	0.4
Indiantown	1.4	7.2	North Martin Co.	4.7	11.6
FM Water Co.[1]	0.2	0.2	Martin Downs	2.0	2.7
Hydratech	2.1	4.9	River Club	0.1	0.1
Intracoastal	2.1	4.9	Ocean Breeze[1]	0.1	0.1
Miles Grant[2]	0.3	0.3	New Palm City	1.6	7.8
Oz Development[3]	0.1	0.1	New South	0.6	1.5
Pinelake Village	0.2	0.2	New Middle	0.1	5.0

1. No longer active
2. Re-named Utilities, Inc.
3. Re-named Beacon 21



PUBLIC WATER SUPPLY WELLFIELD LOCATION

• HYPOTHETICAL WELLFIELD DESIGNATION

Figure 33 MAJOR PUBLIC WATER SUPPLY WELLFIELDS IN MARTIN COUNTY

Figure 34 ACTUAL VS. COMPUTED WATER LEVELS IN WELL M-140

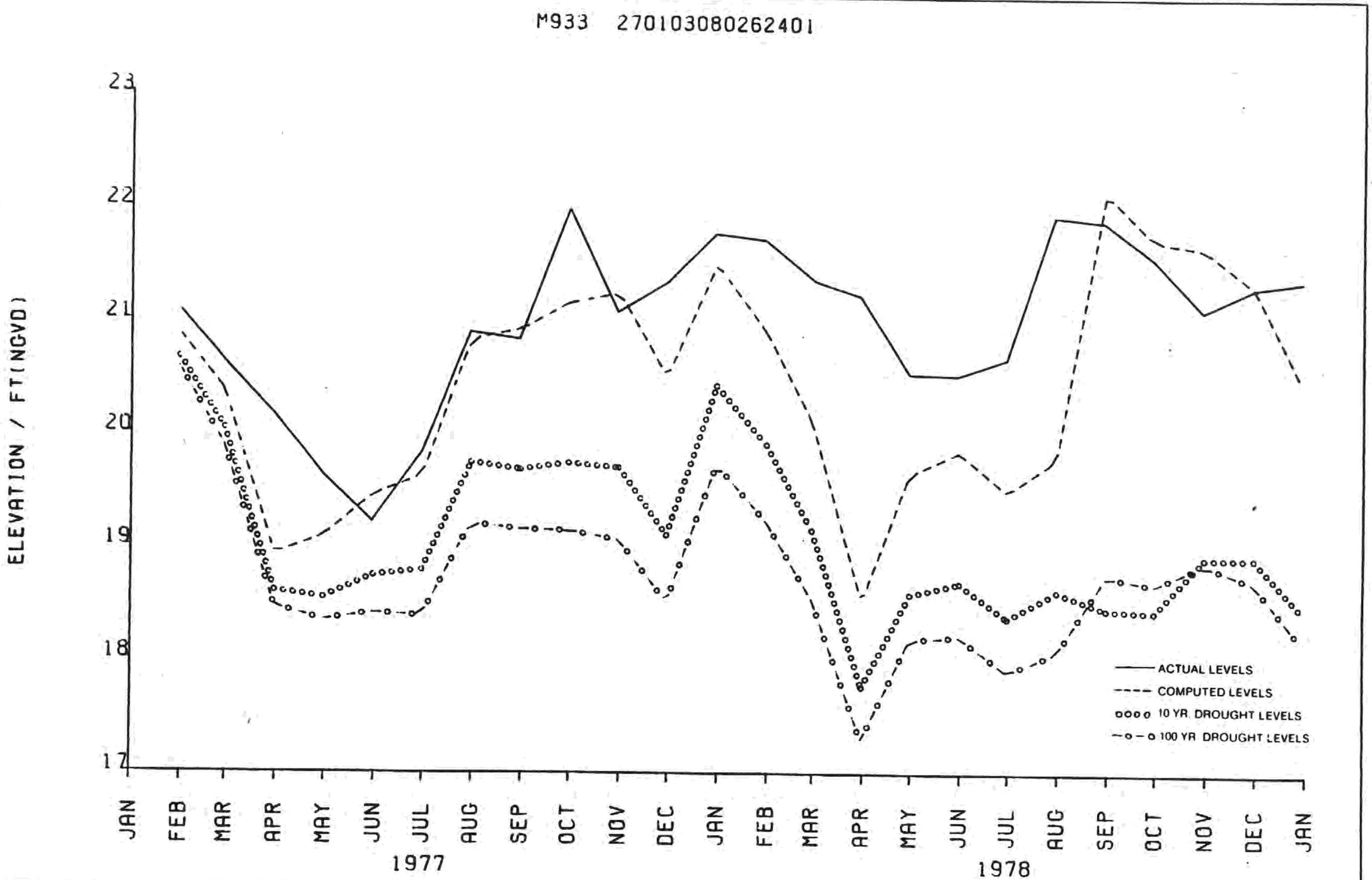


Figure 35 ACTUAL VS. COMPUTED WATER LEVELS IN WELL M-933

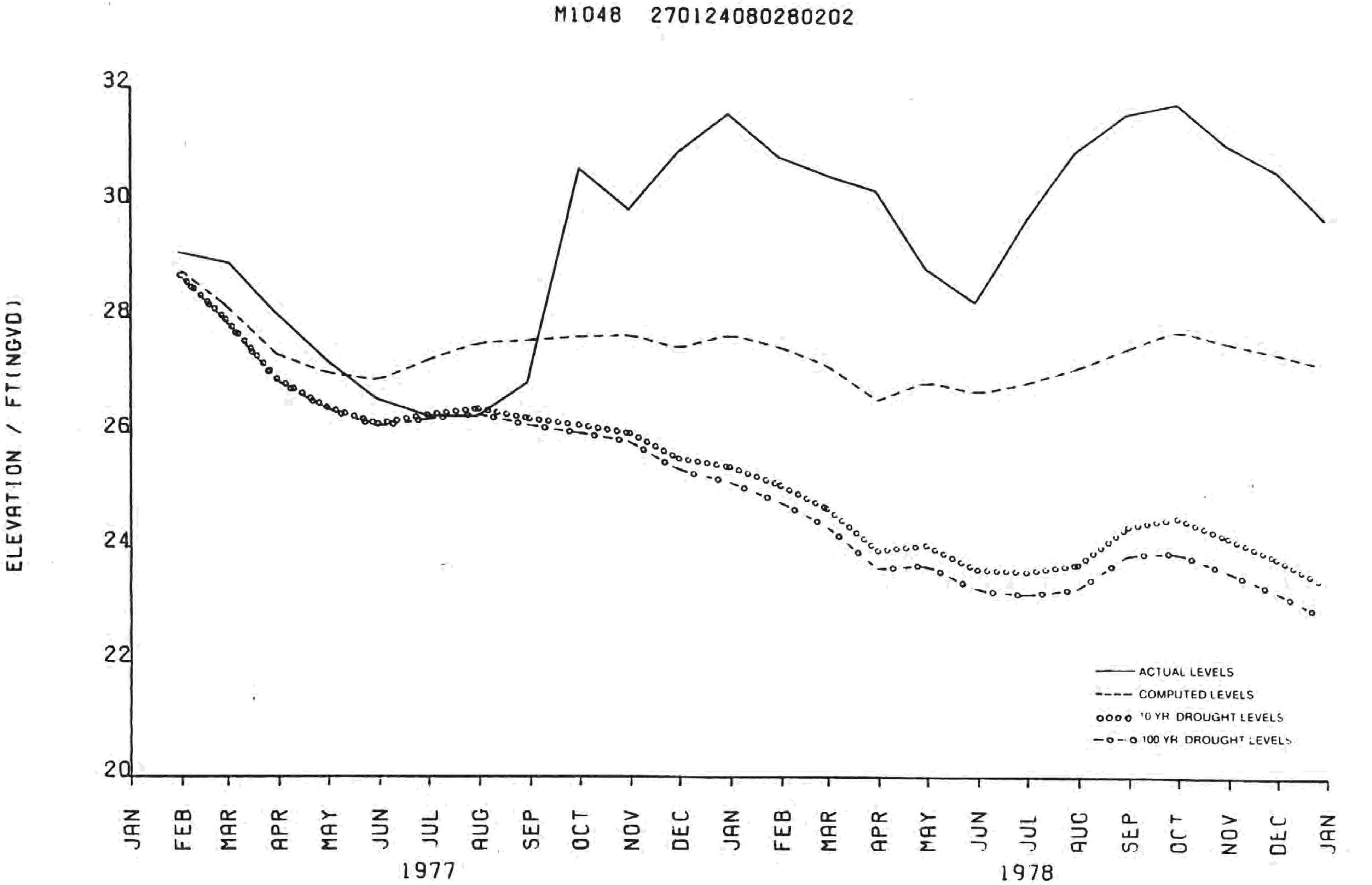


Figure 36 ACTUAL VS. COMPUTED WATER LEVELS IN WELL M-1048

Figure 37 ACTUAL VS. COMPUTED WATER LEVELS IN WELL M-147

Calibration of the model requires that the computed regional ground water flow system reflect the actual conditions for the county. Comparison of the calibrated water levels (Figure 38) and wet season water table contours (Figure 13) indicates that the computed versus actual conditions are only apparent locally. Similarities between the two water table maps suggest that the regional simulation of the county-wide ground water system is representative of actual conditions.

As illustrated in Figure 38, the calibrated water levels for October 1978 do not imply that the corresponding well field withdrawals for this period have overly-stressed the aquifer. Although not shown, the computed water levels for each month of 1977-78 have not indicated negative impacts on the aquifer due to well field pumpages.

Scenario I: The calibrated model was modified to reflect the existing and committed land use and water demands of 1983. The principal change in the 1983 land use from that of 1980 was a shift from vacant to urban. The alteration in land use, however, was not significantly reflected by the model.

The well field demands were increased substantially from those used in the prior simulation, and additional well fields were included to account for this increase. Table 12 lists the 1983 existing and committed water demands and the corresponding utility. Of the additional well fields, three hypothetical well fields were required to meet the expanded water withdrawals. These three well fields, New Palm City, New South, and New Middle, were located within the model to reflect population centers and may not represent the optimal locations hydrogeologically. Since the water demands are estimates, the withdrawal rates were not adjusted for seasonal fluctuations. The total well field withdrawals for this period are approximately 22 MGD.

Although not depicted here, the configuration of the water table was not significantly altered due to the 1983 existing and committed water demands. Although the increased water demands are substantial, the additional well fields incorporated into the model were dispersed such that the withdrawals did not have a regional impact. Differences between the calibrated model and this scenario only occurred locally. A decline in water levels of four feet and two feet took place at the north Martin County and city of Stuart well fields, respectively. This decline is apparent only at the well field's model locations within the model. A detailed discussion of these well fields is presented in a later section.

Scenario II: The model was adjusted to represent the future buildout conditions for Martin County. The major land use change for this future scenario was from vacant to urban. Again, the model was not significantly sensitive to land use modifications.

The water demands are listed in Table 12 for buildout population. Since these figures are estimates, they were not adjusted for seasonal fluctuations. Also, the demands were sited at existing well fields or corresponding future population centers and were not sited based on a hydrogeological assessment. The total buildout pumpage for this scenario is approximately 57 million gallons per day. Even though the buildout pumpage is more than twice the 1983 existing and committed pumpage, this increased withdrawal did not have a regional impact on the Surficial aquifer.

Local impacts on the water table aquifer were evident at the nodal location of several major well fields (see Figure 39). Drawdowns of approximately 20 and 7 feet occurred at the Indiantown and Intracoastal well fields, respectively. The average water level for the one square mile grid which encompasses the city of Stuart well field was about 3 feet above sea level. The increased withdrawals of 7.8 MGD and 5.0 MGD for the hypothetical well fields, New Palm City and New Middle, respectively, also resulted in noticeable declines in the water tables. Buildout pumpage for the north Martin County well field was increased dramatically to 11.6 MGD. The average nodal water level for this well field was approximately 35 feet below sea level. The model suggests that the Surficial Aquifer System may not supply the quantity of water which buildout conditions require. Such a drop in the water level would certainly cause salt water intrusion within the aquifer.

In order to assess whether the assumption of 100 percent occupancy would significantly affect the results of the regional simulations, the buildout water demand was reduced by a factor of 15% at the well field sites to reflect an 85 percent occupancy rate. Although the drawdowns at the well fields were not as great, the water level decline was still noticeable at the sites mentioned above. While the city of Stuart well field maintained a water level elevation of approximately 7 feet above sea level, the water table elevation at the north Martin County well field dropped below sea level. The computed water level elevation at the north Martin County well field was 20 feet below sea level. Again, salt water intrusion would occur. In essence, the configuration of the water table did not change appreciably when water demands were decreased by a factor of 15 percent in the simulation.

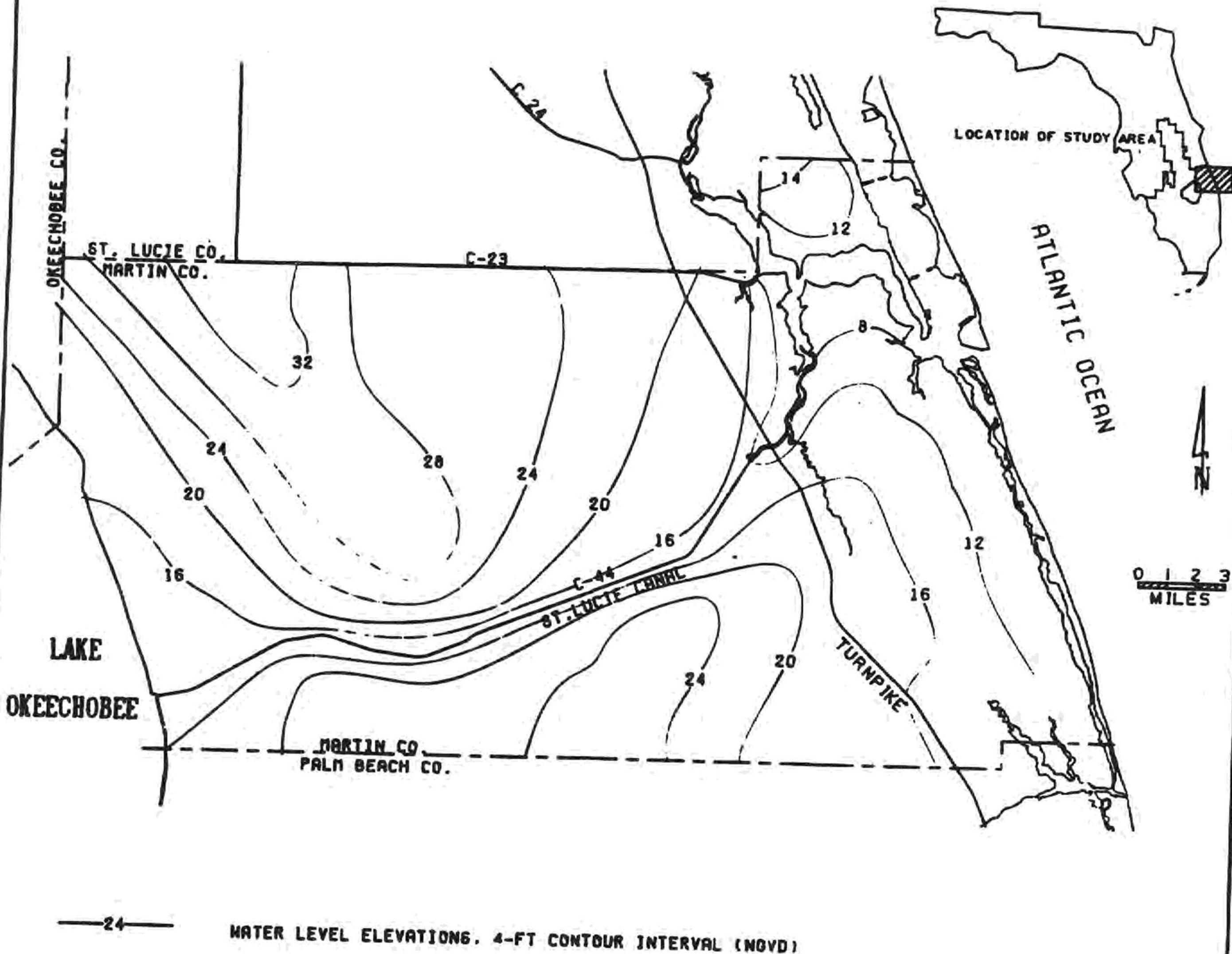
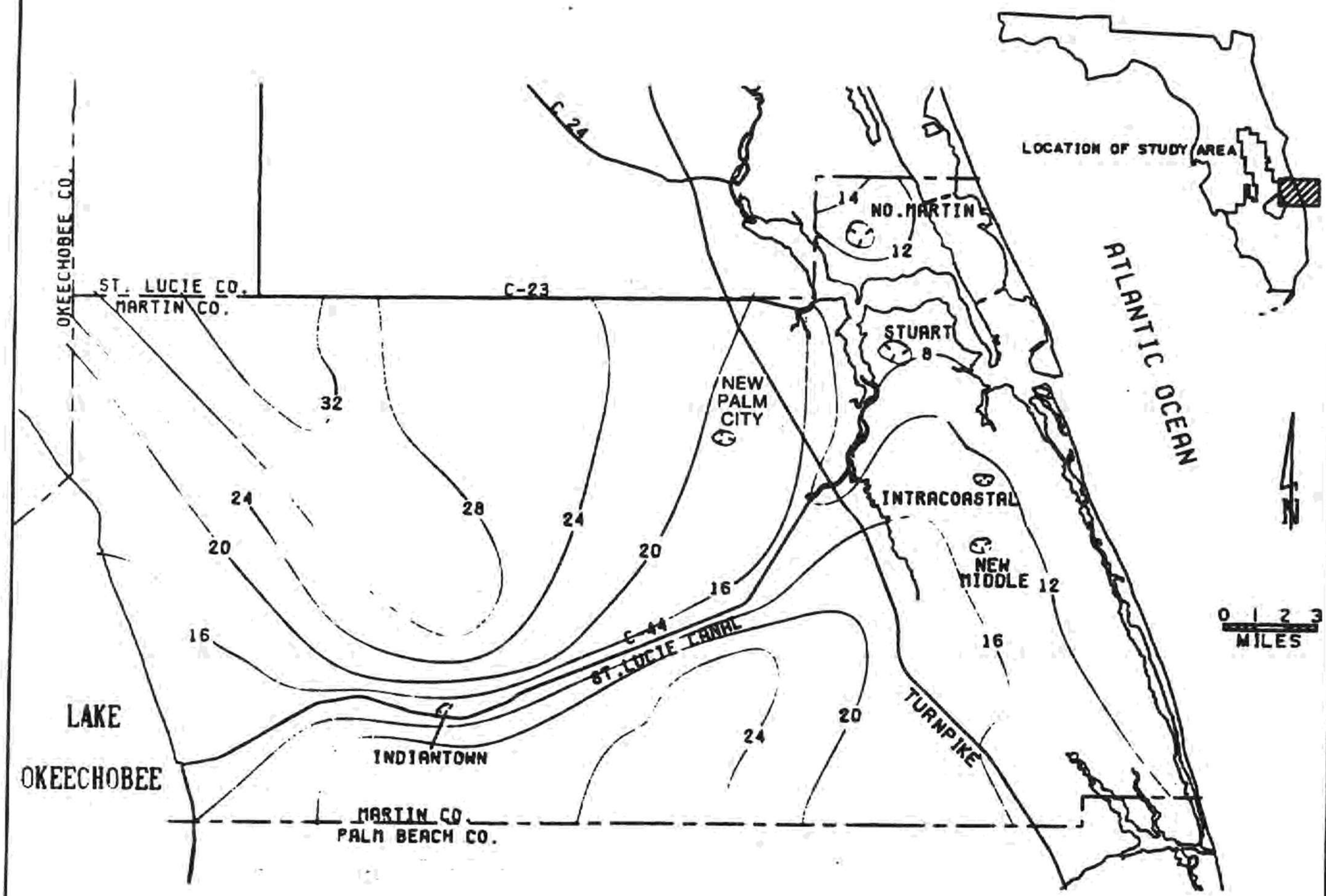


Figure 38 CALIBRATED WATER LEVELS FOR 1977-78, MARTIN COUNTY



—24— WATER LEVEL ELEVATIONS. 4-FT CONTOUR INTERVAL (NGVD)

LOCATION OF WELLFIELD DRAWDOWN

NEW HYPOTHETICAL WELLFIELDS

Figure 39 COMPUTED LEVELS UNDER BUILDOUT PUMPAGE, MARTIN COUNTY

The regional model suggests that whether the demand reflects 100 or 85 percent occupancy is of secondary importance. Of prime importance is the quantity withdrawn at the local level, and, consequently, determining the safe yield of the aquifer on a specific site basis prior to well field commitment.

Scenario III: The model was subject to various drought conditions along with the buildout pumpage listed in Table 12. The drought scenarios consisted of one in 10, 20, 50 and 100 year droughts which correspond to 41, 39, 37 and 36 inches of rainfall per year, respectively. Rainfall employed in previous simulations was approximately 54 inches per year or that of a normal year.

Regionally, the water table declined, and the water level contours or equipotential lines receded from those calibrated employing normal rainfall. Figures 40 and 41 illustrate the water table map for the 1 in 10 and 1 in 100 year droughts, respectively. The water levels, as expected, were lowered as the severity of the droughts increased. All of the drought scenarios dictate that the maintenance of water levels by recharge is crucial in meeting the buildout water demands of the county. The importance of maintaining the water table regionally is amplified at the local level.

Although the pumpages employed in this scenario were consistent with those in the previous simulation, the sequence of drought conditions resulted in a further decline in the water table at the major well fields. The average water elevations for both the Hydratech and Intracoastal well fields were approximately 3 and 0.5 ft. above sea level for the 10 and 100 year droughts, respectively. Buildout pumpage at the Indiantown well field is estimated at 7.2 MGD, and although this well field receives a considerable amount of recharge from the St. Lucie Canal, an additional decline in the water table of about one foot would occur due to the droughts. Water levels at the hypothetical New Palm City and New Middle well fields were also only several feet above sea level. Imposing the drought situations on the Stuart and north Martin County well fields resulted in a decline in the water table below sea level. The buildout pumpage for Stuart is 6.9 MGD. This water withdrawal, coupled with the droughts, affected the average nodal water level considerably. Water levels for this node were -5 to -11 feet below sea level for the one in 10 and 100 year droughts, respectively. At the north Martin County well field water levels for either drought condition were more than 40 feet below sea level. The model indicates that the buildout pumpage and the effects of droughts will have a detrimental effect on the Surficial aquifer at both the Stuart and north Martin County well fields.

Since the county-wide model employs a relatively large grid system of one square mile and the well field withdrawals are restricted to a single node, a finer grid system was utilized for both the Stuart and north Martin County well fields. The finer grid system, due to its resolution, can account for each well within the two well fields which may provide a more realistic simulation of the effects of future water demands. The individual modeling of both the Stuart and north Martin County well fields are described in the following section.

City of Stuart Well Field

The results of the county-wide model indicate that the present Stuart well field may not successfully meet future water demands. For this reason, the area was modeled using a finer grid matrix to afford better resolution. U. S. Geological Survey's two-dimensional model was employed; a documentation of this model is available from Trescott (1984). Fundamentally, this ground water flow model operates in the same manner as the county-wide model. The input data was taken from the previous model with the exception of rainfall and evapotranspiration. Rainfall utilized represented a normal dry season, which is approximately 22 inches, and the corresponding evapotranspiration was set at 33 inches.

A 60 by 60 grid matrix was used which consisted of 60 grid blocks in both the north-south and east-west direction. The nodal spacing within each grid block was 500 feet. The borders of the model area were represented by constant head boundaries. Along the Intracoastal and the St. Lucie Estuary, the constant head was fixed at 0 and 0.5 feet above mean sea level, respectively. The South Fork of the St. Lucie River maintained a constant head of one foot above mean sea level. The constant head at the southern boundary which transects land surface was represented by the water table elevation at the end of the dry season for 1978 (see Figure 42). This southern constant head boundary provided a continuous source of recharge to the simulated area due to the scheme employed in the model. Therefore, the following simulations were regarded as liberal evaluations since the analysis provides an infinite supply of recharge in the southern portion of the area.

The model was calibrated for the end of the dry season for 1978. At this time, the well field operated 25 wells with a water withdrawal of approximately 2.7 MGD. Water withdrawals were distributed uniformly

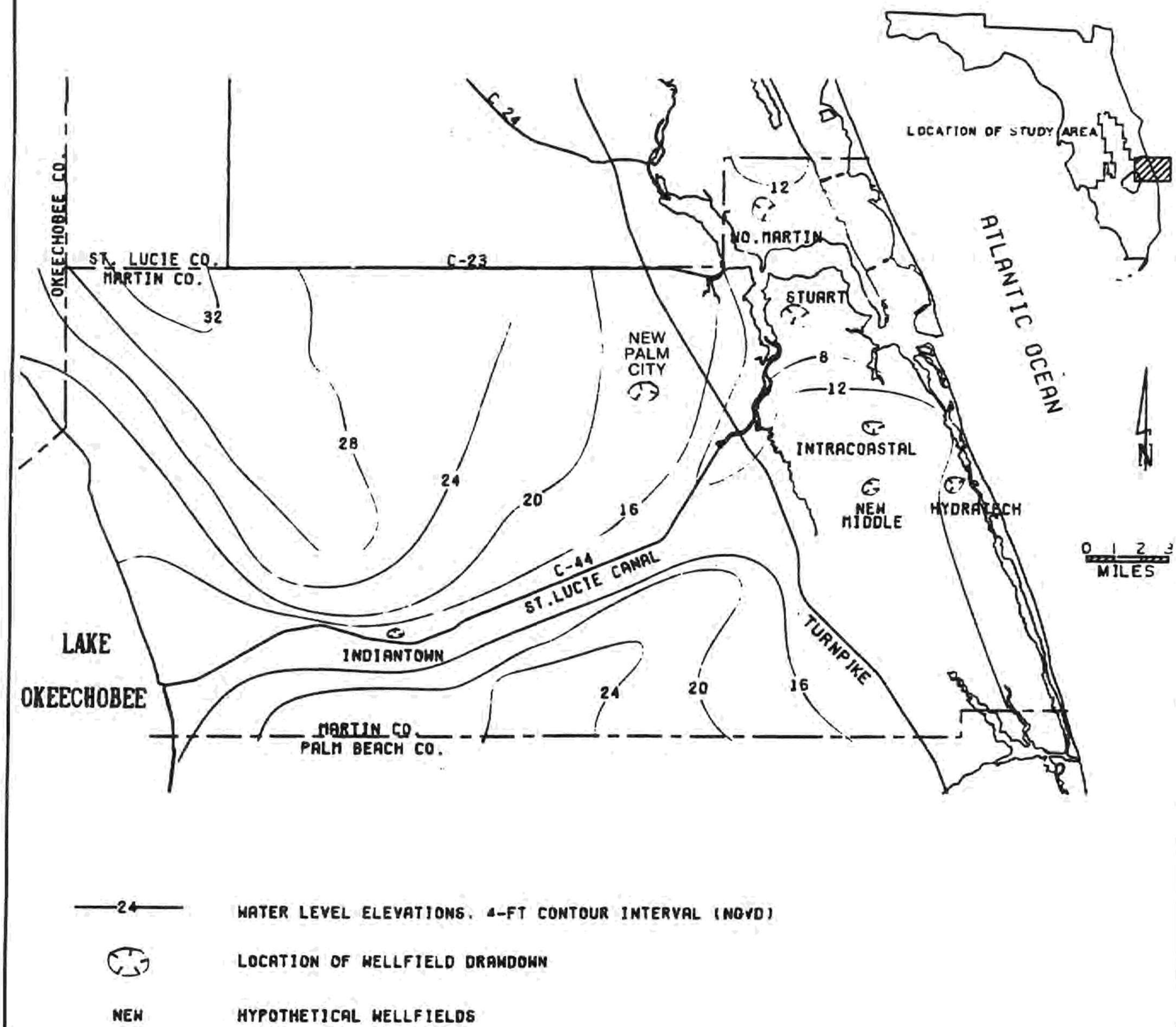


Figure 40 COMPUTED WATER LEVELS FOR 10-YEAR DROUGHT UNDER BUILDOUT PUMPAGE, MARTIN COUNTY

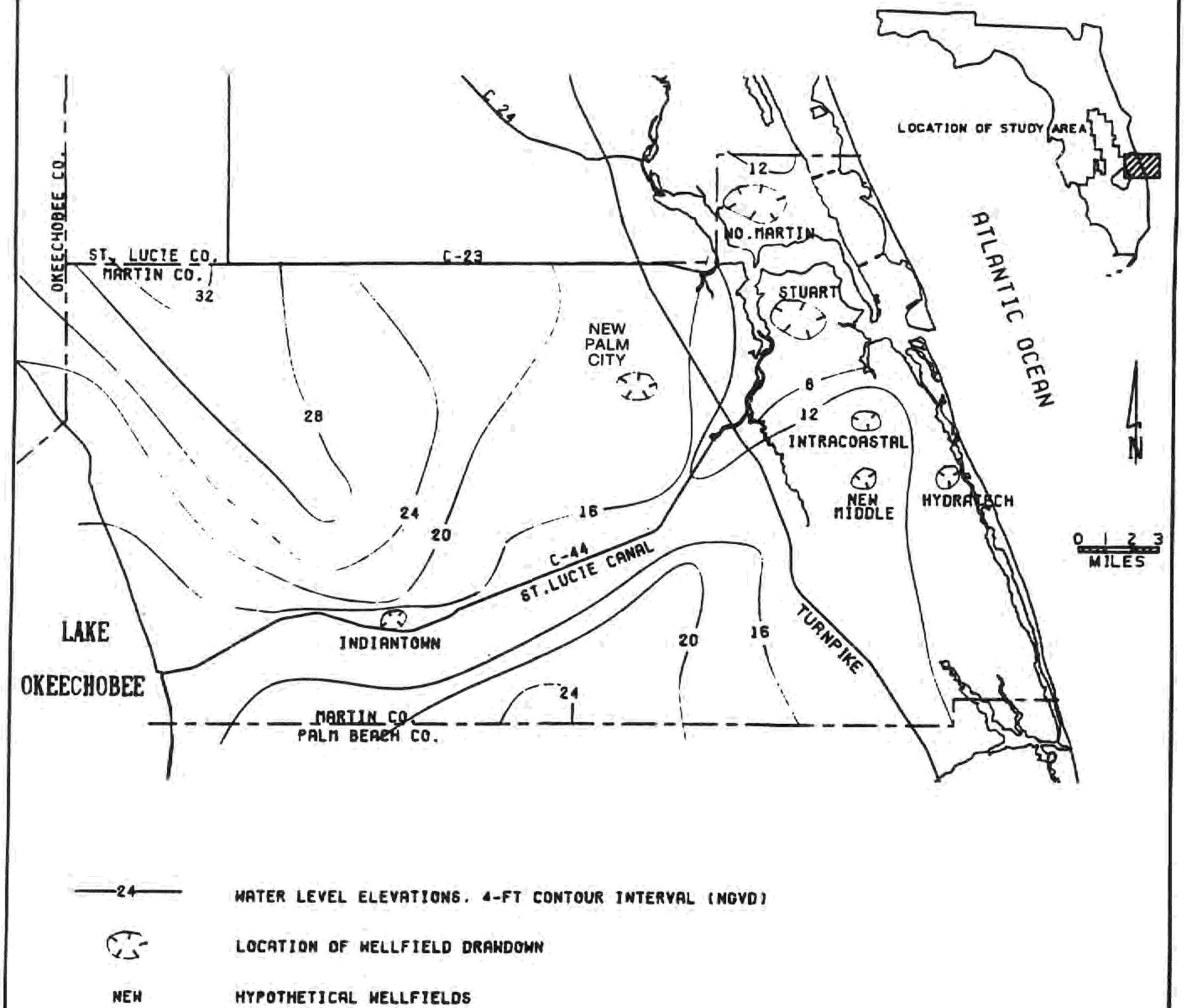


Figure 41 COMPUTED WATER LEVELS FOR 100-YEAR DROUGHT UNDER BUILDOUT PUMPAGE, MARTIN COUNTY

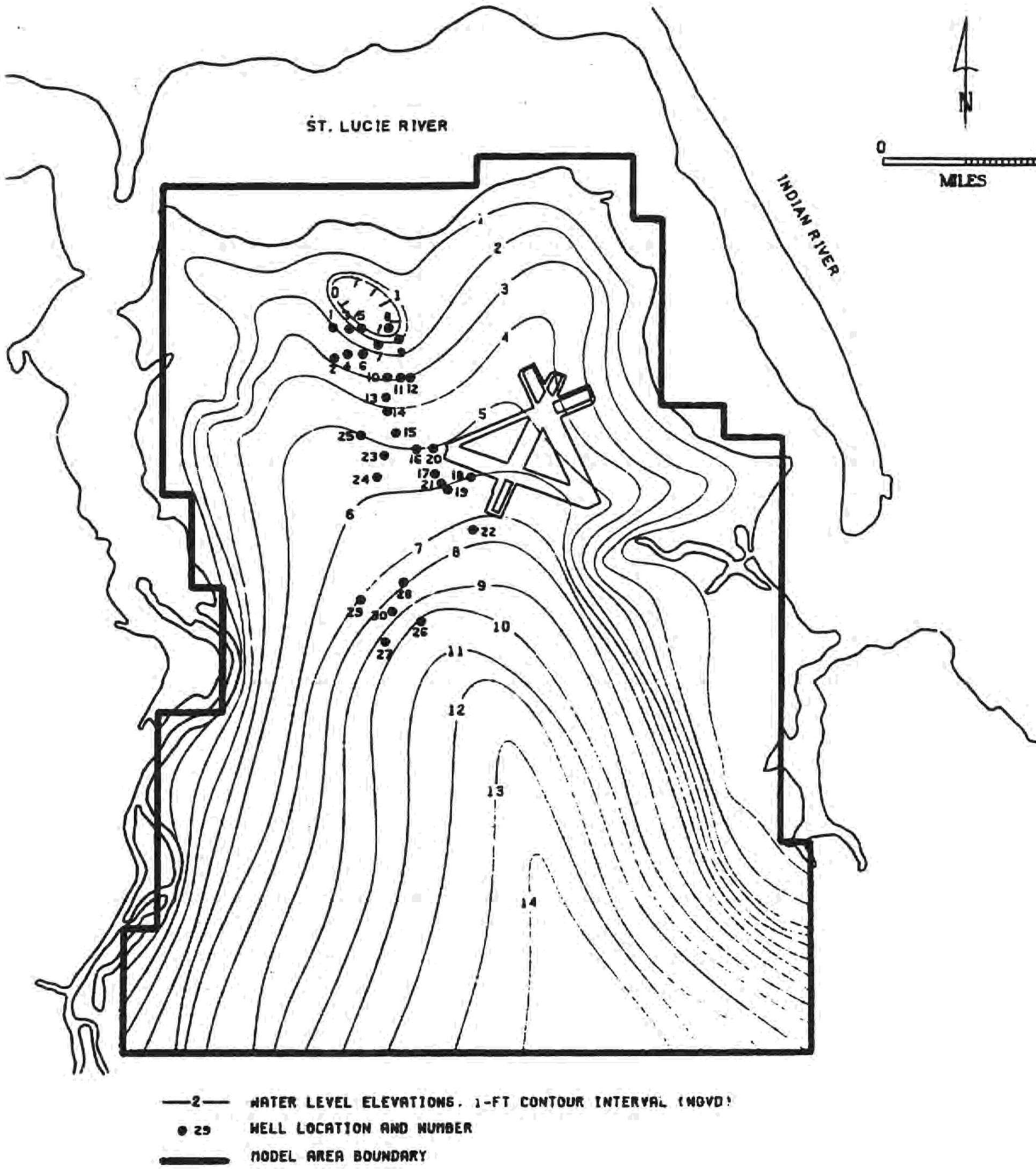


Figure 42 WATER TABLE MAP, CITY OF STUART AREA, JUNE 1978 (FROM CH2M HILL, 1979)

uniformly distributed among the wells. The average water decline at each well point due to this pumpage was approximately 10 feet. The actual water table condition is shown in Figure 42, and the calibrated model is illustrated in Figure 43. Both figures indicate that the water table was at or below sea level for an area of approximately 200 acres due to the well field withdrawal. The model suggests that the 0.0 foot equipotential line (msl) was only about one mile from the salt water of the St. Lucie Estuary. A maximum head of 4 feet above msl was maintained between the St. Lucie and the low water table of the well field by the model. The historic record implies that salt water intrusion was not evident nor confirmed for this period. Differences between the actual conditions versus the calibrated conditions were probably due to the withdrawal distribution among the wells.

The water withdrawals were increased to represent the 1983 existing and committed water demand of 5.1 million gallons per day. An additional five wells, wells 26 through 30, were included in the model to reflect existing conditions (see Figure 44). Pumping withdrawals were uniformly distributed among these wells at a constant rate to meet the existing and committed water demand of 1983. With the exception of these variables, the additional input parameters required to run the model were identical to those employed in the calibration.

The computed water level decline at the wells ranged between 7.5 feet at the southern end of the well field to 23.5 feet at the northern end of the well field. Compared to the calibrated model, the cone of depression expanded considerably due to the increased water withdrawal. Drawdowns at or below sea level encompassed an area of 835 acres or 1.3

square miles, which is over four times greater than that computed in the calibrated model (see Figure 43). The maximum computed head between the St. Lucie Estuary and the well field was only 2 feet above mean sea level. In addition, the northern edge of the cone of depression was computed to be 4,000 feet from the estuary.

The hazard of salt water intrusion becomes increasingly more probable as the cone of depression expands. The relationship between the fresh water-seawater interface according to the Ghyben-Herzberg equation requires one foot of fresh water head per 40 feet of aquifer thickness. Based on this equation and assuming that the average saturated thickness of the aquifer is 180 feet; a fresh water head of approximately 4.5 feet above sea level is required to prevent salt water intrusion. Therefore, maintaining the water table at this elevation between the cone of depression and the fresh water-salt water interface would provide the necessary protection against salt water intrusion.

The buildout water demand of 6.9 million gallons per day was uniformly allocated to all of the wells within the well field. The maximum drawdown occurred at the northern end of the well field where a water level decline of 35 feet was computed. In part, this steep decline in the water table was due to the comparatively low transmissivity of the aquifer. More importantly, the wells in northern peninsular Stuart are in close proximity to one another such that a decline in the water level at one well affects that of another. This accumulative interference between wells results in a subsequent lowering of the water table. At the southern end of the well field, the newly added wells have a greater distance between them and their effects on one another were slight. The decline in water levels for wells 26 through 30 did not exceed 10 feet (see Figure 45).

Due to the buildout pumpage, the water table declined to a level at or below sea level for an area of roughly 2,560 acres, or 4 square miles. At its closest proximity, the cone of depression was computed to be 2,500 feet away from the St. Lucie Estuary. The maximum water table elevation between the estuary and the cone of depression was one foot. The Ghyben-Herzberg equation would indicate that the migration of salt water from the estuary to the well field would be entirely possible under these circumstances.

The scenarios reflecting existing-committed and buildout water demands indicate that detrimental effects of salt water intrusion may result if the well field is improperly managed. Increasing pumpages at the southern wells while lowering those at the northern limit of the well field could provide the protection needed. Additional wells may also be necessary to meet future water demands and it is recommended that they be placed in the southern portion of peninsular Stuart.

The actual water levels for May 1982 are illustrated in Figure 46. The figure portrays two distinct cones of depression which are most probably due to allocating a relatively large percentage of the pumpage to the southern wells (wells 26-30). Subsequently, a lower percentage of the withdrawals was distributed to the northern wells. This uneven distribution of the pumpage resulted in higher water levels between the St. Lucie Estuary and the southern cone of depression. At this time the maximum day withdrawal was 4.7 MGD. In contrast, the 1978 pumpage was approximately 2.7 MGD and the cone of depression is much closer to the St. Lucie Estuary (see

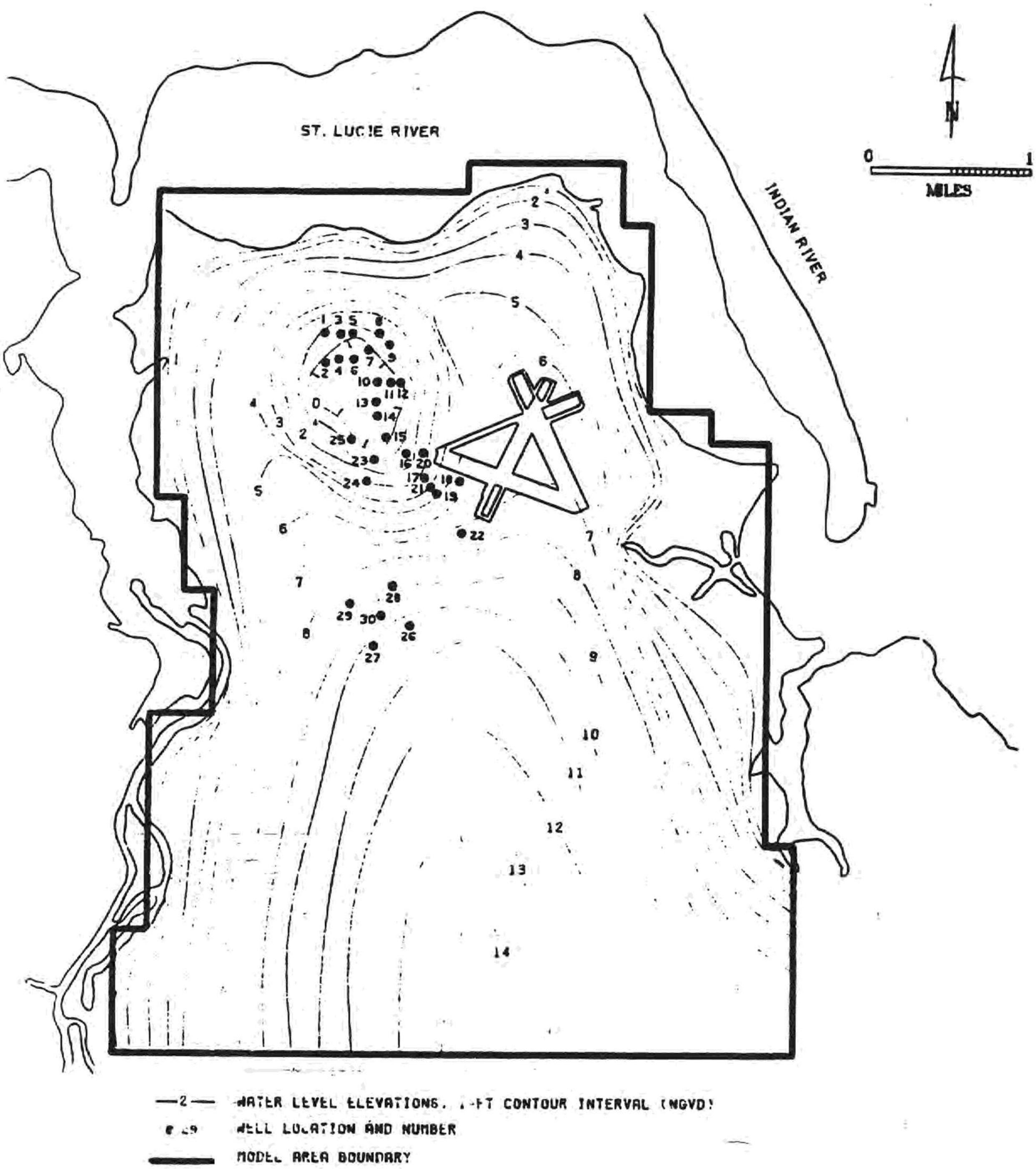


Figure 43 **MODEL CALIBRATED WATER TABLE MAP, CITY OF STUART AREA (DRY SEASON 1978)**

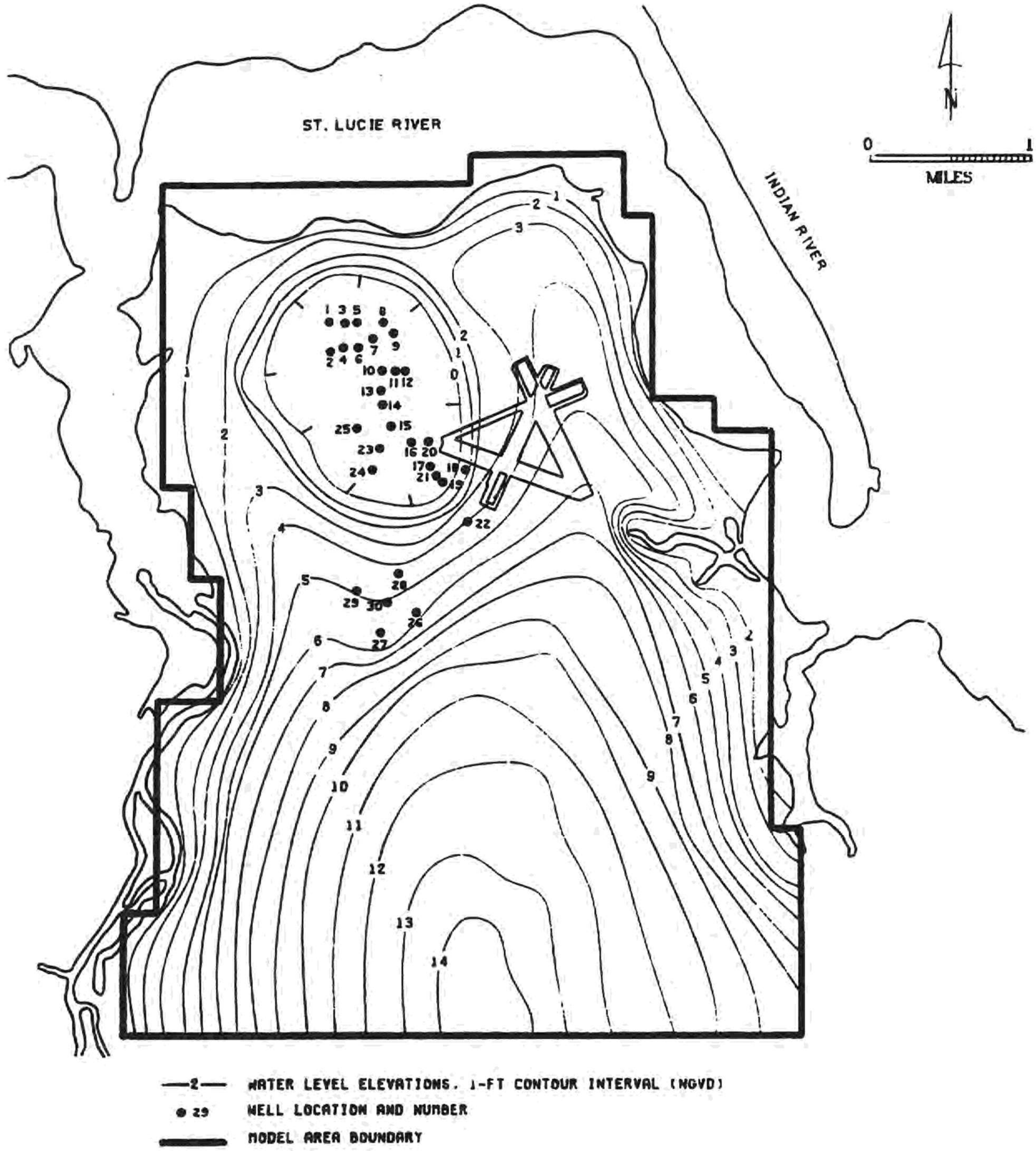


Figure 44 COMPUTED WATER LEVELS UNDER EXISTING COMMITTED PUMPAGE, CITY OF STUART AREA

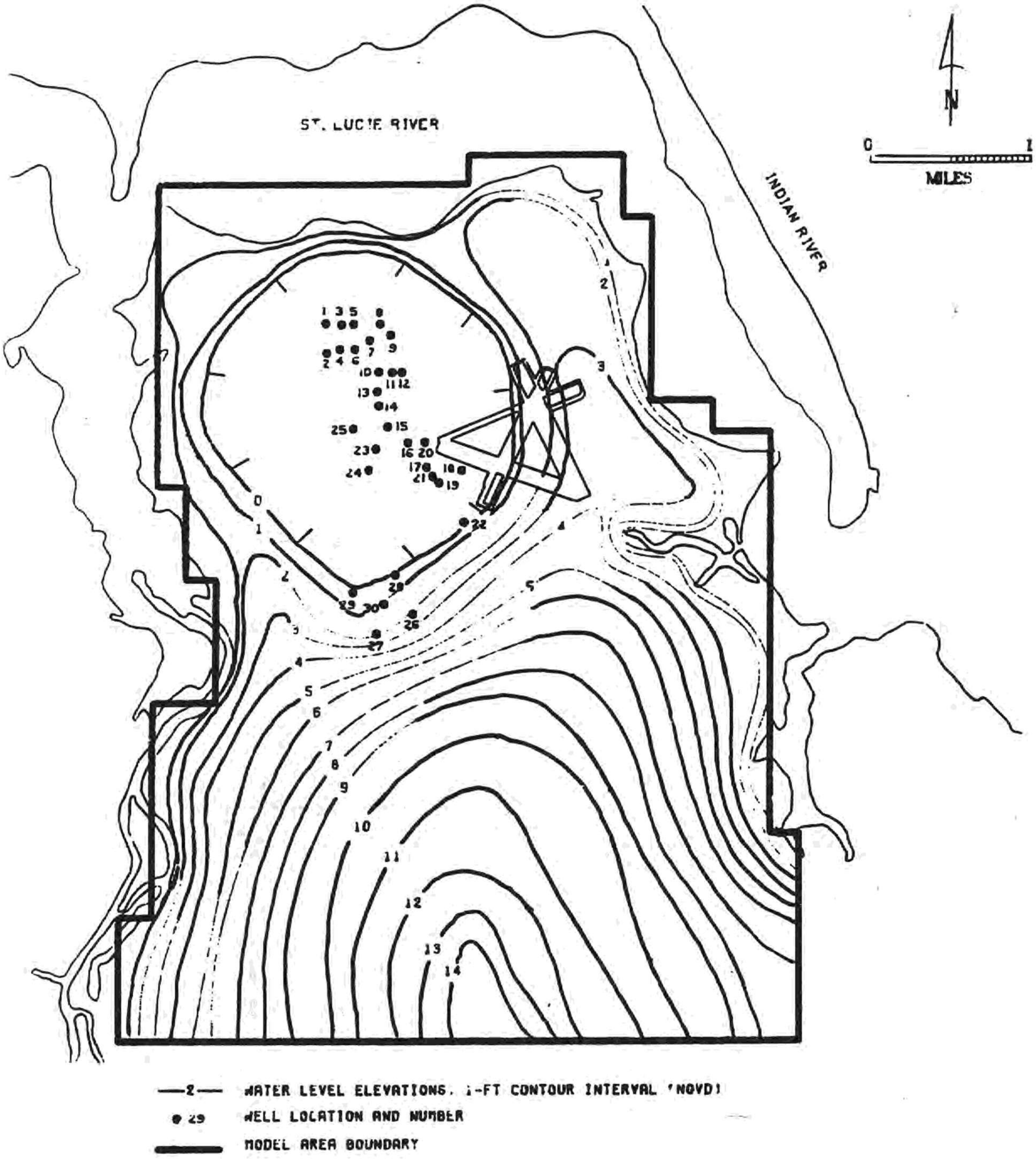


Figure 45 COMPUTED WATER LEVELS UNDER BUILDOUT PUMPAGE, CITY OF STUART AREA

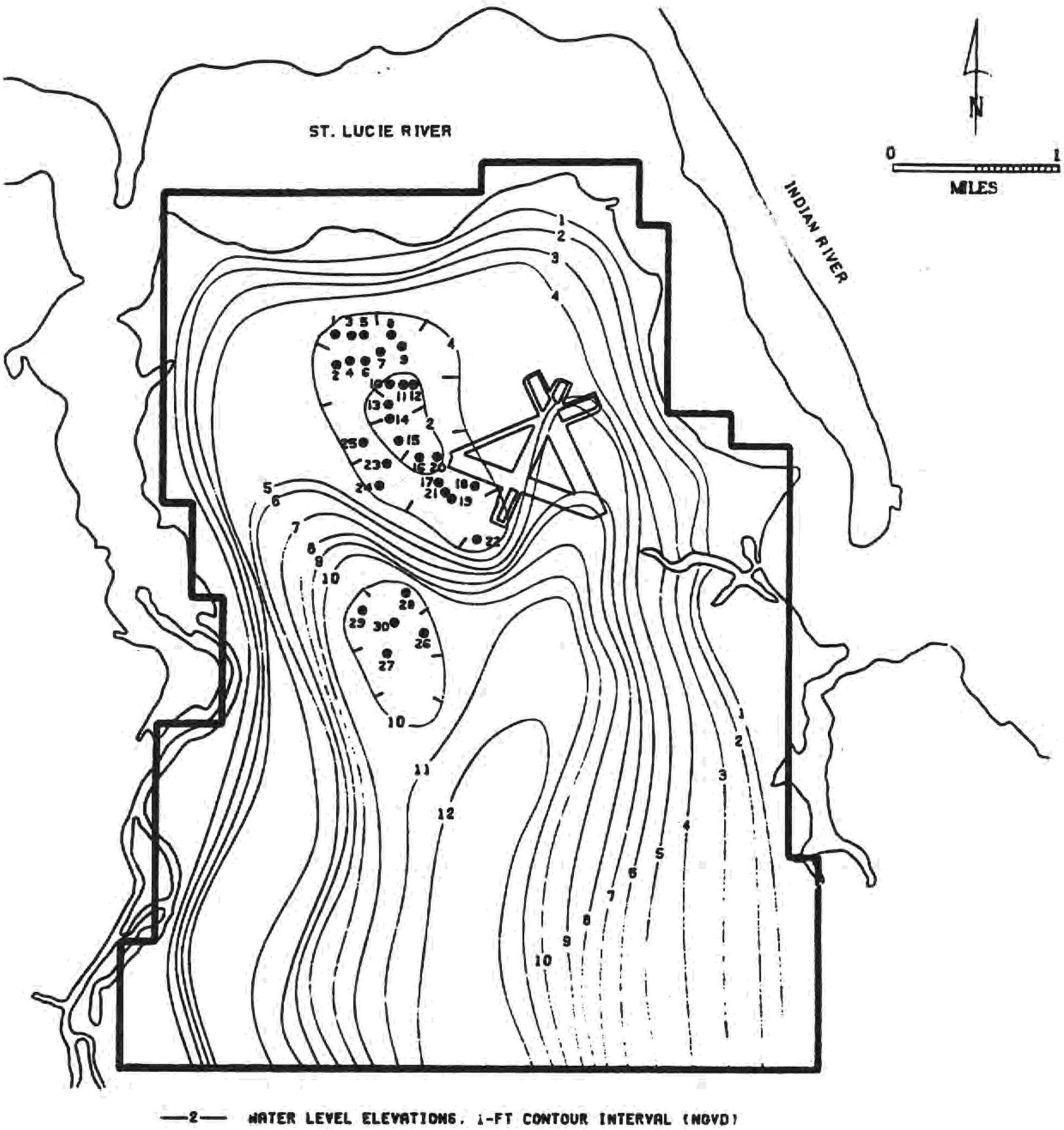


Figure 46 WATER TABLE MAP, CITY OF STUART AREA (MAY 1982)

Figure 42). The two figures indicate that while the amount of water withdrawn from the aquifer is important, the distribution of the withdrawal among the wells is very significant and can be a crucial factor for controlling and abating salt water intrusion.

The existing-committed pumpage of 5.1 MGD was again simulated and this pumpage was unevenly allocated to the 30 wells in order to reflect 1982 conditions. The water demand for the existing-committed scenario is slightly more than the actual maximum day pumpage of 1982. Five wells (wells 26-30) in the southern end of the well field were allocated 30% of the total water demand, and the remaining 25 wells received 70% of the 5.1 MGD pumpage. The resulting cone of depression due to this non-uniform distribution of the pumpage is shown in Figure 47. The computed water levels for this scenario also illustrate two cones of depression, which is the case for the 1982 actual water table conditions. In addition, the computed water levels between the cone of depression and the St. Lucie Estuary are higher than those computed in the scenario employing the equivalent pumpage but uniformly distributing it among all of the wells.

The model indicates the general hydrogeologic conditions within the Stuart well field. However, the operation records of each well should be made available for future modeling endeavors. Such information would include the quantity of water pumped per well and the duration of withdrawal. In this manner, the well field could be modeled more realistically.

North Martin County Well field

The county-wide water resource assessment suggests that the existing-committed and buildout water demands may result in salt water intrusion as well as have detrimental environmental impacts. The potential of salt water intrusion was again simply analyzed by comparing the computed water levels with those necessary to maintain seawater at the base of the aquifer according to the Ghyben-Herzberg equation. The environmental impacts considered were those effects which the well field withdrawal may have on the wetlands within the area. Since the withdrawal of water results in lowering the water elevation, the effects of lowering water levels within wetland areas could be significant. Water depths within wetlands seldom exceed one foot; therefore, if the well field induces a water level decline of 0.1 foot in the wetlands, the water depth would be reduced by 10%. Subsequently, this could reduce the surface area of the wetland by 10% due to the lack of relief (Personal Communication, Helfferich, 1985). Maintenance of water levels in the wetlands are required to support the flora and fauna indigenous to these areas. Consequently, well field withdrawals could seriously impact this ecological system. An attempt to simulate those effects is considered in a following scenario.

The north Martin County well field was modeled with a finer grid system to provide better resolution. Again, the U. S. Geological Survey's two- dimensional model was used and the input data was that used in the county-wide model. In addition, the rainfall and evapotranspiration represent a normal dry season of 22 and 33 inches, respectively.

The model consisted of 40 grid blocks in the north-south direction and 50 grid blocks in the east-west direction. The nodal spacing within each grid block was 500 feet. A constant head of 0 ft msl was placed along the model boundaries for the Intracoastal Waterway and the St. Lucie Estuary. The constant head was set at one foot above sea level for the North Fork of the St. Lucie River. Actual water table elevations were used to represent the constant head boundary at the northern and northwest model borders. The northern and northwest boundaries recharge the simulated area continuously due to the scheme employed in the model. Therefore, the ground water flow scheme employed was considered a limitation of the model, since it could recharge the aquifer excessively. The existing and proposed well locations for the modeled area are shown in Figure 48.

The actual water table elevation for 1984 mid dry season is shown in Figure 49. Ground water flows mainly to the south and radiates to both the east and west. The calibrated model also reflects these ground water conditions for this period (see Figure 50). At that time, the north Martin County well field was operating eight wells (designated as wells A through H on Figure 48) which were withdrawing approximately one million gallons per day. This pumpage was evenly distributed among the existing wells. The computed water level decline ranged between 3.6 and 7.0 feet at the individual wells. Within the 500 square foot grid block the average drawdown did not exceed one foot; therefore, the calibrated model indicates that the withdrawal of one million gallons per day from the present well field does not significantly impact the Surficial Aquifer System.

The 1983 existing-committed water demand of 4.7 million gallons per day was evenly distributed among the existing wells. Drawdowns at each well due to this pumpage were considerably greater than those computed in the calibrated model in which pumpage was only 1 MGD. The average water decline

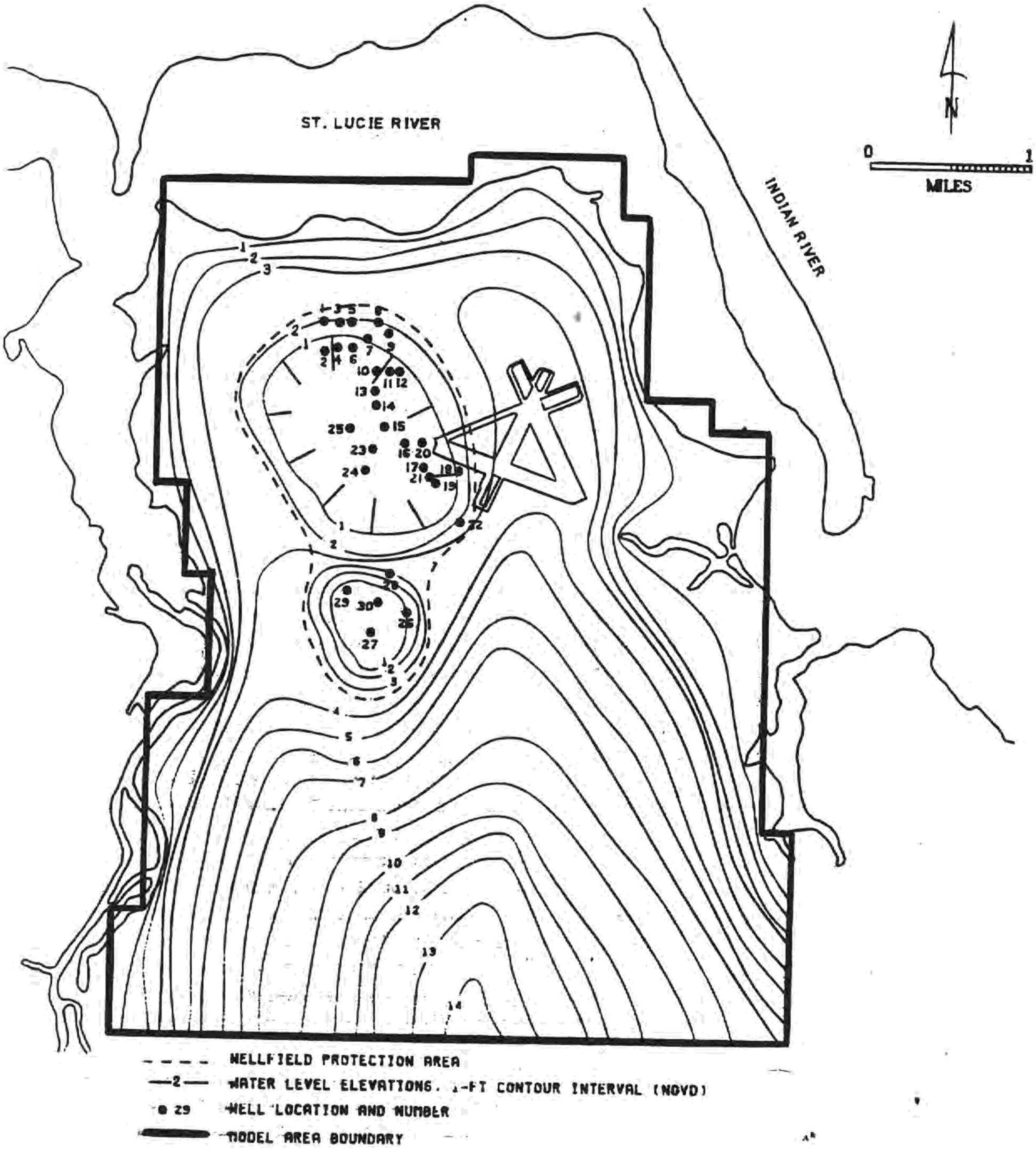


Figure 47 COMPUTED WATER LEVELS UNDER REDISTRIBUTED EXISTING-COMMITTED PUMPAGE, CITY OF STUART AREA

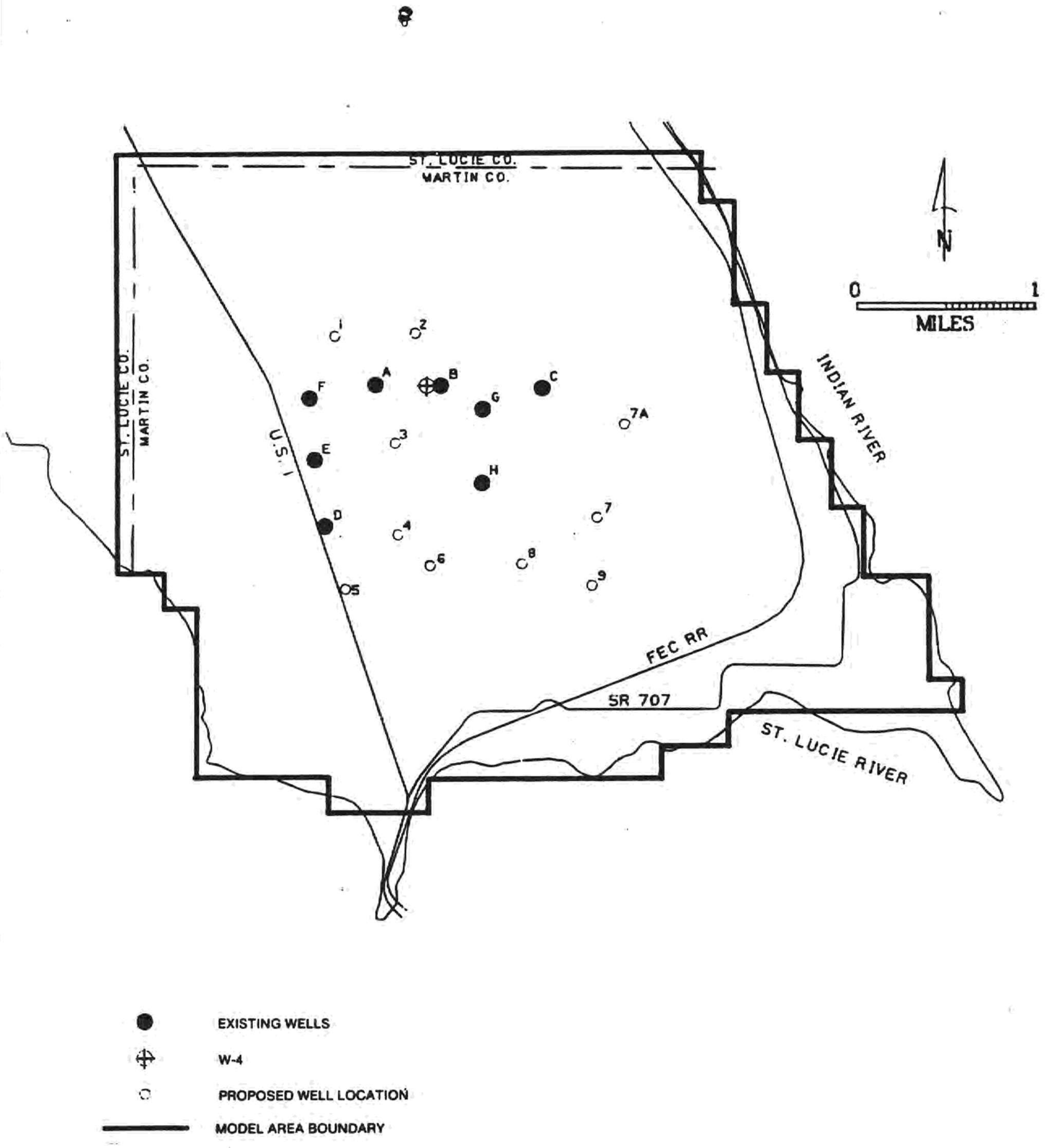


Figure 48 WELL LOCATION MAP OF THE NORTH MARTIN COUNTY WELLFIELD

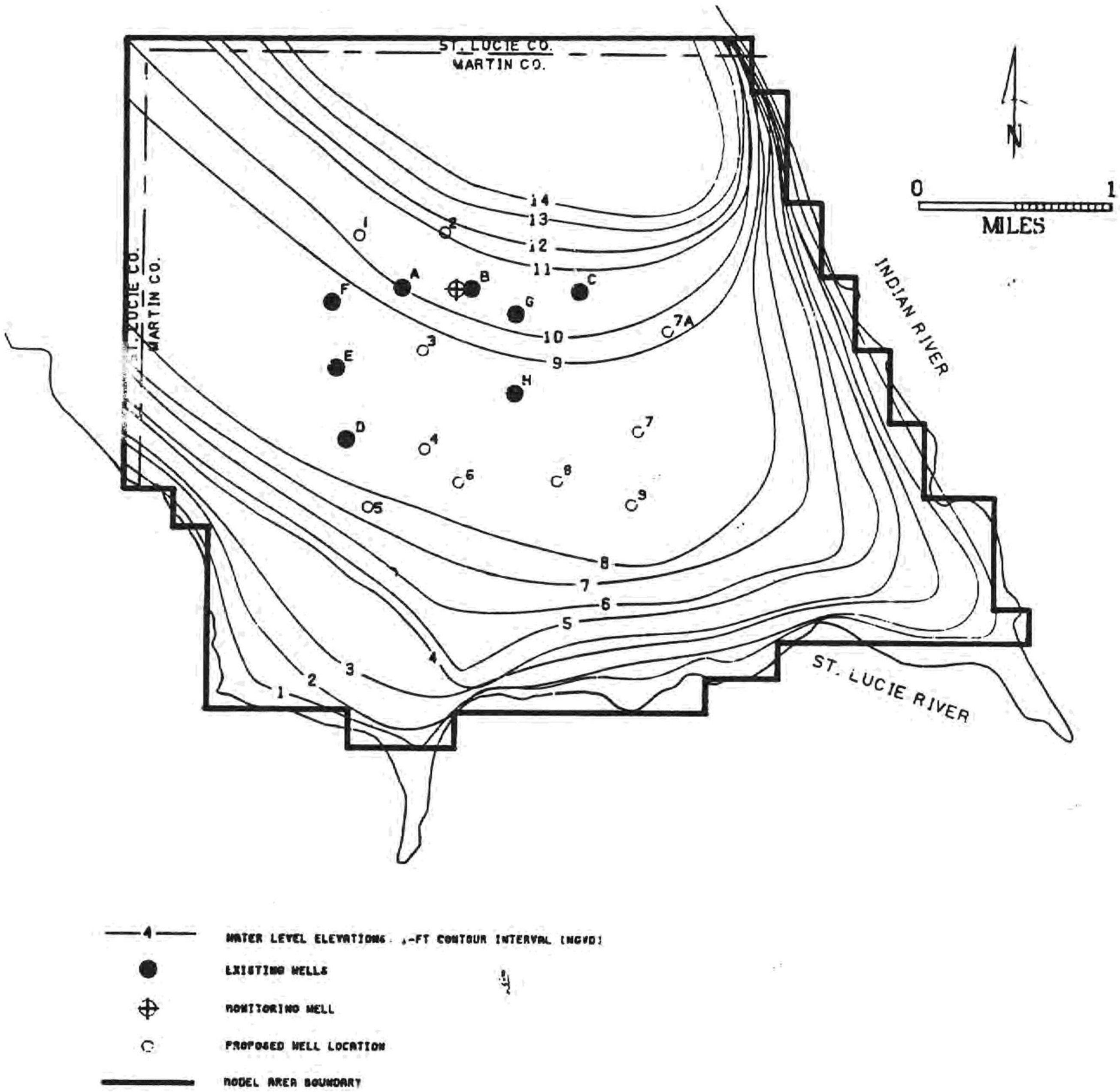


Figure 49 WATER TABLE MAP, NORTH MARTIN COUNTY PENINSULA (1984 MID DRY SEASON)

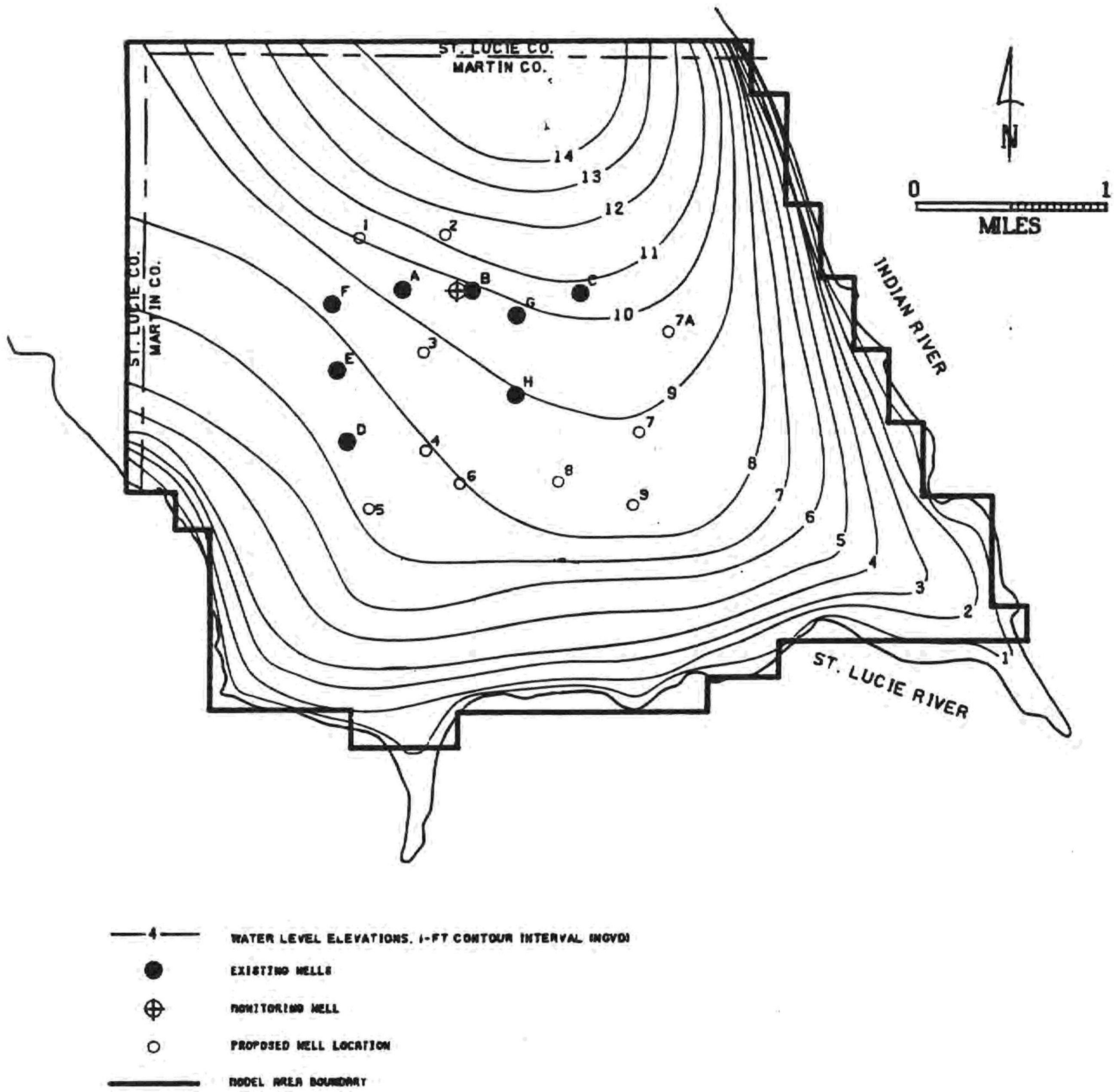


Figure 50 MODEL CALIBRATED WATER TABLE MAP, NORTH MARTIN COUNTY WELLFIELD. (1984 MID DRY SEASON)

per well was approximately 36 feet. The configuration of the cone of depression was that of a semi-circle, which was caused by ground water movement, principally to the south, and also because the orientation of the well field is mainly east-west. The water level declined to elevations at or below mean sea level for an area of approximately 800 acres or 1.25 square miles. Although the expansion of the cone of depression is significant, the computed water levels were maintained high enough to prevent salt water intrusion. However, the effects of the cone of depression on wetlands within the area could be detrimental. Assuming no recharge, water elevations in the wetlands could potentially equilibrate the level of the cone of depression.

Fifteen additional wells have recently been proposed for the north Martin County well field. The proposed well locations are shown in Figure 48. Six proposed wells were incorporated into the model, and the 1983 existing-committed pumpage was allocated to these wells and the existing wells. Of these 14 wells the average water decline per well was 21 feet. Although the cone of depression encompassed approximately the same area as that of the previous scenario, it was not as deep. (Even though the water withdrawals are the same in both scenarios, incorporating additional wells into the model subsequently enlarges the well field which results in a more shallow cone of depression.) Table 13 depicts existing and proposed wells incorporated into the model under varying pumpage scenarios.

An additional four proposed wells were then input to the model, bringing the total number of wells simulated to 18. Again, the existing and committed water demand of 4.7 million gallons per day was uniformly distributed among these wells (Table 13). The average water decline at the wells was 15.5 feet, which is less than half of that computed for the eight existing wells withdrawing this demand. The cone of depression is broad due to the enlargement of the wellfield, however, it remained shallow in comparison to the previous scenarios.

Within a 500 by 500 square foot grid block the average computed water table elevation under existing and committed pumpage at the 18 wells was no more than two feet below sea level (see Figure 51). This maximum decline in the water table corresponds to a drawdown of approximately 11 feet for the grid block. Within the northern peninsula, the Surficial Aquifer System is approximately 160 feet thick. According to the Ghyben - Herzberg equation, the

TABLE 13. WELLS INCORPORATED INTO EXISTING-COMMITTED AND BUILDOUT PUMPAGE SCENARIOS AT NORTH MARTIN COUNTY WELL FIELD

Scenarios Utilizing 14 Pumping Wells:

Existing Wells		Proposed Well Number	
A	E	1	7A
B	F	2	7
C	G	3	
D	H	4	

Existing-Committed pumping rate per well = 0.34 MGD (0.53 cfs)
Buildout pumpage rate per well = 0.81 MGD (1.26 cfs)

Scenarios Utilizing 18 Pumping Wells:

Existing Wells		Proposed Well Number	
A	E	1	6
B	F	2	7
C	G	3	7A
D	H	4	8
		5	9

Existing-Committed pumping rate per well = 0.26 MGD (0.40 cfs)
Buildout pumpage rate per well = 0.63 MGD (0.98 cfs)

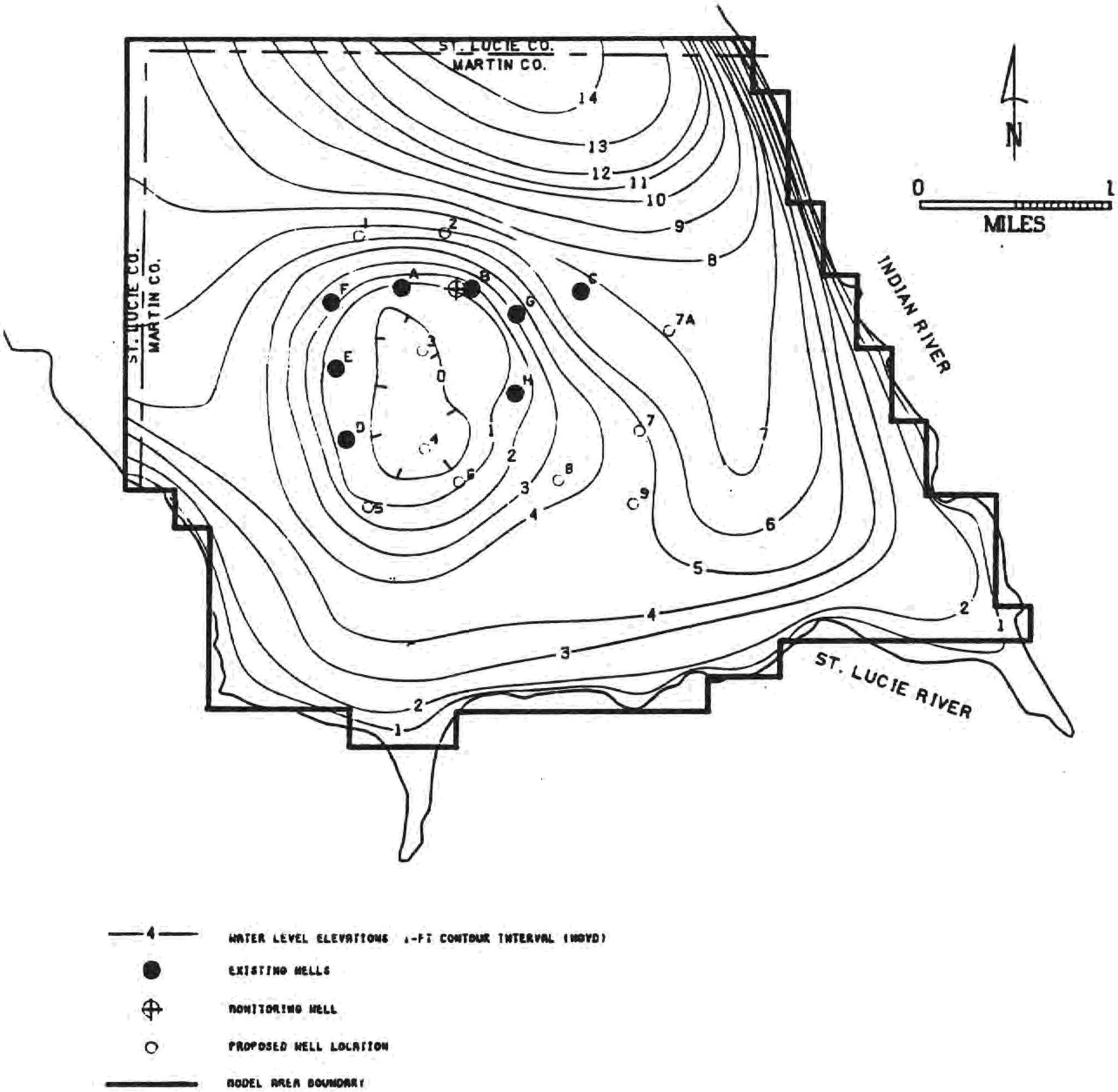


Figure 51 COMPUTED WATER LEVELS UNDER EXISTING AND COMMITTED PUMPAGE FROM 18 WELLS, NORTH MARTIN COUNTY WELLFIELD

minimum water elevation required to prevent salt water intrusion is, therefore, 4 feet above mean sea level. This minimum water table elevation appears to be maintained when the 18 wells are withdrawing only 4.7 MGD. However, the model indicates that increasing the pumpage to 5 million gallons per day and distributing the withdrawal among the 18 wells would not prevent salt water intrusion.

Wetlands inside or within the reach of the cone of depression may be affected by withdrawing the existing and committed pumpage of 4.7 MGD at the north Martin County well field. Figure 52 depicts the wetlands in the vicinity of the well field. Insufficient recharge to the wetlands and aquifer could result in identical water levels of both systems.

The buildout water demand was estimated to be 11.6 million gallons per day. This withdrawal is substantial in comparison to the 1983 existing-committed pumpage. The buildout water demand was allocated to the existing wells, and computed water levels indicated that the Surficial aquifer could not supply such a large quantity of water when utilizing only eight wells. In addition, since the computed water levels had declined below the well casing, such a condition would render the wells inoperable.

The withdrawal of 11.6 million gallons per day was distributed to the existing wells plus six of the proposed wells (Table 13). An average computed water decline at each well was 80 feet or approximately 70 feet below sea level. The maximum drawdown per grid block of 500 square feet was almost 60 feet. Between the cone of depression and the salt water of the St. Lucie Estuary the computed water table was at most only 2 feet above mean sea level. The model indicates that operating 14 wells at this pumpage may invite salt water intrusion. In addition, the wetlands within the vicinity of the well field would certainly be impacted.

The buildout pumpage was then uniformly distributed to ten of the proposed wells and also to the eight existing wells. Again, due to the enlargement of the well field, the cone of depression was broader but also shallower. The average computed water decline was 60 feet per well. More importantly, due to the expansion of the cone of depression, it extended into the St. Lucie Estuary. Therefore, this scenario indicates that salt water intrusion would be inevitable.

The model illustrates that the existing well field and a water demand of one million gallons per day does not significantly affect the Surficial Aquifer System. The 1983 existing-committed water demand of 4.7 million gallons per day may best be met by enlarging the well field to 18 wells. It would appear that by expanding the well field the water table would remain at the required elevation necessary to prevent salt water intrusion. However, the cone of depression would probably have detrimental effects on the wetlands within the area, especially in absence of recharge. Scenarios representing the buildout water demand of 11.6 million gallons per day imply that the Surficial aquifer cannot supply this quantity of water within the north peninsula area. Such a withdrawal would invite salt water intrusion and also seriously impact the environment in wetland areas.

Since the existing-committed and buildout pumpage are estimates, the model was employed to simulate the design capacity of the well field. Currently, the water treatment plant is designed, at maximum, to process approximately 3.8 MGD. This quantity was uniformly distributed among the 18 wells listed in Table 12. The water declines or drawdowns at the individual wells ranged from 10 to 14.5 feet. The cone of depression at or below sea level encompassed an area of approximately 23 acres, and the maximum drawdown per grid block was 8 feet. In addition, the computed water levels were at an elevation high enough to prevent salt water intrusion. Figure 53 illustrates the computed water table elevation for this scenario. The model indicates, as expected, that the water withdrawal of 3.8 MGD would have fewer detrimental effects than either the existing-committed or buildout water demands. The scenario indicates that while salt water intrusion may be prevented, the degree to which the wetlands would be impacted is not precisely known. Also shown in Figure 53 is the well field protection area which is discussed in detail in a following section.

The wetlands within the vicinity of the north Martin County well field were mapped and are illustrated in Figure 52. Water accumulates within the wetland because the soil is less permeable or a hardpan underlies the wetland and retards the downward percolation of water. However, if the water table is significantly depressed, water within the wetlands can infiltrate to the underlying aquifer. The aquifer and the wetlands can be viewed as a two layer system, an upper layer of less permeable material which impedes ground water flow and a bottom layer of permeable material which composes the aquifer. For purposes of water withdrawals, wells penetrate the more permeable lithology of the aquifer. The hydrographs illustrated in Figure 19 for wells W-4A and W-4B indicate the effects of the two layer system in the north Martin County well field area. The deeper well (W-4A) has a lower water elevation than that of the shallow well (W-4B). The lower water level

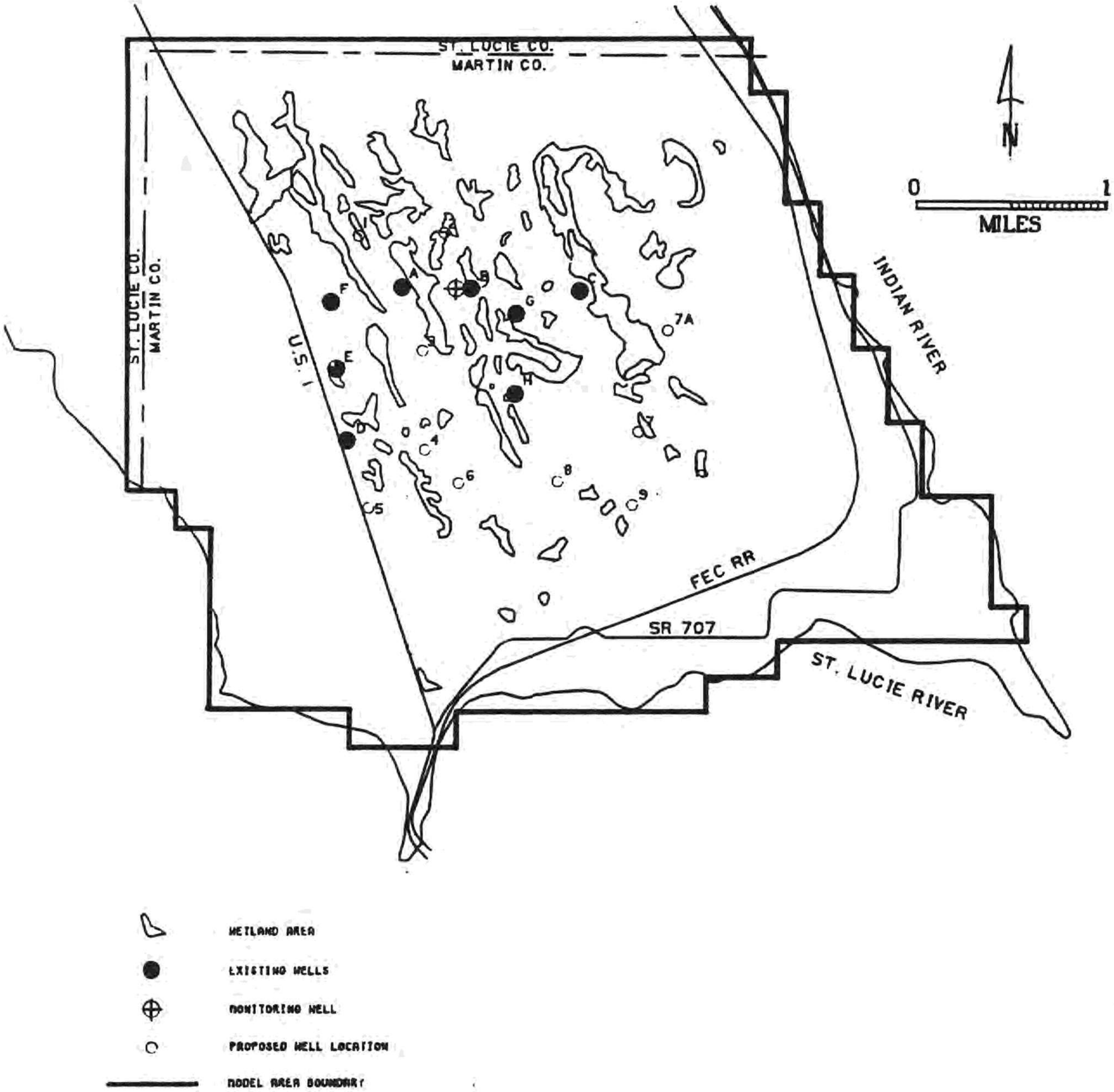


Figure 52 WETLANDS IN THE VICINITY OF THE NORTH MARTIN COUNTY WELLFIELD

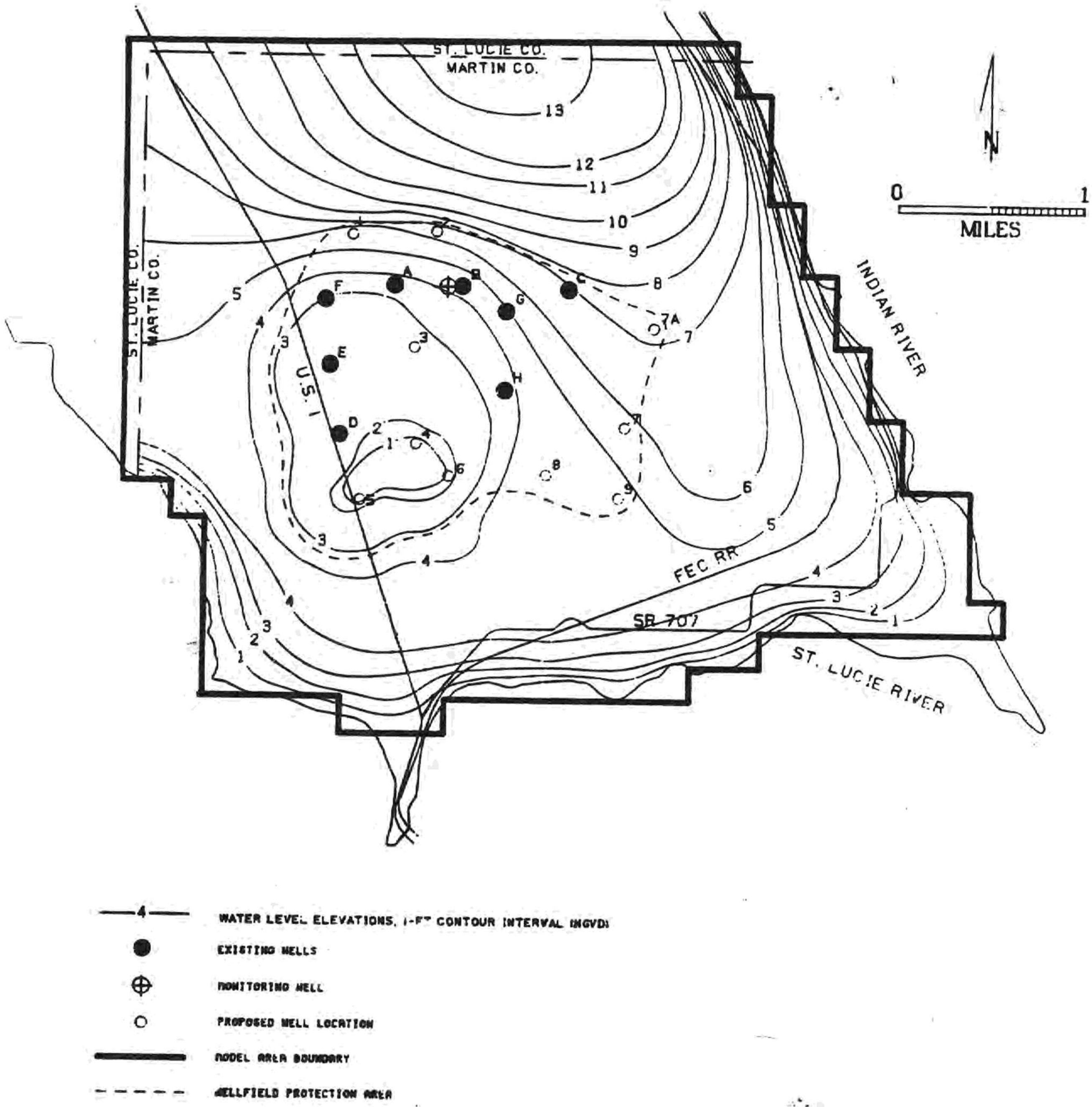


Figure 53 **COMPUTED WATER LEVELS FROM 18 WELLS AT CURRENT WATER PLANT CAPACITY FOR NORTH MARTIN COUNTY WELLFIELD WITH WELLFIELD PROTECTION AREA, MARTIN COUNTY**

in the deep well is probably due in part to the well field pumping within this zone. The shallow well has a higher water elevation and is not immediately affected by the withdrawals of the well field. However, the water elevation of the shallow well converges with that of the deep well as time passes (see Figure 19) as a result of the well field pumpages. This same effect of declining water elevations could occur in wetland areas in the vicinity of the well field. The location of well W-4 is shown in Figure 48.

In order to assess the well field withdrawals on the wetlands, the model was revised. Wetland areas were incorporated into the model and the original permeability of these areas was decreased by 10% to reflect the low permeability of the wetlands. The pumpage remained at 3.8 MGD and the same 18 wells were employed in this scenario. Since the permeability of these areas was decreased, the cone of depression expanded and deepened. The cone of depression was at or below sea level for an area of approximately 350 acres, or about 14 times larger than that of the previous scenario. The maximum water decline per grid block was computed to be 11 feet and the drawdown at the wells remained the same as that computed previously. The model indicates that well field withdrawals may seriously impact these wetlands. Assuming no recharge, a continuous withdrawal of this magnitude could potentially lower the water levels of the wetland to those computed. However, the computer model is limited, since the low permeability values assigned to the wetland areas penetrate the full thickness of the aquifer and do not realistically reflect the two layer system as explained. A three-dimensional computer model would be required to analyze this layered system. Therefore, the results of this simulation should be regarded as only an approximation of the impact on wetlands by well field withdrawals. The model indicates that neither scenario, employing a withdrawal of 3.8 MGD allocated uniformly to the 18 wells, would result in salt water intrusion.

As mentioned, a normal dry season rainfall of 22 inches was used in the computer simulations. Under normal dry conditions, the model indicates that a withdrawal of 5 million gallons per day evenly distributed among 18 wells (see Table 12) may not prevent salt water intrusion. However, the existing-committed water demand of 4.7 million gallons per day evenly distributed among the same 18 wells appears to maintain the 4 foot water elevation required to prevent salt water intrusion. Therefore, in order to prevent salt water intrusion during a normal dry season, utilizing this well field configuration, the maximum amount of water available at the north Martin County well field appears to range between 4.7 and 5.0 million gallons per day. This scenario, however, does not consider impacts on wetland areas.

The above water withdrawals could necessitate further reduction during drought conditions in order to prevent salt water intrusion. The occurrence of a 1-in-10 year drought would reduce the rainfall to 16.4 inches during a normal dry season. Subsequently, a reduction in withdrawals from the aquifer would also be required to maintain the water level elevation high enough to prevent salt water intrusion. Under these conditions, a withdrawal of 2 million gallons per day was evenly distributed among the 18 wells (see Table 9). The model indicates that to prevent salt water intrusion during a 1-in-10 year drought the maximum withdrawal may be limited to 2 million gallons per day. Increasing the pumpage over 2 million gallons per day may invite salt water intrusion during a 1-in-10 year drought. The water table and well field configuration for this scenario are shown in Figure 54.

An alternative well field configuration was evaluated to assess the significance of well locations. This configuration is shown in Figure 55 and includes the 8 existing wells along with 10 new potential well sites. The potential well sites were located in the north-central portion of the peninsula in order to take advantage of the higher water table in this area. Since the water table is higher in this area, an increase in available drawdown is also possible. In addition, the constraint of salt water intrusion is not as severe. However, the potential well sites are closer to the constant head boundary incorporated in the model. As mentioned, the constant head continuously supplies recharge to the aquifer. If the potential well sites were located too close to this northern boundary, excessive recharge could occur and the simulation would be unrealistic. Therefore, several configurations were tested until it became obvious that the effects of this recharge boundary were not apparent using the new well field configuration that was eventually selected.

The above 18 wells were simulated under a 1-in-10 year drought condition for a dry season, which is 16.4 inches of rainfall. To prevent salt water intrusion the maximum withdrawal appears to be 4.5 million gallons per day. The maximum computed water level decline at an individual well was 20 feet. The computed water table for this scenario, along with the alternative well field configuration, is shown in Figure 56.

The alternative well field configuration was simulated under the normal dry season rainfall of 22 inches. The model indicates that well field withdrawals could be increased under these conditions

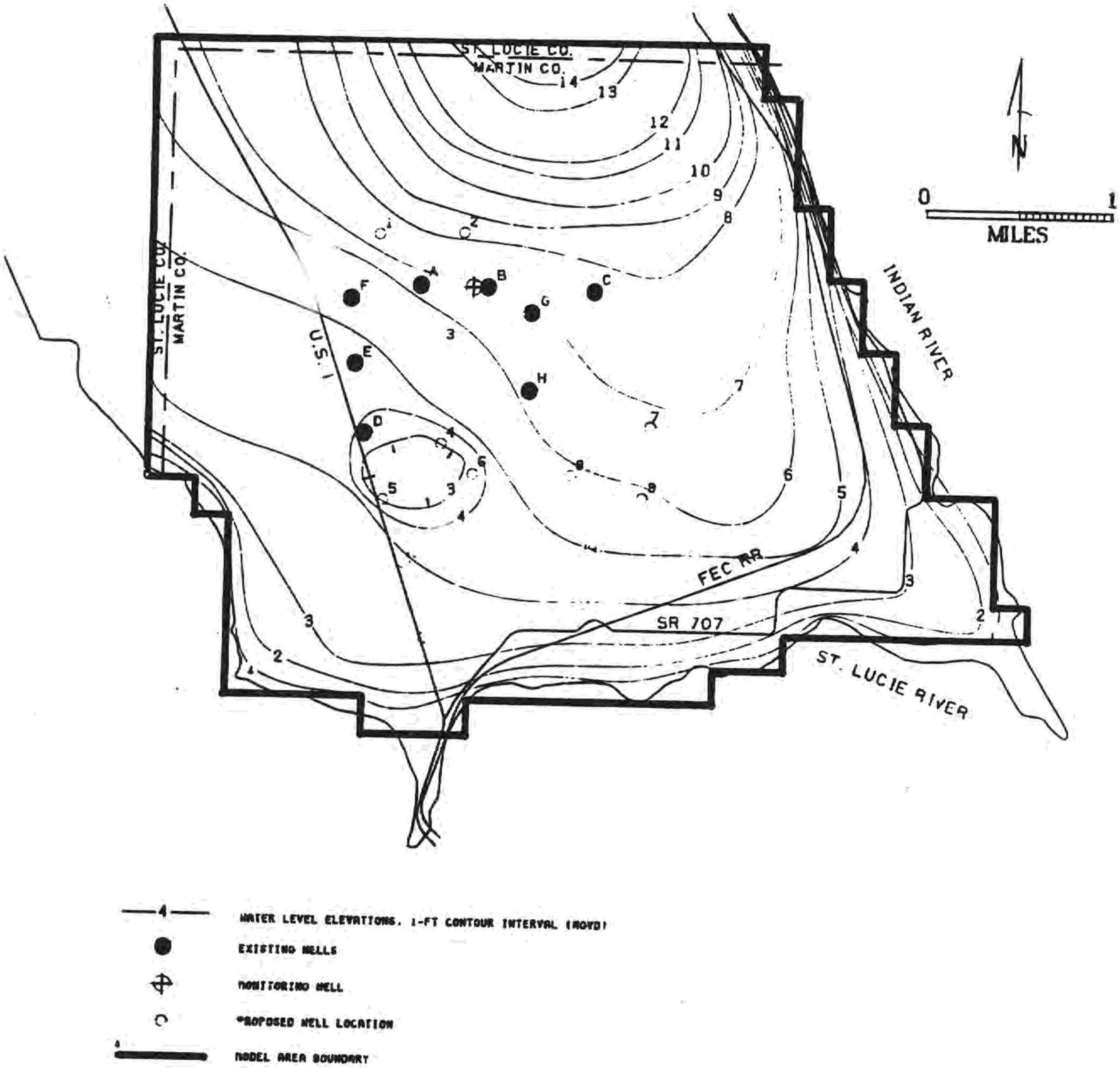


Figure 54 COMPUTED WATER LEVELS UNDER 1-IN-10 YEAR DROUGHT CONDITIONS, LIMITED BY SALTWATER INTRUSION (WITHDRAWAL OF 2 MGD FROM 18 WELLS)

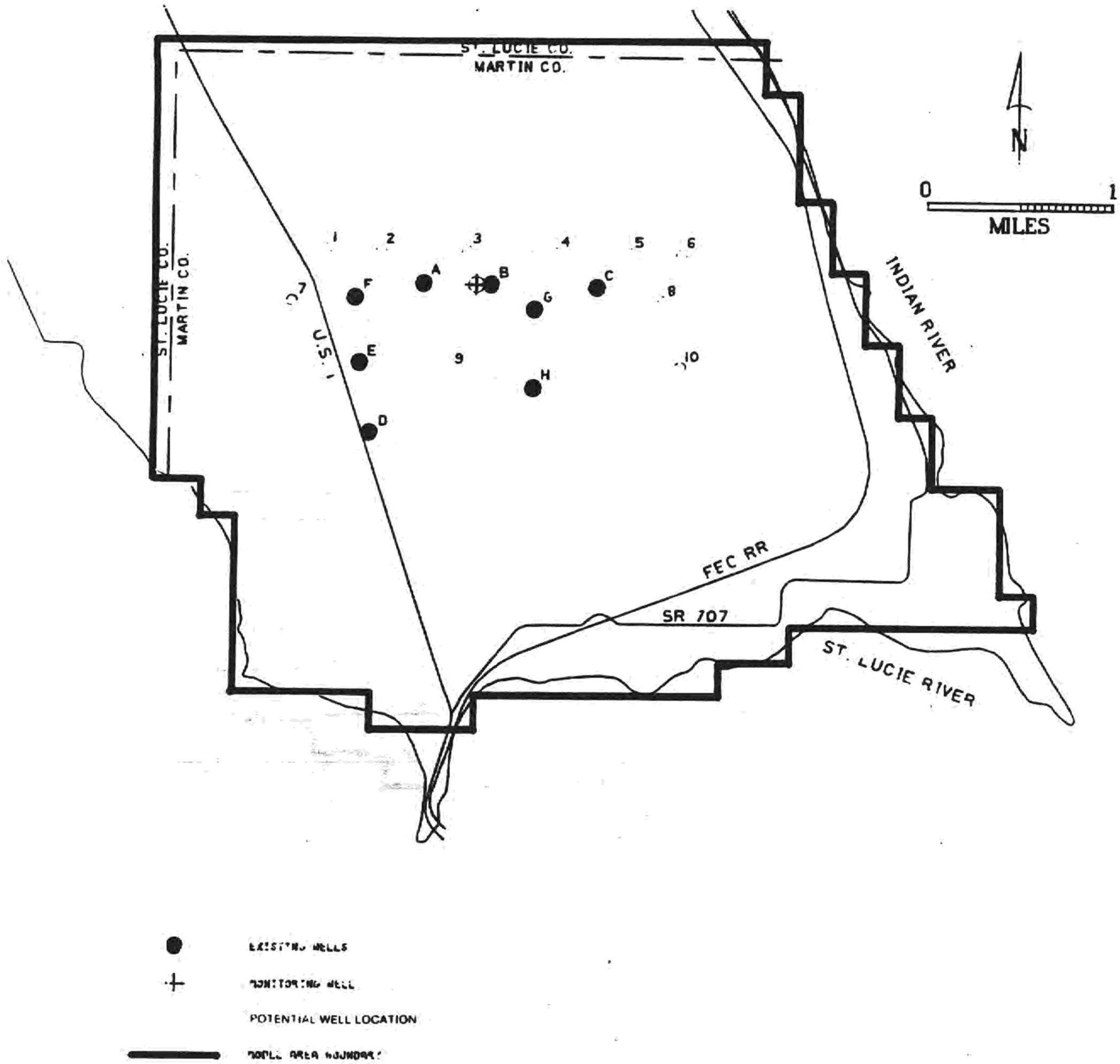


Figure 55 NORTH MARTIN COUNTY WELLFIELD WITH POTENTIAL WELL SITES RELOCATED

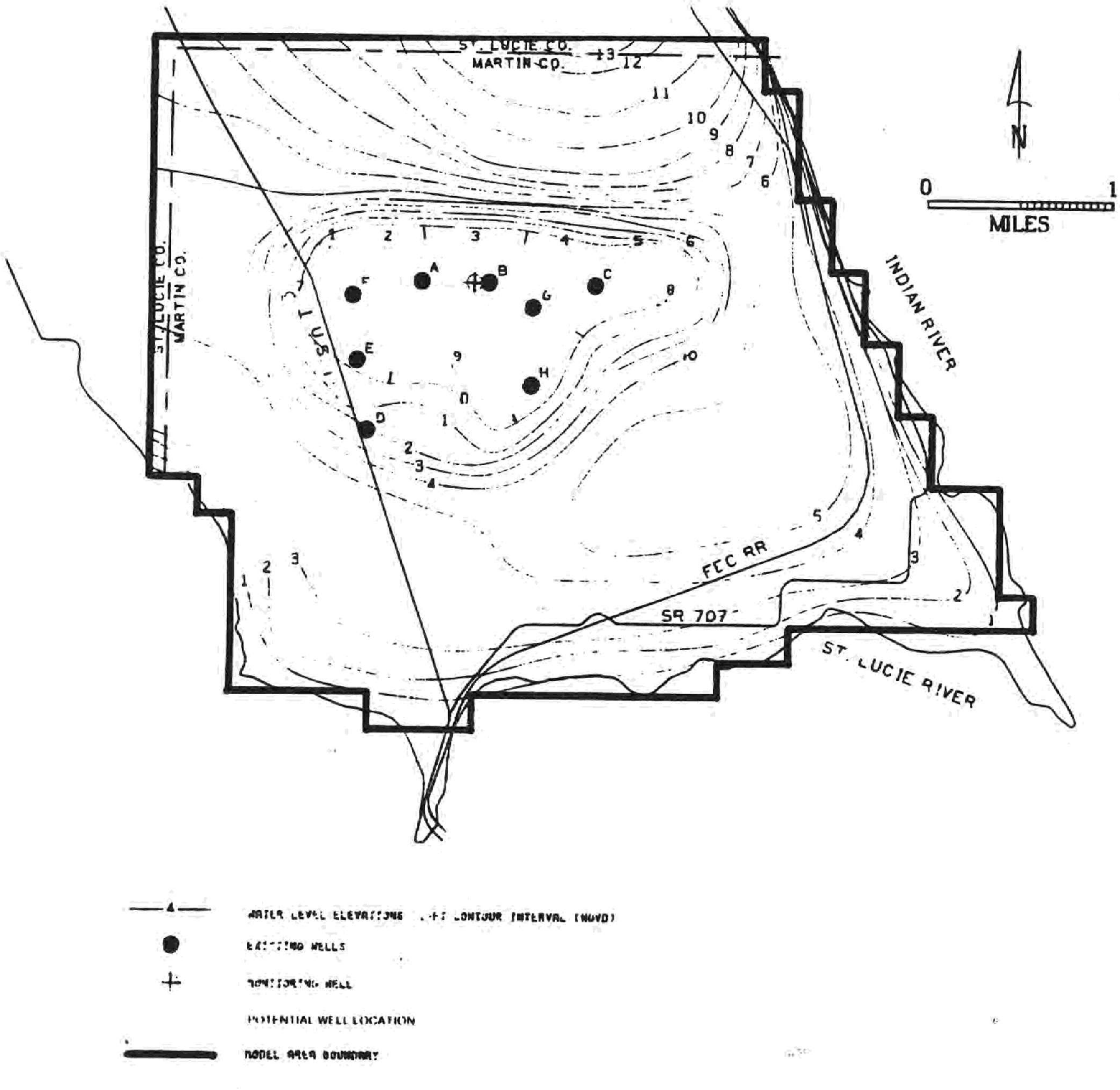


Figure 56 COMPUTED WATER LEVELS UNDER 1 IN 10 YEAR DROUGHT CONDITIONS, LIMITED BY SALTWATER INTRUSION (WITHDRAWAL OF 4.5 MDG WITH POTENTIAL WELL SITES RELOCATED)

and yet prevent salt water intrusion. The maximum withdrawal available, utilizing the new well field configuration and normal dry season conditions, appears to be as much as 7 million gallons per day. Although the shape of the cone of depression is similar to that of the previous scenario of 4.5 million gallons per day under drought conditions, the maximum computed drawdown at a well was 30 feet. The impact of the withdrawals on wetlands was not considered and the withdrawals were limited only by salt water intrusion.

It is evident that the well field configuration is a crucial factor in determining the maximum withdrawal from an aquifer. The configuration presented illustrates one alternative well field orientation. In order to determine the maximum quantity of water available, a thorough site specific study would be mandated to determine an optimal well field configuration. The significant differences in water availability between the existing and proposed well sites and the existing and new potential well sites are shown in Table 14.

Floridan Aquifer System

Introduction

The water resources of the Floridan Aquifer System in the Upper East Coast Planning Area of the SFWMD were assessed through the use of a two dimensional ground water flow model. The Upper East Coast Planning Area includes all of Martin and St. Lucie Counties and the eastern portion of Okeechobee County. The model was calibrated and validated (Trost, 1987, in press) to ascertain that it accurately reflected the hydrogeologic conditions of the Floridan Aquifer System. This ground water flow model was then used to simulate the impacts of various withdrawals from the aquifer system in Martin County.

Due to rapid growth and development in eastern Martin County, it may become necessary to consider the Floridan Aquifer System as a potential source of water supply at some point in the future. At the present time, nearly all of the public water supply well fields in Martin County withdraw water from the Surficial Aquifer System. Water from the Floridan Aquifer System could be utilized to augment the water supply, but the economic impacts will be considerable due to the cost of well construction and desalination.

Water Availability Criterion

The criterion utilized in this study to limit or constrain withdrawals from the Floridan Aquifer System in Martin County was that water levels would not be allowed to drop below land surface. If the water levels in this aquifer system drop below land surface, due to excessive stress on the aquifer from pumpage or prolonged discharge, wells in the area will cease to flow. The current SFWMD management policy for this area does not allow the installation of pumps on wells which penetrate the aquifer in order to regain or augment the natural flow. The intent of this policy is to avoid adverse effects on existing legal users of water from this aquifer system. Excessive pumpage from wells could cause regional and localized water level drawdowns in the Floridan Aquifer System. This condition could force many property owners who currently rely on valved, naturally flowing wells to purchase and install pumps.

Enforcing this water-level criterion as rigidly as possible is also extremely important from an overall water resource management standpoint. All of Martin County is a region of discharge for the Floridan Aquifer System. All water flowing through the aquifer system that is not discharged from wells or lost as diffuse upward leakance through the Hawthorn confining unit eventually discharges into the ocean where the aquifer crops out.

TABLE 14. AVAILABILITY OF GROUNDWATER FROM THE SURFICIAL AQUIFER SYSTEM UNDER VARIOUS DROUGHT FREQUENCIES AND WELLFIELD CONFIGURATIONS NORTH MARTIN COUNTY WELLFIELD*

Wellfield Configuration	Normal Dry Season	1-in-10 Year Drought
8 Existing Wells and 10 Proposed Well Sites	4.7 - 5 MGD	2.0 MGD
8 Existing Wells and 10 New Potential Well Sites	7 MGD	4.5 MGD

*Limited by salt water intrusion, potential impacts on wetlands not addressed

The installation of pumps to achieve greater yields from wells in the coastal portions of Martin County will result in excessive drawdowns of the potentiometric surface of the Floridan Aquifer System. The drawdowns around these well fields would cause localized reversals of the natural hydraulic gradient, and water that would normally discharge to the sea would be captured by man. This natural "front" of water flowing towards the sea must be maintained in order to avoid inland migration of seawater into the Floridan Aquifer System.

Water Resource Assessment

The ground water flow model was used to assess the availability of water from the Floridan Aquifer System in Martin County. The finite difference grid used in the model was superimposed on a map of existing public water supply well fields in Martin County. The well fields were then assigned a node location on the model grid so that the impacts of withdrawals at these well fields could be determined. Each node in the model grid measures two miles on a side. If more than one well field fell into a single node, the total discharge from each well field was assigned to that node.

The existing or committed demands and projected buildout demands for the 17 existing well fields in Martin County are shown on Table 15. The demands for three hypothetical well fields, the New Palm City, New Middle, and New South well fields, are also shown on Table 15. These demands are based on population projections.

Since the water from the Floridan Aquifer System must be desalted, the actual water demands were adjusted to obtain a raw water demand. The raw water demand reflects a recovery efficiency of 70% for a reverse osmosis plant (Khanal, 1980). However, higher efficiencies may be possible.

A simulation was performed utilizing the existing and committed raw water demand for each of the 20 well fields. The resulting drawdowns were excessive in coastal Martin County, in particular in

TABLE 15. WATER DEMANDS FROM PUBLIC WATER SUPPLY WELL FIELDS IN MARTIN COUNTY

WELLFIELD	EXISTING & COMMITTED DEMANDS (MGD) Actual	EXISTING & COMMITTED DEMANDS (MGD) Raw Water*	PROJECTED BUILDOUT DEMANDS (MGD) Actual	PROJECTED BUILDOUT DEMANDS (MGD) Raw Water*
North Martin County	4.7	6.70	11.6	16.60
Oz Development Corp.[1]	0.1	0.14	0.1	0.14
Ocean Breeze Park[2]	0.1	0.14	0.1	0.14
Pinelake Village	0.2	0.30	0.2	0.30
Southern States Utilities	0.9	1.30	0.9	1.30
River Club	0.1	0.14	0.1	0.14
St. Lucie Falls Devel. Corp.	0.5	0.70	2.1	3.00
Martin Downs	2.0	2.90	2.7	3.90
City of Stuart	5.1	7.30	6.9	9.90
New Palm City	1.6	2.30	7.8	11.10
Banyan Bay	0.4	0.60	0.4	0.60
Miles Grant Country Club[3]	0.3	0.40	0.3	0.40
Intracoastal Utilities	2.1	3.00	4.9	7.00
New Middle	0.1	0.14	5.0	7.10
Hydratech Utilities	2.1	3.00	4.9	7.00
Piper's Landing	0.1	0.14	0.1	0.14
Indiantown Co.	1.4	2.00	7.2	10.30
New South	0.6	0.90	1.5	2.10
Hobe Sound	0.2	0.30	1.1	1.60
FM Water Co. - Tequesta[2]	0.2	0.30	0.2	0.30

*Amount of raw water required to meet actual demands due to 70% recovery efficiency of reverse osmosis plants.
1. Re-named Beacon 21
2. No longer active
3. Re-named Utilities, Inc.

the north Martin County peninsula and the Stuart area. Drawdowns measured over 78 feet and 100 feet, respectively, in these areas. The high drawdowns in these areas are due to the low transmissivity and storativity of the Floridan Aquifer System in the coastal part of Martin County.

The initial model simulation indicated that the Floridan Aquifer System alone cannot meet the existing and committed demands. However, the aquifer could be used to augment ground water supplied from the Surficial Aquifer System. Subsequent model runs entailed adjusting the discharges at each of the well fields until an optimal head distribution was attained in the Floridan Aquifer System. This optimal head distribution was obtained when the maximum possible amount of water was withdrawn from each well field and water levels did not drop below land surface anywhere in eastern Martin County.

The maximum amounts of raw water from the Floridan Aquifer System that can be withdrawn from each well field are shown on Table 16. The raw water yields were then adjusted to show the amount of desalted water available. The percent of committed and buildout demands that can be met at each of the well fields is also tabulated. This information is also depicted graphically in Figure 57.

According to the results of the model simulations, the total committed and buildout water demands of several of the smaller well fields in Martin County can be met from the Floridan Aquifer System. These well fields include the Oz Development Corporation, Ocean Breeze Park, Banyan Bay, Miles Grant Country Club, Piper's Landing, and the FM Water Company of Tequesta. It should be noted, however, that Ocean Breeze Park and FM Water Company are now inactive well fields.

A substantial percentage (nearly 75%) of committed and buildout demands can be obtained from the Floridan Aquifer System at the Pinelake Village, Southern States Utilities, and River Club well fields.

TABLE 16. AVAILABILITY OF WATER AND PERCENT OF DEMAND THAT CAN BE SUPPLIED BY THE FLORIDAN AQUIFER SYSTEM IN MARTIN COUNTY

WELL FIELD	RAW WATER (MGD)	DESALTED WATER (MGD)	% OF DEMAND SUPPLIED* Existing	Buildout
North Martin County	1.97	1.38	29	12
Oz Development Corp.[1]	0.14	0.10	100	100
Ocean Breeze Park[2]	0.16	0.11	100	100
Pinelake Village	0.22	0.15	74	74
Southern States Utilities	0.97	0.68	75	75
River Club	0.10	0.07	73	73
St. Lucie Falls Devel. Corp.	0.70	0.50	100	23
Martin Downs	1.45	1.02	50	37
City of Stuart	1.49	1.04	20	15
New Palm City	.68	.48	30	6
Banyan Bay	0.60	0.40	100	100
Miles Grant Country Club[3]	0.40	0.30	100	100
Intracoastal Utilities	0.97	0.68	32	14
New Middle	0.14	0.10	100	2
Hydratech Utilities	1.13	0.79	38	16
Piper's Landing	0.14	0.10	100	100
Indiantown Co.	3.04	2.13	152	30
New South	0.90	0.60	100	43
Hobe Sound	0.39	0.27	130	19
FM Water Co. - Tequesta[2]	0.30	0.20	100	100

* Percent demand rounded up to nearest whole number.
1. Re-named Beacon 21
2. No longer active
3. Re-named Utilities, Inc.

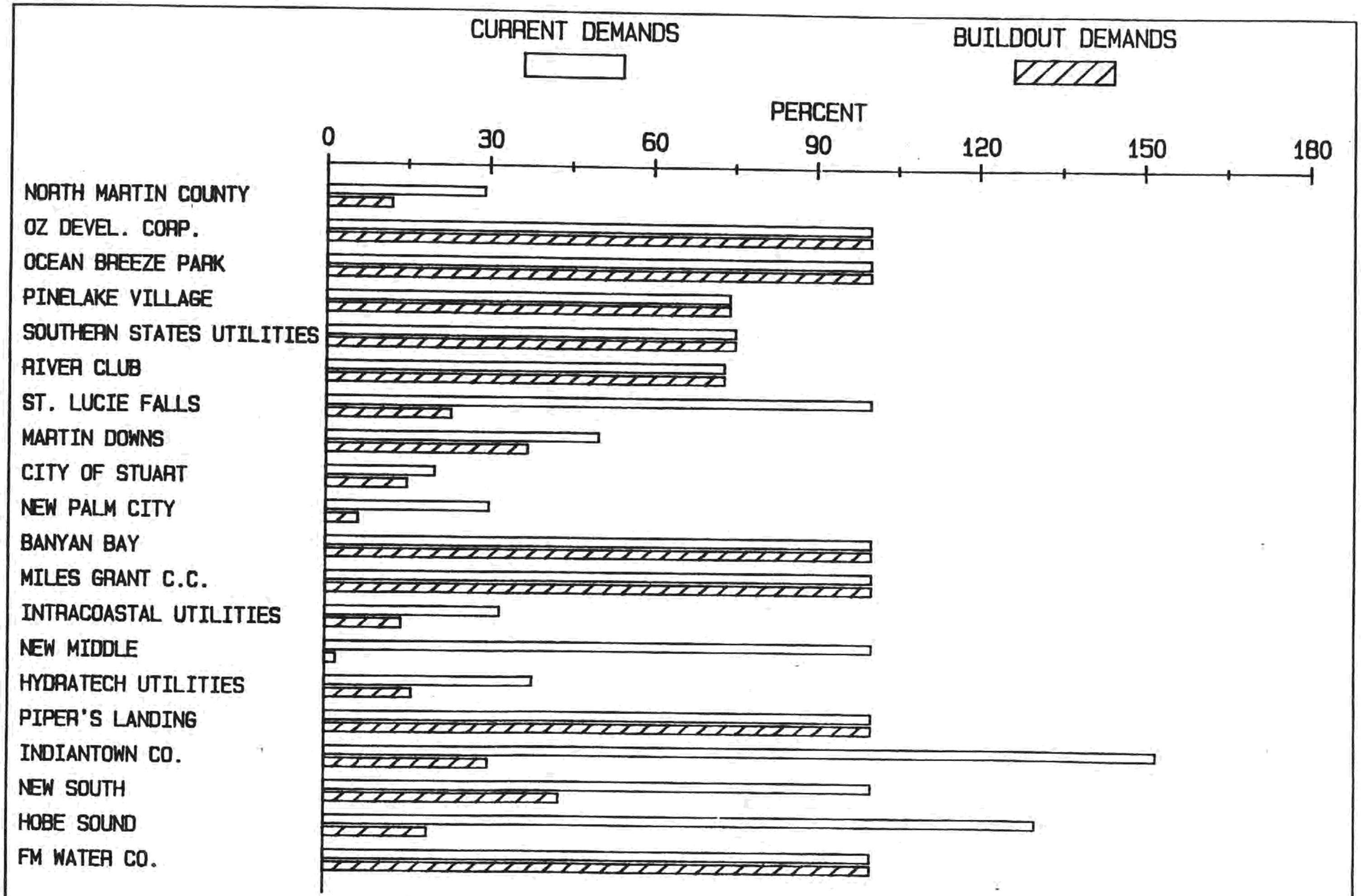


Figure 57 THE PERCENT OF DEMAND THAT CAN BE SUPPLIED BY THE FLORIDAN AQUIFER SYSTEM AT MARTIN COUNTY WELLFIELDS

There are several well fields where less than 30 percent of committed and less than 15 percent of buildout demands can be met. These include the north Martin County, Stuart, and New Palm City well fields. Decreased water availability at these locations may prove to be more critical at the north Martin County and Stuart well fields, since these well fields serve the two major population centers in the county.

The model simulations indicate that approximately 2.6 MGD of raw water can be withdrawn from the Floridan Aquifer System in the north Martin County area. About 1.97 MGD of this total amount can be obtained from the north Martin County well field. The remaining 0.63 MGD can be withdrawn from the Pinelake Village, Southern States Utilities, Oz Development, and River Club well fields in the surrounding areas. Approximately 2.3 MGD can be withdrawn from the Floridan Aquifer System at the Stuart well field.

A computer program was written to determine the availability of ground water from the Floridan Aquifer System if wells were evenly distributed geographically over large sub-regions within Martin County (Trost, 1987, in press). Figure 58 depicts these subregions and the amount of water that can be withdrawn from each 2 X 2 mile block within the subregions as well as the total amount of water available in each subregion. The effects of well interference due to expanding cones of depression are taken into account in these estimates of water availability. The amount of water available is limited by the criterion that water levels are not permitted to drop below land surface. The amounts of total available water in each of the nine blocks which cover the Martin County area have been adjusted in areas with large surface water bodies (blocks 1 and 5).

The maximum withdrawal rates for each 2X2 mile block shown on Figure 58 represents the availability of water if the withdrawals are evenly spaced within each four square mile block over the total subregion. This withdrawal rate is usually less than the maximum rates per well field determined in the model simulation as shown on Table 16. The rates available at each nodal block (well field location) in the model simulation are higher because the only stresses upon the aquifer system are reflected at the grid blocks where a well field is located. Hence, more water is available at an individual node if there are no well fields placed in the surrounding area.

Discussion of Model Results

Ground water from the Floridan Aquifer System can be utilized to augment water obtained from the Surficial Aquifer System to meet buildout water demands of Martin County; however, ground water from this aquifer system is saline and will require treatment to attain potable standards.

A total of 15.9 MGD of raw water or 11.1 MGD of desalted water can be obtained from the Floridan Aquifer System at the existing public water supply well field locations in Martin County. A total of 1.97 MGD and 2.30 MGD of raw water can be withdrawn from the Floridan Aquifer System at the north Martin County and Stuart well fields, respectively.

If wells penetrating the Floridan Aquifer System were evenly distributed in each four square mile region (2 X 2 mile block) within Martin County, a total of 113 MGD of raw water or 79 MGD of desalted water could be obtained from the aquifer throughout the entire county. This amount of water is constrained by the management criterion that water levels in the aquifer system do not drop below land surface. Water levels in the Floridan Aquifer System should not be allowed to drop below land surface due to possible adverse effects on existing legal water users and the potential of inland migration of seawater into the aquifer system in coastal areas.

WASTEWATER RECLAMATION

Consideration of wastewater reclamation in the Martin County Water Supply Study is important because of the potential for efficient use of the water resource coupled with appropriate and beneficial disposal of wastewater effluent. Wastewater reclamation will benefit Martin County in several major ways:

1. By providing a quality, reliable source of irrigation water for large scale landscape demands.
2. By improving the level of treatment of wastewater and by providing an approved beneficial means of disposal.
3. By creating an additional source of ground water recharge in many areas of the county.
4. By reducing the demand on the ground water resource by large scale landscape irrigators.

In other areas of south Florida wastewater has become an important priority source of irrigation water. Elaborate systems have been designed for the Naples area golf courses while wastewater has been available for large and small scale irrigators in St. Petersburg for several years.

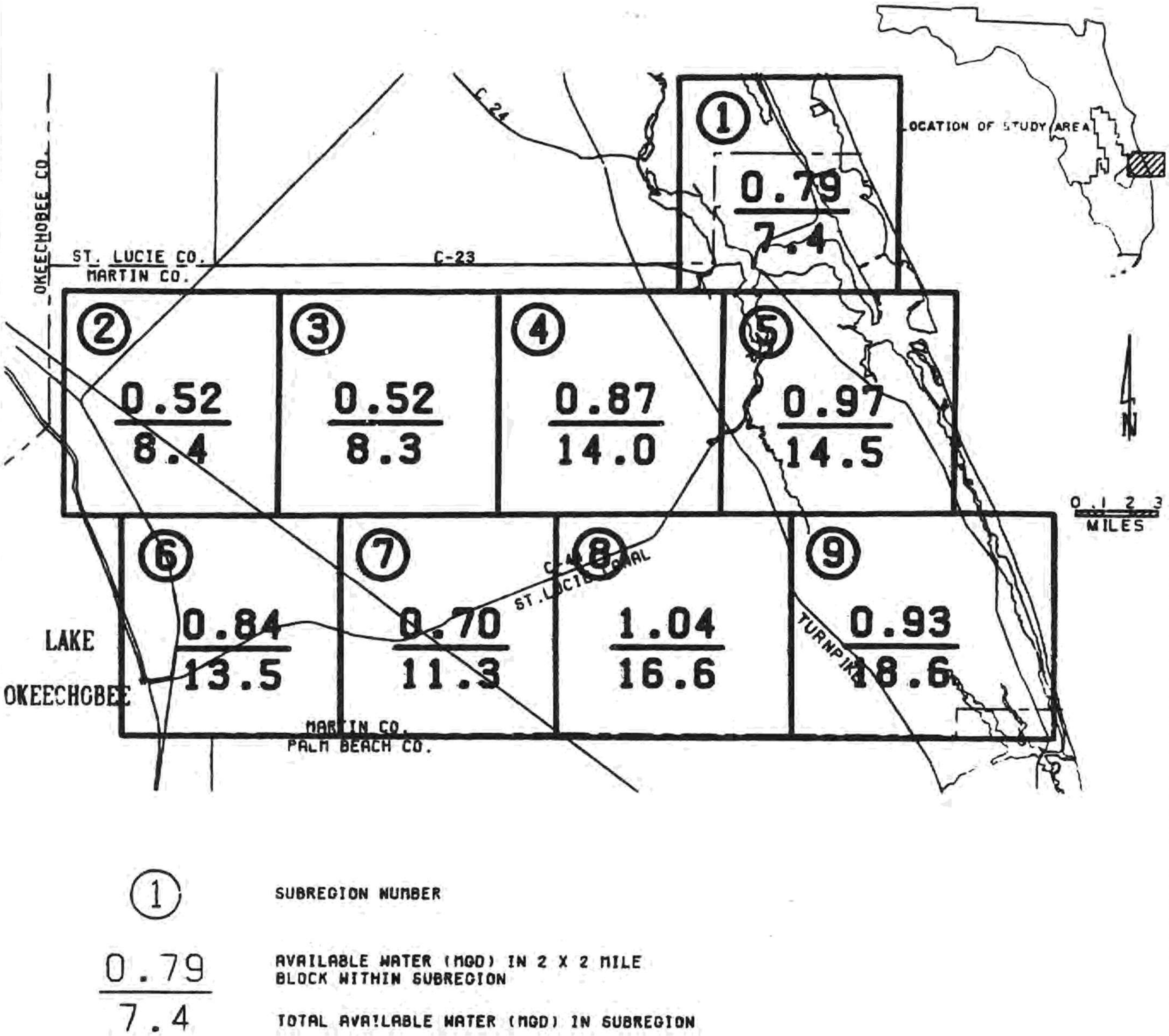


Figure 58 SUBREGIONS IN WHICH MAXIMUM ALLOWABLE WITHDRAWAL RATES FROM THE UPPER FLORIDAN AQUIFER ARE DETERMINED

In Palm Beach County, a number of golf courses are being scheduled to receive wastewater effluent from the Loxahatchee River Environmental Control District (ENCON). The use of reclaimed wastewater in most new systems including ENCON, Naples, and St. Petersburg is backed up by the use of deep injection wells. These wells are used during periods of wet weather when irrigation demands are extremely low and during events when the quality of effluent treatment cannot be assured (eg. physical or chemical/biological treatment plant breakdowns).

As water conservation continues to make more sense for local governments, wastewater reclamation serves as an important tool in water supply demand planning. The inclusion of wastewater reclamation potential in this study reflects a position of responsibility towards efficient management of the water resources in and by Martin County.

The values presented in this section provide projections of levels of implementation of wastewater reclamation efforts in Martin County. Because the county has not completed the Wastewater Master Plan, and information is not available as to location and capacity of specific "future-build" treatment plants and service areas, this study delineates supply-demand scenarios for localized systems only. These scenarios are based upon existing and buildout supply calculations and have alternative levels of implementation for potential reuse systems. The intent of this effort will be to assess the regional potentials for wastewater reclamation in the urban areas of Martin County. In the implementation of any wastewater reclamation system, many factors must be taken into consideration. Factors such as soils, topography, physical location, user profiles, public reaction and sentiment, present source (potential source), etc., all affect potential users. Factors such as treatment processes, present or potential disposal, service area, transportation routes, bonded indebtedness, treatment plant age and condition, service area characteristics and collection systems, and influent characteristics all affect the potential supplies.

This study will draw conclusions as to the most evident of the variables in a supply-demand network for wastewater reclamation potential. Geographic location and physical proximity factors will be the basis for apparent conclusions regarding the most and least feasible networks pairing users and suppliers within geographic areas.

Methodology

In developing wastewater reclamation scenarios, the first step was to identify regional areas within Martin County which might be served by integrated supply networks. The county's planning areas were investigated, but in many cases these areas were too widespread or crossed geographic barriers such as the St. Lucie Canal. Thus there was a need to modify these geographic areas to divisions that would be more suitable for the physical implementation of wastewater reclamation networks.

The county was divided into 10 reclamation (reuse) planning areas. These areas are built upon aggregations of whole Traffic Analysis Zones (TAZs). The reuse planning areas and their TAZ's are listed by footnote in Table 17.

Populations were derived from the population figures supplied by Martin County for this study. Table 17 (Part A) represents populations derived from existing and committed figures, as well as area populations at buildout (Part B) based upon county projections.

In both Parts A and B of Table 17, the "Green Acres" columns provide projections of the number of potential wastewater irrigated acres on golf courses and other major irrigated landscape tracts such as parks and recreation areas and sports playing fields. Acres in Part "A" are based upon information supplied by the Martin County Planning Department and by review of planning documents such as "Applications for Development Approval" for Developments of Regional Impact. Acres in Part "B" are derived by adding Part "A" totals and totals for "future" acres next described.

In Part "B", acreage beyond existing and committed is based upon a calculation using the ratio of golf course acreage to population. For Martin County the present ratio is approximately 17 acres per 1000 population. A figure of 20 acres per 1000 population was used to adjust the present ratio for trends observed in and outside of the county (such as in Palm Beach County) and the additional acreage resulting from projected public access areas such as parks and recreational areas.

The columns headed "Potential Demand" result from calculations made by multiplying the "Green Acres" by a factor of 1 inch irrigation per week. An application rate of 1 inch per week is an established preferred rate of effluent irrigation on golf courses in south Florida. This 1 inch of irrigation per week translates to 4,000 gallons per acre/day (average). This resultant figure is expressed as the potential irrigation demand on identified large landscape irrigation parcels within each reuse area.

TABLE 17. ESTIMATED EXISTING AND FUTURE (BUILDOUT) DEMANDS FOR IRRIGATION OF GREEN AREAS IN MARTIN COUNTY WITH RECLAIMED WASTEWATER, BASED ON THREE LEVELS OF USE (25%, 50% and 100%) OF THE AVAILABLE SUPPLY

A. Existing and Commited Land Uses

					TARGET REUSE 25%			TARGET REUSE 50%			TARGET REUSE 100%		
Reuse Area[1]	Pop.[2]	Green Acres[3]	Potential Demand[4] (gallons)	Wastewater Flow[5] (gallons)	Supply Available[6] (gallons)	% Green Demand Met[7]	Excess[8] (gallons)	Supply Available[6] (gallons)	% Green Demand Met[7]	Excess[8] (gallons)	Supply Available[6] (gallons)	% Green Demand Met[7]	Excess[8] (gallons)
A	21608	216	864000	1997587	499397	57.80	0	998793	115.60	134793	1997587	231.20	1133587
B	9612	238	952000	1079165	269791	28.34	0	539583	56.68	0	1079165	113.36	127165
C	23765	251	1004000	3854711	963678	95.98	0	1927356	191.97	923356	3854711	383.94	2850711
D	21350	499	1996000	2172024	543006	27.20	0	1086012	54.41	0	2172024	108.82	176024
E	20964	559	2236000	1803894	450973	20.17	0	901947	40.34	0	1803894	80.68	0
F	1937	339	1356000	107403	26851	1.98	0	53701	3.96	0	107403	7.92	0
G	18727	340	1360000	1534883	383721	28.21	0	767442	56.43	0	1534883	112.86	174883
H	5827	441	1764000	446737	111684	6.33	0	223369	12.66	0	446737	25.33	0
I	3047	119	476000	1130741	282685	59.39	0	565370	118.78	89370	1130741	237.55	654741
J	2844	135	540000	277188	69297	12.83	0	138594	25.67	0	277188	51.33	0

B. Buildout

					TARGET REUSE 25%			TARGET REUSE 50%			TARGET REUSE 100%		
Reuse Area[1]	Pop.[2]	Green Acres[3]	Potential Demand[4] (gallons)	Wastewater Flow[5] (gallons)	Supply Available[6] (gallons)	% Green Demand Met[7]	Excess[8] (gallons)	Supply Available[6] (gallons)	% Green Demand Met[7]	Excess[8] (gallons)	Supply Available[6] (gallons)	% Green Demand Met[7]	Excess[8] (gallons)
A	49327	770	3081544	6786439	1696610	55.06	0	3393219	110.11	311675	6786439	220.23	3704894
B	12783	301	1205688	1584140	396035	32.85	0	792070	65.69	0	1584140	131.39	378452
C	30768	391	1564200	5150624	1287656	82.32	0	2575312	164.64	1011112	5150624	329.28	3586423
D	47626	1025	4098008	6578487	1644622	40.13	0	3289243	80.26	0	6578487	160.53	2480478
E	28809	716	2863576	3250953	812738	28.38	0	1625477	56.76	0	3250953	113.53	387377
F	12572	552	2206824	805682	201420	9.13	0	402841	18.25	0	805682	36.51	0
G	89109	1748	6990544	7657817	1914454	27.39	0	3828909	54.77	0	7657817	109.55	667273
H	14170	608	2431464	1826053	456513	18.78	0	913026	37.55	0	1826053	75.10	0
I	33563	729	2917304	6365283	1591321	54.55	0	3182642	109.10	265338	6365283	218.19	3447979
J	10869	296	1182016	577913	144478	12.22	0	288956	24.45	0	577913	48.89	0

[1] "Reuse Planning Area" comprised of county Traffic Analysis Zones (TAZ's)
- A - 1,2,3,5,6,7,8,10
- B - 4,14,15
- C - 9,11,12,13,16,17,18,19,20,21,22,23
- D - 24,25,26,27,28,29,30,31
- E - 32,33,34,35,36
- F - 37,99
- G - 38,39,40,41,42,43,44,45
- H - 46,47,48,49,50
- I - 96,97
- J - 100

[2] Existing and Committed population data from Martin County Planning Dept. Buildout based on estimates provided by Martin County.

[3] Green areas include golf courses, and other large irrigated tracts such as parks and recreational areas. Existing and Committed based on data from Martin County Planning Dept. and DRI's. Buildout based on existing and committed land use data plus an estimated 20 acres per additional thousand population.

[4] Calculated as the number of green acres x 4000 gal/day/acre (average irrigation rate of 1" per week)

[5] Based upon potable (indoor) demand supplied by utility systems

[6] Column 5 factored by (Target %) availablity

[7] Percentage of large scale irrigated acres demand met by available (factored) supply

[8] Excess gallons available for other reclamation demand in reuse area

The wastewater flow (potential supply) was calculated as being equal to the indoor water demand supplied by utility systems.

The target reuse scenarios are meant to demonstrate the amounts of reuse that would be achieved under alternative levels of implementation and to specify how much of that could come from traditional use patterns, such as application to golf courses. These levels of effluent use are set at 25%, 50%, and 100% of listed treatment plant output to correspond with low, medium, and high levels of implementation efforts.

Because the wastewater treatment and disposal planning process is just getting underway in Martin County as was explained in the introduction, and because the potential users could only be specified in general, it was not possible to give detailed policies and costs which would achieve the alternative levels of implementation. The most common constraint to full implementation will be cost. Under two of these scenarios, 25% and 50%, some effluent supply will be unavailable. The resulting two columns represent the percentage of demands met on identified "green acres" and the additional supply (in gallons) available for other methods of wastewater disposal in the specific reuse area. All of the water in these columns is considered to be available for gross disposal which, when netted out, will provide some recharge to local surficial aquifers.

Upon review of Parts Aand B of Table 17, it is evident that under both existing and committed and buildout conditions reclamation at the low implementation level (25%) would come close to meeting green area demand only in the Stuart area (Reuse Area C).

In an effort to both optimize ground water recharge and to develop alternative water sources for existing and projected "Green Acreas" demands, reclamation efforts utilizing between 50% and 75% of available effluent should be targeted. The quantities available (see Table 17) at these target levels represent the most promising mechanisms for recharging the ground water system. Large scale irrigation users combined with low cost percolation pond systems will make reclamation efforts feasible in most reuse areas.

Considering the logistical problems involved in disposing of supplies not being used on large scale landscaping, 50-75% target programs aimed at "Green Acres" users probably should not be designed for reuse areas E, F, H, and J. These low demand areas present reclamation opportunities only if on-site reuse is practiced on large scale PUDs and similar developments.

WATER CONSERVATION/ DEMAND REDUCTION

Introduction

This section outlines opportunities for Martin County in the area of water conservation/demand reduction. While demand reduction programs are clearly necessary during a water shortage, there are also many important reasons for implementation of long term demand reduction programs.

In Chapters 373 and 553, Florida Statutes, regional and local governments are mandated to promote, encourage, and require water conservation/ demand reduction. These laws, together with the State Water Plan and Local Government Comprehensive Plans, require the inclusion of efficient use provisions. Other factors providing strong community and personal motivation for water conservation/ demand reduction include commodity and monetary savings, the protection and preservation of the environment, and the certainty of a quality standard of living.

This section does not provide quantitative estimates of water savings through specific measures or programs. The specifics of successful water conservation efforts vary greatly throughout the country. Because of a lack of experience and documentation in the Martin County area, this section will be limited to a presentation of general opportunities available to the county in the area of water conservation/demand reduction.

Potential Program Goals

While successful water conservation programs generally appear to be similar in scope and function, the range of activities and methods used, the diversity in the participating populations and water users, and the climate/geography of the local area vary widely. Therefore, the level of success achieved has also varied quite substantially.

One basic concept must be asserted. Properly planned long term water conservation programs can coexist with efficient drought management programs. The basic tenet that needs to be applied is that long term programs voluntarily reduce unnecessary water use to efficient levels. Drought management ordinances impact the same uses and use behaviors, but on a mandatory basis. Long range planners and code/law enforcement people must coordinate efforts to assure continuity of the programs.

In states such as California and Arizona, water conservation programs have started with drought management efforts and achieved permanent long term demand reductions of urban residential water use of up to 30%. In areas where substantial population growth is expected, the combination of new construction requirements together with comprehensive retrofit programs offers potential reductions ranging from 10-30%, depending on population projections to buildout.

Proper water supply facilities planning that considers factors of long term water conservation can lead to eventual savings in both capital expansion and operating costs.

Types of Water Conservation Programs

All comprehensive water conservation/demand reduction programs should include methods for both indoor and outdoor water use. The remainder of this section will focus on commonly accepted water conservation techniques that are seen as opportunities for Martin County in establishing a long term water conservation program. Noted along with each technique will be an explanation of the effect of the technique on the potential quantity saved and/or on the county.

Indoor Conservation

Residential

New Construction: This involves implementation of Chapter 553.14 F.S. which requires the installation of low flow showerheads, faucets, and low volume toilets. Martin County should establish rigid standards for inspection, enforcement, and public (contractor) education in implementing this state law. This chapter also sets product standards for plumbing equipment which should be used in retrofit programs in the county.

Retrofit: The county should consider the implementation of a county-wide plumbing equipment retrofit program, similar to the effort carried out by the city of Orlando in 1983. In that program Orlando installed (at utility expense) five direct charge-selected water conserving devices in residences and commercial domestic facilities such as office buildings and hotels. While the District is still in the process of evaluating the effectiveness of the Orlando program, preliminary analysis shows a substantial reduction in indoor water use. Other properly run retrofit programs have also shown success in reducing water demand.

Commercial

In many public and commercial buildings, water conservation has been achieved historically because of the standards for plumbing equipment amenable to commercial settings. Products such as the metered flush valve on toilets and urinals are designed to achieve the stated use at a minimum of demand. Also, industry has long seen to reducing the use of commercial process water demand, merely for the purpose of reducing operating expenses.

Martin County should inventory this sector's status in relation to state-of-the-art water demand technology and offer specific suggestions for improvement. The county should also highlight those commercial concerns already achieving an adequate level of water conservation.

Outdoor Conservation

In looking at standard irrigation equipment and practices, it appears that a majority of those who irrigate both residential and public/commercial landscapes apply more water than is necessary for the healthy growth of the plant life. In essence, most landscape irrigation could and should become more water efficient.

Achieving a water efficient goal for landscape irrigation will not only assist in long term capital reduction and operating costs for the county's water supply utilities, but will also help protect the county's well fields from excessive drawdowns and saline contamination. In areas where excessive irrigation re-enters the soil system but not the supply source, such as in confined aquifers, the reduction of the excess is seen as an opportunity for both the water supply utility and the environment. Methods by which the county could reduce the excessive demands for irrigation water include:

An Efficient Water Use Landscape Code

Adoption and enforcement of a comprehensive Landscape Code which has as a central theme the design, installation, and use of drought tolerant, low water use plants and techniques is highly recommended. This code should require preservation of existing native plant communities, proper water retaining site preparation and installation techniques, a balance of geographically suitable native and drought tolerant/low water use exotics, and requirements for efficient, minimal irrigation systems specifying state-of-the-art water conserving and low volume irrigation equipment.

A Public Education Campaign

In addition, the county should develop opportunities to support its efforts at structural water conservation as outlined above, with a comprehensive behavioral modification program designed to instill in the public an appreciation of, and a respect for, water use efficiency.

A comprehensive water conservation public awareness and education program should include, as a minimum:

- Development and implementation of a water conservation curriculum for school children of Martin County.
- A public information office dealing strictly with water conservation/community education. This needs to be a long term proactive program designed to reach community leadership organizations.
- A recurring vocal commitment of support by the County Commission and local government bodies for continued water conservation/ demand reduction.
- A long range water supply utility study (included in the County's Water Master Plan) addressing the goals and programs aimed at achieving demand reduction.
- A detailed commitment to water conservation program goals in the County's Comprehensive Plan.
- An annual commitment of funds for the ongoing financial demands of a long term, comprehensive water conservation program.

The District, through its local government planning assistance program, can offer assistance to the county in the specific analysis and design of a comprehensive water conservation/demand reduction program specifically designed for the needs of Martin County and its municipalities.

GROUND WATER DEVELOPMENT POTENTIAL

County-Wide Water Resource Assessment

This section attempts to quantify the maximum amount of water available in Martin County under various limitations. Several definitions of water "availability" are examined (see Appendix 2).

Basin Yield

Rainfall is a major source of water. A normal rainfall for Martin County is approximately 50.85 inches per year, which translates into 2.42 MGD per square mile. For the entire county area (560 square miles), the absolute maximum water available is 1,350 million gallons per day or 1.5 million acre-feet per year.

A major portion of rainfall, however, is lost to evapotranspiration (ET). At the present time, the county is not highly developed; therefore, ET is not suppressed. The average ET is about 40 inches per year, which leaves about 11.8 inches per year for recharge to the Surficial Aquifer System. Without any imported canal recharge to the Surficial Aquifer System, this 11.8 inches of recharge translates to a pumpage of approximately 290 MGD for the entire county. This is the minimum amount of water available in the county. ET, however, can be reduced by lowering the water table through land use changes. Hence, the realistic water availability is about 290 MGD when normal ET rates are given consideration.

It is understood that Lake Okeechobee can supply an additional amount of water through the St. Lucie River and other canals to the county. The source of this water, in some instances, is outside of the county and cannot be relied upon on a continuing basis, especially during times of drought. Rainfall recharges the Surficial Aquifer System. Below this aquifer lies the vast Floridan Aquifer System. The piezometric head of this confined aquifer is currently above land surface. Hence, local rainfall does not directly recharge this aquifer system. Furthermore, current SFWMD management policies require that the piezometric head shall not be lowered below land surface due to excessive withdrawals in the area. In addition, the thick confining beds retard the possibility of direct rainfall recharge to the aquifer. Thus, confined aquifers can be "mined" to a certain point, but cannot be considered as a "continuing" source. The amount of water that can be withdrawn from this confined aquifer during the next 20 years, water quality notwithstanding, is being studied (Trost, in prep.). The quantity within Martin County is reproduced in Figure 58. The confined aquifer can produce from 113 MGD to 225 MGD in the county for the next 20 years before piezometric heads will fall to land surface.

With the above discussions, it is clear that rainfall recharge to the Surficial Aquifer System is the continuing renewable source of water in the county. The following sections describe how much water can be withdrawn from the water table aquifer in Martin County according to different limitations.

Rechargeable Ground Water Reservoir

In essence, a ground water reservoir can be created by pumping water from an aquifer using wells, and then allowing the vacated volume in the aquifer to be recharged by rainfall. To vacate the largest possible volumes, the wells should be uniformly distributed over the entire aquifer. When multiple wells pump simultaneously, their drawdowns or resulting cones of influence may overlap and superimpose. The effects of this well interference can ultimately cause large regional water level declines within the aquifer. A computer program was written to determine the maximum quantity of water that can be withdrawn from the Surficial Aquifer System in order to create additional storage for rainfall recharge.

Pump Installation Capacity

Although not mentioned in the attached proposed criteria for permittable water (Appendix 2), a maximum day pumpage is often specified when a water use permit is issued by the SFWMD. This is the maximum amount that is allowed to be pumped out of the well. This amount is computed using the county-wide model of the Surficial Aquifer System under the following conditions:

a. Wells are cased 120 feet from land surface.
b. Allowable drawdown is 2/3 of casing or 2/3 of aquifer depth.
c. Water levels are 1-in-10 year drought end of dry season.
d. Pumpage duration is 210 days.

The result of this computation is shown in Figure 59. The map illustrates the self-limiting constraints of a well on a square mile basis and does not take into consideration other criteria which are paramount for the management of the water resources of the county.

Saltwater Intrusion

As discussed previously (according to the Ghyben-Herzberg principle), one foot of fresh water head above sea level can maintain sea water 40 feet below sea level in the aquifer. If the fresh water in the aquifer is able to maintain the sea water below the base of the aquifer, then the aquifer is free of sea water intrusion. Assuming the aquifer is 180 feet thick, the Ghyben-Herzberg equation would require a water level elevation of 4.5 feet above sea level.

Salt water intrusion occurs mainly in coastal areas. Currently, there is no significant salt water intrusion in Martin county. Based on the definition of safe yield used here (Appendix 2), a 1-in-100 year drought should not induce coastal salt water intrusion. A simulation of the 1-in-100 year drought without pumpage, however, maintained a water elevation above that required by the Ghyben-Herzberg equation. Therefore, the lower level of either of the two water elevations are those determined by the Ghyben-Herzberg equation. The maximum allowable withdrawal (county-wide) under this condition is estimated to be 445 MGD. The areal distribution of these allowable withdrawals is shown in Figure 60.

Environmental Impacts

According to the proposed criteria presented in Appendix 2, permittable water must not "adversely impact wetland hydroperiods during a 1-in-10 year drought event such that the natural vegetation is altered or eradicated". One way to interpret the above statement is from the viewpoint of evapotranspiration. Evapotranspiration rates decrease in conjunction with the lowering of the water table due to drought conditions. Subsequently, less water is available for vegetation. Assuming that under current withdrawal conditions a 1-in-10 year drought does not alter or eradicate the vegetation, then the ET amount associated with a 1-in-10 year drought is enough to sustain the vegetation. That is, on the average, ET can be suppressed to a 1-in-10 year amount without adverse environmental effects. Hence, if average rainfall is available to recharge to the aquifer, the ground water availability will be:

Average Rainfall - ET for a 1-in-10 year drought

ET during a 1-in-10 year drought is reduced to approximately 35 inches in Martin County; thus, the rechargeable rainfall is 15.85 inches. This is equivalent to an average of 0.79 MGD/sq. mile, or 440 MGD for the entire county. Figure 61 shows the areal distribution of unit area pumping capacity, limited by environmental impacts.

Recommended Allowable Withdrawal

The composite map depicts the average daily withdrawal capacity of the Surficial Aquifer System (Figure 62) limited by both salt water intrusion (see Figure 60) and environmental impacts (see Figure 61). The composite map illustrates the lower water withdrawal of the two limits set by these concerns

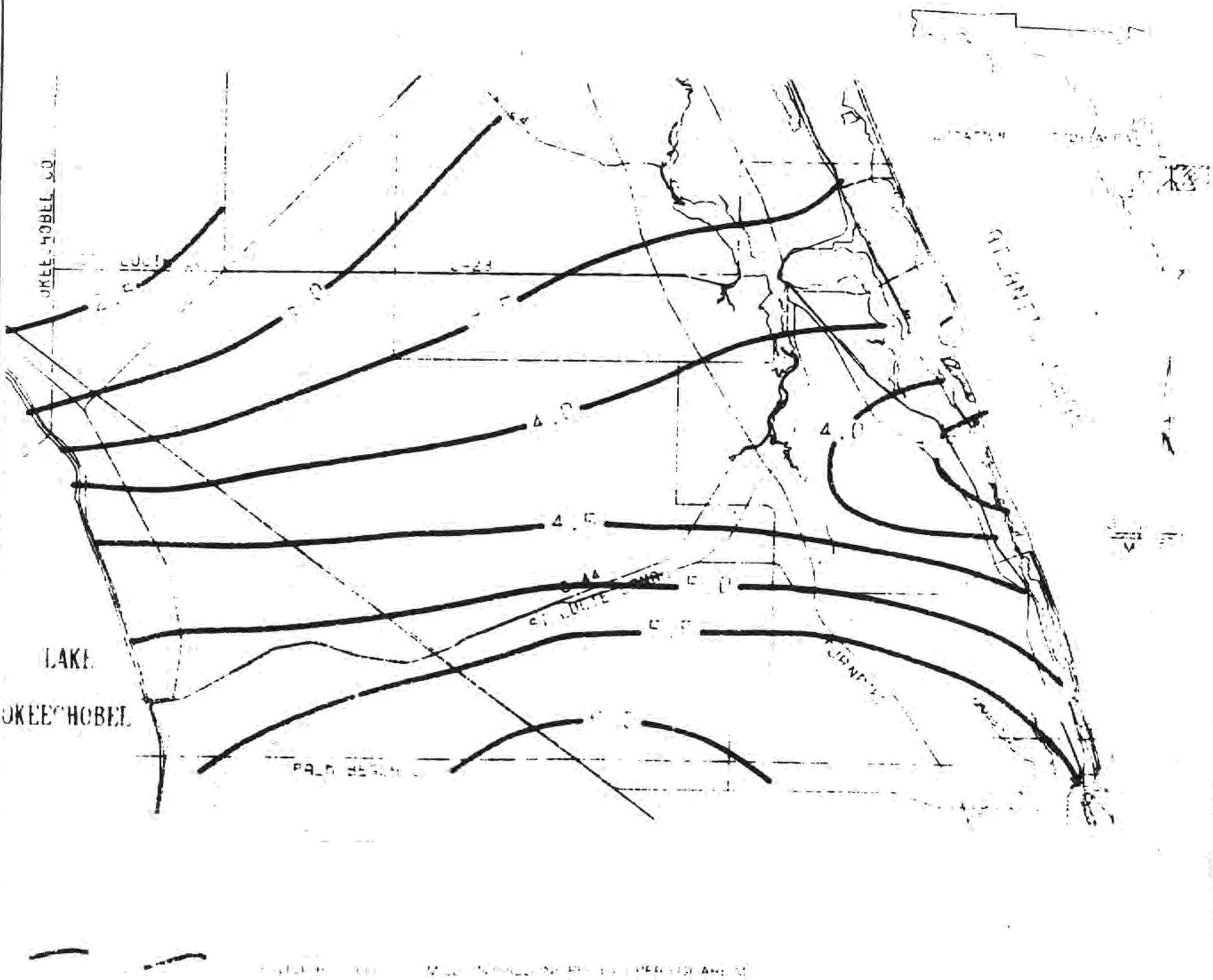


Figure 59 MAXIMUM DAILY PUMPING CAPACITY OF THE SURFICIAL AQUIFER, MARTIN COUNTY

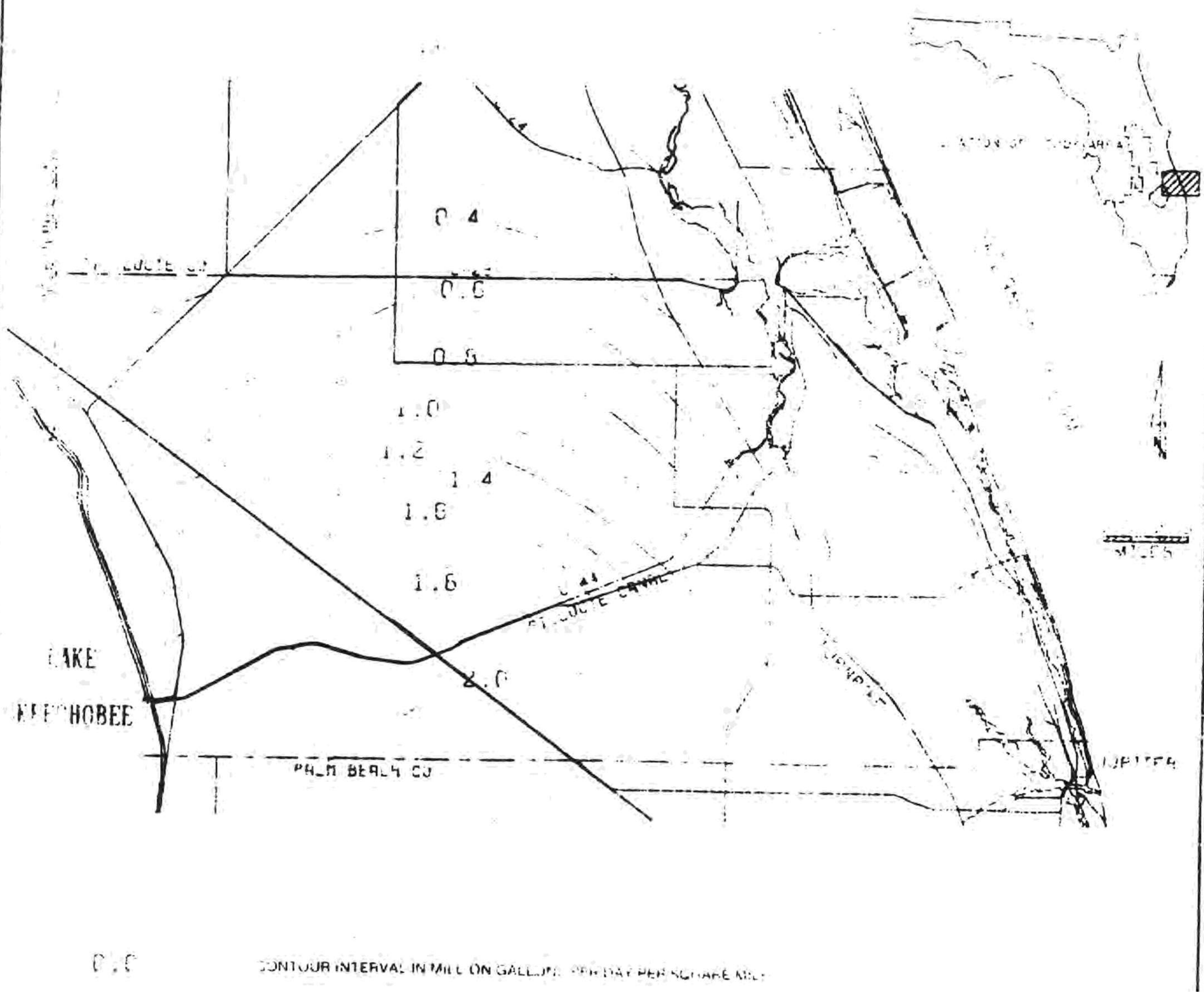


Figure 60 WITHDRAWAL CAPACITY OF THE SURFICIAL AQUIFER LIMITED BY SALTWATER INTRUSION IMPACT, MARTIN COUNTY

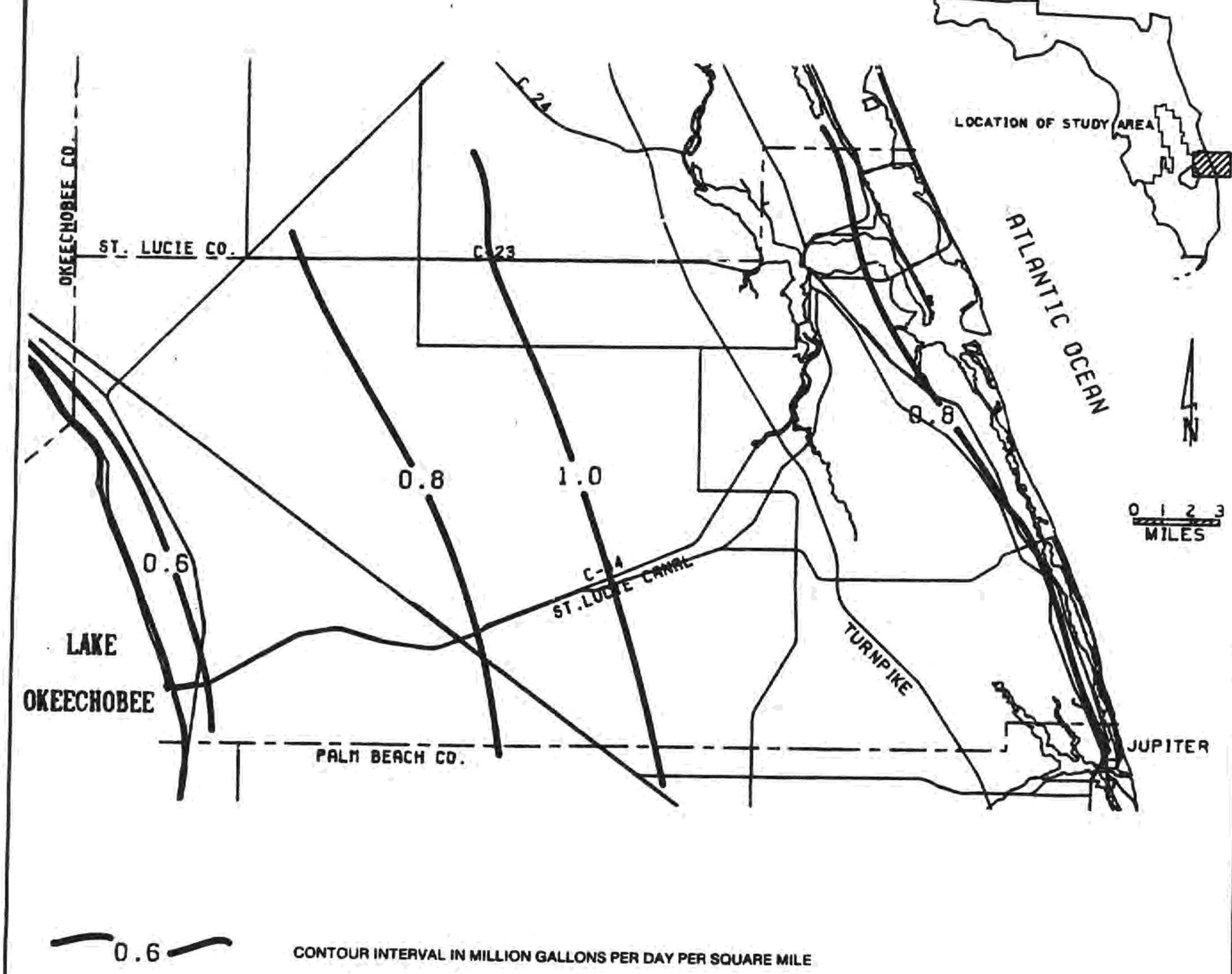


Figure 61 WITHDRAWAL CAPACITY OF SURFICIAL AQUIFER (LIMITED BY ENVIRONMENTAL IMPACTS), MARTIN COUNTY

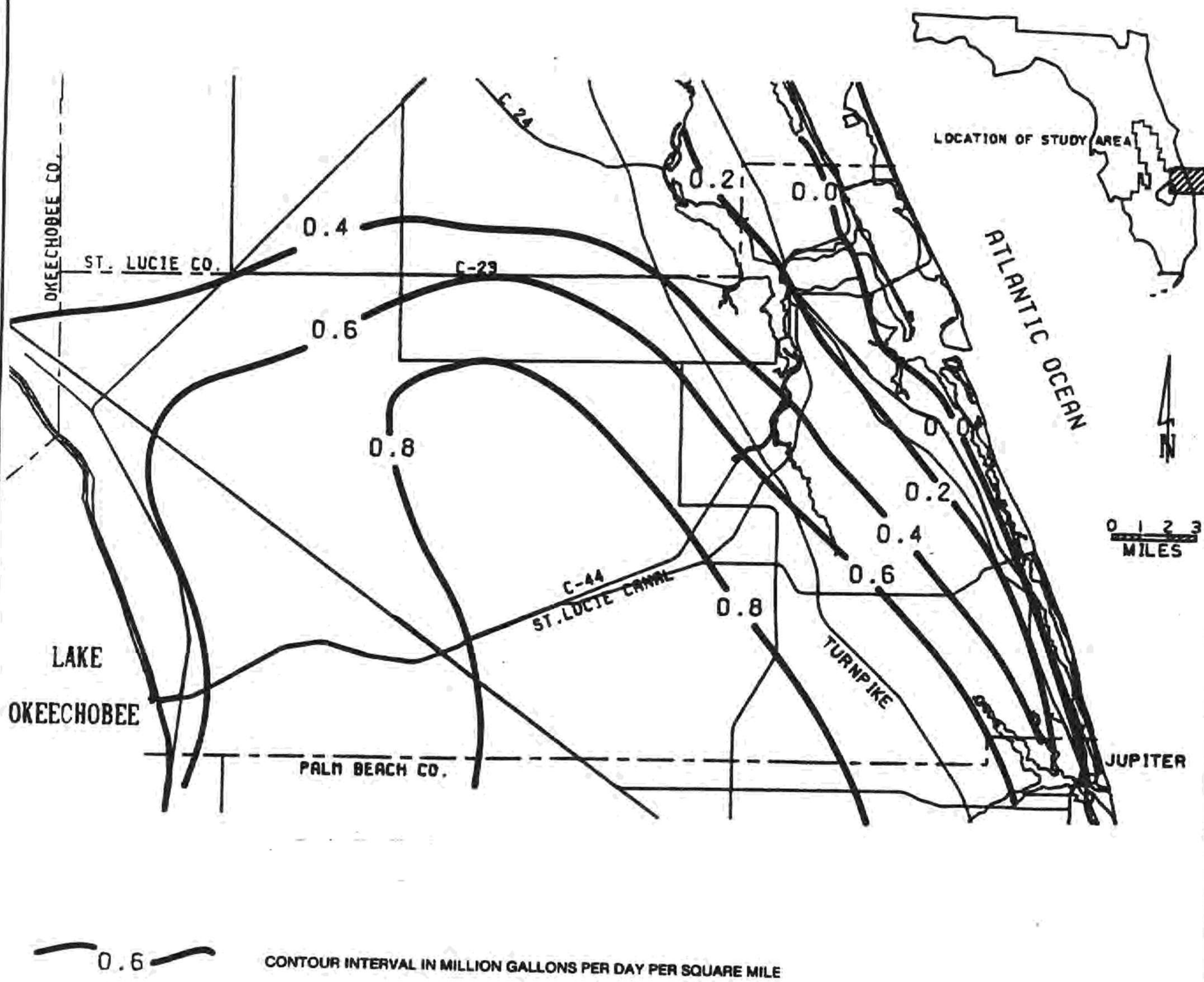


Figure 62 WITHDRAWAL CAPACITY OF SURFICIAL AQUIFER (LIMITED BY SALTWATER INTRUSION AND ENVIRONMENTAL IMPACTS), MARTIN COUNTY

(see Figure 62). Subsequently, the average daily pumping capacity was reduced to 308 MGD due to combining both of these considerations on a countywide basis. The composite map is considered to be the local withdrawal capacity of the aquifer per square mile. Hence, if a utility is serving a given square mile area, the utility can be designed such that the withdrawal is within these bounds. In addition, if an area has a permitted withdrawal greater than that illustrated in Figure 62, the allocated water can be reduced accordingly when the permit is subject to review.

Land Use Impacts on Water Quality,

The ambient ground water quality of the Surficial Aquifer System is generally good. However, the effects of man's activities can result in a deterioration of this important resource when proper management is not implemented. Applied management for the protection of ground water should parallel the potential sources of contamination. Contamination can be defined as the artificially induced degradation of natural ground water. Major sources of contamination result from agricultural, industrial, domestic, and waste disposal activities.

Agricultural Activities

The principal practices responsible for contamination of ground water due to agricultural activities are irrigation, chemical fertilizers and pesticides, and animal waste. Irrigation return flow is the irrigated water that returns to the aquifer by infiltration. These waters are subject to evapotranspiration; in this process the mineral constituents of the water, namely chlorides, become concentrated as the water is lost to evapotranspiration. This problem can be amplified when the water from the Floridan Aquifer System is used for irrigation since it naturally has a high chloride content. The dissolution of these salts also includes calcium, magnesium, sodium bicarbonate, sulfate, chloride, and nitrate (Todd, 1980). The flushing of these minerals from the aquifer can be further complicated during periods of drought. Irrigation return flows from agricultural practices will continue to be a source of ground water contamination within the foreseeable future. As new techniques are developed for application and management of irrigation waters, and more efficient use is made of crop types, this problem could decrease in severity (Miller, 1980).

Irrigation return flow can also concentrate both pesticides and chemical fertilizers; however, a portion usually leaches through the ground to the water table. The primary fertilizers are compounds of nitrogen, phosphorus, and potassium. Phosphate and potassium fertilizers are readily adsorbed on soil particles and seldom constitute a pollution problem. Nitrogen, however, is only partially used by plants or adsorbed by soils and is the primary fertilizer pollutant. Principally, pesticides are applied to control, destroy, or mitigate pests. Pesticides employed in agricultural areas can be a significant source of ground water contamination. Even in minute concentrations, pesticides can have serious consequences in relation to the potability of water. Most pesticides are relatively insoluble in water, while others are readily absorbed by soil particles or subject to microbial degradation (Todd, 1980).

Where animals are confined within a limited area, such as for beef or milk production, large quantities of animal waste can accumulate. For the 120 to 150 days that a beef animal remains in a feedlot, it will produce over a half ton of manure on a dry weight basis (Todd, 1980). Manure carries highly concentrated pollutants which may consist of salts, organic foods, and bacteria which can percolate to the ground water.

Changes in water management practices for farming may be effective in reducing the degradation of ground water quality. However, when thousands of acres are employed for agricultural purposes, the task of sampling water quality and providing the proper treatment becomes cumbersome. Figure 63 designates the agricultural area for Martin County.

Industrial and Commercial Activities

Although only a small portion of Martin County consists of industrial and commercial land use types (see Figures 64 and 65), the effects of these activities can result in significant alteration of ground water quality. Underground storage and transmission of a wide variety of fuels and chemicals are common practices for industrial and commercial installations. Potential contamination may cover the full range of inorganic and organic chemicals which could include phenols, acids, heavy metals, cyanide, and other constituents.

The major uses of water in industrial plants are for cooling, sanitation, and manufacturing. Ground water pollution can occur where industrial wastewater is discharged into ponds and lagoons.

Additional sources of contamination associated with these land uses are spills and surface discharge. At industrial sites, surface discharges occur during the transfer of liquids and leaks from pipes and valves. Recent spills of fuels at airports within Florida have

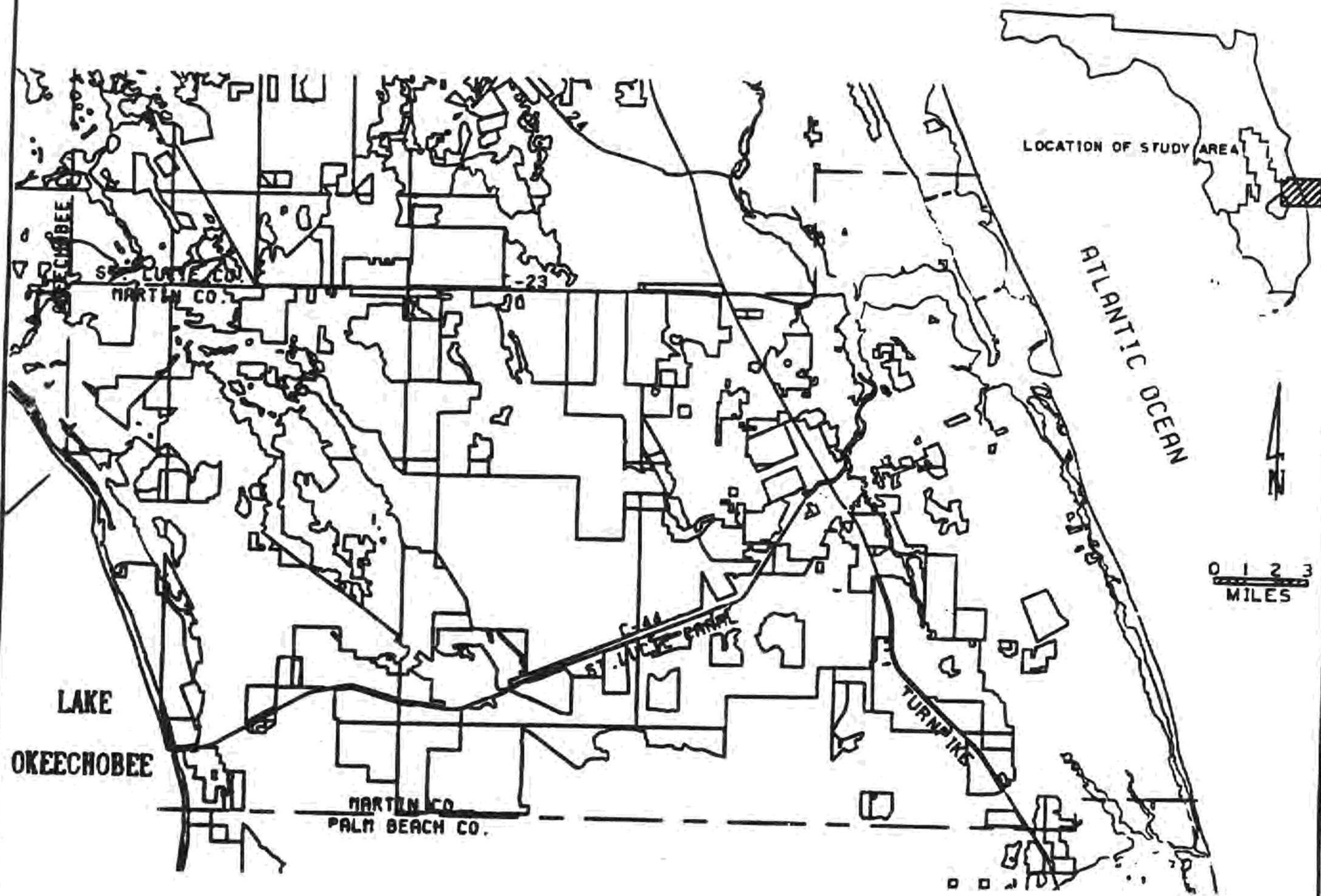


Figure 63 AGRICULTURAL LAND USE AREAS, MARTIN COUNTY (1979-81 DATA)

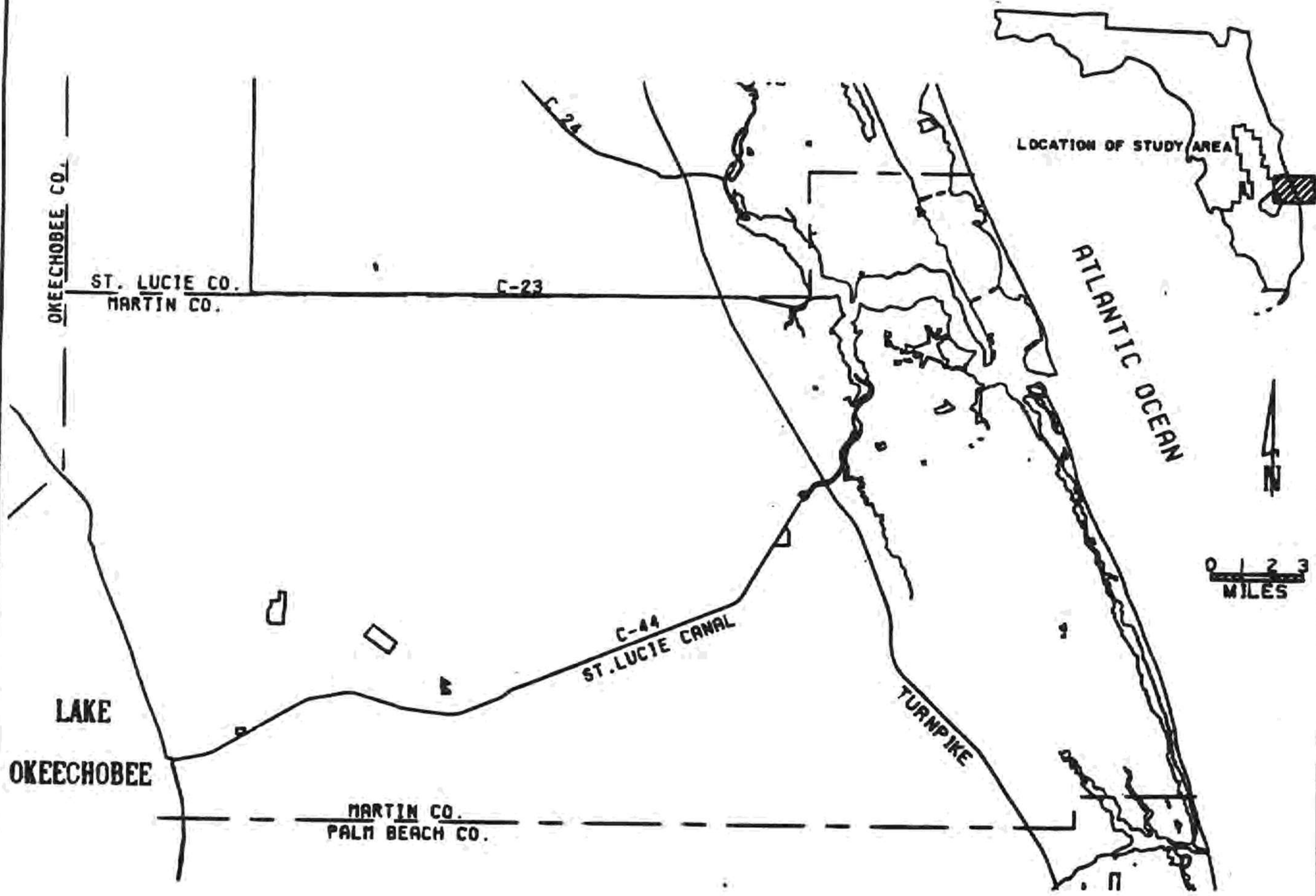


Figure 64 INDUSTRIAL LAND USE AREAS, MARTIN COUNTY (1979-81 DATA)

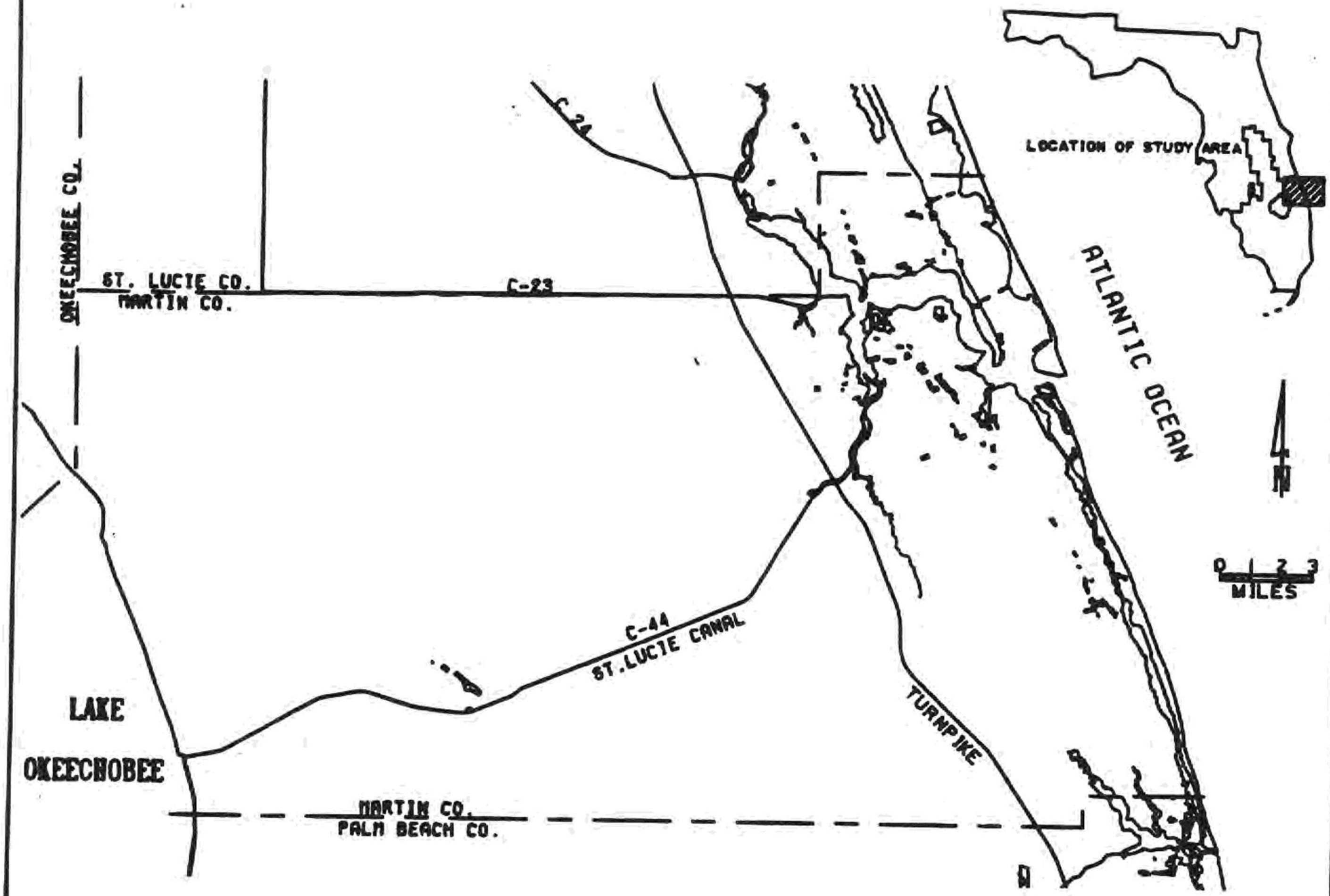


Figure 65 COMMERCIAL LAND USE AREAS, MARTIN COUNTY (1979-81 DATA)

also occurred which discharge a significant amount of hydrocarbons into the water table. Pollution can also occur from the intermittent dumping of fluids on the ground, especially near gasoline stations, small commercial establishments, and construction sites. Accidents involving pipelines, storage tanks, railroad cars, and trucks can release large quantities of pollution. Hazardous and flammable liquids are often flushed by rainfall from highways; this action may aid in transporting pollutants to the water table. Oil discharged from automobiles is also a common problem (Todd, 1980).

Solid materials are frequently stockpiled at construction and industrial sites. Stockpiles may consist of solid waste or raw materials that are either placed in permanent or temporary storage. Precipitation falling on unsheltered stockpiles causes leach-ate to infiltrate into the ground. Chemical constituents associated with these practices may include heavy metals, salts, and other inorganic and organic matter.

Septic Tanks

Septic tanks and cesspools are the largest contributors of wastewater to the ground and are the most frequently reported sources of ground water contamination (Freeze, 1979). The most severe problems with septic tanks are cases where pathogenic organisms survive, but the overall health hazard from domestic tanks is only moderate. The major concern associated with septic tanks is the relatively high concentrations of nitrate. Excessive concentrations of nitrate in drinking water can impart a bitter taste and may cause physiological distress. Waters containing more than 45 mg/l of nitrate can also be harmful to infants.

Regional ground water quality problems have been recognized, especially in those areas of the greatest densities. Where the density of on-site disposal systems have created problems, collection of domestic wastewater by public sewers and treatment at a central facility is the most common alternative. Where sewer systems are not economically feasible, prevention of ground water quality problems has normally been achieved by low density zoning. Increased regulation of septic tank siting can be implemented along with state of the art design and construction practices (Miller, 1980).

As areas develop and reach the critical septic tank density, residential land use may be required to use alternative measures of sewage disposal. Areas which have exceeded the established critical density should be evaluated to determine the corrective measures needed. Major septic tank areas for Martin County are shown in Figure 66.

Landfills

Within Martin County there are five landfills, one of which is active. It is located in the northern portion of the county several miles west of the Florida Turnpike. Figure 66 also illustrates the landfill locations within the county.

To assess the effects of a landfill on the ground water system, the history of the landfill should be obtained to determine the content of the landfill. Once this is determined, the chemical constituents expected to be within the landfill can be evaluated. Sampling for these chemicals may expedite the assessment of the landfill's impact. In addition, the ambient or background quality of the ground water should be acquired so that significant differences between the potentially contaminated water and the natural characteristics of the ground water may be ascertained. The range of typical inorganic chemicals often associated with leachate emanating from landfills is listed in Table 18. Leachate may also contain a number of organic materials as well. Liquid industrial wastes placed in landfills can contain toxic constituents.

TABLE 18. COMMON RANGES FOR VARIOUS INORGANIC CONSTITUENTS IN LEACHATE FROM LANDFILLS

Parameter	Representative Range (mg/L)
K^+	200-1000
Na^+	200-1200
Ca2+	100-3000
Mg^+	100-1500
Cl^-	300-3000
SO_4^{2-}	10-1000
Alkalinity	500-10,000
Fe (total)	1-1000
Mn	0.01-100
Cu	<10
Ni	0.01-1
Zn	0.1-100
Pb	<5
Hg	<0.2
NO_3^-	0.1-10
NH_4^+	10-1000
P as PO_4	1-100
Organic Nitrogen	10-1000
Total dissolved organic carbon	200-30,000
COD (chemical oxidation demand)	1000-90,000
Total dissolved solids	5000-40,000
pH	4-8

(After Freeze, 1978)

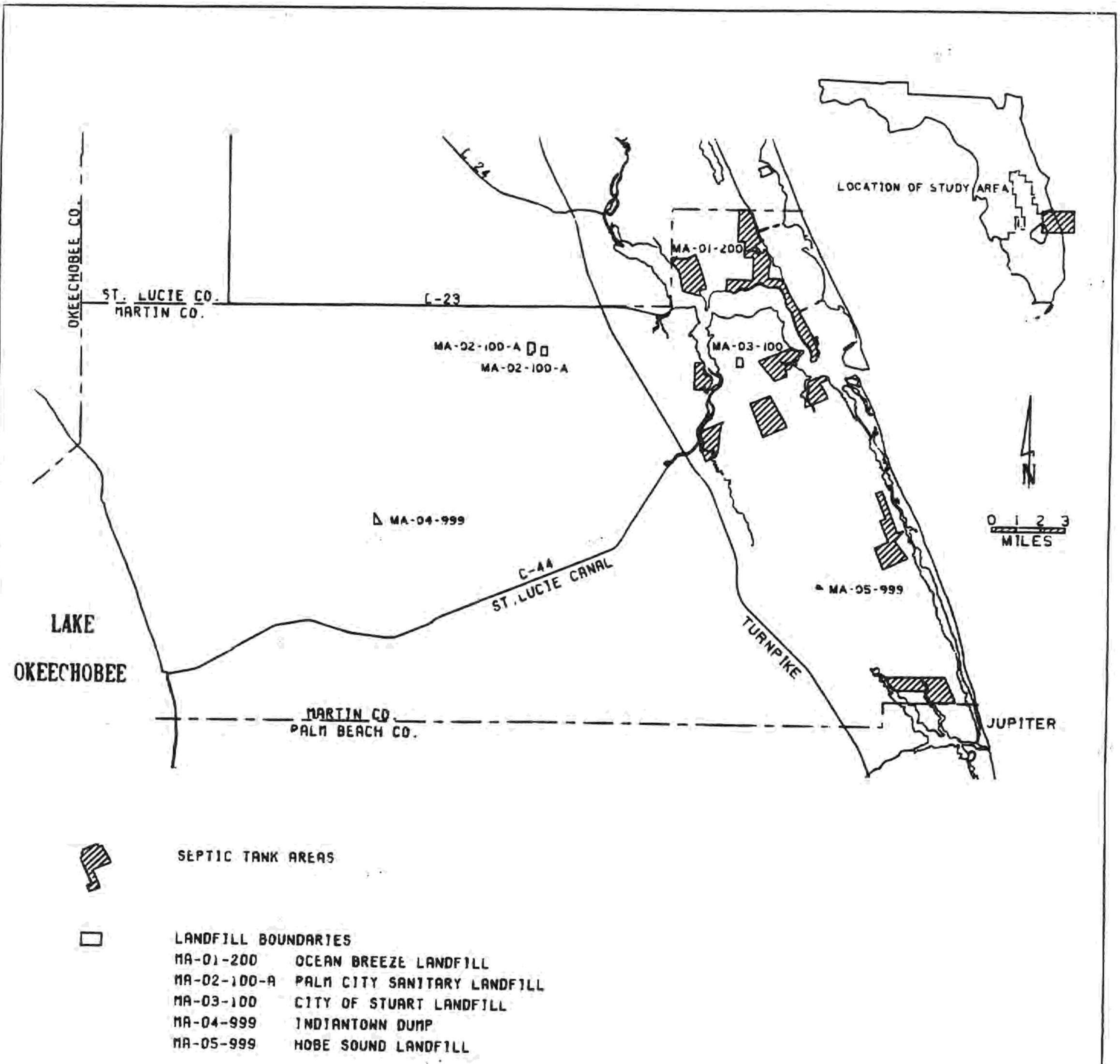


Figure 66 LANDFILL AND SEPTIC TANK LOCATIONS, MARTIN COUNTY

Downward flow of leachate may threaten ground water resources. Outward flow of leachate causes springs at the periphery of the landfill or seepage into surface water bodies.

In Martin County, landfills overlie relatively permeable material which can allow the downward percolation of leachate. In addition, the water table is normally within a few feet of land surface and, therefore, the leachate can be easily intercepted. The production of leachate can occur whether the landfill is active or inactive and may continue for decades.

City of Stuart Landfill

The city of Stuart landfill is located in close proximity to the well field (see Figure 67). The landfill was in operation before 1950 and the construction method was trench and fill. A portion of the waste materials were disposed of directly within the ground water prior to 1972. The character of the waste material has not been determined. The landfill was closed in 1980 and the water quality has been monitored periodically by the U. S. Geological Survey. Located on the south side of the landfill is monitoring well M-1174. The concentrations of ammonia and organic nitrogen are indicative of highly concentrated leachate. The analysis for dissolved solids and chemical oxygen demand also suggests the presence of leachate. Several chemical constituents for this well and additional monitoring wells are shown in Table 19.

TABLE 19. WATER QUALITY AT THE CITY OF STUART LANDFILL (Concentrations in mg/l)

	M-1174	M-1175	M-1176
Ammonia & Organic Nitrogen	100.0	2.0	2.0
Total Dissolved Solids	1,830.0	592.0	580.0
Chemical Oxygen Demand	320.0	10.0	45.0
Chloride	150.0	50.0	44.0
Iron	22,000.0	590.0	36,000.0
Lead	12.0	6.0	13.0
Zinc	140.0	220.0	120.0

It has not been determined whether the leachate from this landfill has impacted the Stuart well field which is only one mile from the landfill (see Figure 67). It is sufficient to say that wells should be monitored to determine if a detrimental impact exists. Figure 68 illustrates the nature of leachate migration.

Additional landfills and waste disposal sites which have been monitored include the Frenz Enterprise Sludge Disposal site near Indiantown, the Town of Ocean Breeze landfill, and the Palm City sanitary landfill which has been permitted for expansion.

All landfills and waste disposal sites should be evaluated on an individual basis to determine if subsequent ground water contamination has occurred. Impacted areas may necessitate the collection and treatment of leachate to assure a safe potable water supply. Wells should be installed and monitored to determine if any significant change in water quality has occurred. New landfills should be properly designed to minimize environmental effects and for management of leachate production. Proper design and operation of new sites which include the use of liners and diversion trenches can help in eliminating the input of surface water and ground water to the landfill. Recharge from precipitation can be controlled with proper design such as steepness of slope, permeability of cover material, and the use of vegetation for cover.

The contamination of ground water may occur from numerous sources, and the type of pollutant is often associated with a particular land use. Affected areas range in size from small septic tanks to waste disposal sites. Nearly all substances are soluble to some extent in water and many chemicals are highly toxic in minute concentrations. Limits for primary and secondary drinking water standards are listed from the Florida Administrative Code in Table 20.

The characteristics of the Surficial Aquifer System also determine the movement of a particular pollutant. Clays and organic matter within the ground may absorb trace metals and organic pollutants. Greater movement of pollutants tend to be through more permeable zones within the aquifer.

Wetland Areas

Aside from the need to protect well fields from various land uses, the need to protect the ecological system from well field development is paramount. One such ecological system which is known for aesthetic value in Martin County is the wetland areas. Continuous well field withdrawals could lower the water levels within these wetlands and thus have detrimental effects. The wetlands support a wide range of fauna and flora. In addition, wetlands provide hydrogeologic benefits by modifying runoff such that flood peaks are reduced. Wetlands within the county are shown in Figure 69. Wetlands are generally defined as those lands which are periodically flooded or which have ground water at, above, or near land surface for a major part of the year.

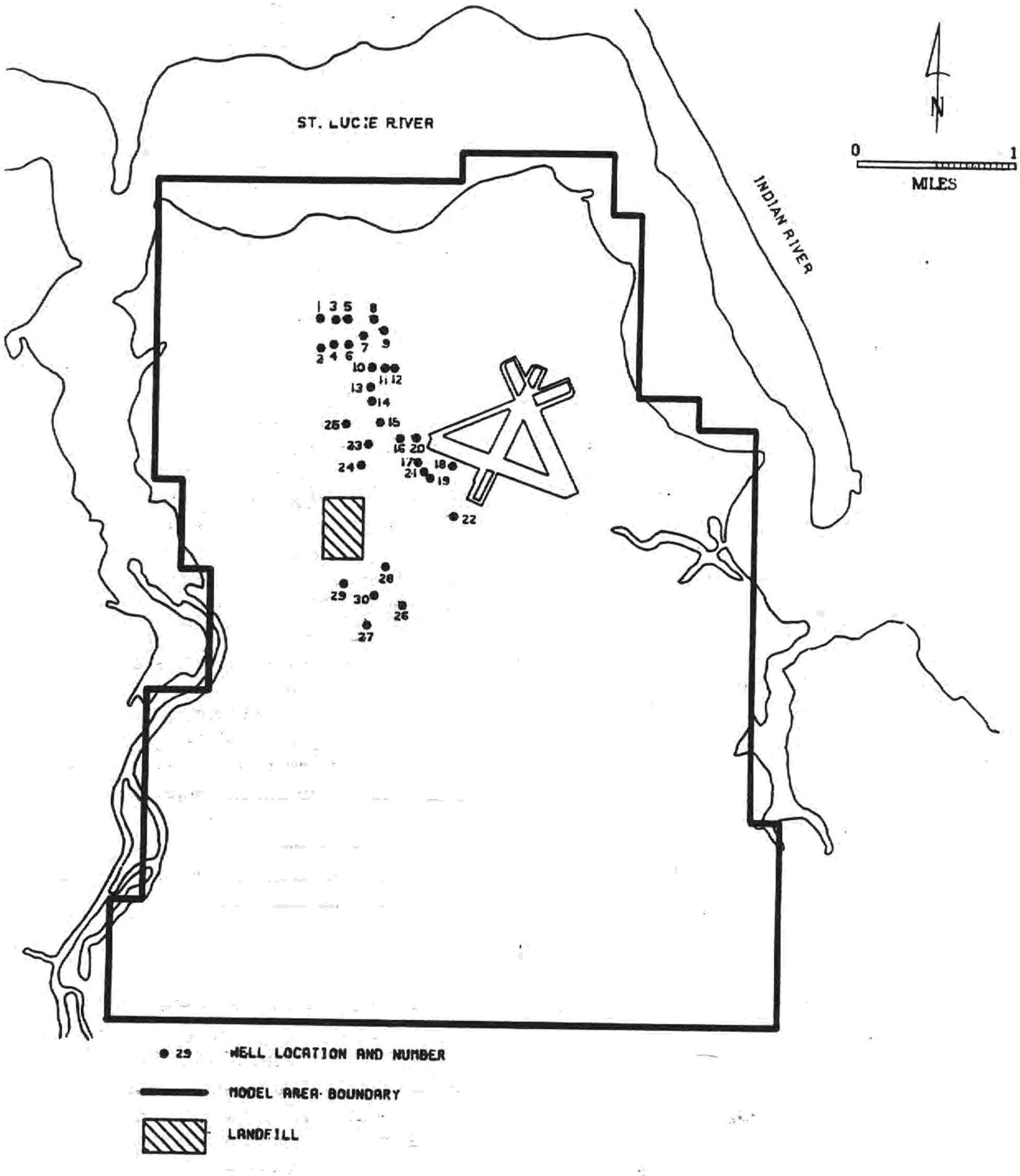
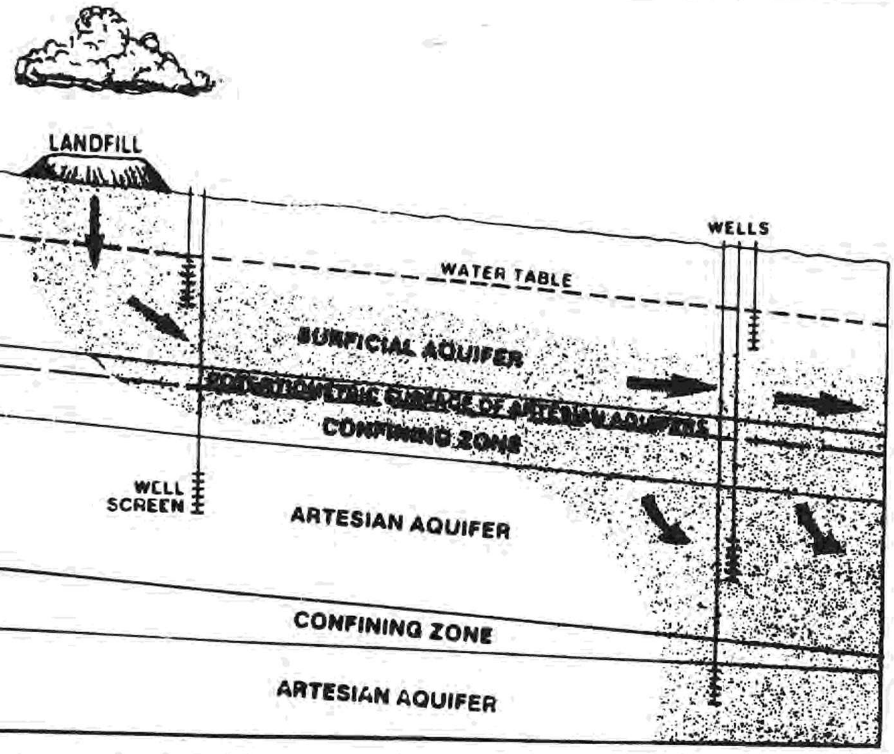
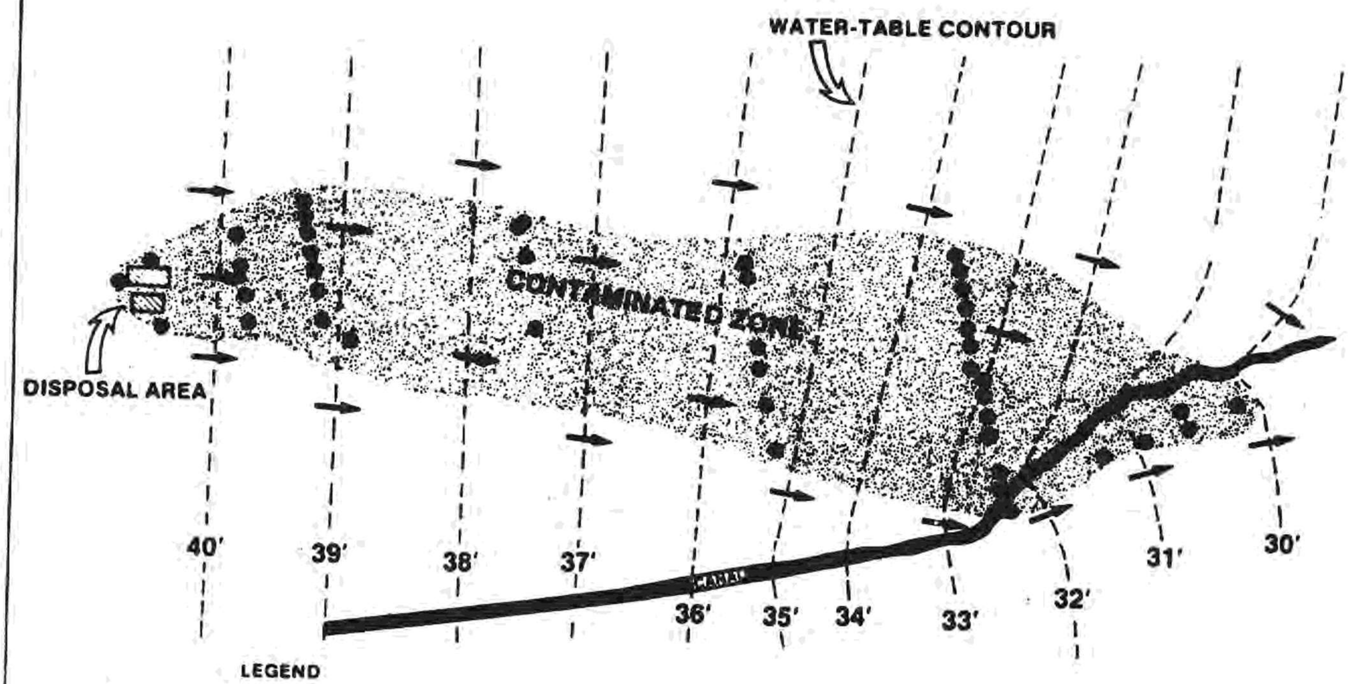


Figure 67 LOCATION OF CITY OF STUART WELLFIELD AND CLOSED STUART LANDFILL



CROSS-SECTIONAL VIEW (MODIFIED FROM MILLER, 1980)



PLAN VIEW
(MODIFIED FROM PERLMUTTER AND LIEBER, 1970)

Figure 68 MOVEMENT OF LEACHATE PLUME WITHIN GROUND-WATER

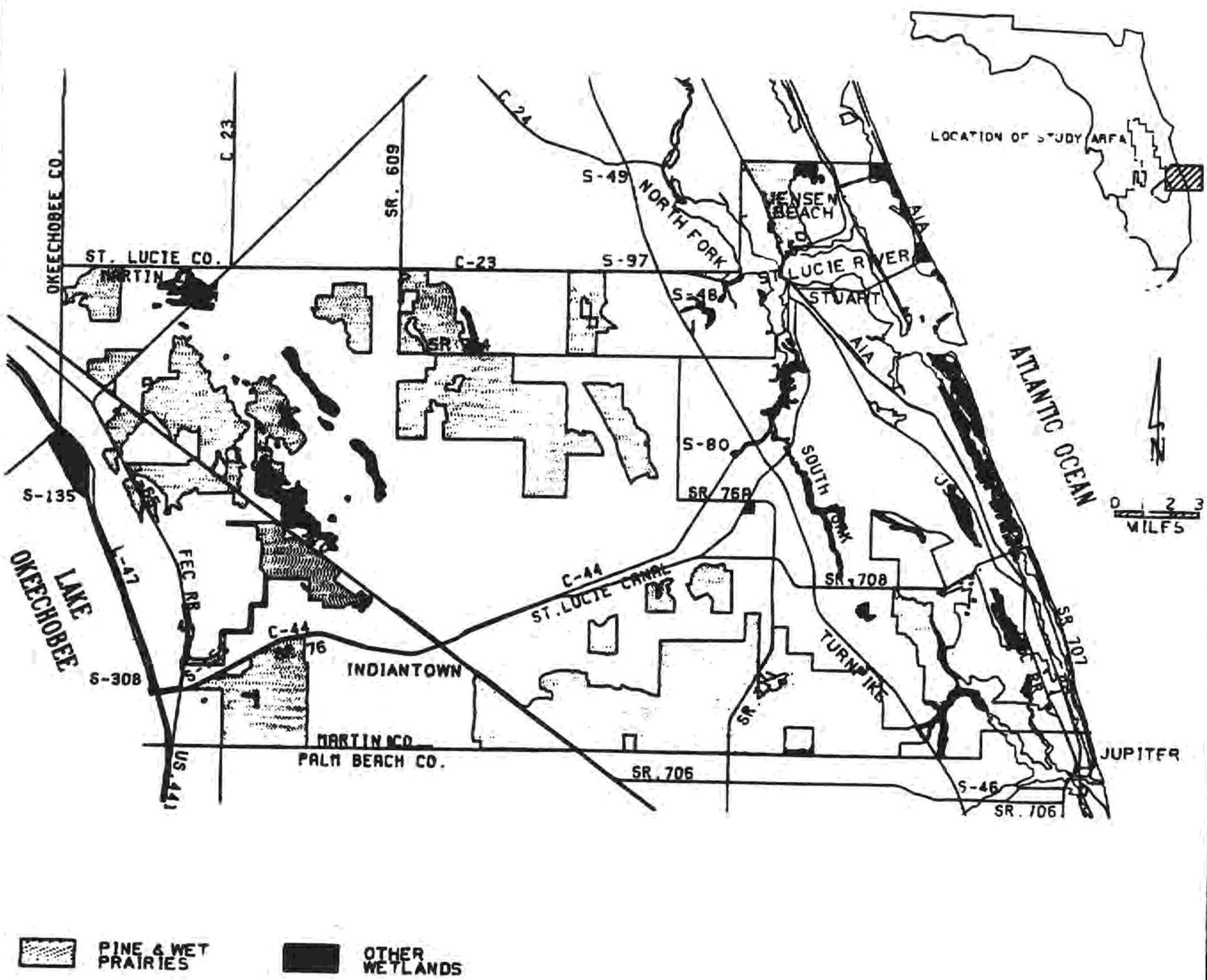


Figure 69 DESIGNATED WETLANDS (1979 DATA) MARTIN COUNTY

TABLE 20. PRIMARY AND SECONDARY DRINKING WATER REGULATIONS, FLORIDA ADMINISTRATIVE CODE, 1982

Primary Substances	Concentration (mg/l)
Arsenic (As)	0.05
Barium (Ba)	1
Cadmium (Cd)	0.010
Chromium (hexavalent, as Cr)	0.05
Lead (Pb)	0.05
Mercury (Hg)	0.002
Nitrate (as N)	10
Selenium (Se)	.01
Silver (Ag)	.05
Sodium	160

Secondary Substances	Concentration (mg/l)
Chloride (Cl)	250
Color	15 color units
Copper (Cu)	1
Iron (Fe)	0.3
Manganese (Mn)	0.05
Odor	3
pH	6.5 min.
Sulfate (SO_4)	250
Total dissolved solids (TDS)	500
Zinc (Zn)	5

Viable wetlands within Martin County are often very shallow depressions with little relief. The vegetation within the wetlands does not tolerate deep standing water, and the typical wet season water depths seldom exceed one foot (Personal Communication, Helfferich, 1985). The downward percolation of water within the wetlands is impeded by the organic mat which precipitates with the sand and calcium of the Surficial Aquifer System to form what is commonly known as hardpan. The hardpan is a semi-permeable unit which underlies the wetland but is above the main producing zone of the aquifer. Since the hardpan confines the aquifer to an extent, the water levels within the wetland are often higher than that of the aquifer. Figure 19 illustrates the relatively high water levels for well W-4B which is shallow in depth, in contrast to well W-4A, which penetrates the main aquifer. The wells share a common location and are adjacent to both wetlands areas and the north Martin County well field. The shallow well (W-4B) maintains a water level several feet above the deep well (W-4B); however, the water level of the shallow well declines and almost converges with that of the deep at the end of the hydrograph. The drawdown within the shallow well may be due to the well field withdrawals.

Drawdowns within active well fields are usually several feet, therefore, wetland areas can be significantly affected. As mentioned, the wet season water depths within functional wetlands seldom exceed one foot depending upon the hydroperiod. In addition, due to the shallow relief of wetland areas, a well field which impacts a wetland by 0.1 foot of drawdown would reduce the surface area of a wetland by 10%. Of course, the water level decline due to well field withdrawals could exceed a drawdown of 0.1 foot depending upon the quantity of water pumped, the permeability of the hardpan, and the amount of recharge to the aquifer and the wetland. In essence, all the above factors influence the water levels in the wetlands and the producing zone of the aquifer.

Figure 52 illustrates the wetland areas in the vicinity of the north Martin County well field. The area mapped was bounded by U.S. 1 to the west, SR 723 to the east and south, and the county line to the north. Wetlands within this area are viable and should remain in an undrained state. According to Helfferich (written communication, 1985), since water depths in this area seldom exceed one foot, a water table drawdown of less than 10 percent, or 0.1 foot, should be incorporated into well field design to maintain the existing environmental condition. The attempt to simulate the amount of drainage in the wetlands by the model should only be considered as a rough approximation. The limitations of the model are such that a two layer system cannot be precisely simulated. Further attempts to model both the wetlands and the aquifer would necessitate a three-dimensional ground water model. In addition, the required data would include water levels within the wetland and the main aquifer, permeability values for both systems, the effects of rainfall and evapotranspiration on each system, and the proximity of the wetlands to the well field. Therefore, to effectively assess the impact of a well field on wetlands, and to acquire the necessary data for this evaluation, would mandate site specific studies. Such an evaluation could certainly indicate that future well field withdrawals may be limited by the corresponding impacts on existing wetlands.

Siting of New Well fields

The most obvious concern associated with well field siting is the migration of pollution. In the selection of a well site, areas that should be avoided include not only those mentioned but also the zones surrounding them which may be contaminated. In addition, environmental concerns such as the protection of wetlands also limit the potential for new well fields. Within Martin County the hydrogeologic properties of the Surficial Aquifer System are such that the development of well fields can best be accomplished by utilizing the aquifer in the southern portion of the county. The transmissivity of the Surficial aquifer in this area is often above 100,000 gpd/ft. Northward, the transmitting capacity of the aquifer declines. However, it is expected that population centers will occur along the entire north-south transect of the county and east of the Florida Turnpike corridor. Hence, use of the aquifer will be required in this area to satisfy population water demands.

With the exception of agricultural, septic tank, and wetlands areas which are extensive, the additional industrial, commercial, and waste disposal areas are relatively small. Well fields tapping the Surficial Aquifer System should be developed at a sufficient distance from these areas to avoid contamination. In addition, well fields should be positioned far enough inland to avoid salt water intrusion.

The development of new well fields must be evaluated on a site specific basis. Factors which should be taken into consideration are land use, population density, and hydrogeologic conditions. Land use impacts on the aquifer should be determined. Potential ground water contamination should be assessed and the quality of water should meet the recommended standards. The projected population densities should be determined for a specific well field site since the water demand required dictates the design of the well field. Well field design such as number of wells and orientation of the well field will also be contingent on the aquifer properties.

Illustrated in Figure 70 are land use and the pumping capacity of the Surficial Aquifer System, limited by salt water intrusion and environmental impacts. Land use types included in Figure 70 are landfills, septic tanks, commercial, and industrial. These areas should be avoided if at all possible in the selection of potential well field sites. However, these areas are concentrated in the eastern portion of the county where the population centers along with the water demands are expected to be located. Therefore, new well field siting will demand a thorough ground water quality analysis on a site specific basis to ensure that potential land use impacts on the aquifer can be abated. Future land use types which could contaminate the Surficial Aquifer System are shown on Appendix 5.

Quantitatively, Figure 70 illustrates the pumping capacity of the Surficial aquifer as explained. The water availability limited under these circumstances is 308 MGD which is over five times the quantity demanded by the total buildout scenario. Therefore, the amount of water which can be supplied by the Surficial aquifer exceeds the buildout demand on a regional basis. Locally, the map depicts contours which represent the pumping capacity of the aquifer in million gallons per day on a square mile basis. If a utility serves a ten square mile area and is located in an area represented by a contour of 0.6 million gallons per day, the utility could be expected to withdraw six million gallons from the aquifer. However, the map is regional and flexibility must be evaluated at each site to determine the quantity of water available from the Surficial aquifer and the best management practices for well field operation at a particular location in conjunction with the needs of the county.

Figure 71 illustrates areas of potential well field development. These areas were based upon the aquifer characteristics as well as future land use types.

The potential for contamination of the Floridan Aquifer System due to land use impacts is limited in Martin County since the entire county is an area of discharge for the aquifer system. That is, the Floridan Aquifer System is not in direct hydraulic connection to the Surficial Aquifer System, because the thick Hawthorn confining beds separate the two aquifers. In addition, the hydraulic head of the Floridan is much greater than that of the Surficial; therefore, downward flow from the water table aquifer to the Floridan is entirely impossible, unless the gradient is reversed.

The transmissivity of the Floridan Aquifer System (Figure 22) is greatest in the central and southern portions of Martin County (see Figure 71). Wells drilled in these areas can be expected to be the most productive. In order to avoid violating the criterion that water levels should not be allowed to drop below land surface, two factors should be considered when siting a new well field. The areas in which both water levels and transmissivity are the greatest have the best development potential for ground water from the Floridan. The area with the best potential for development of the Floridan Aquifer System is located in the southeastern portion of the county. The area is roughly triangular in shape and is bounded by C-44 to the west, the Atlantic Ocean to the east, and the Palm Beach/Martin County border to the south.

WELL FIELD PROTECTION ORDINANCES

The water quality of the Surficial Aquifer System is generally good. Where the ambient ground water quality exceeds the recommended standards, common

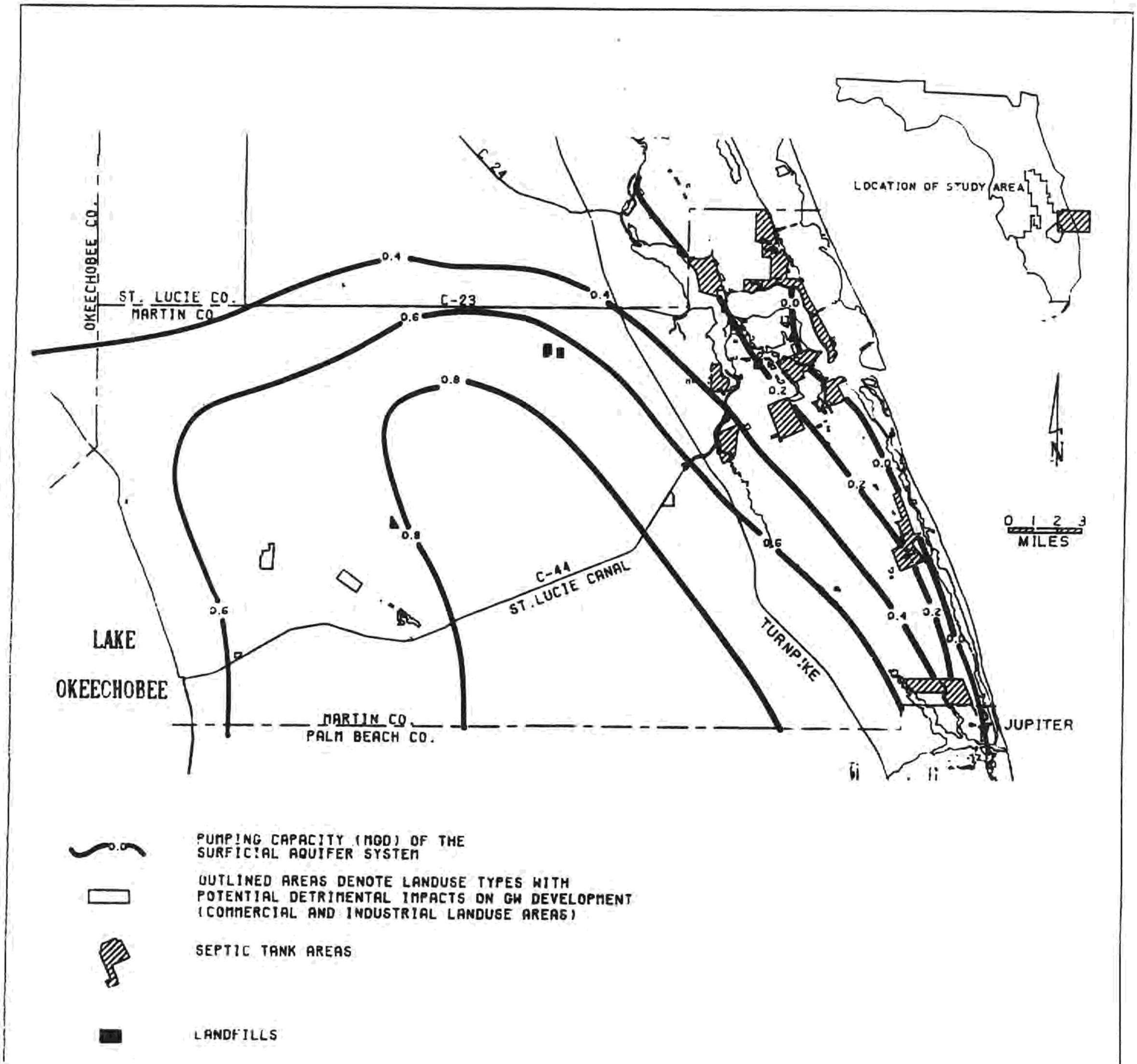


Figure 70 PUMPING CAPACITY OF THE SURFICIAL AQUIFER SYSTEM, (LIMITED BY SALTWATER, ENVIRONMENTAL AND LANDUSE IMPACTS). MARTIN COUNTY

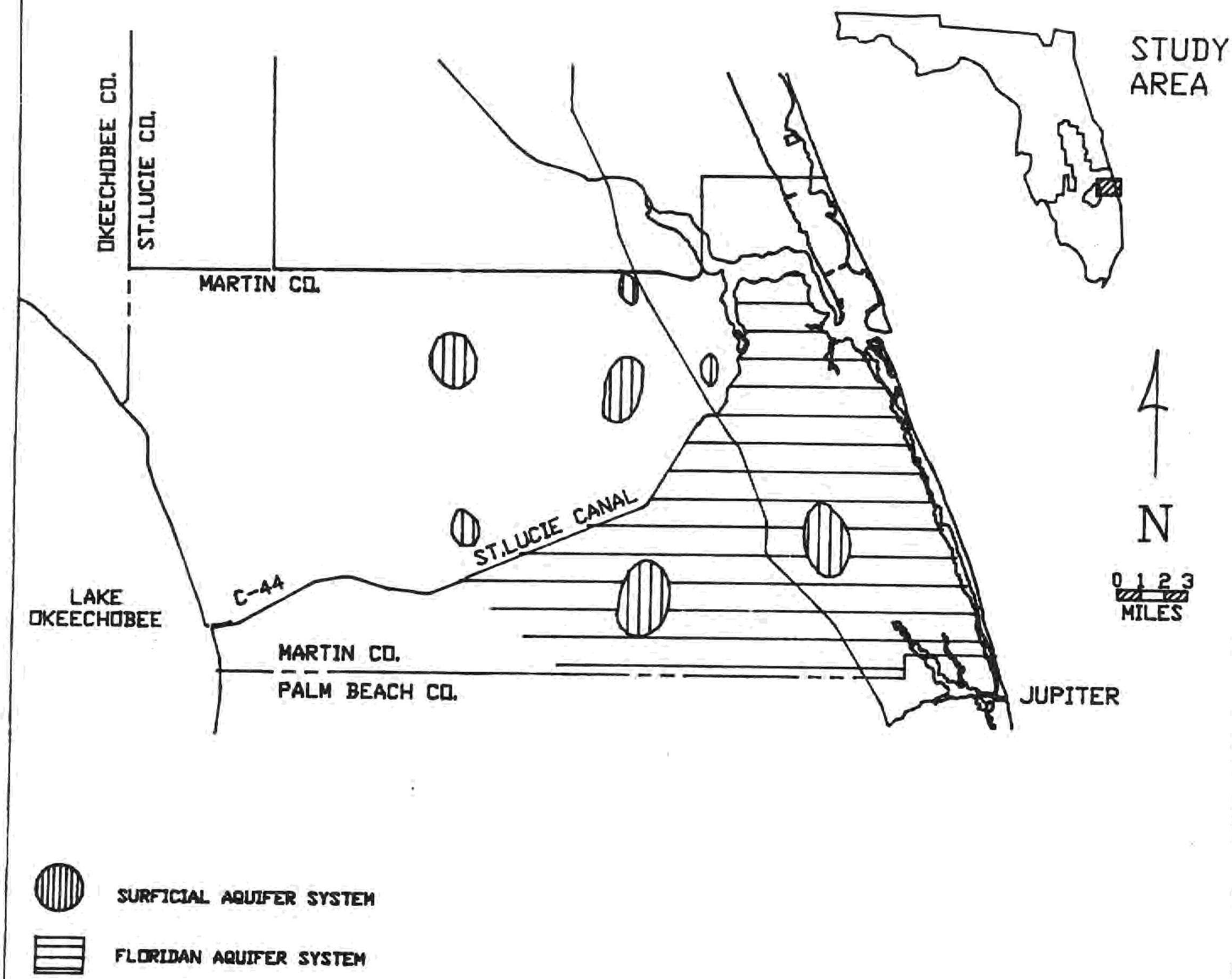


Figure 71 POTENTIAL WELLFIELD DEVELOPMENT AREAS

methods of treatment can be applied; however, the aquifer is susceptible to various levels of contamination which are associated with human activities and the corresponding land use. In order to prevent contamination from these sources, a cone of influence ordinance should be enacted. Figure 72 illustrates the possible effects of land use within the cone of depression of a pumping well.

Conventional water treatment plants may not completely extract certain toxins and bacteria from water withdrawn from public supply well fields. To avoid this danger, some minimal residence time in the water bearing formation is required to allow the toxins and bacteria to dilute, decay, and become harmless before reaching the pumping well. The area where water travels toward the pumping well is called the area of influence. The time required for water to travel from a point, at a given distance away from the well (within the area of influence) to the well itself is called travelling time. Travelling time is computed on the distance between a point and the wellbore divided by the average ground water velocity along this line. The average ground water velocity is computed by the hydraulic gradient, or change in water levels over a unit distance, multiplied by the aquifer permeability. (See Table 21).

TABLE 21. WELLFIELD PROTECTION AREAS

Wellfield	Pumpage (MGD)	Radius of Influence from Center of Wellfield (Feet)	Radius of Influence from an Individual Well* (Feet)
St. Lucie Falls	2.1	1400	200
Hobe Sound	1.1	1000	200
Indiantown	7.2	1300	100
Hydratech	4.9	700	100
Intercoastal	4.9	900	100
Martin Downs	2.7	600	100
New Palm City*	7.8	800	100
New South**	1.5	900	100
New Middle**	5.0	600	100
FM Water Company	0.2	100	100
Miles Grant	0.3	100	100
OZ Development	0.1	100	100
Pine Village Lake	0.3	200	100
Southern States	0.9	300	100
Piper Landing	0.1	100	100
Banyan Bay	0.4	100	100
Ocean Breeze	0.1	100	100

*Pumpage Per Well Equals 0.2 MGD
**Hypothetical Wellfields

Note: Wellfield protection areas for the City of Stuart and North Martin County wellfields are presented in Figures 47 and 53 respectively.

Cone of Depression and Ground Water Velocity

The extent of the cone of depression is dependent upon the quantity of water being pumped, the transmissivity of the aquifer, the configuration of wells in the well field, and the length of time over which withdrawals have been made in the absence of recharge. If these parameters are known, the travel time and velocity of a chemical constituent can be determined. Generally, the more permeable the aquifer and the steeper the hydraulic gradient, the faster a chemical constituent can travel a given distance toward a pumping well. Most often, the travel time is analyzed by ground water flow modeling for a specific area. Such modeling, when properly calibrated, provides the basis for projecting scenarios of travel time and distances in the absence of recharge. The cone of influence ordinance for Dade County, which was the first developed in southeast Florida, is based upon travel times occurring in the longest drought on record in this area, a 210-day drought. Similar ordinances for Broward and Palm Beach Counties are based upon a design drought of this length.

Once the extent of the cone of depression is determined, zoning ordinances can be enacted to protect the well field and aquifer from potential contamination. Allowable land use categories within the cone of depression for Dade County are listed in Appendix 3 The cone of influence ordinance is a preventive measure which can affect the dependence on modern treatment technologies to make contaminated water potable.

Detailed models were constructed for the Stuart and north Martin County well fields to provide better resolution to assess the impacts on water levels due to various pumpage scearios. The 210 day travel time contour and the area of influence were computed. These results are presented in Figures 47 and 53, respectively, for a normal dry season rainfall of 22 inches. Buildout pumpages at the additional major well fields were evaluated using analytical solutions to compute the travel times and the areas of influence

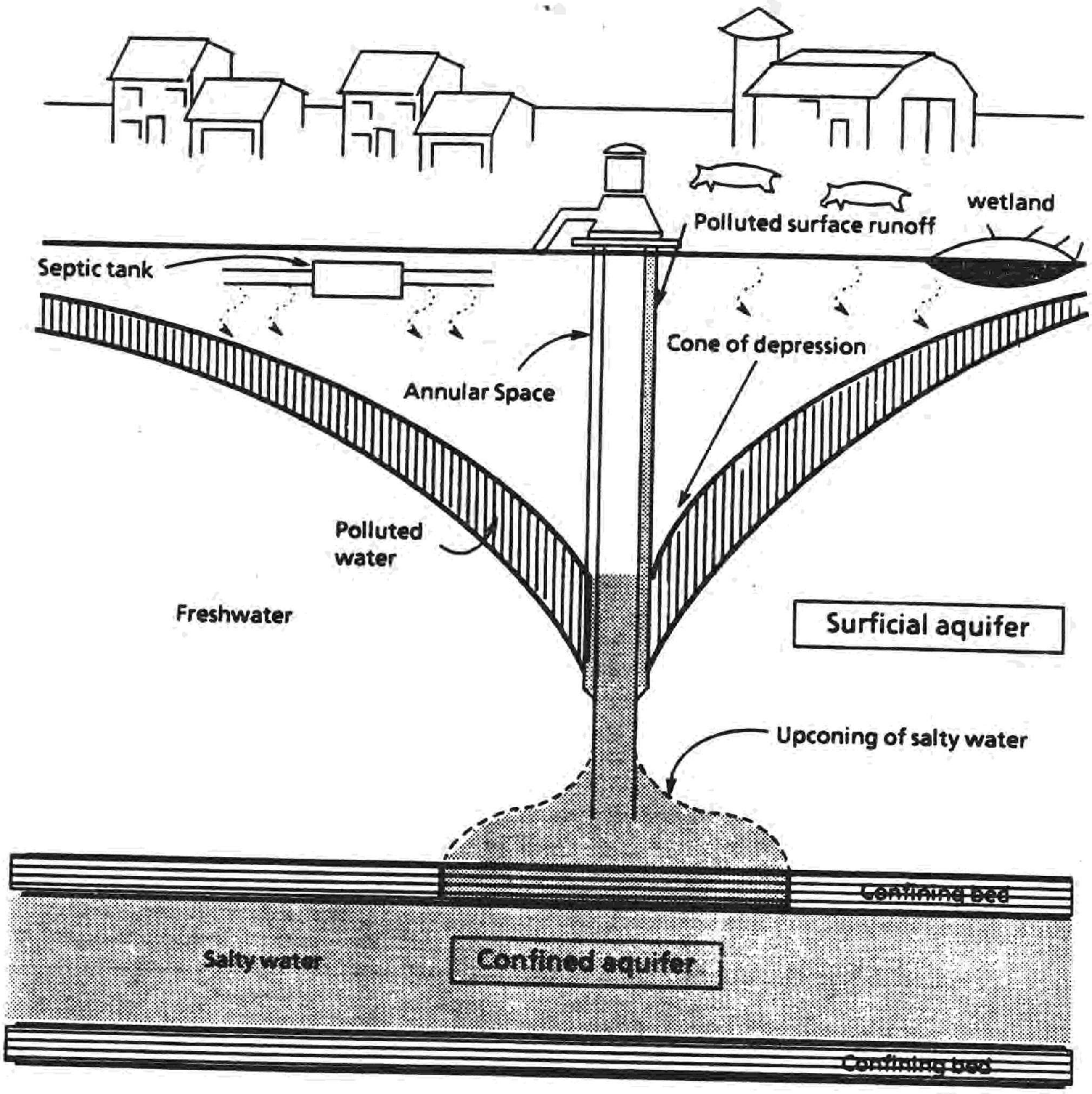


Figure 72 IMPACTS ON THE CONE OF DEPRESSION (MODIFIED AFTER HEATH, 1984)

influence at these well fields. The parameters employed in the evaluation are those used in the regional model. Since the county-wide model can input only one well per node or 1 X 1 mile grid block, the total pumpage was assigned to a single well. This single well would, therefore, represent the entire well field. The radii from the center of the well fields and the radii of the cones of depression were computed for each well and are listed in Table 21. In addition, the total pumpage per well field was arbitrarily divided by 0.2 MGD to approximate the number of wells needed to supply the total quantity of water. The distance listed from either the well field or individual well were calculated for 210 days travel time; however, the well field protection areas presented here were based on a regional evaluation and should be considered as a rough approximation.

SUMMARY

With continued growth in Martin County, additional water will be required to satisfy the expanding population. The buildout water demand has been approximated at 56 MGD for the entire county. The population centers are expected to be east of the Florida Turnpike corridor and new or expanded well fields necessary to meet this water demand are anticipated to be in this area. Both existing and hypothetical well fields were simulated with a ground water flow model to assess these future demands. The regional ground water model indicates that the Surficial Aquifer System can probably meet these demands if properly managed; however, significant declines in the computed water table occurred at several major well fields where the buildout pumpage was high. A more uniform distribution of this water withdrawal would alleviate these declines in localized areas.

The county-wide model also indicates that future water demands may have detrimental effects on the aquifer at both the Stuart well field and the north Martin County well field. These well fields were modeled separately with a fine grid system for better resolution.

The buildout water demand for Stuart is estimated at 6.9 MGD. This pumpage was evenly distributed among the 30 wells within the well field. The model suggests that salt water intrusion could possibly occur if this pumpage is distributed uniformly among the existing wells. The future water demands may be met if pumpages are restricted to the southern portion of the well field. If additional wells are incorporated within the well field, they should also be placed in the southern Stuart area.

The buildout water demand at the north Martin County well field is estimated at 11.6 MGD. The ground water flow model indicates that this pumpage cannot be met without serious detrimental effects. It is estimated that capacity of the Surficial Aquifer System within this area is approximately 3 to 4 MGD.

The remaining buildout water demand would have to be augmented by an alternative source. One such source is the Floridan Aquifer System which could provide approximately 3.6 MGD in the entire northern peninsula. Additional water would have to be transported from other portions of the county.

Ground water from the Floridan Aquifer System can be utilized as an alternative source of water to augment the water supplied from the Surficial Aquifer System. However, treatment will be required to attain potability standards. A total of 15.9 MGD of raw water, or 11.1 MGD of distilled water, can be withdrawn from the Floridan Aquifer System at the existing public water supply well field locations in Martin County. A total of 1.97 MGD and 2.30 MGD of raw water can be withdrawn from the Floridan Aquifer System at the north Martin County and Stuart well fields, respectively.

The top of the Floridan Aquifer System is located at depths of approximately 600 to 800 feet below mean sea level in Martin County. A production well should penetrate the aquifer system an additional 200-500 feet. The cost of an individual well which taps this aquifer system will be much greater than that of a well which tops the Surficial Aquifer System due to these great depths.

There is a potential for well field development in the central and southern portion of Martin County. In these areas, the productivity of both aquifer systems is greatest. In addition, there is less danger of ground water contamination of the Surficial Aquifer System due to the lack of landfills and industrial and commercial wastes in these areas. However, the costs of developing new well fields and subsequently transporting the water to the eastern urbanized portions of the county should be assessed to determine the viability of this alternative. Although ground water development is limited by land use and aquifer productivity in the eastern portion of the county, the total water demand can be met if qualitative and quantitative management practices are employed.

CONCLUSIONS AND RECOMMENDATIONS

SURFACE WATER:

1. The availability of surface water from C-44, the St. Lucie Canal, is insufficient to provide a continuous source of water to Martin County for potable water supply purposes.

2. During periods in which surplus flow from C-44 exists, water could be diverted to recharge depleted wellfield storage, as is practiced in Lee County.

3. Surplus canal water could also be stored in the Floridan Aquifer System in injection wells and recovered for use in the dry season; this technique is being investigated in several areas of the state.

4. Water supplies could potentially be provided from Lake Okeechobee to supplement the St. Lucie Canal source for Martin County public water supplies. Such supplemental supplies from the lake would, however, be subject to restriction during drought periods and would also reduce availability for other existing users of Lake Okeechobee.

5. Therefore, it is recommended that Martin County direct its attention towards utilization of local ground water.supplies prior to considering surface water supplies.

SURFICIAL AQUIFER SYSTEM:

1. Regionally, development of water supplies from the Surficial Aquifer System can, with prudent aquifer and land use management, potentially meet the buildout demands of Martin County. In some localized areas, however, the Surficial Aquifer System will not be able to meet buildout demands.

2. In areas such as the northern Jensen peninsula (north Martin County wellfield), where shallow ground water.supplies will not be adequate to meet buildout demands, other alternatives must be considered and pursued by Martin County. These include (unordered list):
   - Developing a wellfield on the mainland and pumping water to the area.
   - Utilizing the Floridan Aquifer System and desalination technology.
   - Water reclamation and water conservation.
   - Reducing demands by modifying the comprehensive plan.

3. The impact of wellfield withdrawals on existing wetlands cannot be accurately assessed without additional data and better mathematical models. Due to potential adverse impacts on wetlands, the development of improved models and the collection of the necessary data to calibrate and validate these tools, so that accurate assessments can be made, is a high priority task.

4. The city of Stuart may be able to supply buildout demands by emphasizing pumpage from the southern portion of its wellfield. Should additional wells be required to meet these demands, they should be located south of the existing wells. Care should be taken to avoid leachate migration from the closed Stuart landfill. In addition, due to the proximity of salt water to the northern wells, prudent aquifer management calls for emphasis being placed on withdrawing water from the southerly portion of the wellfield, particularly during dry periods.

5. Prior to selecting sites for new wells and committing to their construction, the ambient ground water.quality of the Surficial Aquifer System should be determined.

6. The existing salt water intrusion monitoring well network should be continually assessed and evaluated for significant changes.

FLORIDAN AQUIFER SYSTEM:

1. For areas in which the Surficial Aquifer System is either unavailable (i.e., salt water contamination) or inadequate to meet demands, the Floridan Aquifer System is a potentially economical source for potable water when treated by reverse osmosis. This aquifer system is less likely to be impacted by contamination and drought conditions than the Surficial Aquifer System and withdrawals are unlikely to produce adverse impacts on wetlands. Site specific cost analyses will be required, however, to assess economic feasibility as a public water supply source.

2. An inventory of the abandoned wells which penetrate the Floridan Aquifer System should be prepared. Records of well location, discharge

rates, and salinity should be maintained and evaluated. Those wells which represent a source of contamination to the Surficial Aquifer System should be appropriately plugged. A remedial well plugging program, supported by a variety of public and private funding sources, is needed to expedite abatement of this contamination.

SITING AND PROTECTION OF NEW WELLFIELDS:

1. County-wide planning for locating and acquiring wellfield sites should be expedited. During such studies, any adverse land use impacts on the quality of the Surficial Aquifer System should be determined. In addition, site specific studies to determine aquifer productivity and optimum well design and wellfield configuration will be needed.

2. The productivity of both the Surficial and the Floridan Aquifer Systems is greatest in the central and southern portion of the county. Although contamination is less likely in these areas due to the lack of industrial and commerical land uses and landfills, the potential adverse impacts of withdrawals from Surficial aquifer wellfields on wetlands requires careful attention.

3. Martin County is strongly urged to develop a wellfield protection ordinance to protect existing, and identify and protect future, wellfields. Existing ordinances in Dade and Broward Counties, and the on-going ordinance development effort in Palm Beach County, provide a variety of prototypes to assist Martin County in developing an ordinance best suited to the needs of the county. Financial and technical assistance can be made available from the SFWMD.

NEEDED STUDIES

1. The potential adverse impact of new and expanding wellfields on wetlands cannot be accurately determined with currently available data. Information is needed, particularly on variations in vertical permeability within the Surficial Aquifer System. Site specific information will be necessary until a more adequate data base is established within Martin County.

2. In order to more realistically simulate the impacts of wellfield withdrawals on existing wetlands, a three-dimensional ground water flow model should be utilized in future studies. Such a model can take into account the interactions of the multi-layered system and wetlands hydroperiods. The SFWMD should pursue adaptation, calibration and verification of such a model as a high priority.

3. The modeling conducted as a part of this study was hampered by the lack of detailed operational records for the various wellfields. Specific data should be collected which includes individual well discharges, pumpage durations, and water levels. Such records would permit more accurate mathematical modeling.

4. Due to its close proximity to the city of Stuart wellfield, a detailed study should be conducted at the abandoned city of Stuart landfill. The objectives should be to: 1) determine leachate composition and concentration; 2) ascertain the presence of any health hazard, and 3) define the shape of the leachate plume and its direction of migration.

5. A site-specific consultant study should be performed to determine the optimal configuration of potential wells at the north Martin County wellfield. Such work is necessary to obtain optimal yields from the Surficial Aquifer System.

6. The county is strongly encouraged to examine the potential for reclamation of wastewater as a supplemental source for irrigation of "green areas" as a part of its wastewater master planning.

REFERENCES

Allen, L. H., et al. 1982. Evapotranspiration, Rainfall, and Water Yield in South Florida Research Watersheds: U. S. Department of Agriculture, Agricultural Research Service, University of Florida, Gainesville, Florida.

Brown, M. P. and D. E. Reece. 1979. Hydrologic Reconnaissance of the Floridan Aquifer System, Upper East Coast Planning Area: South Florida Water Management District, Technical Map Series 79-1, Plates 1-10B.

CH_2M Hill. 1979. Investigation of Water Availability in the South Well Field for the City of Stuart: Gainesville, Florida.

Deb, Arun K. 1978. Dual Water Supply Seminar and Workshop: Weston Environmental Consultants and Designers, Weston, Pennsylvania.

Earle, J. E. 1975. Progress Report on the Water Resource Investigation of Martin County, Florida: U. S. Geological Survey Open File Report FL-75-521, Tallahassee, Florida.

Fischer, J. N. 1978. Evaluation of the High Permeability Zone of the Shallow Aquifer, Palm Beach County, Florida, <u>in</u> Brown, M. P., ed. Hydrogeology of South Central Florida, 1978 Field Trip Guidebook: Southeastern Geol. Soc., West Palm Beach, Florida, Publ. 20, p. 1-14.

Freeze, R. A., and J. A. Cherry. 1979. Groundwater: Prentice-Hall, Englewood Cliffs, New Jersey, 604 p.

Gibb, J. P., and E. W. Sanderson. 1969. Municipal and Industrial Wells: Illinois State Water Survey, Urbana, Illinois, Circular No. 98.

Healy, H. G. 1978. Appraisal of Uncontrolled Flowing Artesian Wells in Florida: U. S. Geological Survey, Water Resource Investigation 78-95.

Heath, Ralph C. 1983. Basic Ground Water Hydrology: U. S. Geological Survey, Paper 2220.

Helfferich, B. 1985. Personal Communication: South Florida Water Management District, West Palm Beach, Florida.

Khanal, N. and S. Winn. 1978. Growth of Desalt Plants in Southeast Florida: IDEA Pure Water, Vol. 8, No. 1.

Khanal, N., 1980. Advanced Water Supply Alternatives for the Upper East Coast Planning Area, Parts I and II: South Florida Water Management District, Technical Publication 80-6, West Palm Beach, Florida.

Lichtler, W. F. 1960. Geology and Ground-Water Resources of Martin County, Florida: Florida Geol. Survey Report of Investigations No. 23, 95 p.

Lohman, S. W., 1972. Ground Water Hydraulics: U. S. Geological Survey Prof. Paper 708, 70 p.

MacVicar, T. K., et al. 1983. South Florida Water Management Model Documentation Report: South Florida Water Management District, Technical Publication 84-3, West Palm Beach, Florida.

McCollum, S. H. and O. E. Cruz. 1981. Soil Survey of Martin County Area, Florida: U. S. Department of Agriculture, Soil Conservation Service, Stuart, Florida.

McGraw Hill Publishers. August 1985, Engineering News Record, New York.

Miller, D. W. 1980. Waste Disposal Effects on Ground Water: Premier Press, Berkeley, California.

Miller, James A. 1982a. Configuration of the Base of the Upper Permeable Zone of the Tertiary Limestone Aquifer System, Southeastern United States: U. S. Geological Survey, Open-File Report 81-1177.

Miller, James A. 1982b. Geology and Configuration of the Top of the Tertiary Limestone Aquifer System, Southeastern United States: U. S. Geological Survey, Open-File Report 81-1178.

Miller, James A., 1982c. Thickness of the Tertiary Limestone Aquifer System, Southeastern United States: U. S. Geological Survey, Open-File Report 81-1124.

Miller, James A., 1982d. Geology and Configuration of the Base of the Tertiary Limestone Aquifer System, Southeastern United States: U. S. Geological Survey, Open-File Report 81-1176.

Miller, R. A. 1978. Water Resource Setting, Martin County: U. S. Geological Survey, Water Resources Investigation 77-68.

Miller, R. A. 1979. Water Resources of the Shallow Aquifer, Martin County, Florida: U. S. Geological Survey, Unpublished.

Miller, W. L. 1979. Hydrologic and Geologic Data for the Upper East Coast Planning Area in Southeast Florida: U. S. Geological Survey Open-File Report 79-1543, 99 p.

Miller, W. L., 1980. Geologic Aspects of the Surficial Aquifer in the Upper East Coast Planning Area, Southeast Florida: U. S. Geological Survey Water-Resources Investigations Open-File Report 80-586, 2 sheets.

Parker, G. G., G. E. Ferguson, S. K. Love, and others. 1951. Water Resources of Southeastern Florida, with Special References to the Geology and Groundwater of the Miami Area: U. S. Geological Survey Water-Supply Paper 1255, 936 p.

Scott, W. B. 1977. Hydraulic Conductivity and Water Quality of the Shallow Aquifer, Palm Beach County, Florida: U. S. Geological Survey Water-Resources Investigation 76-199, 22 p.

Shaw, Jon E. and Sharon M. Trost. 1984. Hydrogeology of the Kissimmee Planning Area, South Florida Water Management District, Technical Publication #84-1, 235 p.

South Florida Water Management District. 1980. Water Use and Supply Development Plan: Volume 1, IIIC, Lower West Coast, Florida.

Stodghill, A. M. and M. T. Stewart. 1984. Resistivity Investigation of the Coastal Ridge Aquifer Hydrostratigraphy, Martin County, Florida: South Florida Water Management District, West Palm Beach, Florida.

Todd, D. K. 1980. Groundwater Hydrology: John Wiley and Sons, New York, New York.

Trost, S. 1987. Floridan Aquifer Resource Assessment, Upper East Coast Planning Area: South Florida Water Management District, In Press.

Wedderburn, Leslie A. and M. S. Knapp. 1983. Field Investigation into the Feasibility of Storing Fresh Water in Portions of the Floridan Aquifer System, St. Lucie County, Florida: South Florida Water Management District, Technical Publication #83-7.

Weston, Roy F., Inc. 1976. Cost Curves Developed for EPA 208 Manual.

Weston, Roy F., Inc. 1976. Cost Projections Based on National Average Units Costs.

APPENDIX 1

RAINFALL DROUGHT FREQUENCY AND AVAILABILITY OF SURFACE WATER IN MARTIN COUNTY

RAINFALL DROUGHT FREQUENCY
AND
AVAILABILITY OF SURFACE WATER
IN MARTIN COUNTY

BY

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SOUTH FLORIDA WATER MANAGEMENT DISTRICT

NOVEMBER 1985

ABSTRACT

This report provides statistical information on rainfall drought frequency and on the availability of surface water in Martin County. This analysis is part of a comprehensive study by the South Florida Water Management District to assist Martin County in their water resources planning. The discussion consists of four sections. The first section describes the background and objectives of this study, the connotation of surface water availability, and the definition of C-44 inflow. Section II describes procedures used to prepare data for statistical analysis. The C-44 inflow record was extended by regression with rainfall and the acceptability of the extension was examined. Section III describes procedures used to conduct frequency analyses on the rainfall and C-44 inflow data. The results are presented in a series of frequency curves in the Appendix and the same information is summarized in four isofrequency diagrams (pages 14 to 17). Interpretation and use of the frequency information is illustrated. The final section discusses the implications of the frequency information, reiterates the limitations and assumptions made, and recommends alternatives to increase water availability in Martin County. The results of this analysis indicate that while the C-44 inflow is plentiful during the wet months, it is inadequate to meet the current demand during part of the dry season, and that supplemental releases from Lake Okeechobee are needed for a duration of about one month in a normal year to three months once in 10 years.

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I. INTRODUCTION

As a result of the February 15, 1984 meeting between the South Florida Water Management District (SFWMD) and Martin County, the SFWMD outlined a scope of study to assist Martin County in their water resources planning. The study goal is stated in the documentation of "Martin County: SFWMD Water Resources Planning Assistance Program" as:

> *The study will provide the Martin County Board of County Commissioners with an analysis of water availability and will provide water resource planning recommendations to be used for the county's future growth management strategies.*

As part of a comprehensive study, the Water Resources Division of the SFWMD is committed to provide analyses on rainfall drought frequency and on the availability of surface water in Martin County. A major objective is to quantify the availability of C-44 canal water that can be developed for use in Stuart and other rapidly growing urban areas in Martin County. This report documents the results of the above analyses.

The major source of surface water in Martin County is from C-44 (St Lucie Canal). A minor source of water can also be obtained from C-23, which lies on the boundary of St Lucie and Martin Counties. A decision has been made, however, to exclude C-23 in this study because the major portion of the drainage area of C-23 lies within St Lucie County, and the availability of canal water in C-23 has been known to be limited.

Surface water can be obtained from C-44 by direct withdrawal or by diversion and interception of secondary canal inflows to the canal. An analysis of surface water availability in Martin County is equivalent to analyzing the availability of C-44 inflow. In this report C-44 inflow refers to the portion generated within the canal basin. The portion contributed by Lake Okeechobee is excluded in the analysis because it involves a policy decision of how Lake

Okeechobee storage should be shared among all counties. A SFWMD water supply (computer) model can be used as a tool to address the second question.

Rainfall and flow are highly variable entities. The variability must be quantified in such a way that water resources planning can be made. The goal of this report is to make available a comprehensive series of diagrams depicting the drought frequency distribution of rainfall and surface water availability.

Section II describes procedures used to prepare the rainfall and C-44 inflow data for this analysis. The inflow record is limited and an extension of the historical record by regression is necessary. A number of regression models were compared to select the most appropriate one. The suitability of the extension was also examined. Section III describes procedures used to conduct frequency distribution analyses on the rainfall and inflow data for both calendar months and for durations of one to twelve months. The results are presented in a series of frequency distribution curves in the appendix and the same information is summarized in four isofrequency diagrams (pages 14 through 17). The usefulness of these diagrams depends on their proper interpretation and application. The intention of Section III is to provide such explanations. The final section discusses the implications of the frequency diagrams, reiterates the limitations and assumptions made, and recommends alternatives to increase water availability in Martin County.

II. DATA PREPARATION

Relatively long and good quality rainfall data are available for this analysis. The C-44 inflow data, on the other hand, are not entirely adequate. The quality of the S-308 discharge data is affected by the difficulty in quantifying the lock flow, and the record is too short for rigorous frequency analysis. This section describes procedures used to calibrate the flow data, to extend the flow record, and to examine the suitability of the extension.

Two long term rainfall stations are available within the C-44 basin, one located at S-80 (St Lucie Lock, MRF-7035) and the other at S-308 (Port Mayaca, MRF-51). The quality of data is generally good with relatively few missing records. Since these two stations are located at the two ends of the C-44 basin, the mean basin rainfall was calculated as the arithmetic average of the data from these stations. A total of 31 years of data, covering the period 1952 to 1983, was used for the present rainfall frequency analysis.

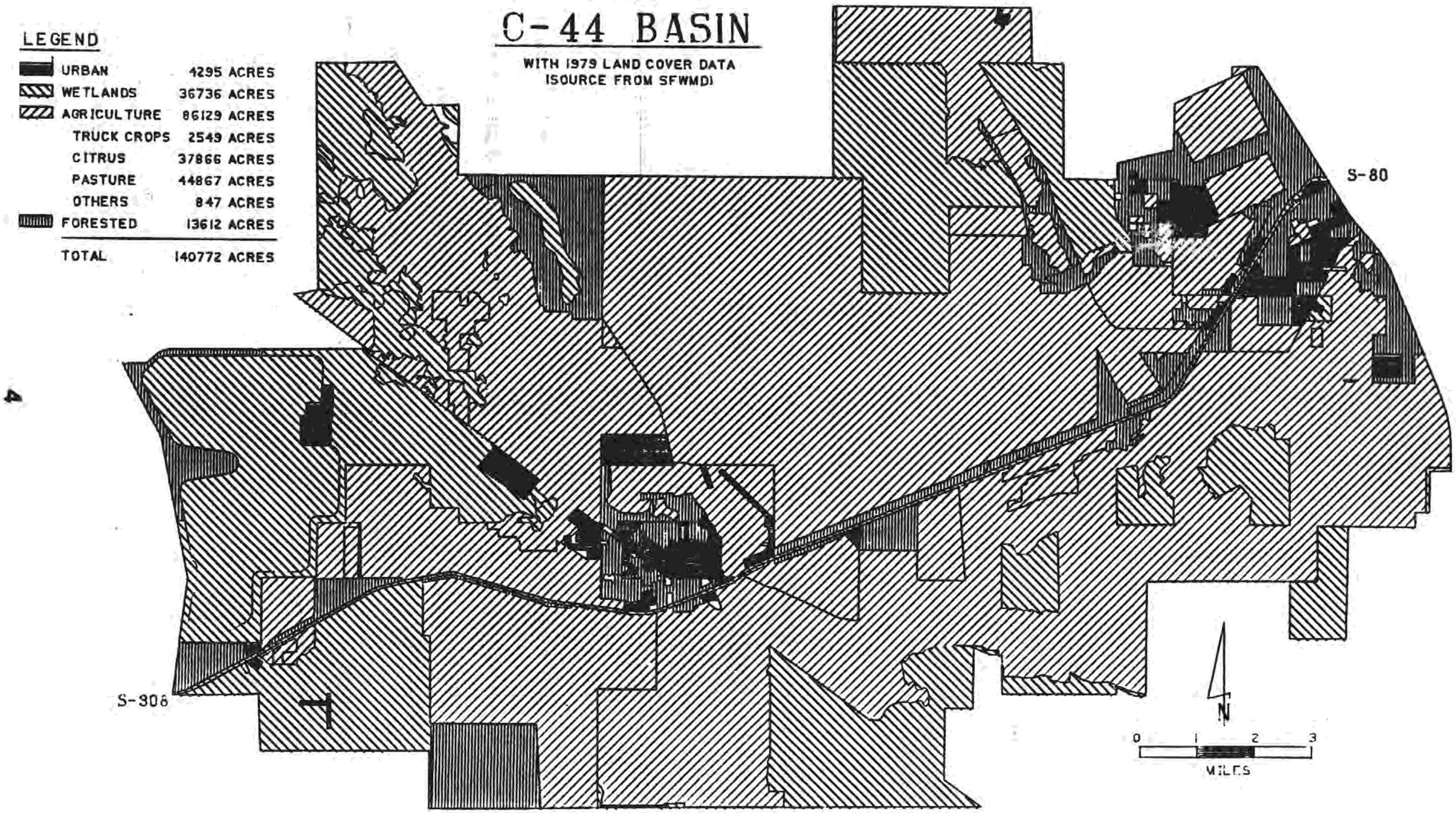
The C-44 inflow was calculated as the difference in discharges of S-80 and S-308, and adjusted for storage change in the channel. Because of the way it was calculated, the C-44 inflow included the effect of the existing (1978-1983) canal water usage in the basin. The calculated inflow represented the net amount available for additional usage as of the conditions in 1978-1983. If calculated inflow was negative, it represented the amount supplemented by Lake Okeechobee. Figure 1 shows the 1979 land use pattern in the C-44 basin, which is considered representative of the 1978-1983 study period. Any major change in land use within the C-44 basin from 1979 may increase or decrease the canal water availability. The canal water availability presented here must then be adjusted accordingly if the change is significant.

Discharge data for both S-80 and S-308 were obtained from the USGS. The USGS data for S-308, however, included only the spillway flow, the lock flow was excluded. Moreover, at the date of this report, only six years of data for S-308 were available because the structure did not exist prior to 1978. Two adjustments of the S-308 data, therefore, were necessary.

FIGURE 1

C-44 BASIN

WITH 1979 LAND COVER DATA
(SOURCE FROM SFWMD)

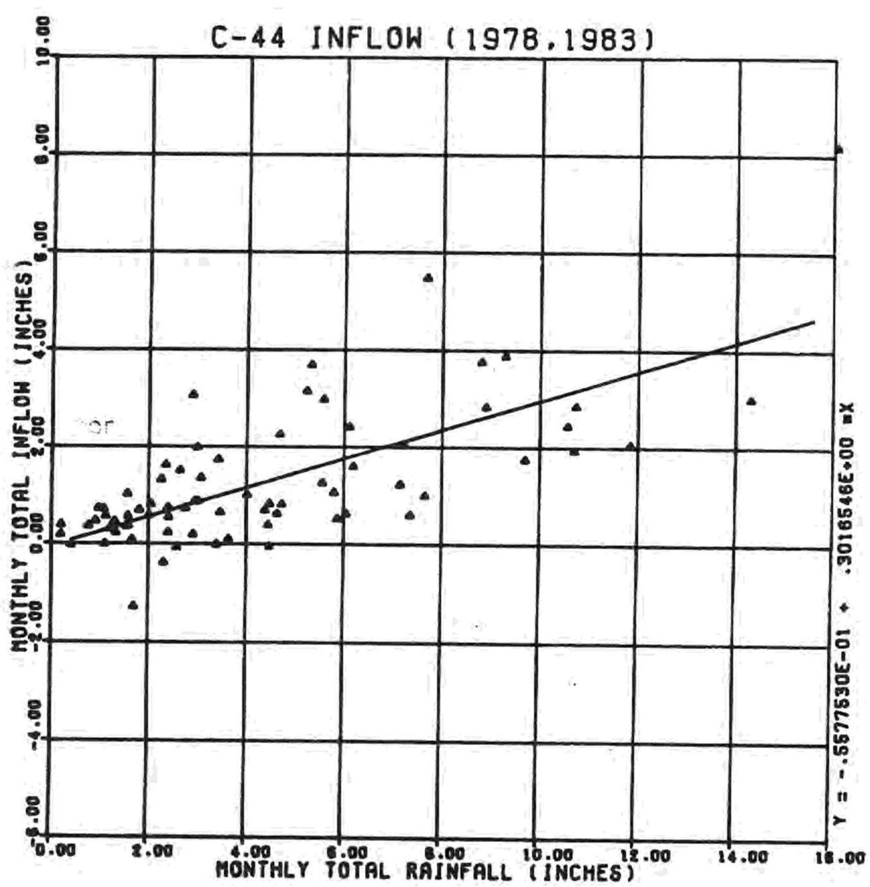


First, the lock flow must be included. Second, the limited record must be extended if possible.

The adjustments of S-308 data were based on work done by Alvin Castro (SFWMD), who applied the South Florida Water Management Model to the Upper East Coast of Florida. Essentially, the adjustments were based on a mass balance method, taking into account the stage difference between Lake Okeechobee and C-44 when the lock was open. Description and application of the computer model can be found in SFWMD Technical Publication 84-3.

The C-44 inflow record was extended by regression with rainfall. The usefulness of the extension is related to the degree of correlation . The first step was to search for a regression model that would optimize the correlation. A number of regression models were examined. These included simple linear regression of inflow versus rainfall, regression of inflow versus rainfall on each calendar month to account for the seasonality effect, and multiple regression of inflow versus concurrent and antecedent rainfall of different durations to account for the antecedent wetness effect. Stepwise multiple regression and graphical plots were used to assist in the selection. Although more complex regression models always improved the correlation coefficient, the improvements were found to be too small (less than 0.04) to warrant their usage. At the end, a simple linear regression model of monthly inflow versus monthly rainfall was selected. This regression equation has a correlation coefficient of 0.72 and is plotted in Figure 2.

Two questions arose after the selection of an appropriate regression model. First, how long the record should be extended, and second, whether the extended record will improve the statistical information. Linear regression with correlation coefficient less than one has a tendency to reduce the variance of the predictions, except when the independent variables used in the extension have greater variability to compensate the reduction. To assure that the extension is worthwhile, a statistical F-test was used to compare the variance before and after the extension. A criterion was set such that if the variance was significantly reduced, the extension would be rejected.



Note: One inch inflow equals 11731 acre-ft, based on basin area of 140772 acres.

Figure 2. C-44 Inflow and Rainfall Relationship

The original record was extended backward from 1978 to 1969, 1960, and 1952. The F-test indicated that, within one percent significance, the extended record back to 1969 was acceptable; beyond 1969, the variance would be significantly reduced. Based on the F-test results, the C-44 inflow record was extended backward to 1969. The rainfall and C-44 inflow data (original and extended) are shown in Table 1.

Some implications can be derived from the regression equation. The negative intercept (-0.056) indicates that there is a net withdrawal from the canal when the monthly rainfall is zero or very small. The positive slope (0.302) indicates that the monthly runoff coefficient is approximately 0.3, which is considered typical in this region.

Table 1. Rainfall And C-44 Inflow Data

Note: All data in inches over basin area of 140772 acres

C-44 Basin Rainfall (Mean rainfall at St Lucie and Port Mayaca locks)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1952	1.28	5.17	2.54	1.67	2.11	2.71	6.76	6.19	3.49	12.53	.08	.25
1953	1.91	2.01	2.07	4.33	.90	13.38	10.96	8.89	10.65	8.82	1.39	1.79
1954	.23	2.70	2.82	5.30	5.54	11.15	7.00	5.20	9.82	4.32	2.33	1.48
1955	1.67	2.35	1.47	3.22	2.11	11.20	6.95	5.83	4.67	2.74	.09	4.60
1956	.82	.95	.53	3.65	2.68	4.75	3.47	5.36	5.27	8.09	.22	1.33
1957	2.78	2.99	3.61	5.97	5.09	3.87	7.65	7.59	6.83	6.07	.97	5.19
1958	8.61	.62	5.81	3.44	7.41	3.73	4.36	3.83	6.83	5.10	.78	4.99
1959	2.84	.34	6.09	3.20	10.03	11.33	6.68	5.55	8.50	7.94	3.63	2.74
1960	.13	6.00	1.24	5.92	4.10	7.89	6.06	4.50	16.15	3.71	1.19	.53
1961	2.99	.50	1.74	1.76	7.31	2.96	2.77	6.87	1.44	5.08	1.50	.03
1962	.62	.84	3.83	5.06	1.32	6.46	8.50	9.24	9.10	2.21	1.45	.14
1963	.88	4.39	1.06	.91	4.55	7.16	4.82	4.80	6.21	3.57	2.68	6.85
1964	1.93	2.65	.41	3.76	3.83	6.79	10.46	12.04	4.68	8.38	.66	1.38
1965	.54	5.01	1.92	.75	.90	10.58	6.10	7.15	5.32	9.73	.36	.91
1966	5.83	4.38	1.71	4.77	4.35	14.25	5.00	5.17	7.08	9.77	1.40	1.00
1967	1.12	3.46	1.43	.05	2.63	10.79	6.16	9.49	7.01	10.92	.63	1.50
1968	.31	2.36	.77	.24	8.99	16.03	6.94	6.03	7.10	9.37	2.42	.00
1969	1.68	1.89	6.60	1.54	9.71	6.59	5.17	5.81	7.12	11.32	2.10	3.13
1970	4.37	4.15	14.97	.02	7.60	8.75	6.12	6.64	5.42	4.44	.05	.16
1971	.34	2.95	1.19	.19	8.14	3.99	9.05	5.76	5.71	7.17	3.59	2.26
1972	1.16	1.86	2.75	4.81	8.93	12.48	8.28	3.57	2.90	2.53	2.58	2.36
1973	2.14	1.92	2.33	1.16	3.70	7.52	13.03	7.61	5.57	5.05	1.15	1.30
1974	1.67	.16	1.23	1.57	2.63	11.29	7.95	6.99	6.89	3.83	2.45	1.09
1975	.66	2.33	1.47	.56	6.56	3.61	13.29	3.04	7.53	3.49	1.10	.46
1976	.24	2.35	.06	1.66	10.13	6.85	3.68	9.59	4.85	1.59	3.28	1.99
1977	3.61	.45	.73	1.01	1.95	3.94	7.03	7.04	9.73	5.78	4.74	4.50
1978	2.40	1.58	2.41	1.66	3.63	7.66	7.15	4.68	5.56	4.47	3.46	7.35
1979	5.32	.19	1.59	2.58	7.65	3.39	2.91	3.07	16.07	2.89	2.64	1.54
1980	2.40	2.95	1.30	2.01	5.87	1.20	4.72	4.63	9.70	2.26	1.81	1.12
1981	.91	1.57	.97	.20	2.31	1.08	4.38	14.31	5.23	2.05	1.10	.41
1982	.76	3.01	10.56	3.42	11.85	8.80	8.90	5.58	6.05	2.99	7.22	1.33
1983	4.45	10.73	4.47	2.76	1.71	6.19	5.80	10.70	6.11	9.29	2.35	4.01

C-44 Inflow (Difference between S80 and S308 flows. 1969-1977 data estimated)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1969	.45	.51	1.94	.41	2.87	1.93	1.50	1.70	2.09	3.36	.58	.89
1970	1.26	1.20	4.46	-.05	2.24	2.58	1.79	1.95	1.58	1.28	-.04	-.01
1971	.05	.83	.30	.00	2.40	1.15	2.67	1.68	1.67	2.11	1.03	.63
1972	.29	.51	.77	1.40	2.64	3.71	2.44	1.02	.82	.71	.72	.66
1973	.59	.52	.65	.29	1.06	2.21	3.87	2.24	1.62	1.47	.29	.34
1974	.45	-.01	.32	.42	.74	3.35	2.34	2.05	2.02	1.10	.68	.27
1975	.14	.65	.39	.11	1.92	1.03	3.95	.86	2.22	1.00	.28	.08
1976	.02	.65	-.04	.44	3.00	2.01	1.05	2.84	1.41	.42	.93	.54
1977	1.03	.08	.16	.25	.53	1.13	2.06	2.07	2.88	1.69	1.37	1.30
1978	.73	.55	.54	.07	.09	5.47	1.22	2.26	1.25	.82	.64	.59
1979	3.69	.18	.37	-.07	.99	-.02	.19	1.35	8.18	3.06	1.50	.36
1980	.23	.86	.45	.57	.51	.30	.81	.62	1.74	1.31	.68	.56
1981	.46	1.01	.72	.38	-.39	.70	.69	3.01	3.15	.80	-.01	-.03
1982	.36	.87	2.44	1.73	2.05	3.76	2.83	2.98	.62	1.98	2.04	.22
1983	.39	2.85	-.05	.72	-1.28	1.59	1.05	1.93	2.41	3.88	1.61	1.00

III. FREQUENCY ANALYSIS

In water supply planning it is important to know the probabilistic distribution of the availability of water in space as well as in duration and seasonal trends. This section describes procedures used to prepare frequency distribution curves for calendar months and for durations of one to twelve months. In addition, a flow duration curve and a frequency table depicting the time occurrences of annual minima are included. The information is summarized in four isofrequency curves (pages 14 through 17). The meanings of the frequency curves are defined to provide guidelines in their proper interpretation and application.

1. Flow Duration Curve

A flow duration curve is not a true frequency distribution curve, because probabilistic levels cannot be assigned to the data. A basic requirement for frequency analysis is that the data must be independent. Monthly or daily data are not independent but are serially correlated. For example, the flow in May is influenced by the flow in April, less by the flow in March, and so on. A flow duration curve is a straightforward presentation of the historical flow record in such a way that the percent of time the flow is exceeded or not exceeded is shown.

Although flow duration curves are not frequency curves, they have been used similarly to frequency curves. When the flow record is too short (less than two years) for frequency analysis, flow duration curves are often used as the sole source of information for hydraulic design and water supply planning purposes. In view of the relatively short historical record available for C-44 inflow (six years), a monthly flow duration curve is shown in Figure 3 for reference.

2. Frequency Distribution Curves, Calendar Month

Frequency distributions by calendar months are useful in water supply planning where seasonal variation is important. Such uses include developing a regulation schedule for a reservoir or projecting irrigation water requirements which vary with season.

The statistical sample is a set of monthly data of an individual calendar month such as, all flows in January, all flows in February, and so on. Since the individual data points are at least 12 months apart, the data can be assumed to be independent. The frequency distributions of the data were plotted on Normal and Gumbel (extremal) probability papers to see which distribution fits the data best. Log distributions (Log Pearson, Log Gumbel, Log Normal, etc.) were not considered because they could not accommodate negative values that were common with C-44 inflow. The differences in fit between the two distributions are small. In a majority of the cases the data fit slightly better in a Gumbel distribution, and based on this a Gumbel distribution was selected for this application.

Irrespective of the distribution used, the trends of the plots are similar. A statistical sample of hydrologic data in a calendar month is a heterogeneous combination of flood events, drought events, and normal events. A frequency distribution plot of such data reveals generally two distinct slopes; the flatter slope belongs to the drought events and the steeper slope to the flood events. Normal events appear to be in the transitional region. For water supply planning purposes, only the normal and drought events are of concern. Accordingly, least squares straight lines were fitted to the lower zone. By examining a number of the scatter plots, it was decided that the fitting should cover the lower two-thirds of the data points, which delineates the slope of the drought events. The calendar month frequency distribution curves for rainfall and C-44 inflow are included in the Appendix (page A2 through A13).

3. Frequency Distribution Curves, Monthly Duration

In water supply planning, it is important to know the critical conditions for various durations of time. Duration frequency curves provide information to define drought itself, to plan the storage capacity of a reservoir, or to determine the amount of supplemental water required from outside sources to satisfy the local demand.

The statistical sample is a set of annual minima of a specific duration, and here one through twelve month durations were included. For example, a sample of two months duration will be a set of two month minima (which may be any two consecutive months) taken from a number of annual cycles. The annual cycle used here is a water year which extends from November through October of the following year. Water year, rather than calendar year, is used to ensure that the entire dry season is included without splitting it into two consecutive annual cycles. This has been shown to produce a better fit on long duration frequencies. The duration frequency distributions for rainfall and C-44 inflow are included in the Appendix (pages A14 through A25).

4. Isofrequency Curves

The frequency distribution curves described above provide basic information to estimate rainfall or C-44 inflow at any probability level. For water supply planning purposes, however, it is seldom necessary to know more than a few probability levels. Isofrequency curves of both calendar months and durations are constructed (Figures 4 through 7) for 50%, 20%, 10%, and 5% probability levels, which correspond to return intervals of once in 2 years (normal year), once in 5 years, once in 10 years and once in 20 years, respectively.

Although estimates at any probability level can be made from the frequency distribution curves, the reliability of the estimates decreases with decreasing probability levels. As a rule, the maximum return interval that can be projected is limited to twice the length of the data record. Considering the lengths of records available, it is permissible to project rainfall up to once in 60 years, and C-44 inflow up to once in 12 years. If the flow extension is considered, it is probably reliable to project C-44 inflow up to once in 20 years. The longest return interval selected for the isofrequency curves is once in 20 years which is considered to be within reasonable confidence limits as well as adequate enough for most water supply planning purposes.

Although the construction procedures of the isofrequency curves for calendar months and durations are essentially identical, the meanings of the two isofrequencies are different. Calendar month isofrequency curves are not frequency hydrographs. The dashed lines (Figures 4 and 5) joining the discrete data points are for visual guidance only and do not indicate that the occurrences are sequential. Therefore, it is incorrect to read a calendar month isofrequency curve as the probable flow or rainfall distribution in a calendar year at the probability level indicated. The probability of such joint occurrences will be very small. The isofrequency curve is simply a concise summary of the same information provided by the basic frequency curves (page A2 through A13).

The duration isofrequency curves, on the other hand, are frequency mass hydrographs (from here on they are also referred to as frequency mass curves). The data points are continuous and it is legitimate to interpolate between them. Frequency mass curves, in addition to concisely summarizing the basic frequency information, can be used directly for many water supply planning purposes. If a mass demand curve is superimposed onto a frequency mass curve, the duration of the critical drought period can be determined as the duration to the interception point. The maximum deviation of the two curves is an estimate of the storage requirement for a reservoir, and in the case of Martin County, it is an estimate of the amount of supplemental water needed from Lake Okeechobee. An example of such an application is illustrated in Figure 7.

The applications illustrated are suitable if the demand can be expressed in constant draft rate, as is the case for most urban water demand. For demands that are variable and probabilistic in nature, such as irrigation water demand, more complex analytical techniques are needed. This may require the construction of frequency demand curves similar to the frequency curves presented here, or the use of water budget modeling to analyze the situation.

5. Frequency Time Table, Annual Minimum

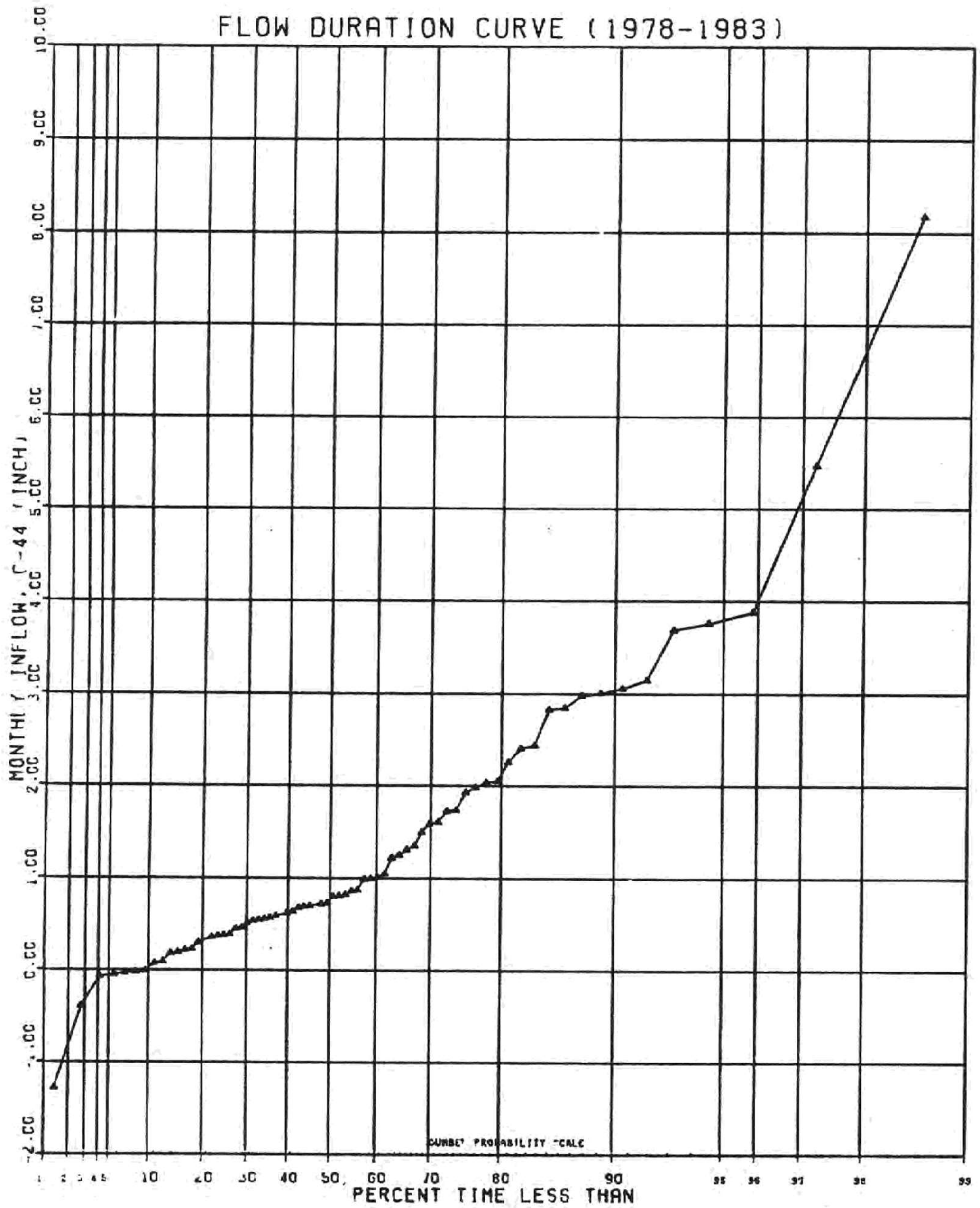
The frequency duration curves provide statistical information on the magnitudes only without reference to the time of occurrence. For example, an annual minimum rainfall of two months duration may occur in any two consecutive months in a calendar year, although it will most likely occur during the dry season. In some planning applications, it is of interest to know when the critical conditions are most likely to occur. A frequency table depicting the times of occurrence of the annual minima is included in Table 2.

Table 2
Frequency Time Table on the Occurrence of Annual Minimum

					RAINFALL							
Duration (months)	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	16%	16%	13%	***23%***	10%	19%	0%	3%	0%	0%	0%	0%
2	23%	***32%***	7%	19%	16%	3%*	0%	0%	0%	0%	0%	0%
3	***48%***	16%	7%	29%	0%	0%	0%	0%	0%	0%	0%	0%
4	***48%***	19%	29%	3%	0%	0%	0%	0%	0%	0%	0%	0%
5	***48%***	36%	13%	3%	0%	0%	0%	0%	0%	0%	0%	0%
6	***87%***	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
					C-44 INFLOW							
Duration (months)	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	7%	13%	20%	13%	7%	***27%***	13%	0%	0%	0%	0%	0%
2	20%	***33%***	7%	7%	7%	20%	0%	7%	0%	0%	0%	0%
3	***27%***	20%	7%	20%	13%	13%	0%	0%	0%	0%	0%	0%
4	***33%***	13%	13%	13%	13%	13%	0%	0%	0%	0%	0%	0%
5	***33%***	***33%***	13%	7%	13%	0%	0%	0%	0%	0%	0%	0%
6	***60%***	27%	7%	7%	0%	0%	0%	0%	0%	0%	0%	0%

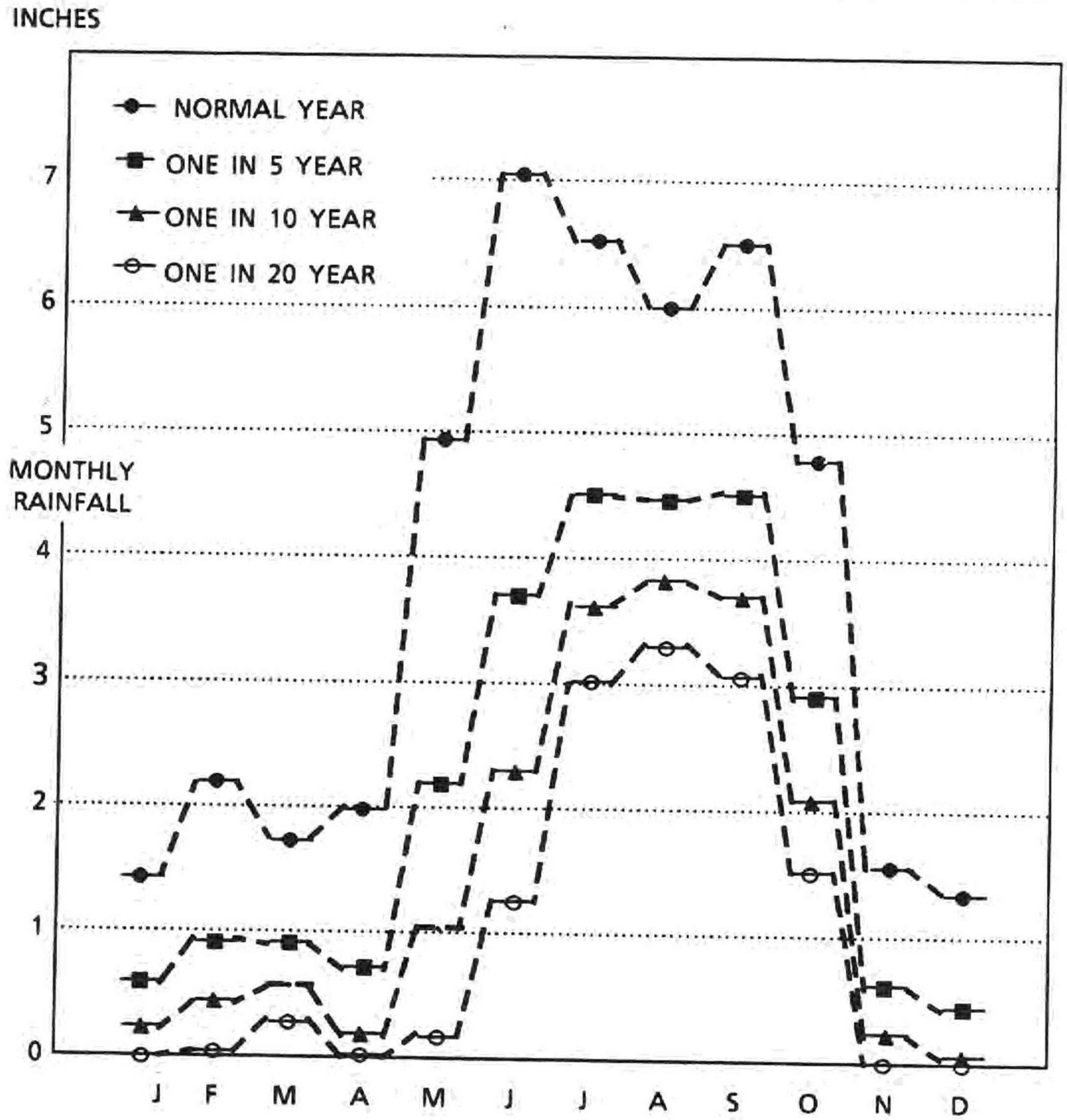
*Example: 3 percent of the time annual minimum rainfall of 2-month duration occurs in April and May (April is the beginning month).

Note: ***Bold*** figures refer to the most frequent time of occurrence.



Note: One inch inflow equals 11731 acre-ft, based on basin area of 140772 acres

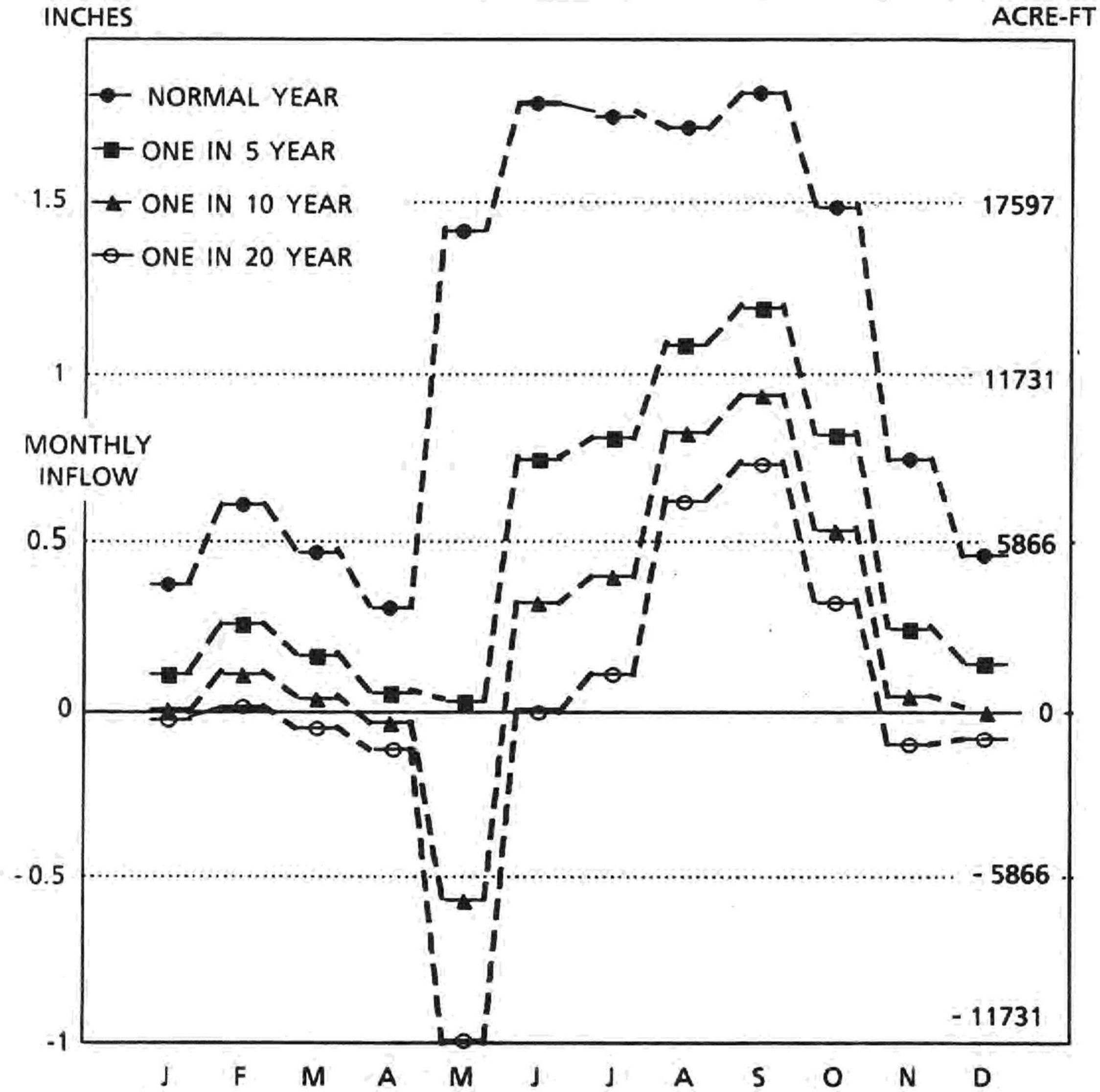
Figure 3. Flow Duration Curve, C-44 Inflow (1978-1983)



(data in inches)

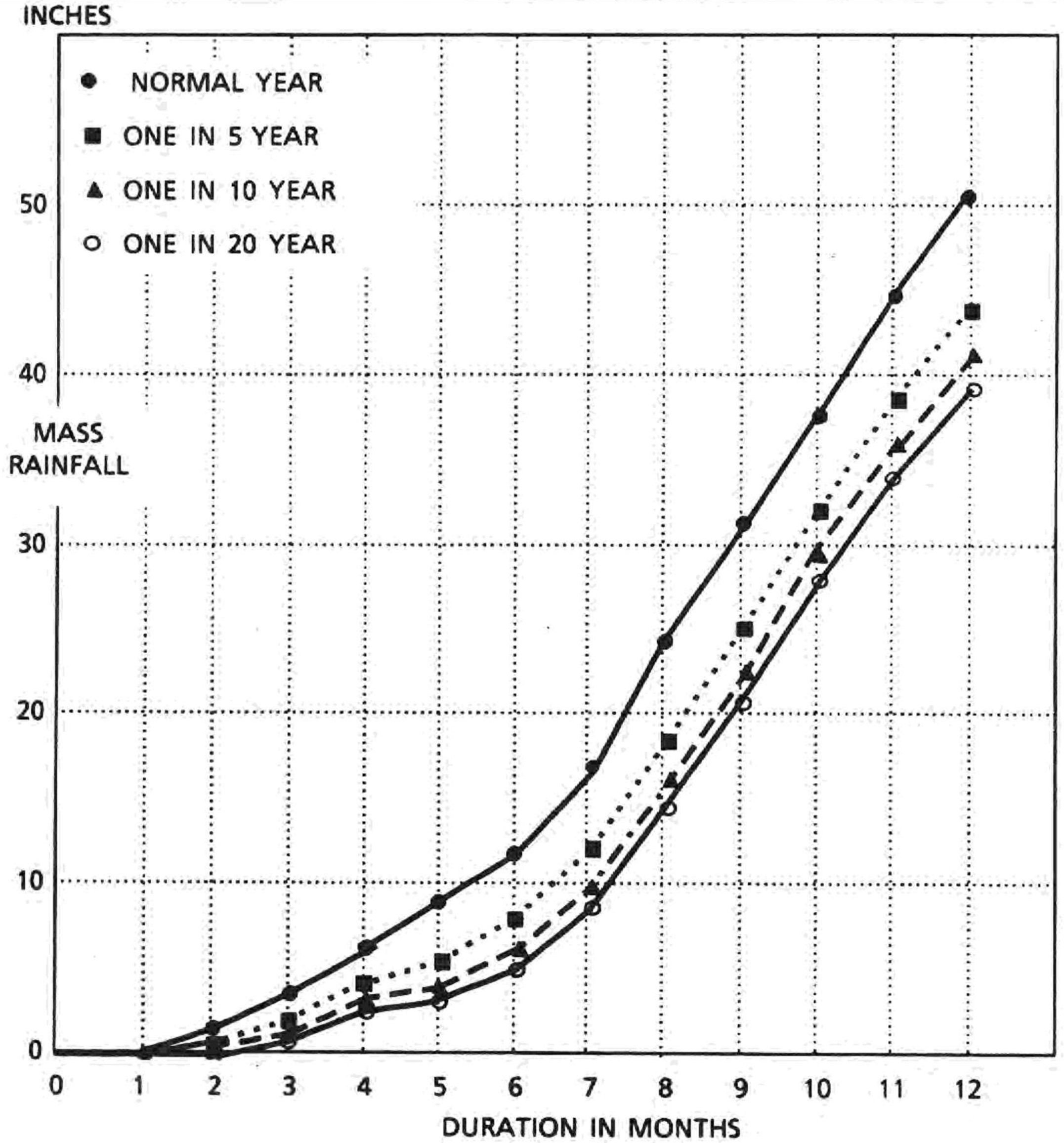
Return Interval (years)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1 in 20	0	.05	.30	0	.20	1.26	3.02	3.33	3.09	1.52	0	0
1 in 10	.22	.44	.57	.19	1.06	2.31	3.66	3.82	3.71	2.11	.22	.06
1 in 5	.59	.96	.93	.74	2.23	3.72	4.53	4.48	4.55	2.92	.62	.46
Normal	1.48	2.20	1.79	2.05	4.99	7.09	6.59	6.05	6.54	4.83	1.58	1.41

Figure 4. Rainfall Isofrequency Curves, Calendar Months



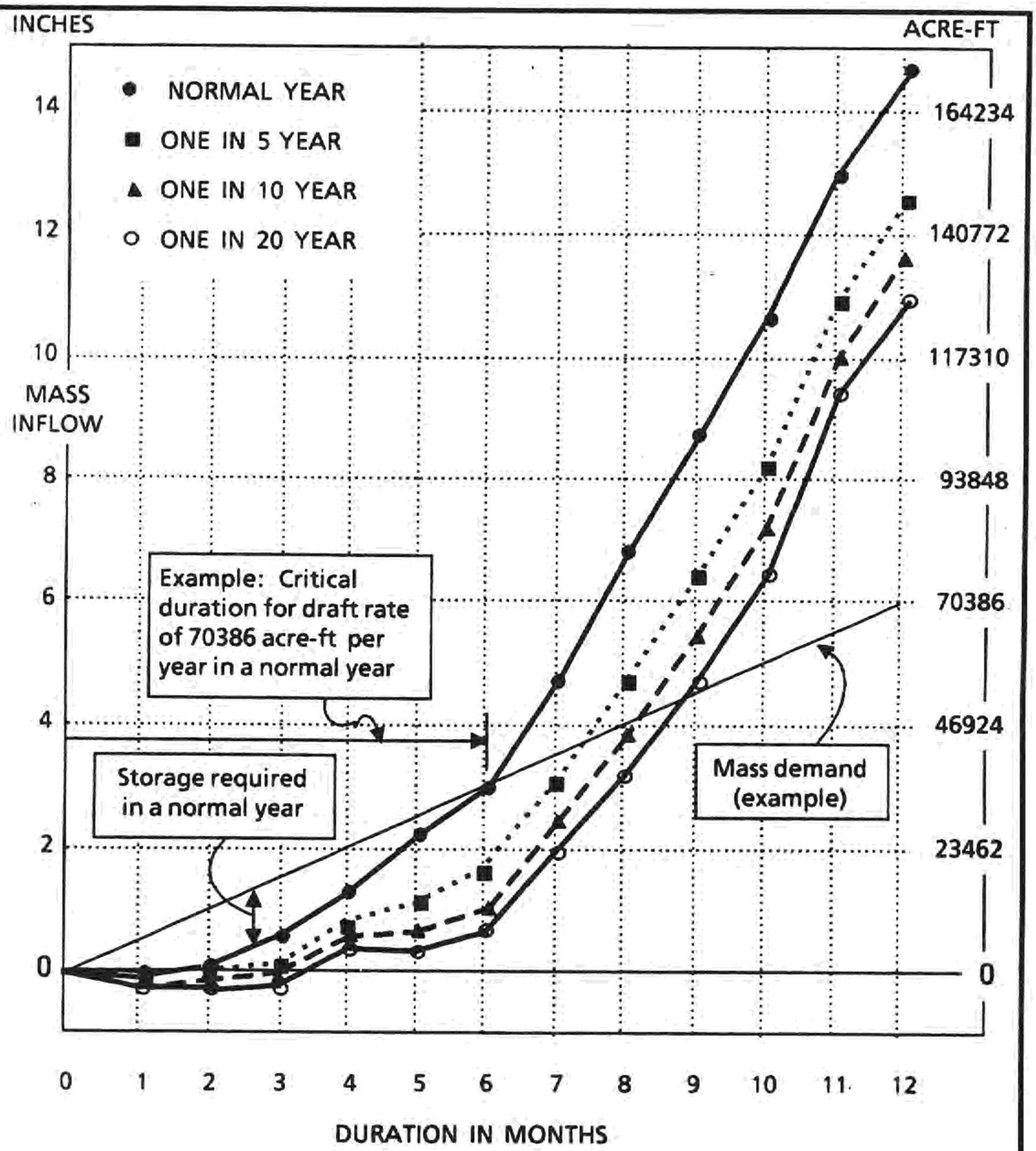
Return Interval (years)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	(data in inches over basin area of 140772 acres)											
1 in 20	-.03	.01	-.06	-.12	-1.08	-.01	.11	.63	.74	.33	-.11	-.09
1 in 10	.05	.12	.04	-.04	-.64	.32	.41	.83	.94	.55	.04	.01
1 in 5	.17	.27	.17	.06	-.04	.76	.83	1.10	1.21	.84	.25	.15
Normal	.44	.63	.48	.32	1.37	1.82	1.81	1.75	1.85	1.53	.75	.47

Figure 5. C-44 Inflow Isofrequency Curves, Calendar Months



Return Interval (years)	1	2	3	4	5	6	7	8	9	10	11	12
	Duration in months (data in inches)											
1 in 20	0	.12	.91	2.66	3.32	5.20	8.73	14.47	20.84	28.03	34.23	39.23
1 in 10	0	.44	1.44	3.35	4.42	6.48	10.27	16.33	22.78	29.86	36.19	41.32
1 in 5	.05	.86	2.15	4.29	5.91	8.21	12.34	18.83	25.40	32.33	38.84	44.14
Normal	.35	1.86	3.86	6.52	9.45	12.33	17.27	24.80	31.62	38.19	45.13	50.85

Figure 6. Rainfall Isofrequency Curves, Monthly Durations



Return Interval (years)	Duration in months 1	2	3	4	5	6	7	8	9	10	11	12
	(data in inches over basin area of 140772 acres)											
1 in 20	-.25	-.34	-.24	.43	.38	.71	1.97	3.20	4.73	6.48	9.40	10.93
1 in 10	-.21	-.23	-.07	.60	.73	1.12	2.46	3.86	5.46	7.22	10.04	11.61
1 in 5	-.15	-.08	.17	.83	1.20	1.68	3.12	4.75	6.45	8.23	10.90	12.53
Normal	-.01	.27	.72	1.38	2.31	3.00	4.69	6.86	8.80	10.63	12.95	14.71

Figure 7. C-44 Inflow Isofrequency Curves, Monthly Durations

IV. DISCUSSION AND RECOMMENDATIONS

The purpose of this report is to provide statistical information on rainfall drought frequency and on the availability of surface water in Martin County. A major objective is to quantify the availability of C-44 canal water that can be developed to meet the growing needs in Stuart and other urban areas in Martin County. This analysis is part of a comprehensive study by the SFWMD to assist Martin County in their water resources planning. The limitations and assumptions of this analysis are reiterated below:

(a) The C-44 inflow was calculated as the difference between the discharges at S-80 and S-308. Because of the way it was calculated, the C-44 inflow included the effect of the existing (1978-1983) canal water usage. The calculated inflow represented the amount available for additional usage as of the conditions in 1979-1983. If calculated inflow was negative, it represented the amount supplemented by Lake Okeechobee. The 1979 land use pattern of the C-44 basin is shown in Figure 1 (page 4). Any major change in land use within the basin from that of 1979 may increase or decrease the canal water availability. The canal water availability presented in this report must then be adjusted accordingly if the change is significant.

(b) The rainfall data were based on the averages from two long term rainfall stations within the C-44 basin, one located at S-80 and the other at S-308. A total of 31 years of data, covering the period of 1952 through 1983, was used in the present analysis. Table 3 compares the rainfall drought frequencies in this report with those currently used by the SFWMD for the upper east coast. The existing SFWMD drought frequencies were based on the average of several long term rainfall stations in Martin and St Lucie Counties with data records through 1977. In comparison, the existing SFWMD estimates are about the same for the longer durations but somewhat higher for the shorter durations. This is because the previous study: (i) covered all of upper east coast and thus used more stations to average rainfall. This has a tendency to smooth out the extremities, (ii) used data through 1977 and thus excluded the 1980-82 drought, and (iii) used Log Pearson Type III distribution for fitting, which may produce slightly different estimates from those produced by the Gumbel distribution used in this analysis.

(c) Relatively long records are available for the rainfall data but only six years of data are available for the C-44 inflow. The C-44 inflow record was extended by regression with rainfall. A statistical F-test was used to check that the variance was not significantly reduced by the extension thereby assuring that the extension is worthwhile. The reliability of the frequency estimates is related to the length of the data record available. In the present case it is permissible, within reasonable confidence limits, to project rainfall up to once in 60 years and for C-44 inflow up to once in 20 years.

Table 3
Comparison of Rainfall Drought Frequencies

Return Interval (years)		Duration In Months 1	2	3	4	5	6	7	12
		(data in inches)							
1 in 10	This report[1]	0	.44	1.44	3.35	4.42	6.48	10.27	41.32
	SFWMD[2]	.15	.98	2.00	3.57	5.11	7.24	10.65	41.96
1 in 5	This report	.05	.86	2.15	4.29	5.91	8.21	12.34	44.14
	SFWMD	.22	1.23	2.63	4.45	6.40	8.87	12.85	44.81
Normal	This report	.35	1.86	3.86	6.52	9.45	12.33	17.27	50.85
	SFWMD	.43	1.94	4.18	6.62	9.54	12.65	17.66	50.99

Notes: (1)Based on average basin rainfall in C-44. Data covered up to 1983.
(2)Based on average basin rainfall in upper east coast (St Lucie and Martin Counties). Data covered up to 1977.

The results of this analysis are presented in a series of frequency distribution curves in the Appendix (pages A2 through A25). The same information is summarized in four isofrequency curves and a frequency table, and from these the following implications are observed:

Figure 4. Rainfall Isofrequency Curves, Calendar Months (page 14)

There is a sharp decrease in rainfall after October. The rainfall remains at about the same low level between November and April but rebounds sometime in May or June. The amount of rainfall in May is most variable. A question is often asked as to whether the dry season in Florida begins in October or November. The results here indicate clearly that the dry season in the C-44 basin begins in November and usually ends in April.

Figure 5. C-44 Inflow Isofrequency Curves, Calendar Months (page 15)

The seasonal trend of the C-44 inflow generally follows that of the rainfall with one exception. In a normal year the flow reaches a minimum in April, and in a drier year it reaches minimum in May. For rainfall, there is no sharp month to month differences during the dry season. The inflow, however, follows a slow recession curve which responds to the cumulative effect of dry season rainfall with a lag of one to two months. The flow in May, similar to rainfall, is most variable and unpredictable, as it is dependent on the arrival of the wet season rainfall. Similar responses have been observed in C-43 (Caloosahatchee River Basin) which, hydrologically, is analogous to C-44.

Figure 6. Rainfall Isofrequency Curves, Monthly Durations (page 16)

The annual rainfall in the C-44 basin is about 50 inches in a normal year and 40 inches once in 20 years. In years drier than normal, there is zero to negligible rainfall for at least one month, and less rainfall than evapotranspiration for at least two months out of a year. In other words, rainfall deficit conditions occur for a duration of at least two months for years drier than normal. Much of the difference in rainfall between dry and normal years can be accounted for in the initial six month duration as indicated by a gradual equalization of the slopes among the isofrequency curves.

Figure 7. C-44 Inflow Isofrequency Curves, Monthly Durations (page 17)

A deficit condition is said to occur when there is more withdrawal from the canal than inflow into it. The part of the isofrequency curve that is below zero delineates the magnitude and duration of the deficit condition. Negative inflow represents the amount currently supplemented by Lake Okeechobee. In a normal year, deficit conditions occur for a duration of about one month and reaches three months once in 10 years. Thus, any additional withdrawal from C-44 will prolong the deficit condition and increase the demand from Lake Okeechobee, unless an alternative source of water is developed or the surplus flow in the wet months can be stored in some way for use later. The situation in the C-44 basin is similar to that of the C-43 basin ---- though the canal flow is plentiful during the wet months, it is inadequate to meet the current demand during some of the dry months and supplemental water from Lake Okeechobee is needed.

Table 2. Frequency Time Table on the Occurrence of Annual Minimum (page 12)

The frequency table indicates that minima of short durations are equally likely to occur in any of the dry months, but for longer durations the time of occurrence is better defined. For example, about 87 % of the time a minimum 6-month rainfall begins in November, but with nearly the same likelihood a minimum 2-month rainfall may occur in November, December, or February (23%, 32%, and 19% respectively).

Under current conditions, supplemental releases from Lake Okeechobee are needed for a duration of about one month in a normal year and three months once in 10 years. Additional withdrawals from C-44 will inevitably impose greater stress on Lake Okeechobee unless an alternate source of water is developed, or a plan to store wet season runoff for use at the time of shortage is implemented.

Storing surplus runoff in surface impoundments is generally inefficient in south Florida as the reservoir would have to be very large but shallow, and the evapotranspiration loss per unit depth of storage would be large. Storing the water in the shallow aquifer is equally difficult because of the lack of storage capacity during the wet months. The following alternatives appear to be reasonable and it is recommended that they should be investigated in detail:

(a) Divert surplus canal flow to recharge depleted wellfield storage as is currently practiced in Lee County, Florida.

(b) Develop wellfields in more inland locations to create cones of depression so as to increase rainfall recharge, and to create storage capacities to store surplus canal water.

(c) Store surplus canal water in the saline artesian aquifer by injection wells and recover the storage for use during the dry season, as is currently under experimentation in Manatee County, Florida.

(d) Increase storage in Lake Okeechobee by backpumping treated runoff during the wet season. The availability of storage capacity in Lake Okeechobee and the cost in treating the runoff may be limiting factors.

REFERENCES

Burgess, R. and Fan,A., "Surface Water Availability of the Caloosahatchee River Basin, " Technical Memorandum, SFWMD, March 1983.

Lichtler,W. F., "Geology and Groundwater Resources of Martin County, Florida," Report of Investigation No. 23, USGS, 1960.

MacVicar, T., Vanlent, T. and Castro, A., "South Florida Water Management Model Documentation Report," Technical Publication 84-3, SFWMD, December 1984.

Mierau, R., "Memorandum Report on Surface Water Availability in the St. Lucie Canal Basin," SFWMD, 1974.

Riggs, H., "Low-Flow Investigation," Techniques of Water-Resources Investigations of the USGS, Chapter B1, Book 1, 1972.

Riggs, H. and Hardison, C., "Storage Analysis for Water Supply," Techniques of Water-Resources Investigations of the USGS, Chapter B2, Book 4, 1973.

SFWMD, "Florida Power & Light Dike Failure and its Impact on Project Facilities of Martin and Okeechobee Counties," Investigation Report, November 1979.

LIST OF APPENDIXES

EXPLANATION ON THE USE OF FREQUENCY DISTRIBUTION CURVES

The frequency distribution curves included in the following pages can be used to project rainfall or C-44 inflow to any drought probability level. The use of these curves is explained below:

1. All data are expressed in inches over the C-44 basin area. This permits comparison of rainfall and C-44 inflow in the same scale. To convert inches to acre-ft, multiply inches by 11731, which is based on a basin area of 140772 acres.

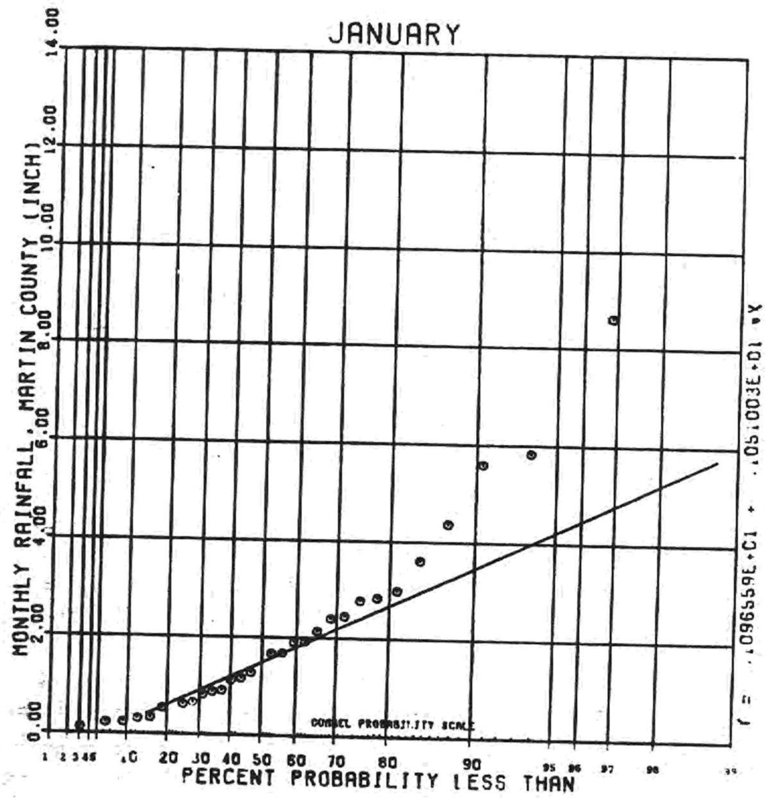
2. The frequency distribution data are plotted on Gumbel probability paper. The x-scale is in percent probability. The reciprocal of the percent probability equals the return interval; for example, a 5 % probability is equivalent to once in 100 / 5 or once in 20 years.

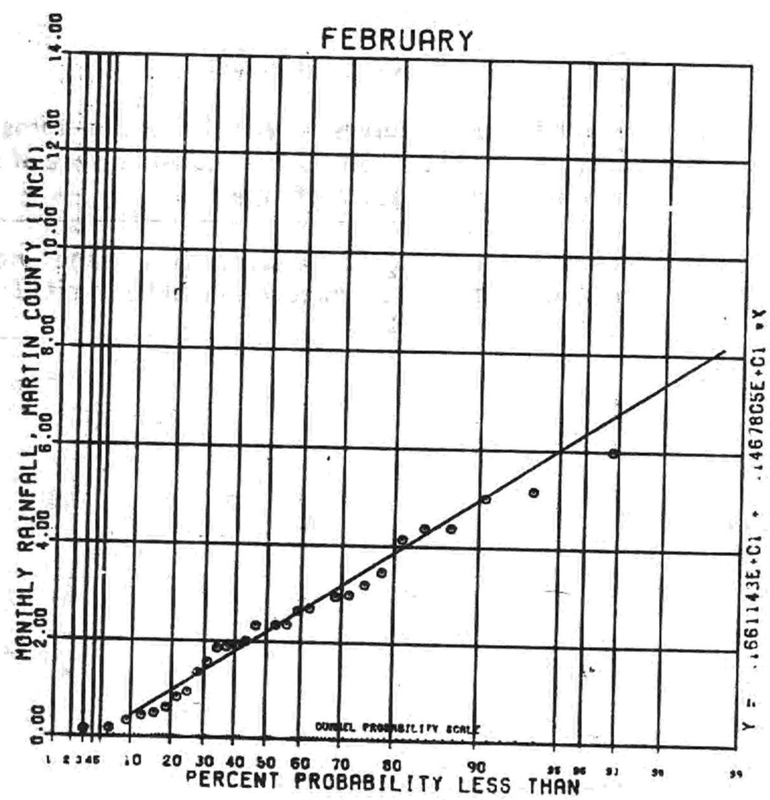
3. The magnitude of rainfall and C-44 inflow at any probability level can be read directly from the curve. In some situations, it is more accurate to calculate from the least squares fitted equation listed along the right side of the graphs. The equation is expressed as $y = A + Bx$, where A and B are the regression coefficients, y is the magnitude of rainfall or inflow, and x is a Gumbel probability transformed variable. The relation between x and probability level P is as follows:

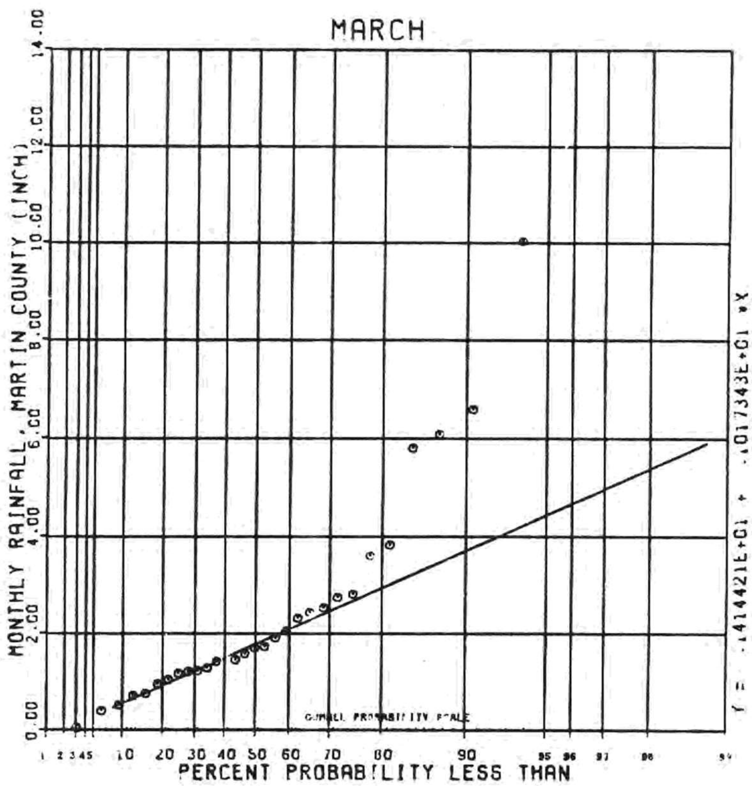
$$x = -\log_e(-\log_e P)$$

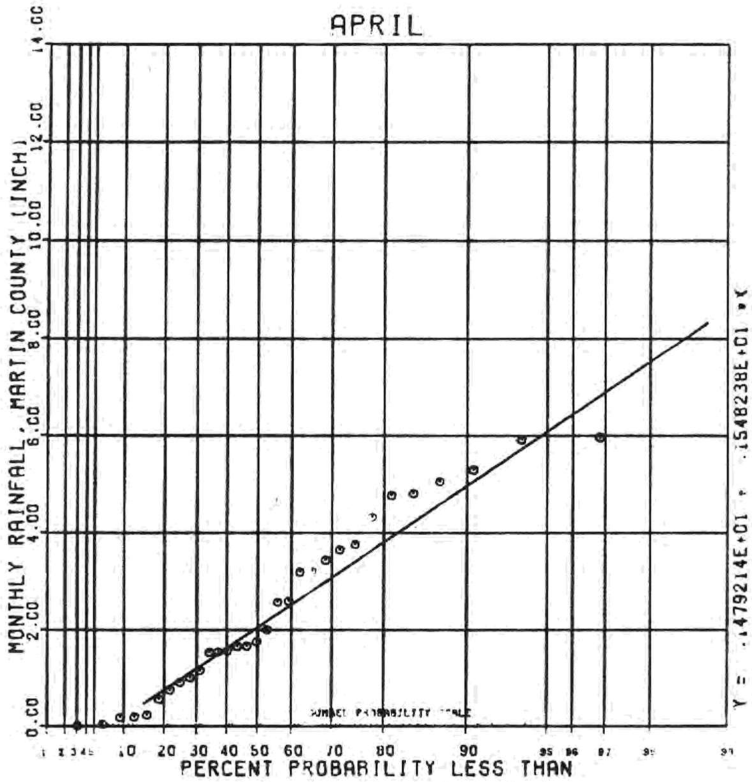
4. For the calendar month frequency curves, only the lower two-thirds of the data points are used in the frequency fitting because only the dry conditions are of concern. Thus, it is permissible only to project droughts but not floods.

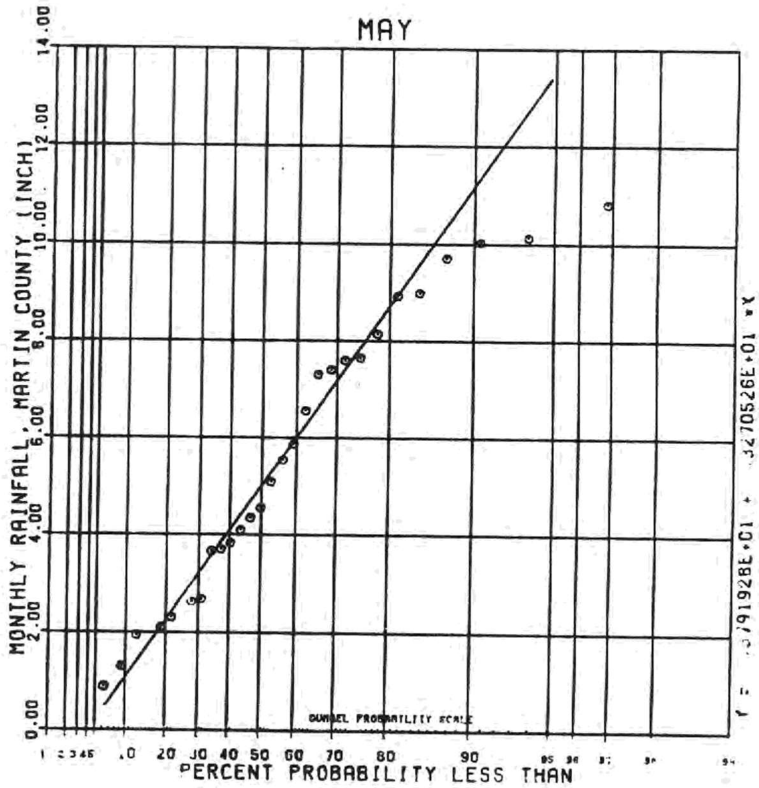
5. The reliability of the probability projection is dependent on the length of data record available for the analysis. In this case, projection should be limited to once in 60 years for rainfall and once in 20 years for C-44.

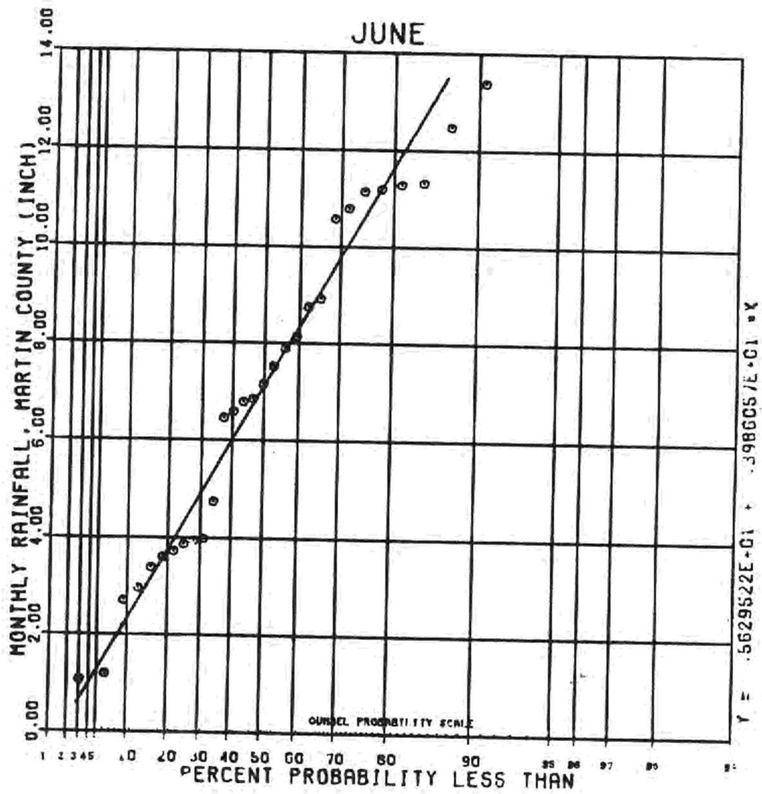

JANUARY
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
PERCENT PROBABILITY LESS THAN
10
20
30
40
50
60
70
80
90
Y = .1096559E+01 + .1051003E+01 *X

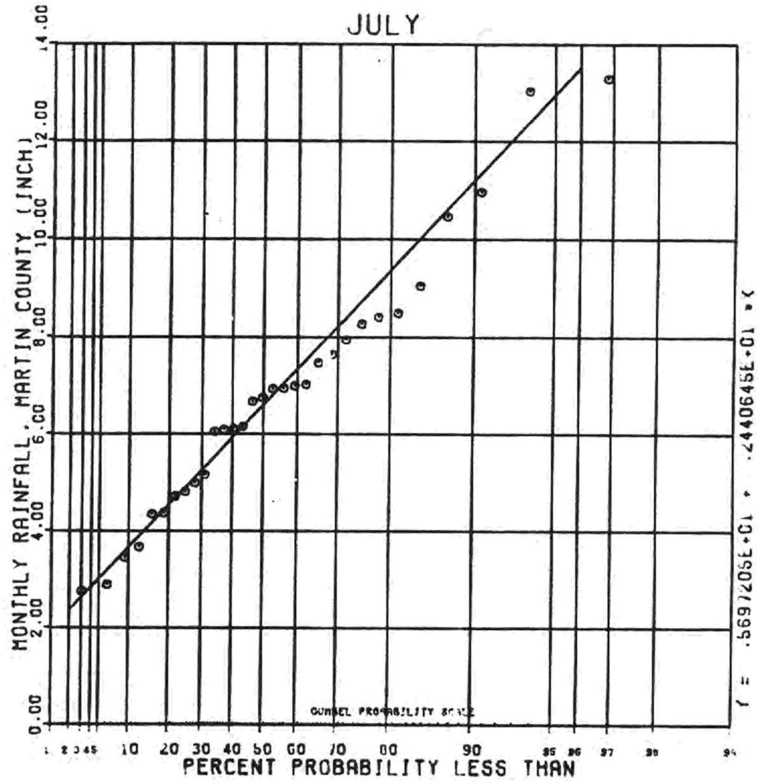

FEBRUARY
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
PERCENT PROBABILITY LESS THAN
10
20
30
40
50
60
70
80
90
Y = .1661143E+01 + .1467805E+01 *X

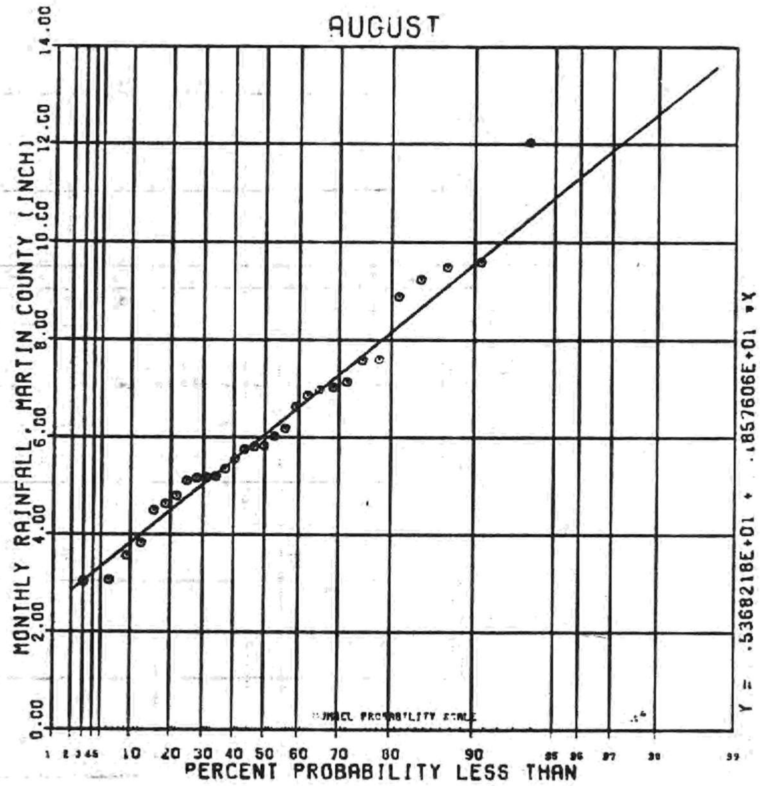

MARCH
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
10
20
30
40
50
60
70
80
90
PERCENT PROBABILITY LESS THAN
Y = .1414421E+01 + .1017343E+01 *X

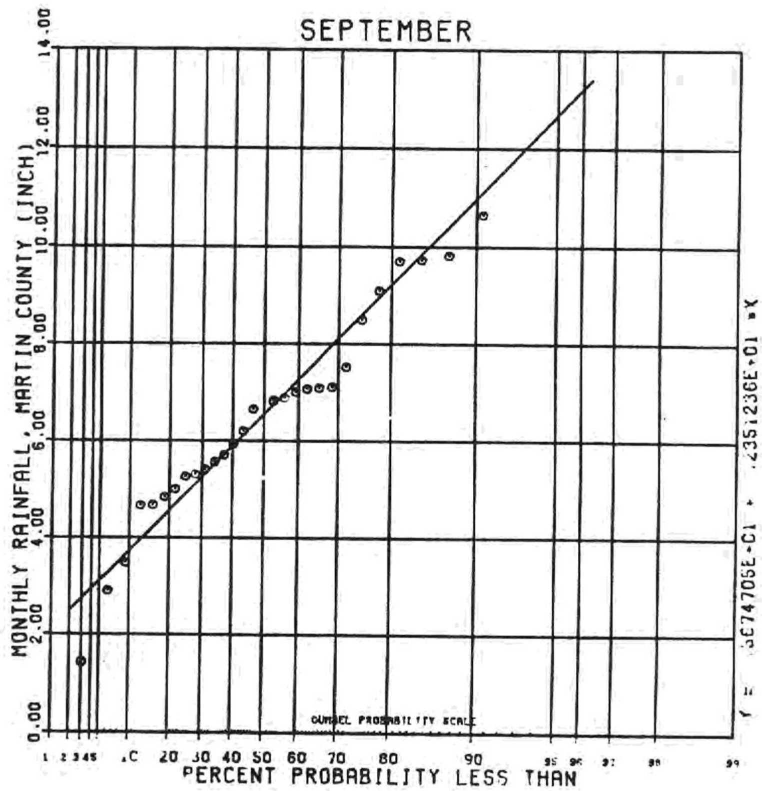

APRIL
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
10
20
30
40
50
60
70
80
90
PERCENT PROBABILITY LESS THAN
Y = .1479214E+01 + .1548238E+01 *X

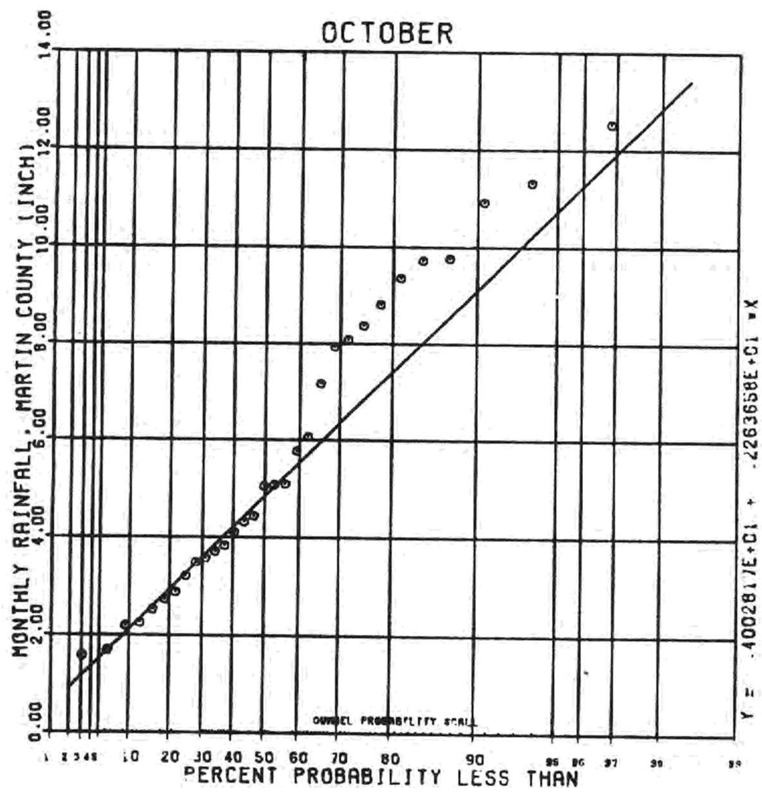

MAY
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
20
40
50
70
80
90

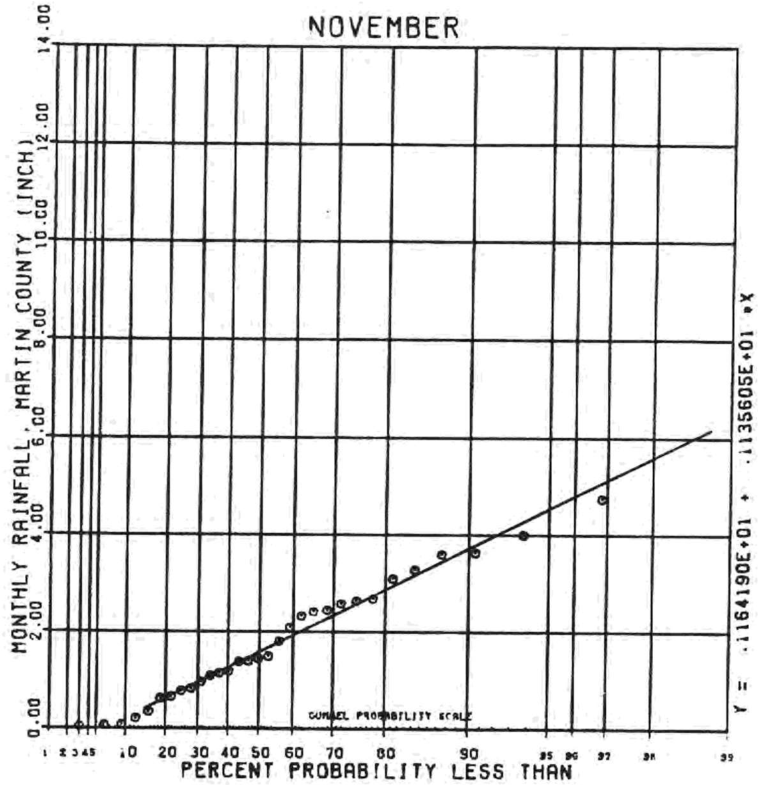

JUNE
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
40
50
70
80
90
Y = .5629522E+01 + .3986057E+01 *X

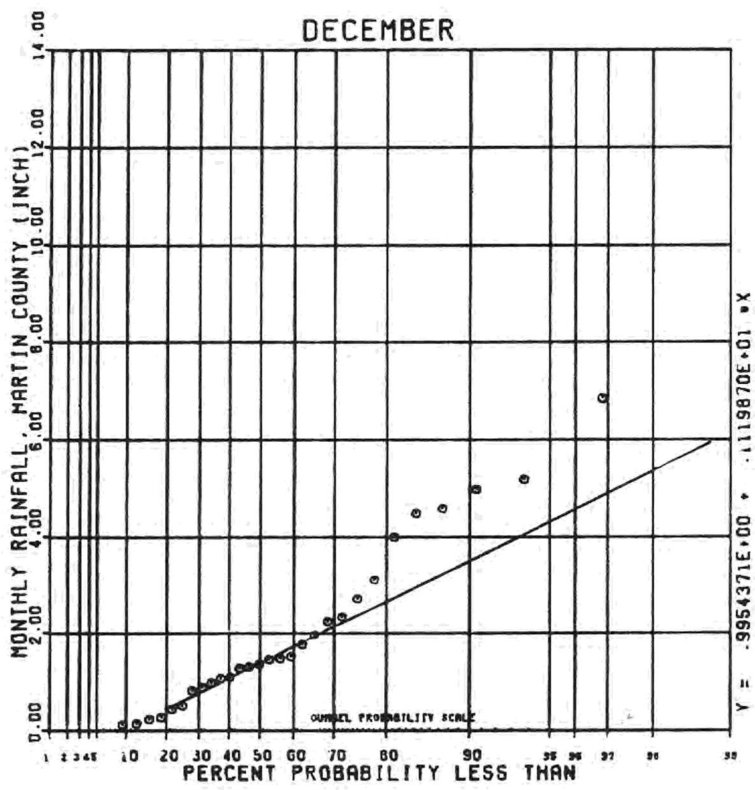

JULY
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .5697205E+01 + .2440645E+01 *X

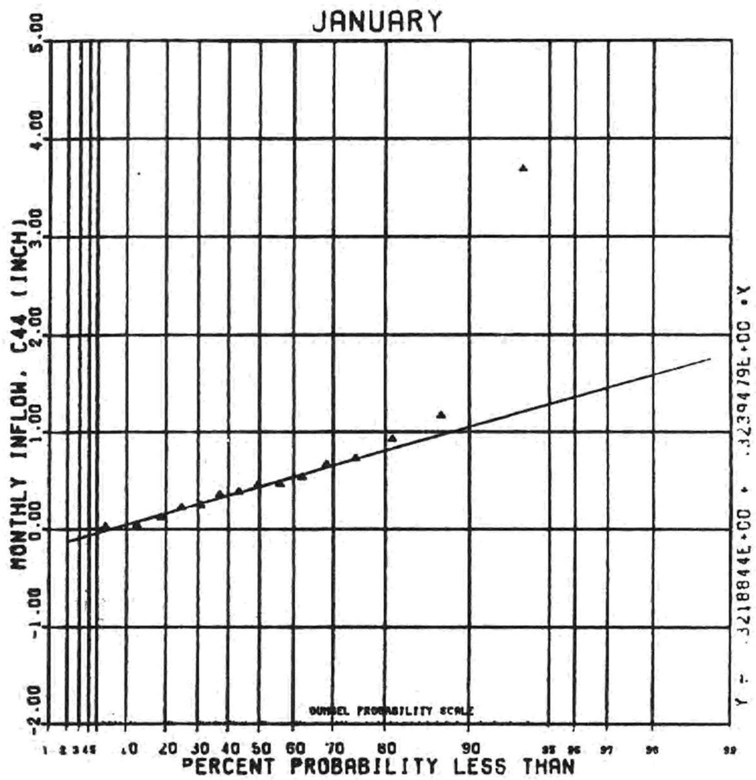

AUGUST
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .5368218E+01 + .1857606E+01 *X

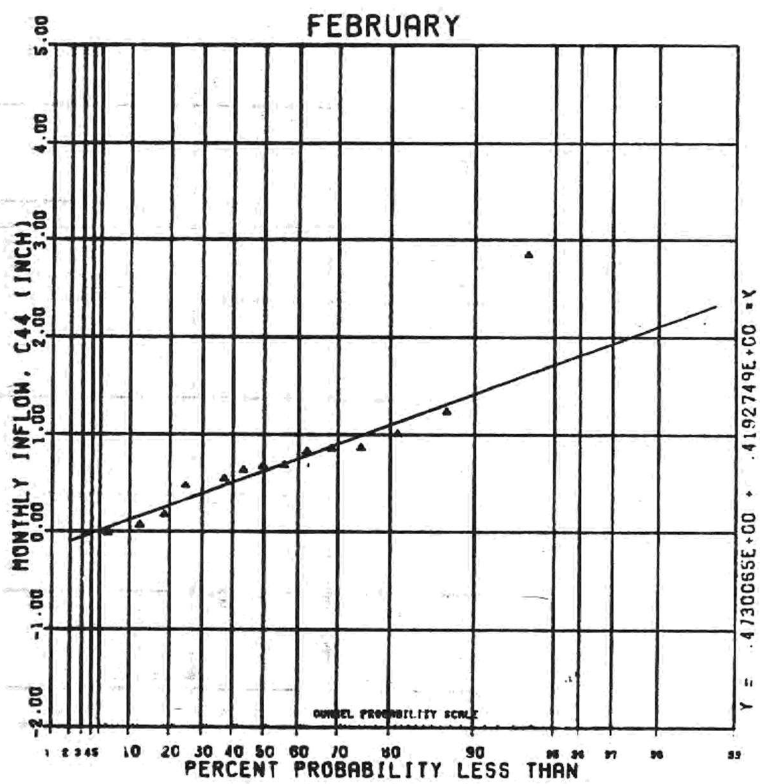

SEPTEMBER
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE

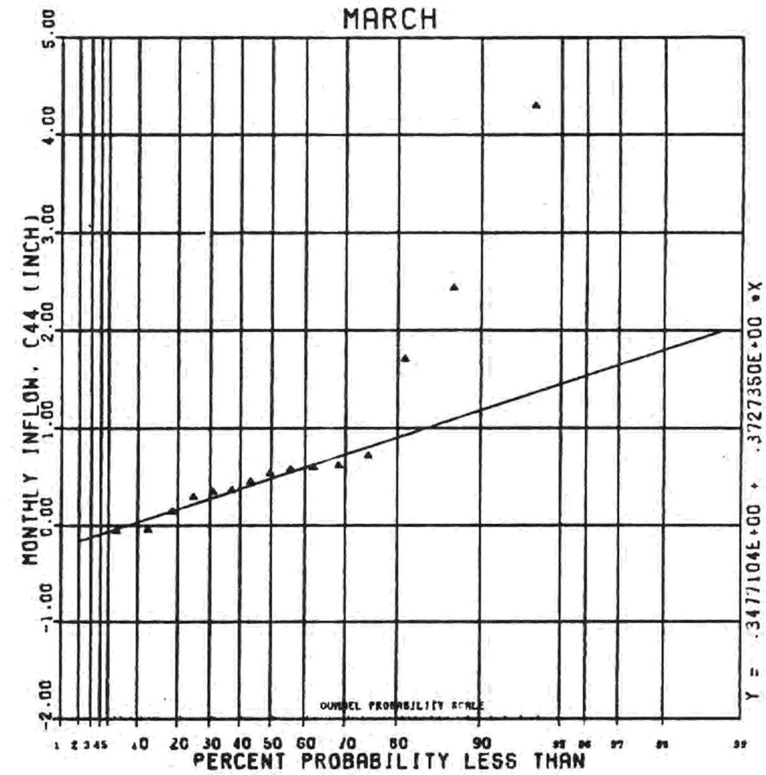

OCTOBER
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE

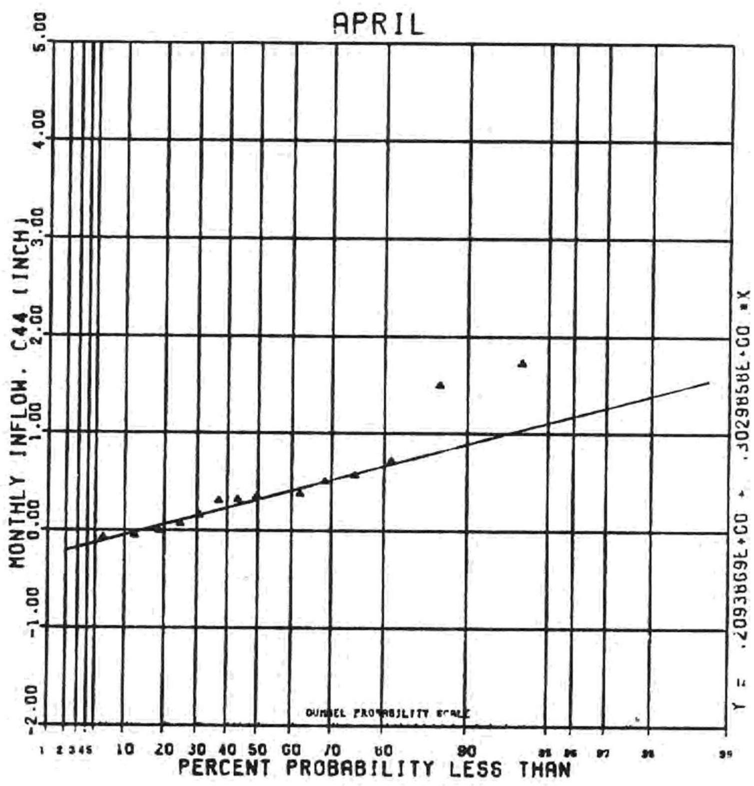

NOVEMBER
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
Y = .1164190E+01 + .1135605E+01 *X

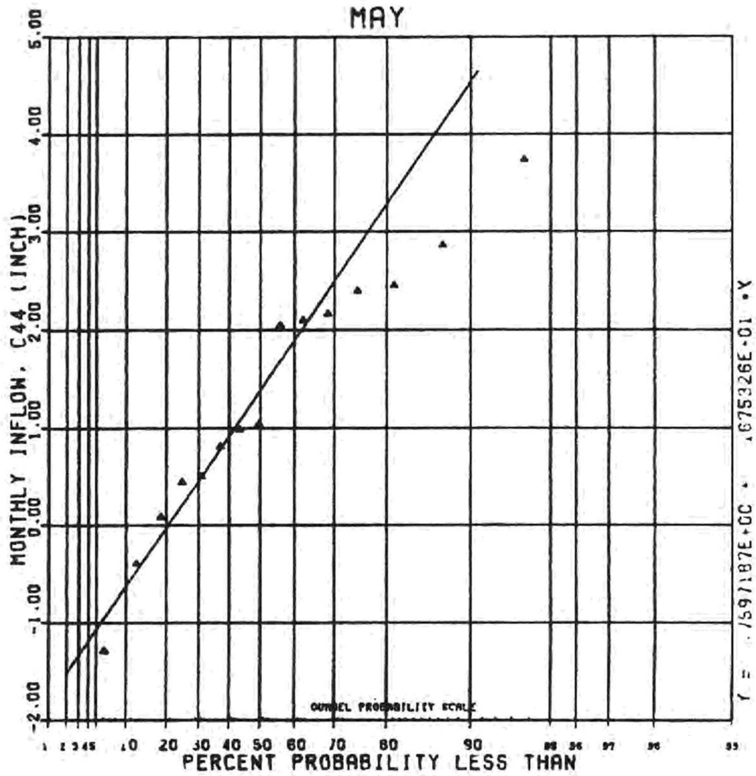

DECEMBER
MONTHLY RAINFALL, MARTIN COUNTY (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
Y = .9954371E+00 + .1119870E+01 *X

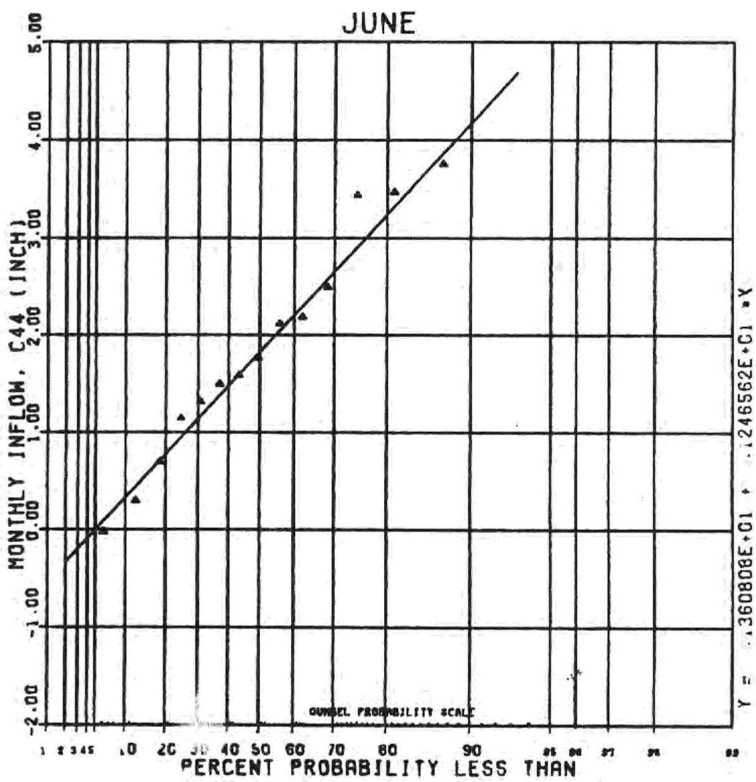

JANUARY
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = .3218844E+00 + .3239479E+00 *X

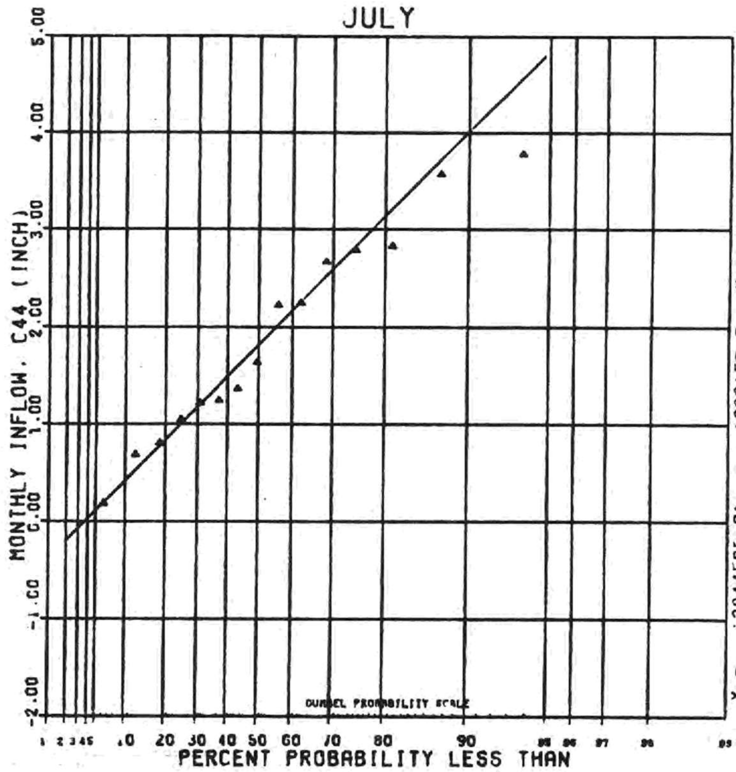

FEBRUARY
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = .4730065E+00 + .4192749E+00 *X

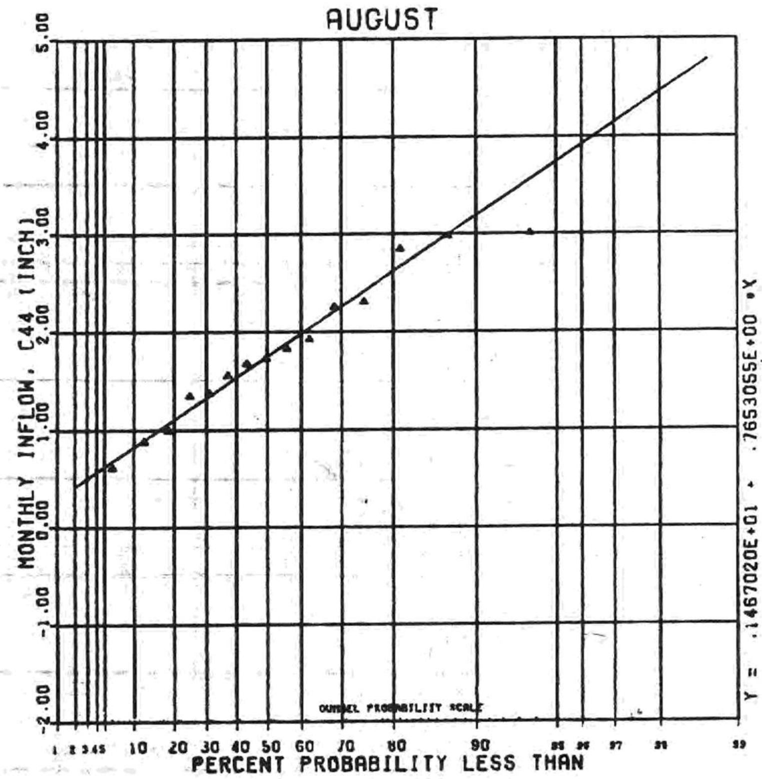

MARCH
MONTHLY INFLOW, C44 (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
Y = .34771104E+00 + .37273350E+00 *X

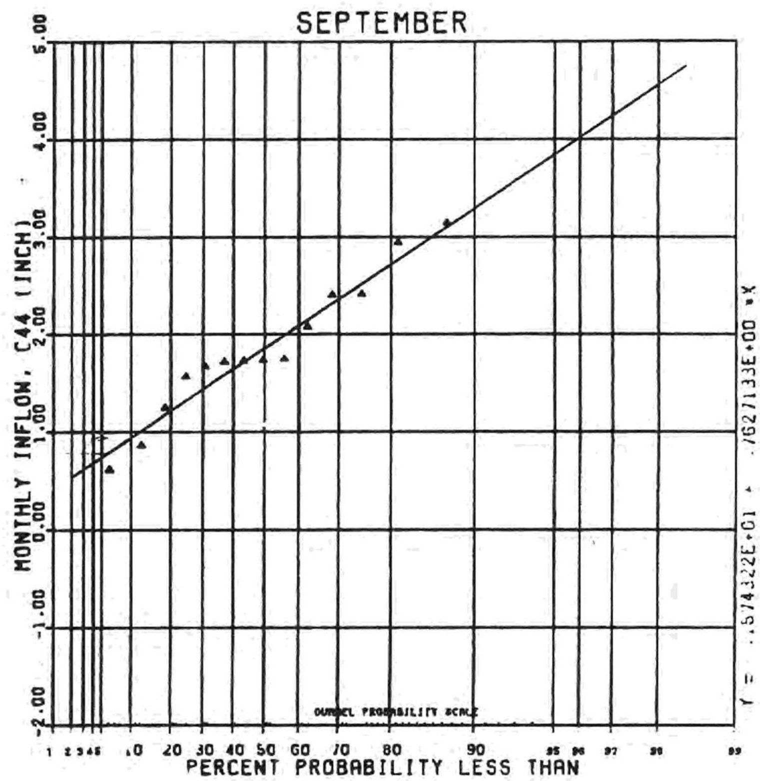

APRIL
MONTHLY INFLOW, C44 (INCH)
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
Y = .20938G9E+00 + .30298588E+00 *X

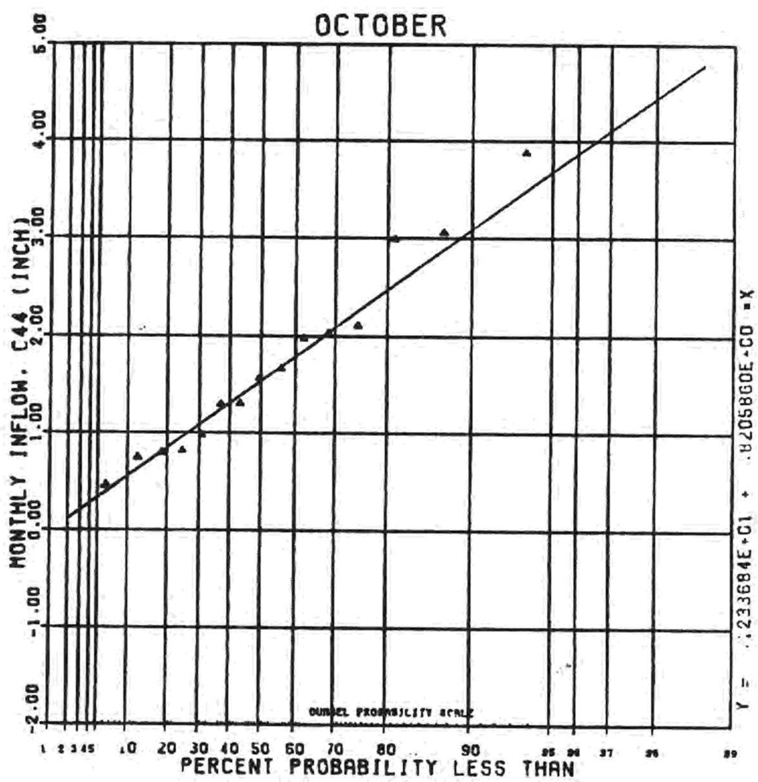

MAY
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
GUMBEL PROBABILITY SCALE
10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .7597187E+00 + .1675326E+01 *Y

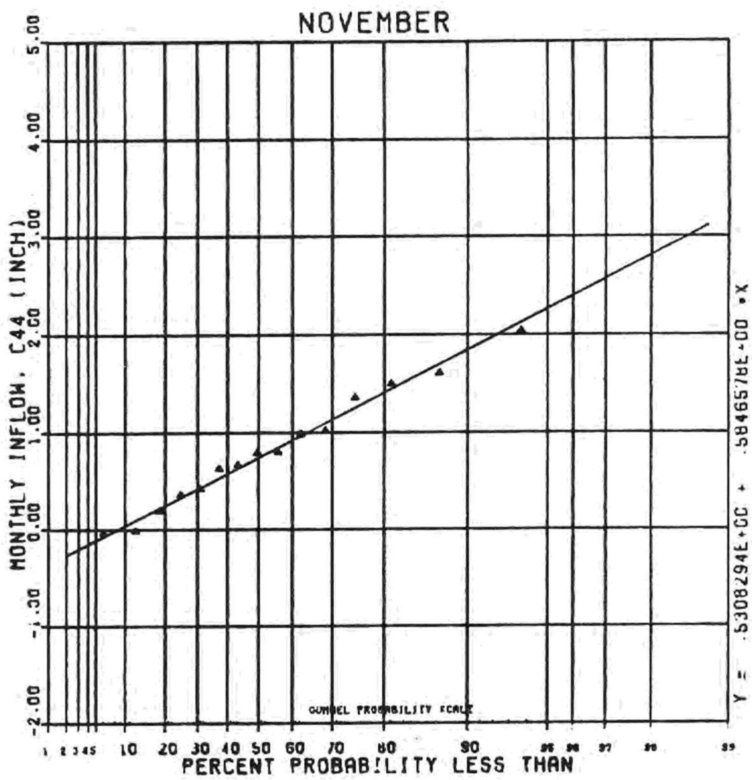

JUNE
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
GUMBEL PROBABILITY SCALE
10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .1360808E+01 + .1246562E+01 *Y

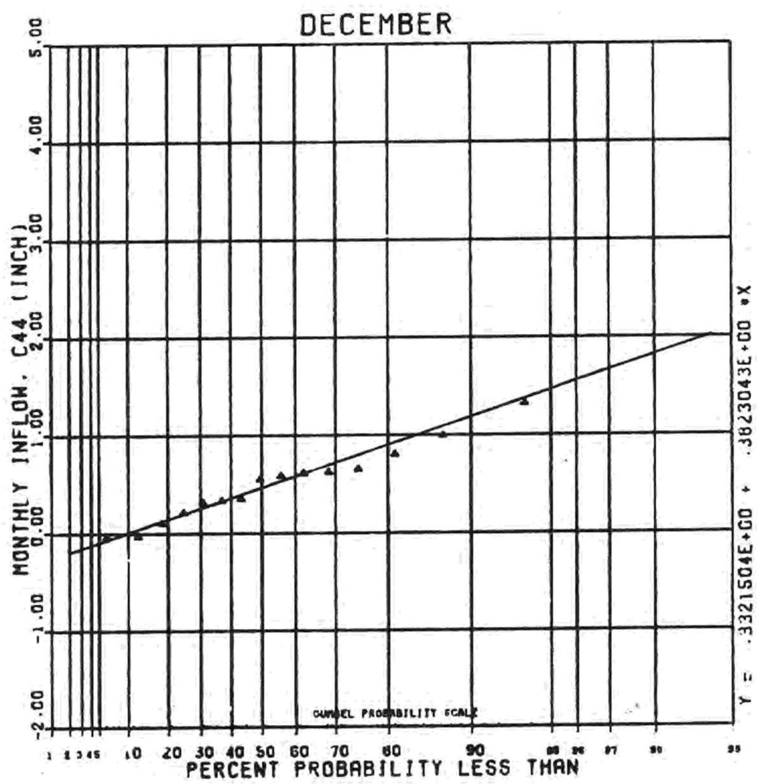

JULY
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
Y = .1384458E+01 + .1162815E+01 *X
1 2 3 4 5 10 20 30 40 50 60 70 80 90 99
PERCENT PROBABILITY LESS THAN

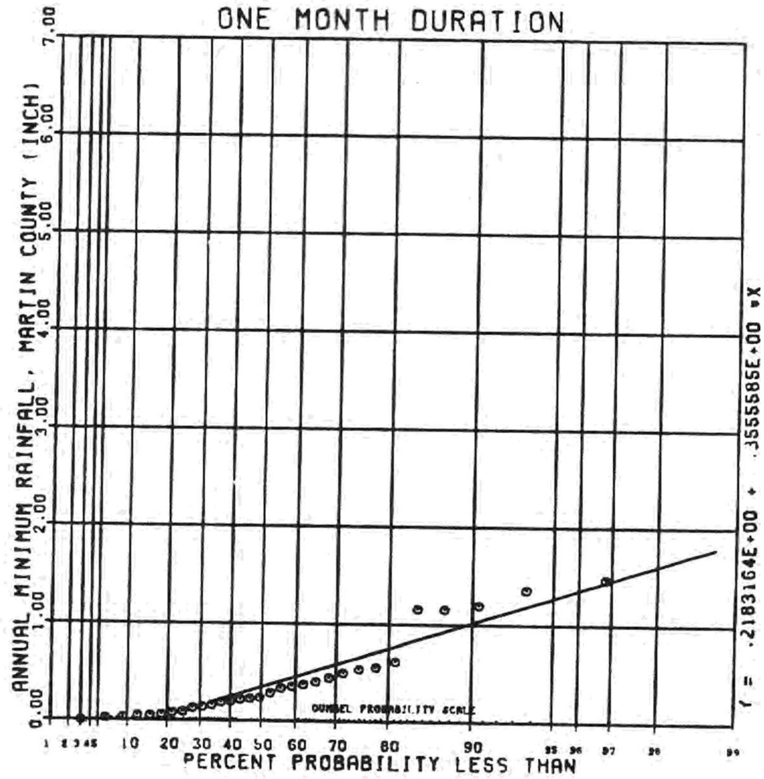

AUGUST
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
Y = .1467020E+01 + .7653055E+00 *X
1 2 3 4 5 10 20 30 40 50 60 70 80 90 99
PERCENT PROBABILITY LESS THAN

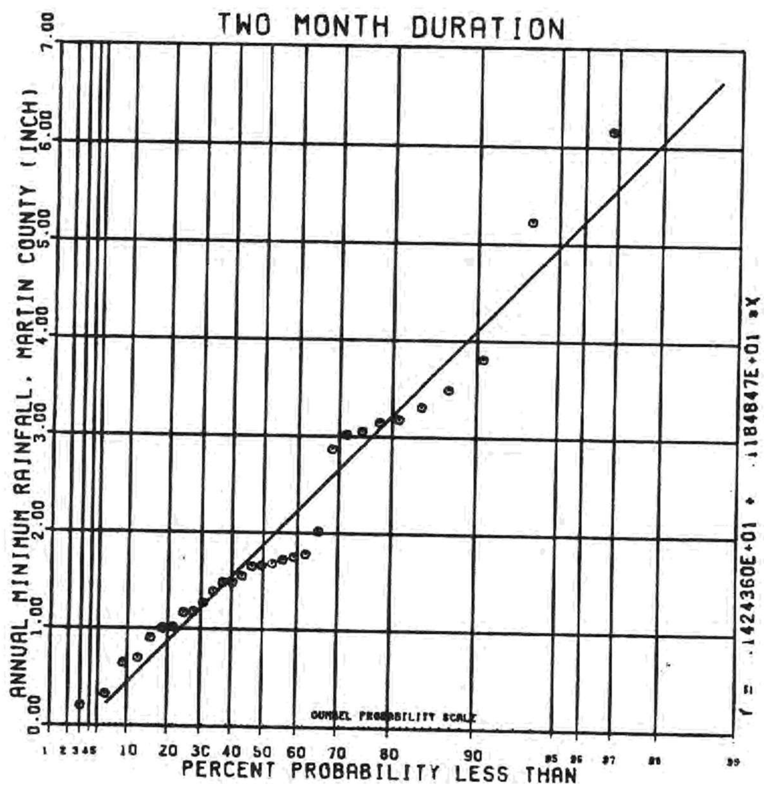

SEPTEMBER
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = .574322E+01 + .762713 3E+00 *X

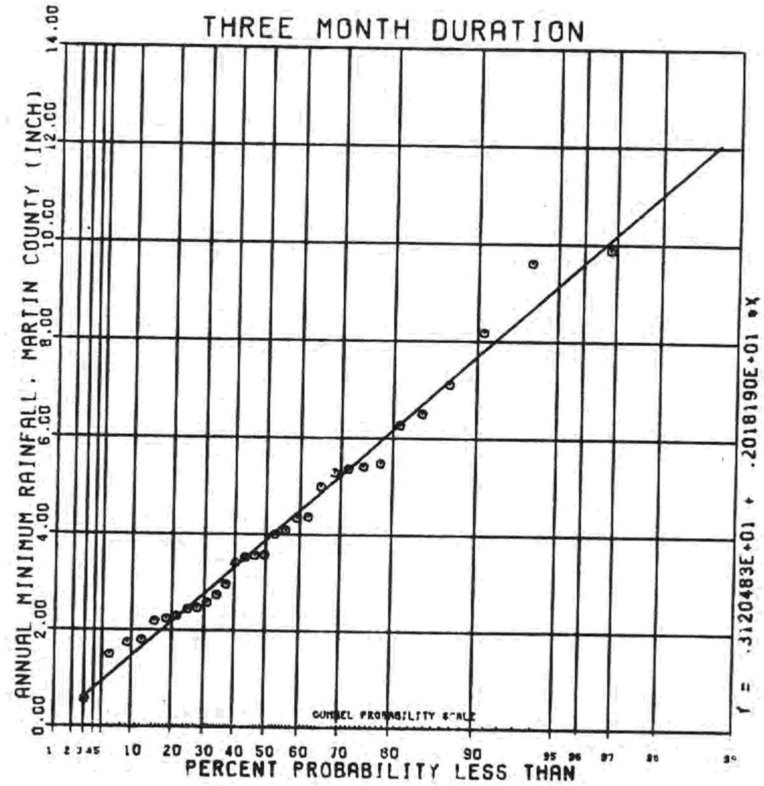

OCTOBER
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = .233684E+01 + .820586OE+00 *X

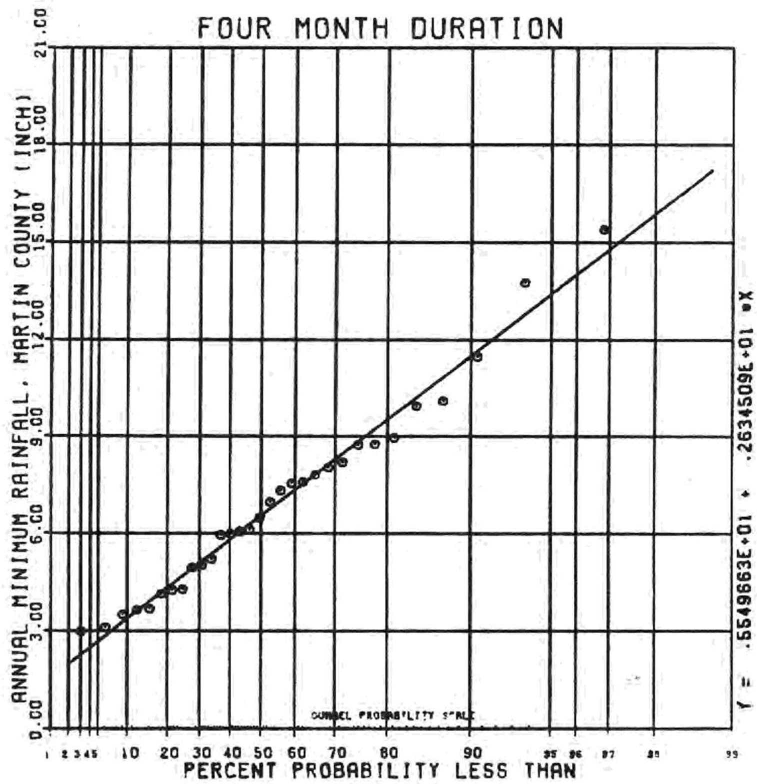

NOVEMBER
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 99
PERCENT PROBABILITY LESS THAN
Y = .5308294E+00 + .5846578E+00 *X

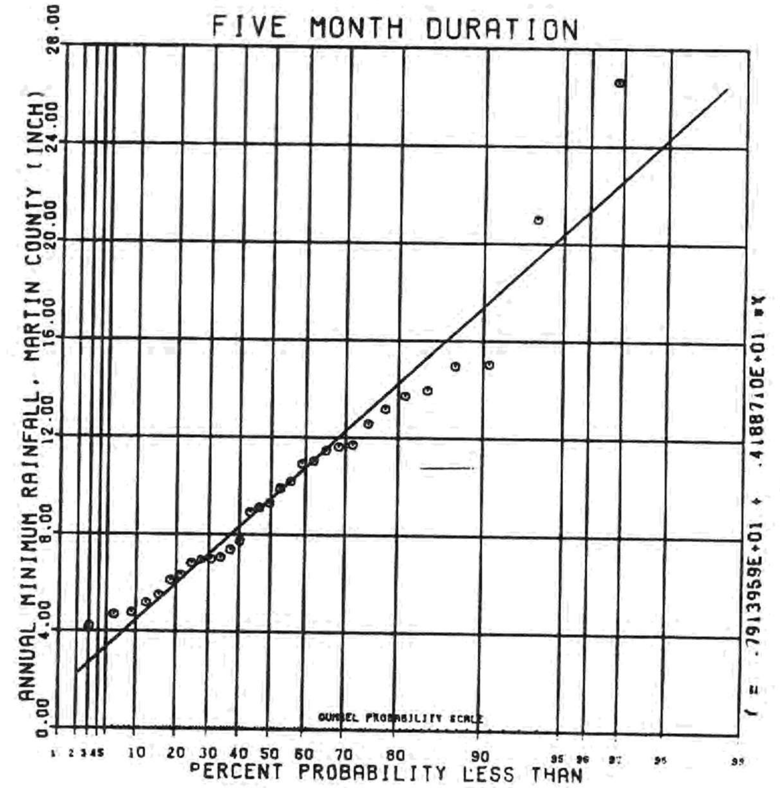

DECEMBER
MONTHLY INFLOW, C44 (INCH)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 99
PERCENT PROBABILITY LESS THAN
Y = .3321504E+00 + .3823043E+00 *X

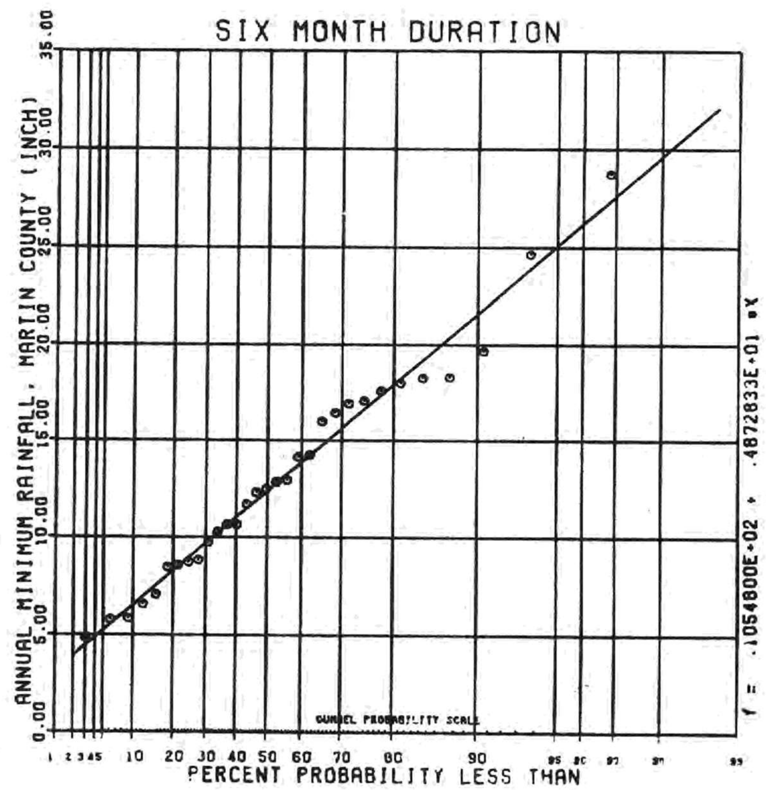

ONE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
PERCENT PROBABILITY LESS THAN
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
GUMBEL PROBABILITY SCALE
Y = .2183164E+00 + .3555585E+00 *X

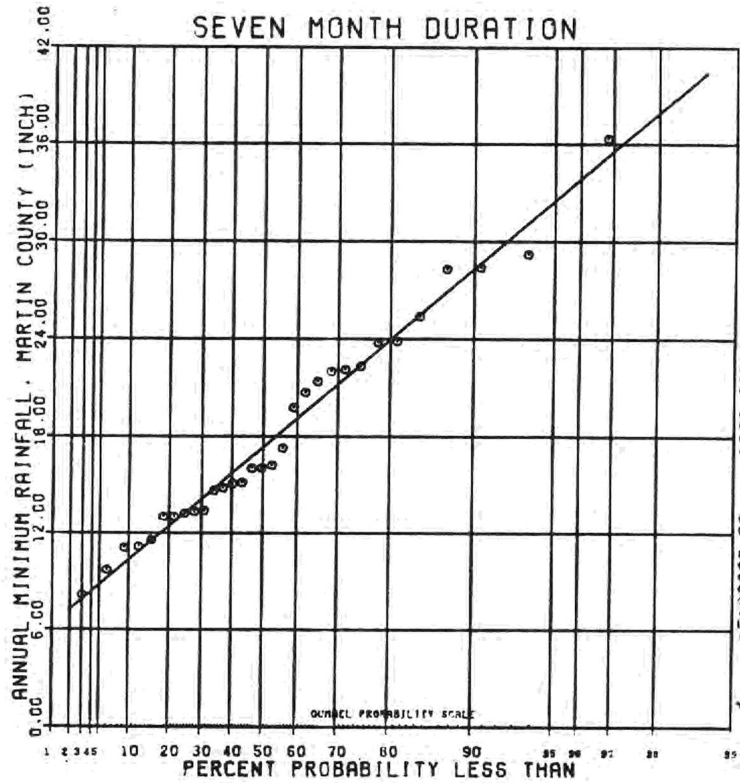

TWO MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
PERCENT PROBABILITY LESS THAN
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
GUMBEL PROBABILITY SCALE
Y = .1424360E+01 + .1184847E+01 *X

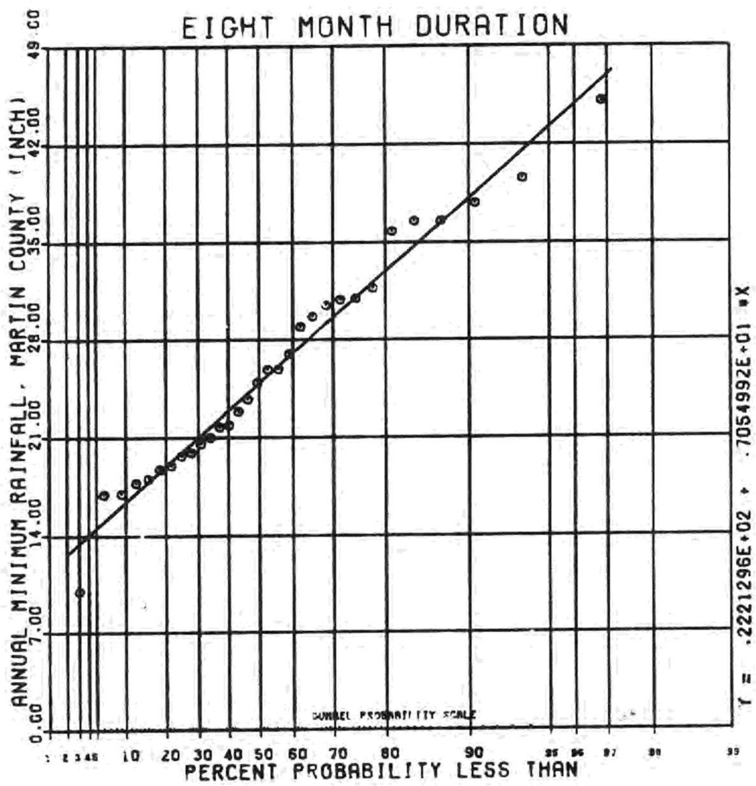

THREE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Y = .3120483E+01 + .2018190E+01 *X
1 2 3 4 5 10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN

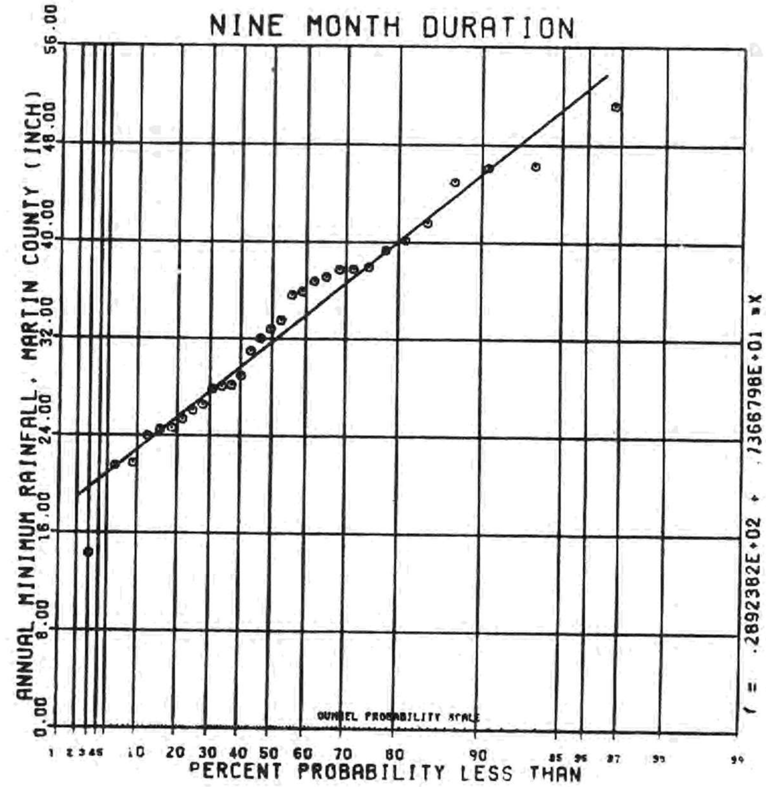

FOUR MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
Y = .5549663E+01 + .2634509E+01 *X
1 2 3 4 5 10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN

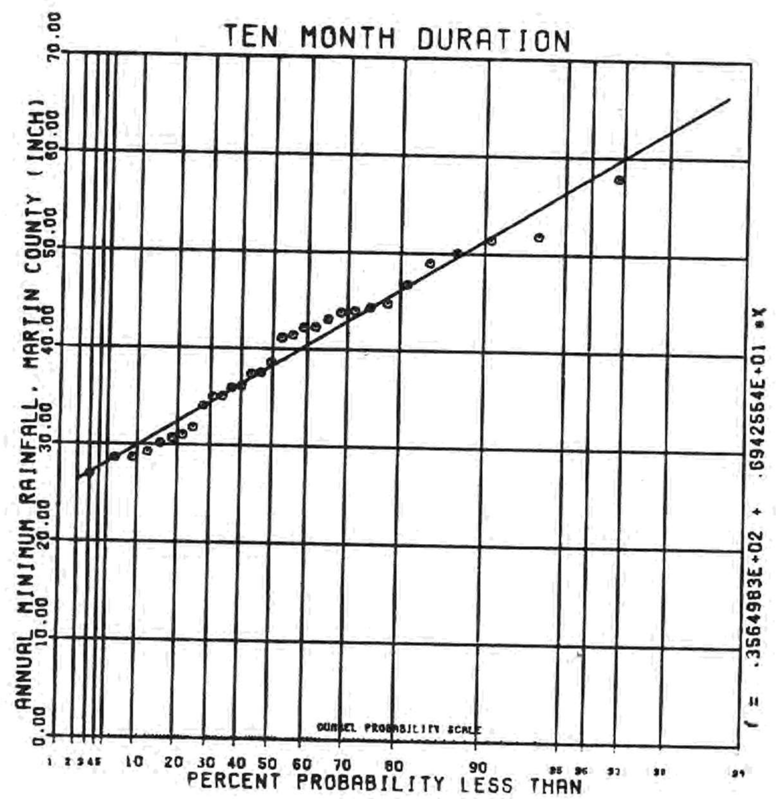

FIVE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .7913959E+01 + .4188710E+01 *X

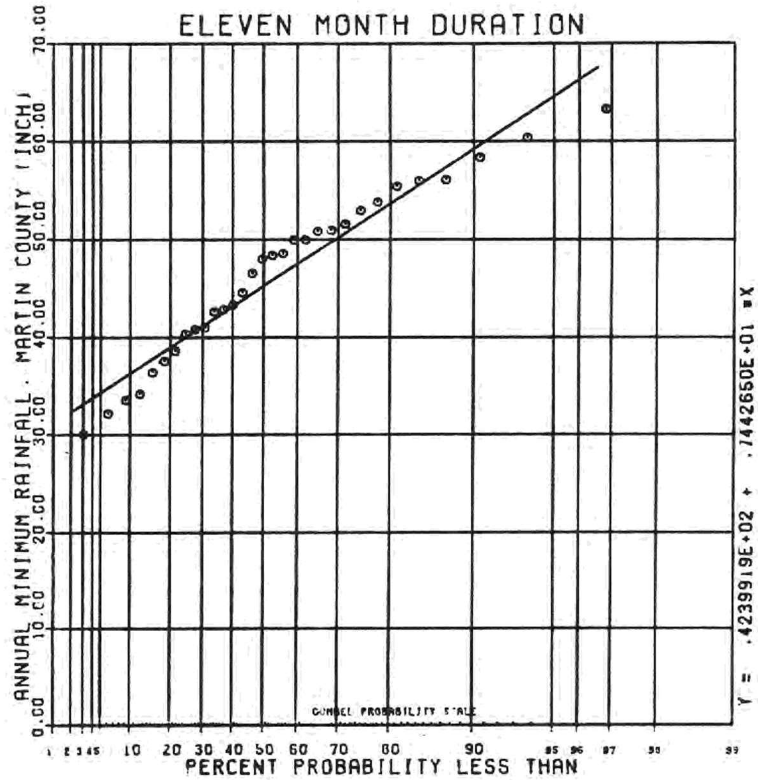

SIX MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN
Y = .1054800E+02 + .4872833E+01 *X

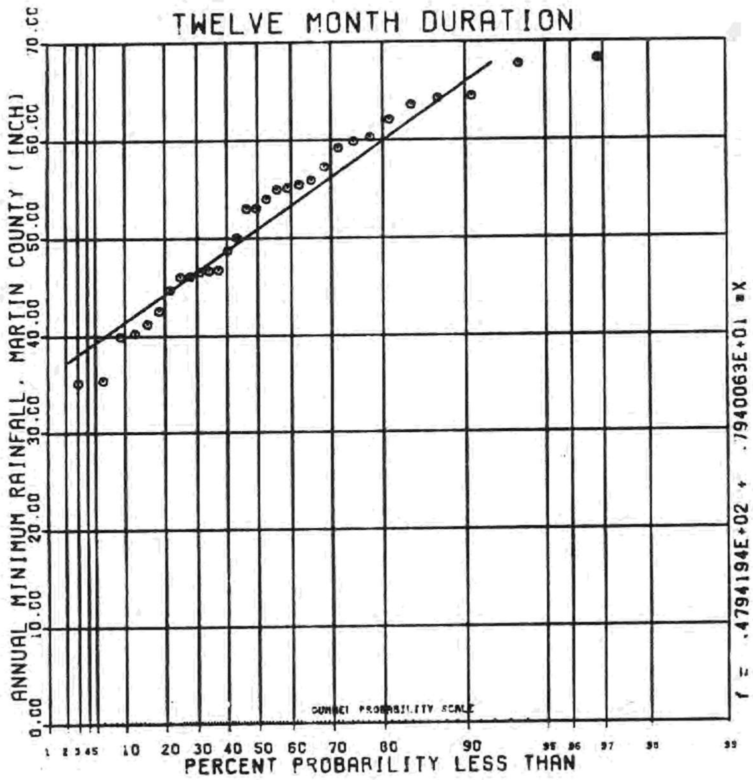

SEVEN MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
Y = .1512966E+02 + .5829162E+01 *X
1 2 3 4 5 10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN

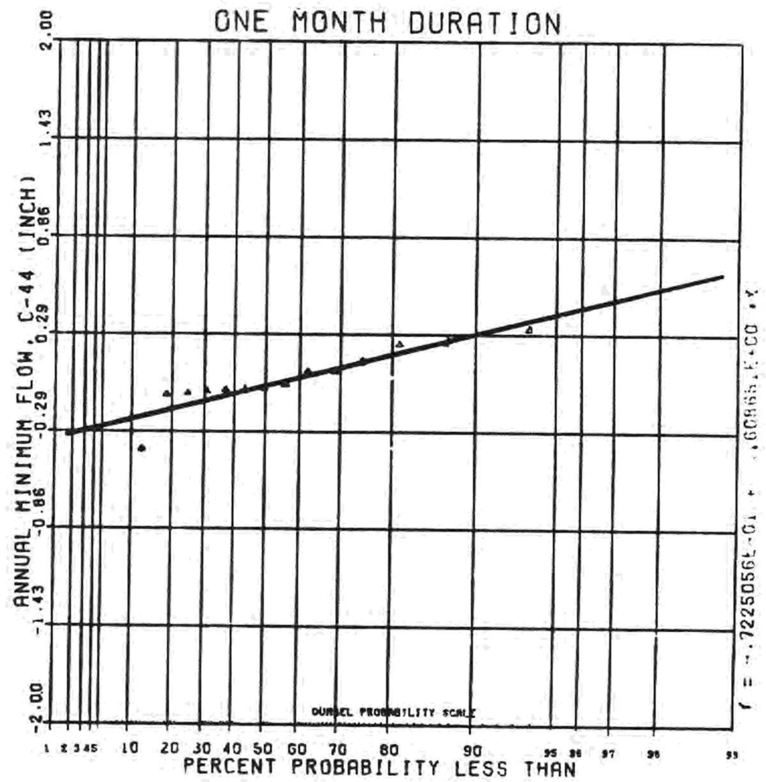

EIGHT MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
Y = .2221296E+02 + .7054992E+01 *X
1 2 3 4 5 10 20 30 40 50 60 70 80 90
PERCENT PROBABILITY LESS THAN

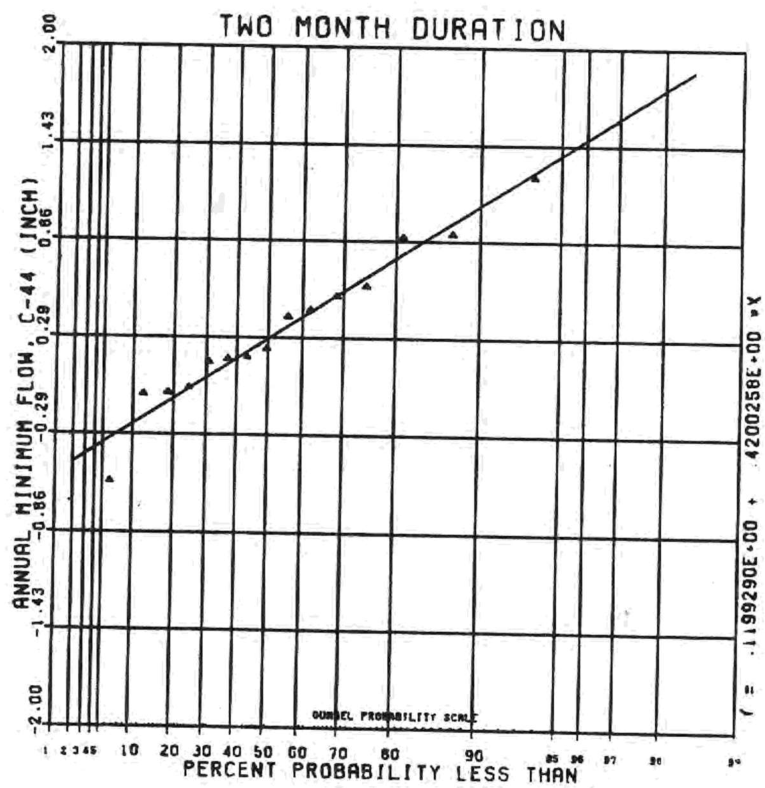

NINE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
GUMBEL PROBABILITY SCALE
Y = .2892382E+02 + .7366798E+01 *X

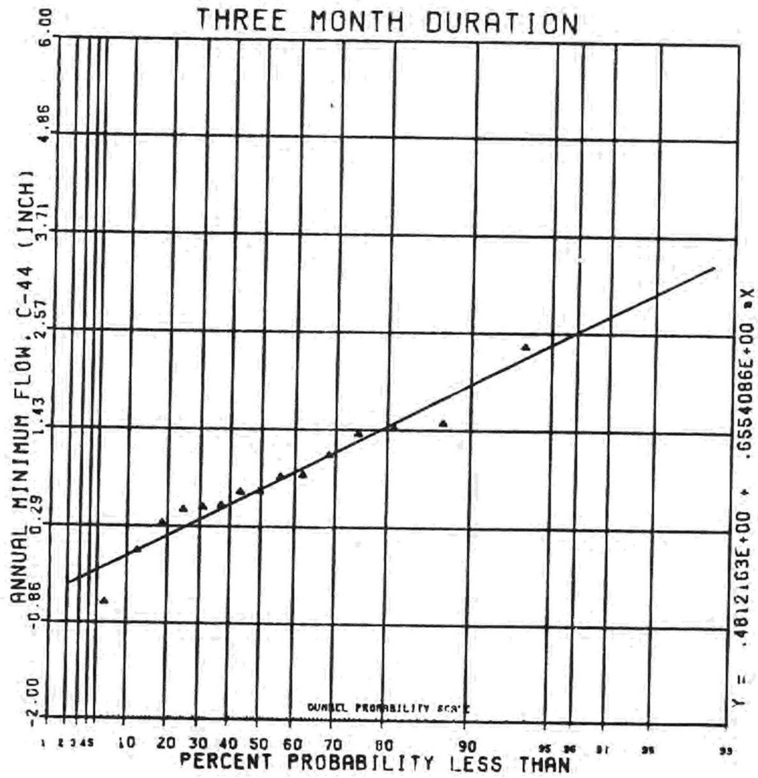

TEN MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
GUMBEL PROBABILITY SCALE
Y = .3564983E+02 + .6942554E+01 *X

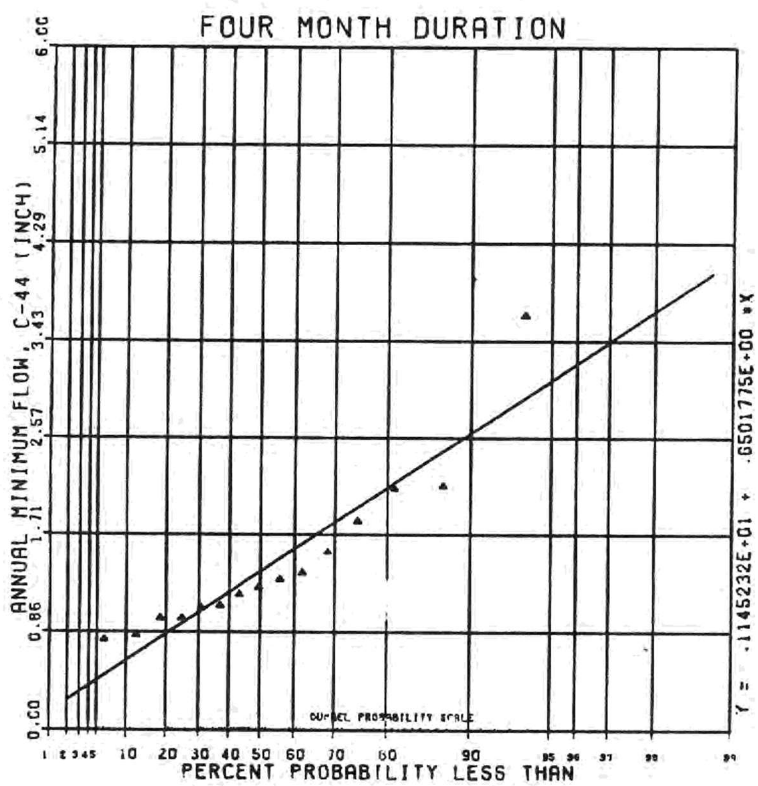

ELEVEN MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
Y = .4239919E+02 + .7442650E+01 *X

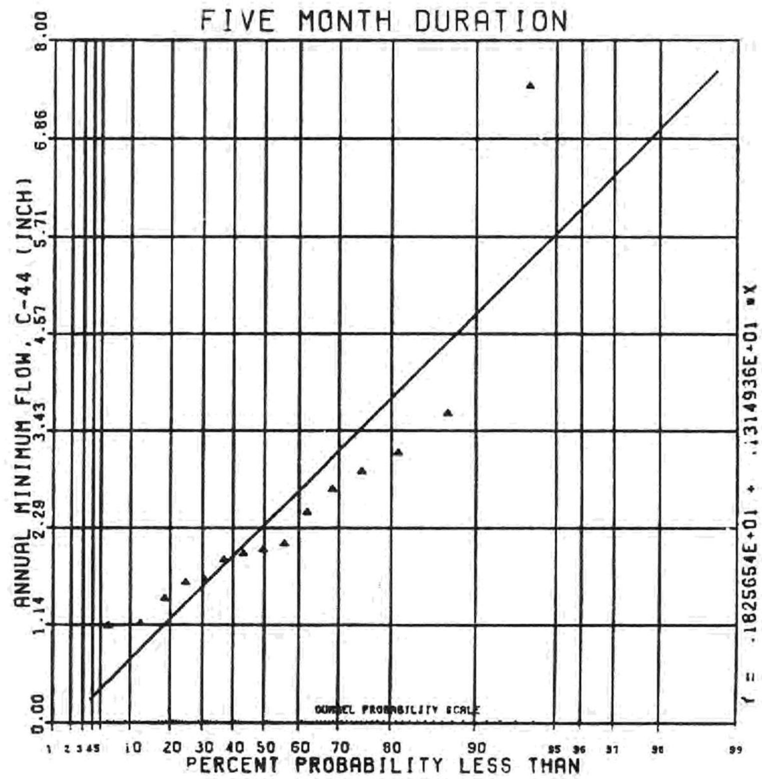

TWELVE MONTH DURATION
ANNUAL MINIMUM RAINFALL, MARTIN COUNTY (INCH)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
PERCENT PROBABILITY LESS THAN
10 20 30 40 50 60 70 80 90
Y = .4794194E+02 + .7940063E+01 *X

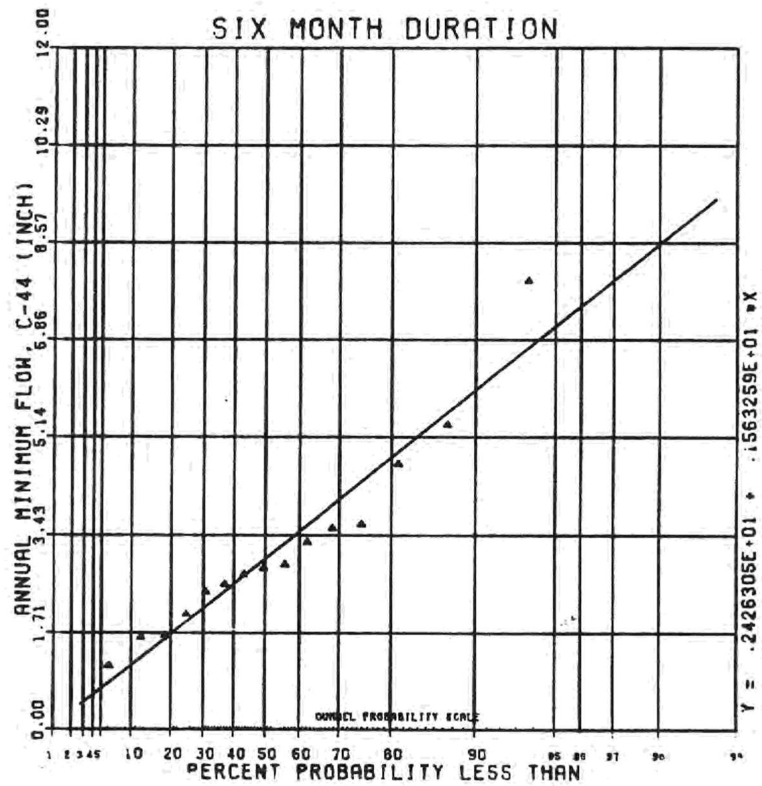

ONE MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
2.00
1.43
0.86
0.29
-0.29
-0.86
-1.43
-2.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = -.7225056E-01 +


TWO MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
2.00
1.43
0.86
0.29
-0.29
-0.86
-1.43
-2.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = .1199290E+00 + .4200258E+00 *X

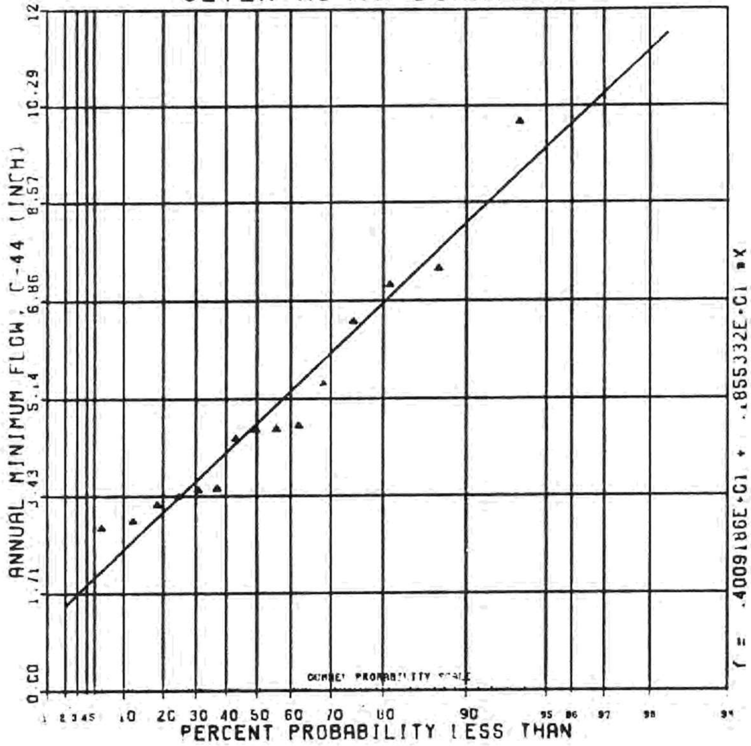

THREE MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
6.00
4.86
3.71
2.57
1.43
0.29
-0.86
-2.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = .4812163E+00 + .6554086E+00 *X


FOUR MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
6.00
5.14
4.29
3.43
2.57
1.71
0.86
0.00
GUMBEL PROBABILITY SCALE
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
Y = .1145232E+01 + .6501775E+00 *X

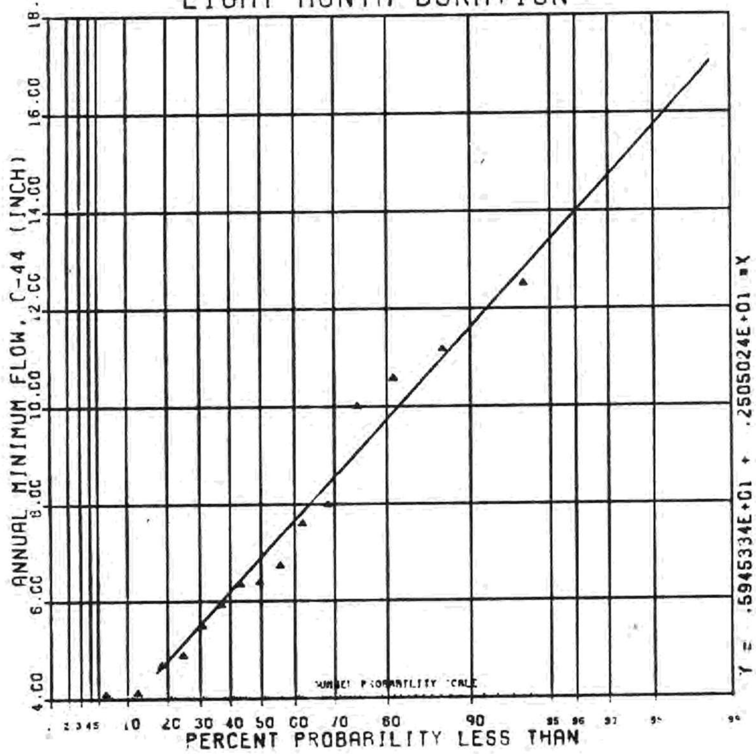

FIVE MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
0.00
1.14
2.29
3.43
4.57
5.71
6.86
8.00
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
Y = .1825654E+01 + .1314936E+01 *X

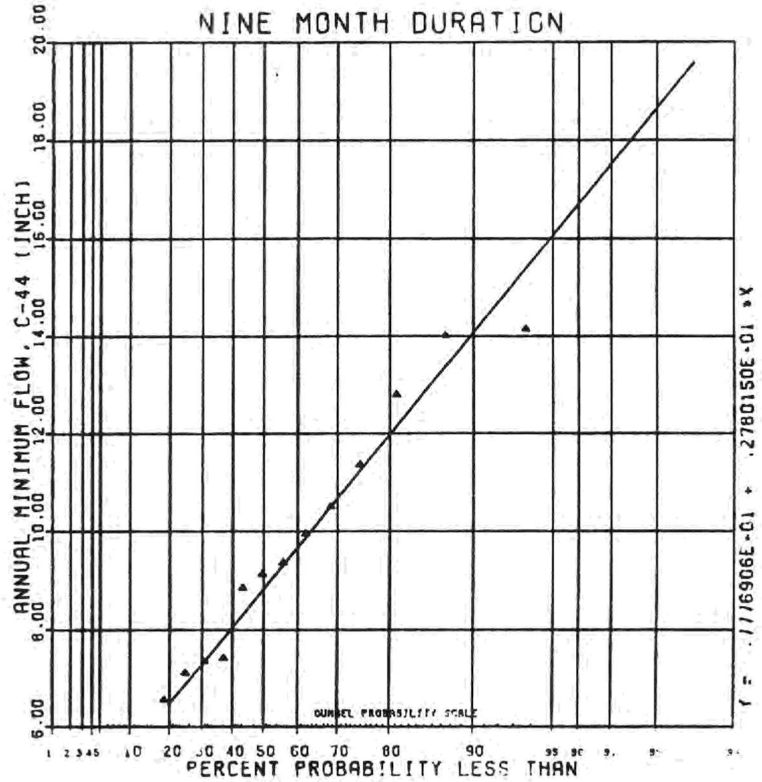

SIX MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
0.00
1.71
3.43
5.14
6.86
8.57
10.29
12.00
1 2 3 4 5 10 20 30 40 50 60 70 80 90 95 96 97 98 99
PERCENT PROBABILITY LESS THAN
GUMBEL PROBABILITY SCALE
Y = .2426305E+01 + .1563259E+01 *X

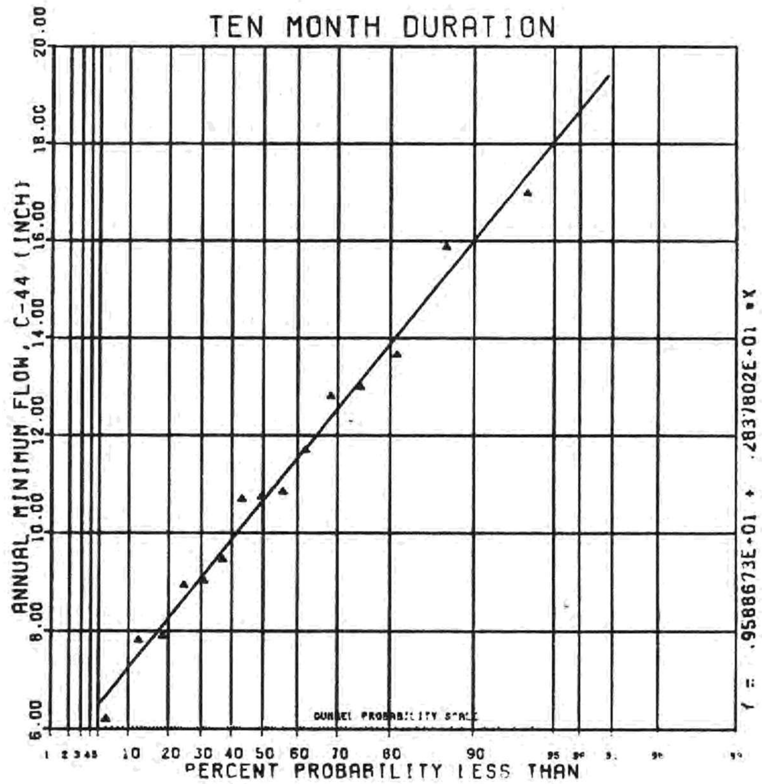
SEVEN MONTH DURATION

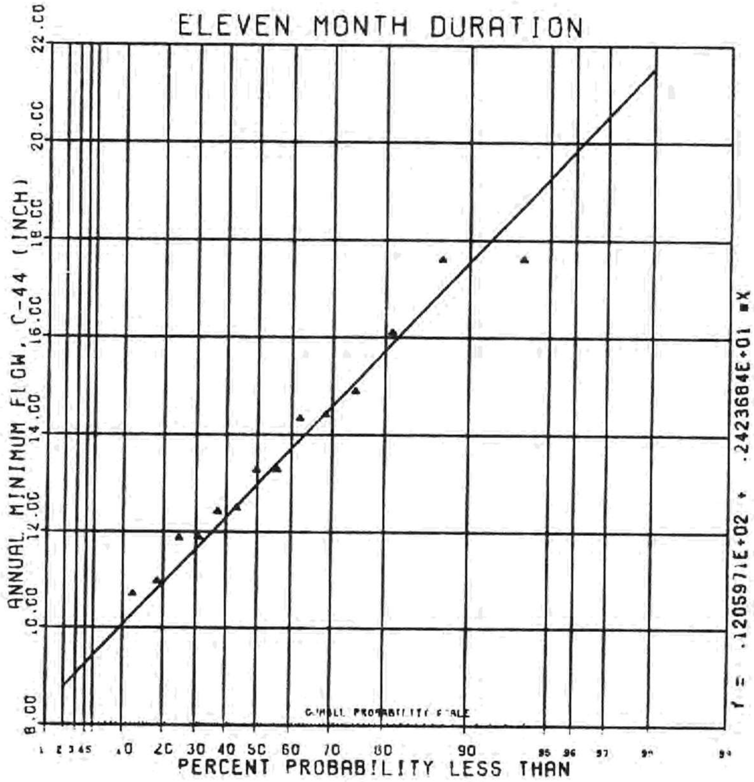


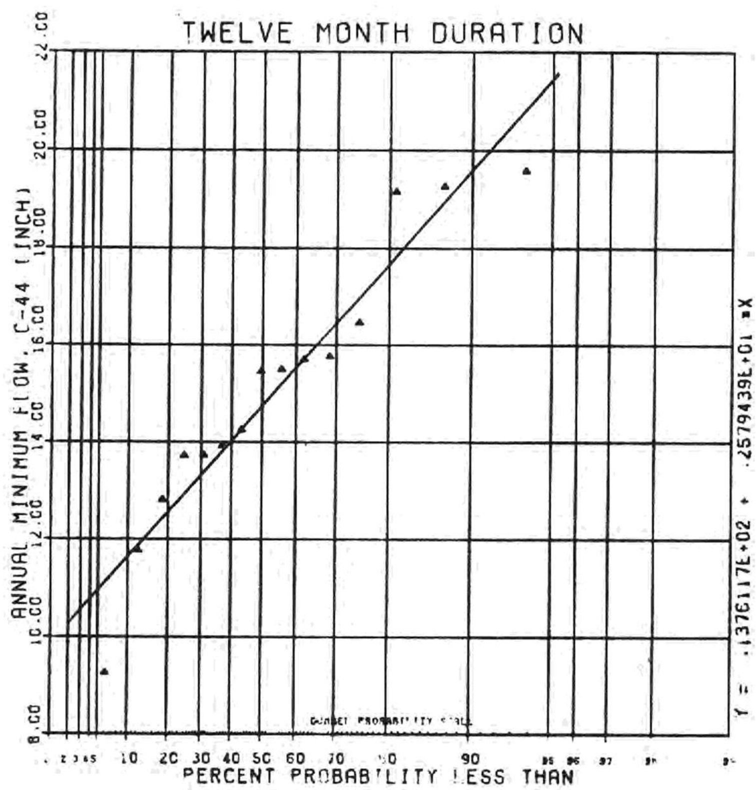
EIGHT MONTH DURATION




NINE MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
GUMBEL PROBABILITY SCALE
10
20
40
50
60
70
80
90
PERCENT PROBABILITY LESS THAN
Y = .7769906E+01 + .2780150E+01 *X


TEN MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
GUMBEL PROBABILITY SCALE
10
20
30
40
50
60
70
80
90
PERCENT PROBABILITY LESS THAN
Y = .9588673E+01 + .2837802E+01 *X


ELEVEN MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
PERCENT PROBABILITY LESS THAN
10
20
30
40
50
60
70
80
90
Y = .1205971E+02 + .2423684E+01 *X


TWELVE MONTH DURATION
ANNUAL MINIMUM FLOW, C-44 (INCH)
8.00
10.00
12.00
14
16.00
18.00
20.00
PERCENT PROBABILITY LESS THAN
10
20
30
40
50
60
70
90
Y = .1376117E+02 + .2579439E+01 *X

APPENDIX 2

PROPOSED CRITERIA FOR PERMITTABLE WATER

APPENDIX 2. PROPOSED CRITERIA FOR PERMITTABLE WATER

Permittable Water (Safe Yield)

Permittable water is that quantity of water available for use in a basin or subbasin area. It includes both water that is already allocated and water that can be allocated in the future.

Permittable water should be determined by evaluation of the following factors:

1. **Basin Yield** - Basin yield is the amount of water that can be withdrawn from all sources in a basin without causing: a) water level or potentiometric head declines on a continuing non-recoverable basis, b) water level or potentiometric head declines which are not in the public interest, and c) coastal saline water intrusion. Basin yield is the upper limit of permittable water, and in most cases, the permittable water will be less than the basin yield.

2. **Presently Allocated Water** - A determination of permittable water must include consideration of the amount of water already allocated and the impacts associated with the existing level of allocations.

3. **Saline Water Intrusion** - Permittable water must not induce saline water intrusion during a 1-in-100 year drought.

4. **Existing Legal Uses of Water** - Existing legal uses of water include permitted uses and exempt uses. Exempt uses include the use of water by a single family dwelling for domestic or irrigation needs from a small diameter well. The permittable quantity of water must not cause adverse impacts on existing legal uses in a 1-in-100 year drought. This means that the withdrawal capability of existing uses must not be decreased by more than 10% in comparison with an average rainfall year (a 100 gpm well must not be impacted to the degree that it will produce 10 gpm less as a consequence of withdrawals by other uses. Reductions in withdrawal capability due to drop in potentiometric head during the drought event are not a consideration.

5. **Environmental Impact** - Permittable water must not adversely impact wetland hydroperiods during a 1-in-10 year drought event. This means that the withdrawals during either the wet season or dry season cannot create such low water level or potentiometric head conditions that the natural vegetation is altered or eradicated.

6. **Land Use** - Permittable water must not adversely impact existing lake levels, that is, lower existing lake levels more than two inches during a 1-in-10 year drought event. Reductions in lake levels due to the drought event are not a consideration.

APPENDIX 3

NONRESIDENTIAL LAND USE PERMITTED IN THE WELL FIELD PROTECTION ZONING OVERLAY DISTRICT (DADE COUNTY)

APPENDIX 3

NONRESIDENTIAL LAND USES PERMITTED IN THE WELL FIELD PROTECTION ZONING OVERLAY DISTRICT (DADE COUNTY)

Abstract Title
Accountants - Bookkeeping
Actuaries
Advertising Office - no printing
Agriculture
Alcoholic Beverage Dist.- no serving
Amusement - Game Room
Animals, Birds, and Tropical Fish - Retail Only
Antique Shops
Apparel Sales, Rentals
Appliance and Fixture Sales (No Service)
Appraisers (no merchandise)
Archery Range
Art Gallery
Art Goods and Bric-A-Brac Shops
Artist Studios
Auction Sales (no hazardous materials)
Auditoriums
Bait and Tackle Shop
Bakeries
Banks
Barbecue Restaurants, Stand, Pits (wood for cooking)
Barber Shop
Bars
Baseball Field
Bath and Massage Parlors
Bicycle Sales (No Service)
Billiard Parlor/Pool Hall
Bindery (books, publications, etc.)
Bingo
Boat Piers, Docks
Book Store (new and used)
Bottled Gas Storage (Liquified Petroleum Gas and Natural Gas only)
Bowling Alleys
Box Lunches - wholesale and retail/with delivery trucks (no truck maintenance)
Broadcasting Studios (radio and T.V., including transmitting station and tower, incidental electrical generation by LP or Natural Gas only)
Business Machines (typewriters, calculators, etc.) Sales (No Service)
Card Club/Public
Carpet Sales
Caterers
Churches
Cigar Making and Sale
Cigarette Vending
Clubs (private)
Coin Laundries (No Dry Cleaning Machines)
Coin Shop
Cold Storage Warehouses and Pre-Cooling Plants
Colleges
Computer Service
Concrete, Cement, Clay Products - Storage and Sales (No Vehicle Maintenance)
Confectionery (and ice cream stores)
Conservatories
Convention Halls
Costuming Shops
Curio Stores
Dance Halls, Schools, Academies
Day Camp
Day Care, Nursery

Department Store
Dependent Children (home for)
Dive Shop
Docks, Piers - Boat
Dog Obedience Training, Training Tracks, Schools
Drapery Stores, Drapery Making
Dressed Poultry and Sea Food Stores
Drive-In Theaters
Drive-Thru Banks and Restaurants
Drug Store
Dry Cleaning Agency (no cleaning on premises)
Dynamite Storage
Electric Substations
Electrolysis Office (removal of hair by electrolytic process)
Employment Agencies
Entrance Gates
Escort Service
Farms
Fishing Camps
Fish Houses, Market, Smoking
Fish - Tropical, Aquariums (retail sales only)
Fire Station
Flea Market
Florist Shops, Flower Importers
Food Distribution (No On-Site Vehicle Maintenance)
Food Sales
Foster Home
Fraternities
Fruit Packing, Fruit Stores, Fruit Stands
Furniture Sales, Rental and Storage (no restoration, no manufacturing)
Furriers (sales and storage)
Garment Manufacturing (No Dyeing)
Gas (Natural Gas, LP Gas) Including Distribution System and Bottling Plant
Glass Blowing
Golf Course Clubhouse
Golf Driving Range
Gun Shop
Haberdashery
Hall for Hire
Health Spa
Hotels, Motels
Ice Cream Stores
Ice Manufacturing, Distributing (emergency electrical generation by LP or natural gas)
Import - Export Office
Insurance Office
Interior Decorators Office, Showroom
Jai Alai
Jewelry Sales (No Manufacturing)
Judo and Karate Instructions
Key Shop
Kindergartens, Day Care
Laundries (all types, no dry cleaning)
Leather Goods Stores (retail)
Libraries (public)
Limestone Quarrying, Aggregate Plant
Liquified Petroleum (LP) Gas
Liquor Package Stores
Livery Stable
Lodges (private)
Lounges
Luggage Sales
Lunches (packaging, catering)
Mail Order Office
Massage Parlor
Meat Market
Men's Store
Messenger Office
Milk Store (drive-in)
Miniature Golf Course
Mission
Mobile Homes - Sales (No manufacturing or repair; and no motor homes or recreational vehicles)

Motel
Modeling (agencies, schools)
Motion Picture Studio (no film developing)
Motion Picture Theatre
Motion Pictures and Equipment - Sales and Rental (no equipment servicing, no film developing)
Moving and Storage Company (No on-site vehicle maintenance)
Municipal Recreation Building
Museums - Public
Music Stores, Teaching
Newsstand
Night Club
Notions Sales
Office Building
Office Professional
Open Air Theaters
Optical Stores
Package Stores
Palmistry
Paneling (wall/retail sales)
Paper Salvage
Parking Lot, Parking Garage (No Auto Pound, No Tow Yard, No On-Site Vehicle Repair)
Passenger Stations (railroad, bus)
Pawn Shops (Swap Shops)
Pet Shops - Retail Sales Only (in air-conditioned building)
Pharmaceuticals (retail)
Photographic Studio (no developing, no printing)
Pillow Renovating
Plant Sales (no propagation)
Plaster Products
Plasterers - Storage Area
Police Station
Pool Rooms
Post Office
Pottery (retail sales only/no manufacturing)
Private Clubs
Produce or Fruit Market
Professional and Semi-Professional Offices (No Medical Laboratory or Clinic)
Public Art Galleries, Museums
Racquet Ball Clubs
Radio - Broadcasting Station, Studio, Transmitting Station/Tower (emergency electrical power by LP or natural gas only)
Railroad and Bus Passenger Stations (No Freight Terminal, No Vehicle Maintenance)
Real Estate Office
Recording Studios
Recreational Facilities
Rentals (household equipment, appliances, tools, hardware, etc.)
Residences
Restaurants
Rock and Sand Yards
Rock Yards (crushing)
Saloons and Bars
Savings and Loan Association
Schools (No Hazardous Materials)
Seafood Stores
Second-Hand Stores (inside only)
Shooting Gallery
Shooting Range, Trap and Skeet
Shopping Center
Showrooms, Salesrooms (no hazardous materials)
Skating Rink
Sororities
Souvenir Stores
Sporting Goods Store
Stationery Stores
Steam Fitting Shops
Storage Warehouse (no hazardous materials)
Swap Shops
Swimming Pools

Tailor Shops

Tattoo Parlor

Telegraph Stations (emergency electrical power by
LP gas only)

Telephone Answering Service

Telephone Exchange

Television (broadcasing studio)

Tennis Courts

Textile Sales

Theaters

Tile Sales (no manufacturing)

Tourist Attractions

Trading Post

Travel Agency

Upholstery Shop

Vegetable Stands

Wall Paper, Panelling (retail sales)

Warehouses (storage of food, fodder, apparel, and
other nonhazardous materials)

Watchman's Quarters

Water Tanks or Towers

Water Treatment Plants

Wearing Apparel Stores

Wholesale Salesrooms and Attendant Storage Rooms
(no hazardous materials)

APPENDIX 4

COST ESTIMATES FOR WATER SUPPLY ALTERNATIVES IN MARTIN COUNTY

COST ESTIMATES
FOR
WATER SUPPLY ALTERNATIVES
IN MARTIN COUNTY

COUNTY OF MARTIN STATE OF FLORIDA

SEPTEMBER, 1984

WILLIAM M. BISHOP CONSULTING ENGINEERS, INC.

TALLAHASSEE AND JENSEN BEACH, FLORIDA

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EXECUTIVE SUMMARY

Presented in this report is a study of the possible water supply sources available to Martin County and estimates of the costs to treat the water from these sources.

There are three water sources available to the County:

1) Surficial Aquifer Source
2) Surface Water Source
3) Floridan Aquifer Source

Descriptions of these three sources are presented in Section 2.0 from the water quality analyses of samples from these sources. Water treatment processes were determined and treatment plants were schematically designed.

Capital and O&M cost estimates were calculated for each water treatment plant to determine the cost to produce 1000 gallons of water. A comparison of these costs should help in determining future water supply plans for Martin County. The cost estimates for the different water sources are:

SOURCE	COST/1000 GALLONS
1) Surficial Aquifer Source	$0.86
2) Surface Water Source	$1.02
3) Floridan Aquifer Source	$0.92

1.0 INTRODUCTION

1.1 Background

The Water Master Plan Phase I, completed for Martin County Board of County Commissioners in 1984, revealed a growing need for potable water in Martin County. The estimated buildout requirements for the North Martin County area alone are 7.8 MGD of water, and the present treatment facilities provide 2.5 MGD. In response to this report, the Board of County Commissioners has initiated a study on the various alternatives of water supply sources and the treatment processes which are applicable to each source.

Three possible raw water sources are available to the county:

1) Surficial aquifer.
2) Surface water.
3) Floridan aquifer.

Each of these sources has unique water characteristics which require different treatment processes.

Figure 1-1 represents a schematic diagram of the geological relationships of the various sources. The surficial aquifer is presently being used by the county for it's water supply and is available in most of the areas. The surface water source would be from the St. Lucie Canal (C-44), just west of the S80 control structure. Generally free from salt water intrusion in this area, the St. Lucie canal also meets the Environmental Protection Agency standards as a drinking water source. The largest of the three sources is the Floridan aquifer. This aquifer is a brackish water source available under most of Florida.

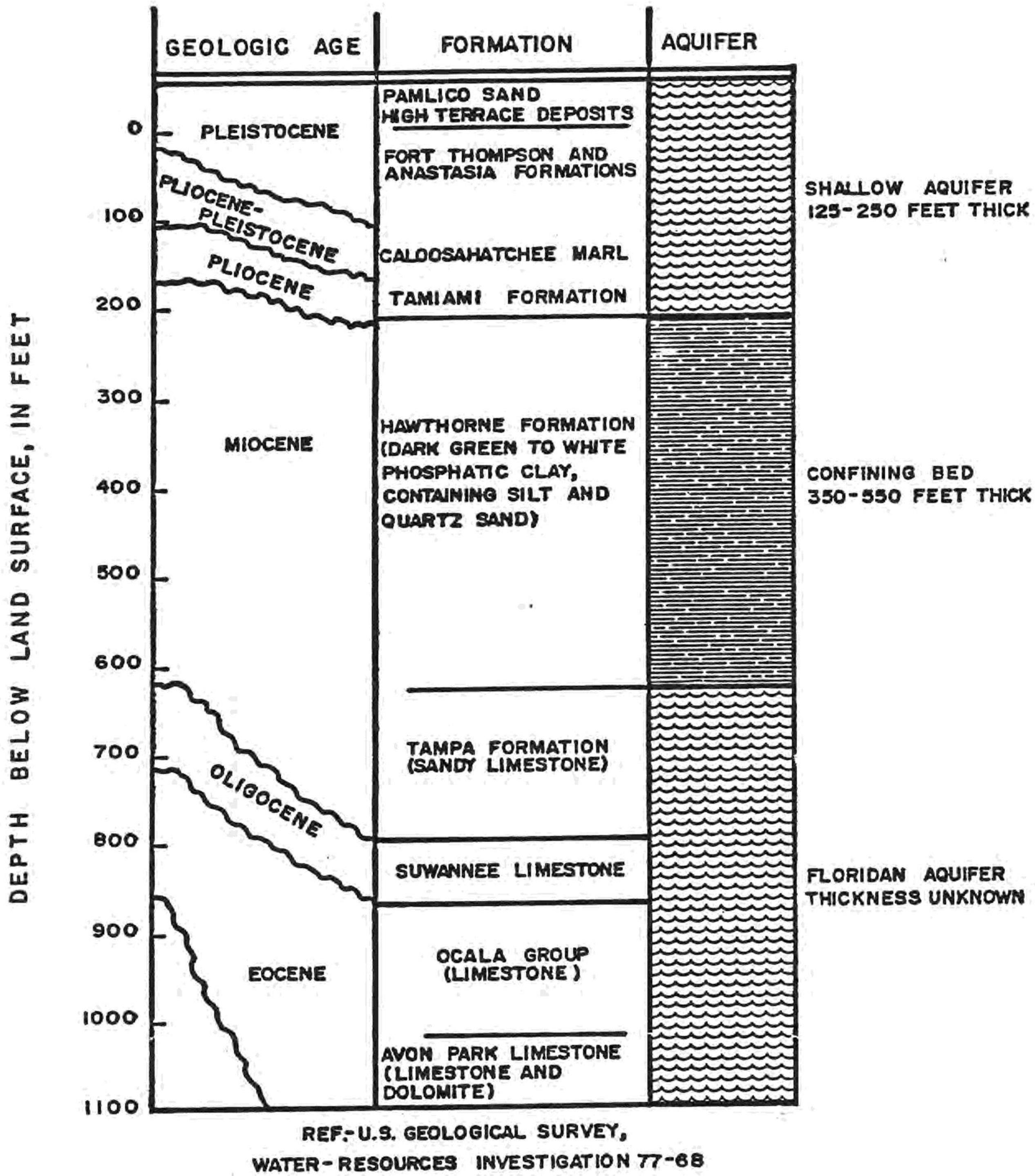

GEOLOGIC AGE
FORMATION
AQUIFER
DEPTH BELOW LAND SURFACE, IN FEET
0
100
200
300
400
500
600
700
800
900
1000
1100
PLEISTOCENE
PLIOCENE-PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PAMLICO SAND
HIGH TERRACE DEPOSITS
FORT THOMPSON AND ANASTASIA FORMATIONS
CALOOSAHATCHEE MARL
TAMIAMI FORMATION
HAWTHORNE FORMATION (DARK GREEN TO WHITE PHOSPHATIC CLAY, CONTAINING SILT AND QUARTZ SAND)
TAMPA FORMATION (SANDY LIMESTONE)
SUWANNEE LIMESTONE
OCALA GROUP (LIMESTONE)
AVON PARK LIMESTONE (LIMESTONE AND DOLOMITE)
SHALLOW AQUIFER 125-250 FEET THICK
CONFINING BED 350-550 FEET THICK
FLORIDAN AQUIFER THICKNESS UNKNOWN
REF.- U.S. GEOLOGICAL SURVEY, WATER-RESOURCES INVESTIGATION 77-68

FIGURE 1-1

1.2 Purpose and Scope

The purpose of this report is to generate engineering cost estimates of water treatment plants which would treat water from the sources mentioned earlier. To accomplish this goal, three steps are required:

1) Determine the type of treatment process applicable to each source.
2) Develop a schematic design of a treatment plant for each treatment process.
3) Estimate the capital costs and the O&M costs for each treatment process.

This information is required before a decision about water supply alternatives can be reached by the County Commissioners.

To aid in the evaluation of the cost estimates, a uniform treatment plant size of 2.5 MGD will be used in this report. This is a fairly standard size plant which is likely to be built by the County to meet it's water supply demands.

2.0 RAW WATER SUPPLY ALTERNATIVES

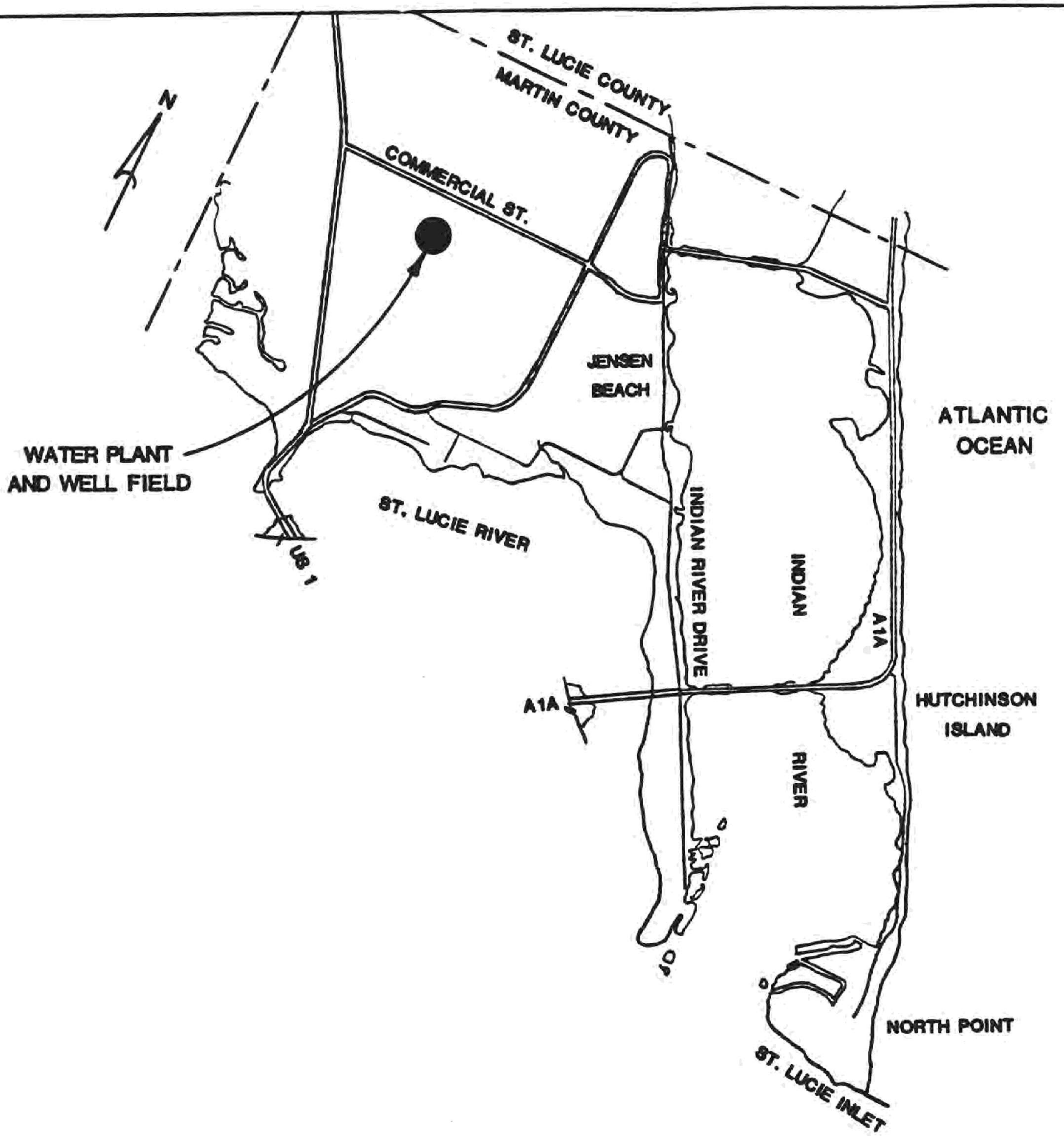
2.1 Surficial Aquifer Source

Of the two available groundwater sources, the surficial aquifer and the floridan aquifer, the surficial aquifer has the best water characteristics and is the source which the County has the most control over. The amount of water in the surficial aquifer is dependent on the amount of water recharged from the surface above it and on the amount of water withdrawn from it through wells.

Figure 2-1 shows the approximate location of the existing water treatment plant and wellfield. This location would logically be chosen for a new water treatment plant and an expansion of the existing wellfield because of it's proximity to the water source and the ease of tying into the distribution system.

The physical and chemical characteristics of water from the surficial aquifer in this area are well within the limits set by the EPA for a raw water source, in fact, it satisfies the EPA standards as a potable water. Water analyses of samples taken from the existing supply wells are included in Appendix A. Interpretation of these analyses indicate that the only treatment processes required are softening, to remove the hardness present; filtration, to remove all of the precipitates generated; and disinfection to insure no pathogenic organisms are present in the supply.

The hardness which is present in the water is caused by calcium being dissolved from the limestone which surrounds the water in the surficial aquifer. There are no strict limits placed on hardness by any agencies, but an established acceptable range is 80-100 ppm. To achieve this amount,



LOCATION MAP
FOR
SURFICIAL AQUIFER WATER TREATMENT PLANT

FIGURE 2-1

the lime softening technique is most commonly used. This is the treatment process used by the present water treatment plant.

2.2 Surface Water Source

The best source for surface water in Martin County would be the St. Lucie Canal. Water taken from the canal to the west of control structure S80 would be fresh water with little chance of salt water intrusion. A salt water wedge may encroach along the bottom, but by placing an intake structure at the upper level of the canal, the salt water could be avoided.

The St. Lucie Canal is one of the outlet canals from Lake Okeechobee and is considered a Class III waterway. This classification is for recreational waters which have uncontrolled access and therefore uncertain quality. Class III waters are not generally suitable as primary drinking water supplies.

To get an idea of the range of water characteristics encountered in this surface water, monthly water samples were taken and analyzed for:

a) Primary inorganics and organics.

b) Secondary inorganics.

c) Purgable halocarbons.

d) Pesticides and PCB.

e) Acid extraction.

f) Base neutrals.

A total of six samples were taken from September, 1984 through February, 1985. The analyses of these samples appear in Appendix B. Interpretation of these analyses indicate that St. Lucie Canal, which is typical of most surface waters, could be used as a source of raw water.

The water exhibits many of the same characteristics as water in Lake Okeechobee, but with higher concentrations of color and suspended solids. One characteristic unique to surface waters in this region is a total hardness averaging over 200. This is a result of the limestone formations in the lake and the canal itself.

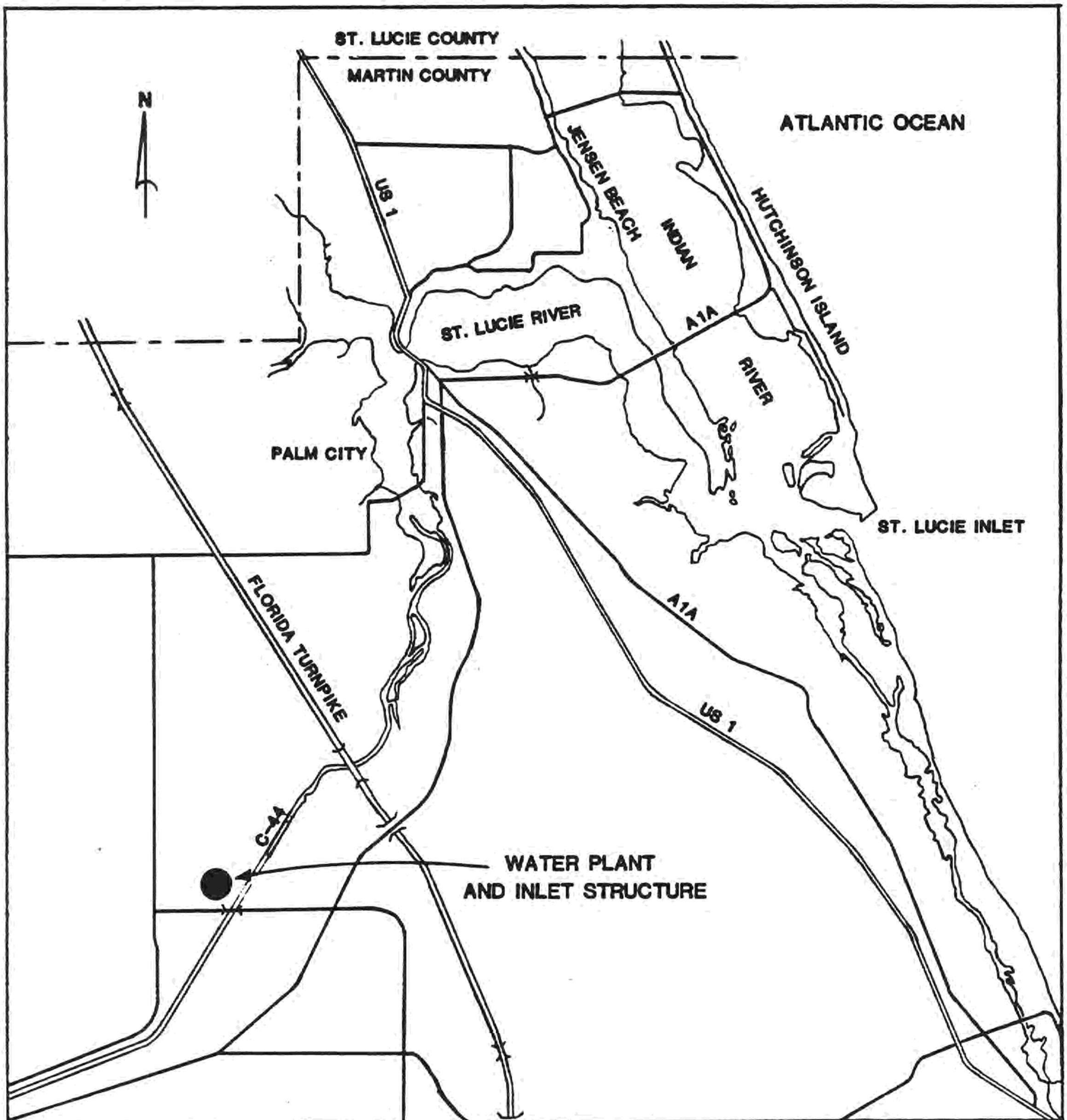
Another feature of the water from the St. Lucie Canal is the non-uniform water quality. The color, pH, turbidity and several other parameters vary depending on rainfall amounts, agricultural activity and other causes. This non-uniform source water will require much more attention by treatment plant operators and result in a non-uniform product water to the distribution system.

The water quality parameters indicate a two-stage treatment process is necessary to treat the water. The first stage will be a coagulation/settling process using alum as the coagulating agent. This process is required to remove the color and suspended solids present in the water. The second stage will be a lime softening process to remove the hardness. A filtration process and disinfection process will follow to produce potable water for the distribution system.

Figure 2-2 shows the proposed location for the surface water treatment plant. This location allows for the plant to be near an intake structure on the St. Lucie Canal. It also enables the County to use existing right of ways on Citrus Boulevard to tie into the existing distribution system and service a larger area of the County.

2.3 Floridan Aquifer Source

The second groundwater alternative is the Floridan Aquifer. This deep aquifer, 600 to 900 feet deep, is located under most of Florida. In the



LOCATION MAP
FOR
SURFACE WATER TREATMENT PLANT

FIGURE 2-2

South Florida area it is a brackish water source with a higher concentration of chlorides than the other sources available to the County.

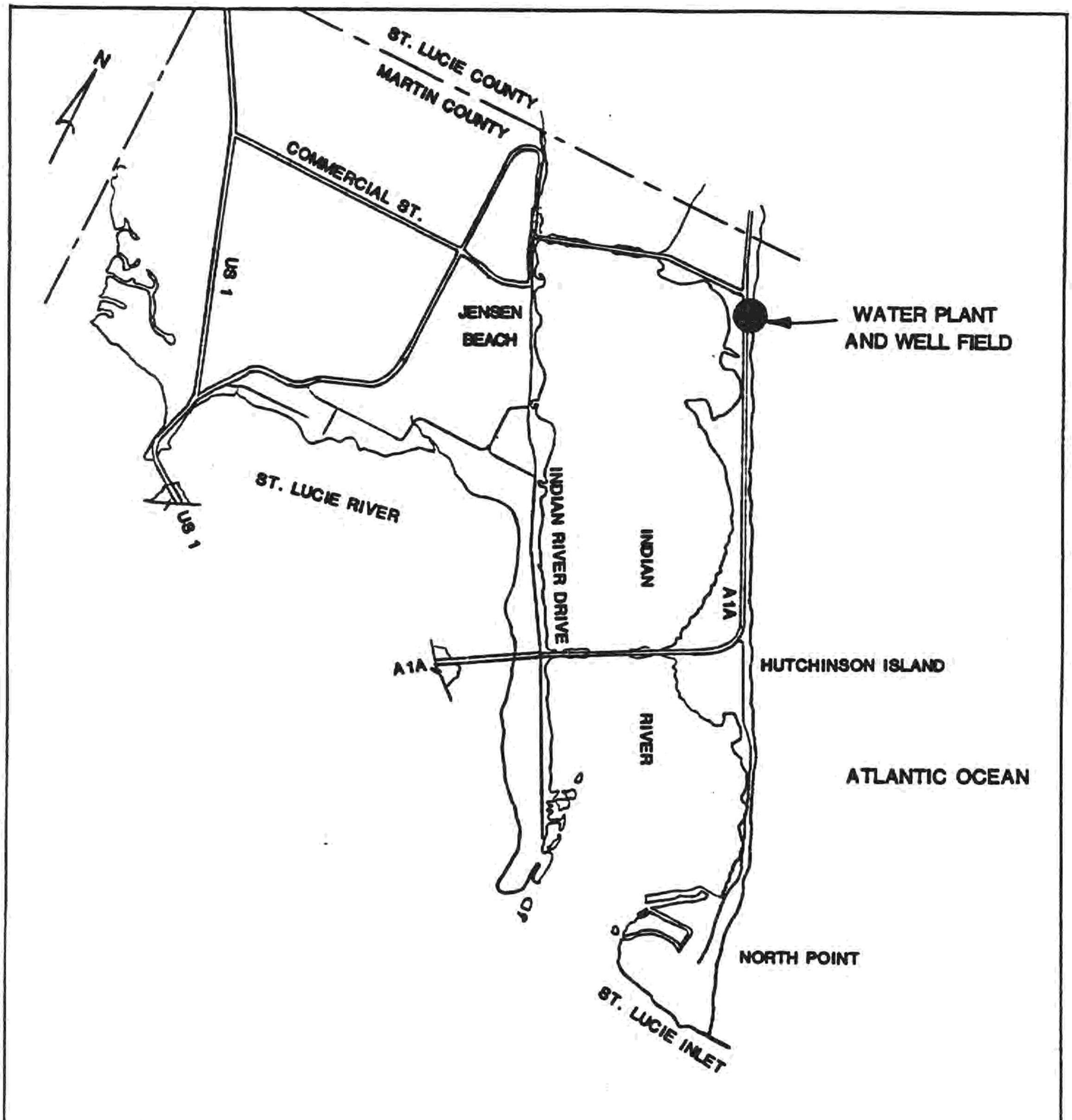
Water quality characteristics are available from several existing wells in the area. Water analysis from two such wells are in Appendix C. These analyses indicate a high concentration of total dissolved solids and chlorides. The other parameters are within an acceptable range to be suitable as a raw water source.

There are presently three treatment processes available for desalting large volumes of brackish or salt water:

1) Flash distillation.
2) Electrodialysis.
3) Reverse osmosis.

Of the three alternatives, reverse osmosis (RO) is the most technologically advanced. With many plants already operational in the South Florida area, this process should also be used in this situation.

One advantage of this type of treatment plant is that it can be housed in a standard architectural building which can be blended into the surrounding buildings instead of the typical, industrial type, structure associated with water treatment plants. Figure 2-3 shows the proposed location of the RO treatment plant and wellfield. By locating it on Hutchinson Island, the pressure in the distribution system can be boosted where it is most needed. The island, being further away from the existing water source, has the lowest pressures in the distribution system.



**LOCATION MAP
FOR
FLORIDAN AQUIFER WATER TREATMENT PLANT**

FIGURE 2-3

3.0 WATER TREATMENT PLANT ALTERNATIVES

3.1 Lime Softening Plant

Lime softening does more than just remove the calcium and magnesium hardness present in the water, it also aids in the removal of iron and manganese, organic material, bacteria, viruses and other suspended solids. This reduces the load on the filters and allows them to work more efficiently. This is the type of water treatment plant presently in operation in North Martin County and is producing an acceptance product water for distribution.

The lime softening process uses lime to precipitate the calcium out of the water in the form of calcium carbonate. This is accomplished in the steps shown in Figure 3-1, the flow diagram for a lime softening water treatment plant.

The raw water is first aerated to remove gases, which are in solution, and to oxidize any iron which may be present in the water. After aeration, the lime is fed into the water as a slurry from the chemical feed room. The rate of feed is determined by the actual hardness of the water being treated. Once the lime slurry is added to the water, it enters a rapid mix step. This insures maximum contact of the lime with all of the water. The next step is the reaction basin which allows sufficient contact time for the chemical reaction to occur. The final step in the lime softening process is settling. This allows the precipitate to settle as a sludge out of the water, leaving a water with less hardness and fewer suspended solids.

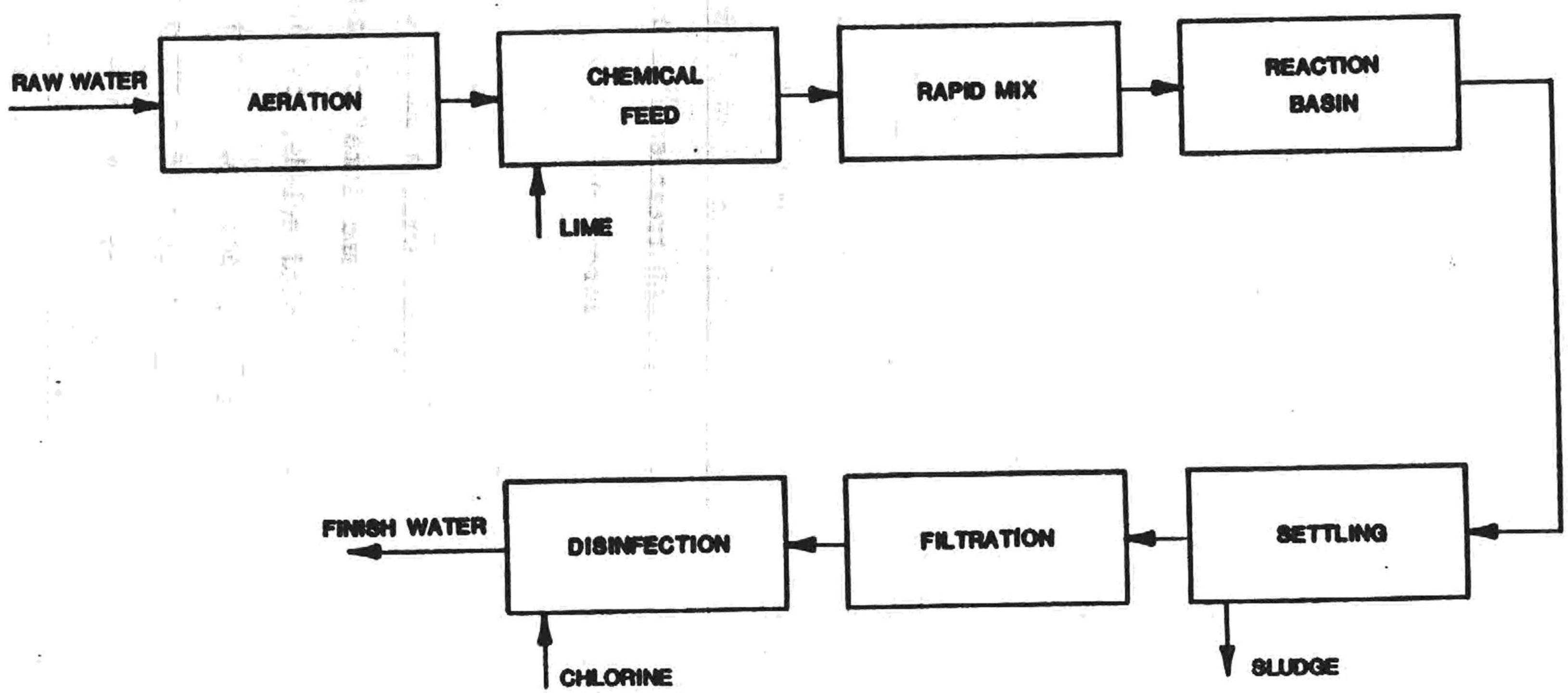
Once the lime softening process is complete, the water is passed through a rapid sand filter to remove any remaining precipitate and suspended solids. The final step in this treatment process is to disinfect the water to remove any pathogenic organism which may be present. This is accomplished by the addition of chlorine to the water.

Figure 3-2 shows a schematic site plan of a lime softening water treatment plant. The raw water first enters the softening unit. This unit combines the first five steps shown on the flow diagram (Figure 3-1), aeration is accomplished by an aerator located above the inlet to the softening unit. The chemical feed, mixing, reaction and settling occur in different zones of this unit. The sludge is drained and transported to the sludge drying basin for dewatering.

After softening the water proceeds to the filters where chlorine is injected, and then taken to the distribution system or to the storage tank. The filters are cleaned with water from the washwater recovery basin. All processes are controlled from the operations building, which has direct access to the chemical feed and storage area. A 2.5 MGD treatment plant of this type requires a site of approximately 10 acres for all of the structures and holding ponds.

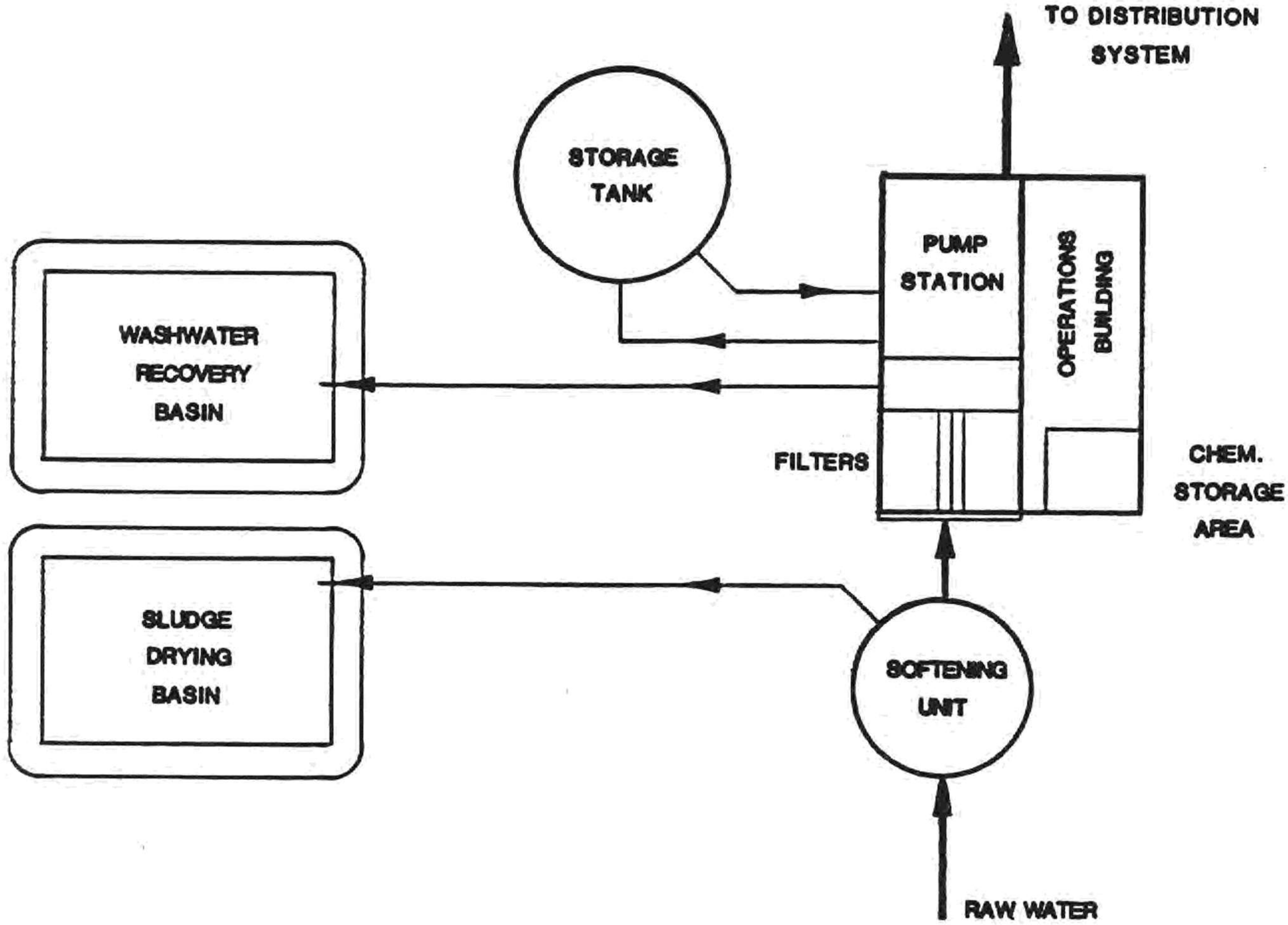
3.2 Surface Water Plant

As mentioned earlier, the surface water plant will need to be a combination of two treatment processes, coagulation and lime softening. The coagulation plant is required to remove suspended solids, colloidal particles and color. It also helps remove nutrients, bacteria, viruses and organic materials. This is accomplished by the addition of a coagulant chemical to the water, the most common coagulant being aluminum sulfate



FLOW DIAGRAM
LIME SOFTENING PLANT

FIGURE 3-1



SCHEMATIC SITE PLAN OF LIME SOFTENING PLANT

FIGURE 3-2

commonly known as alum. The lime softening plant is required to remove the hardness which is present most of the time in this surface water source. This is the same process described in Section 3.1 of this report. At times, one or the other process may not be required, depending on the raw water conditions, and may be bypassed.

Figure 3-3 is a flow diagram for the proposed surface water treatment plant. The raw water is drawn from the St. Lucie Canal through an intake structure and pumped to the treatment plant. This pumping provides the required head for plant operation. The coagulation process is performed on the water first. This removes most of the suspended solids and allows the lime softening process to be carried out more efficiently.

Alum is fed, as a slurry, into the water at a rate determined by jar tests performed on the raw water present at the time. The continually changing raw water characteristics require constant monitoring by the plant operators. The next step is to mix the alum with the water to insure contact with the suspended solids. After rapid mixing, the solution of raw water and alum are slowly mixed in the flocculation step to allow agglomeration of the discrete particles into larger particles which will settle out later. In the settling step the velocity gradients of the water are reduced to allow the large particles to settle, as a sludge, to the bottom.

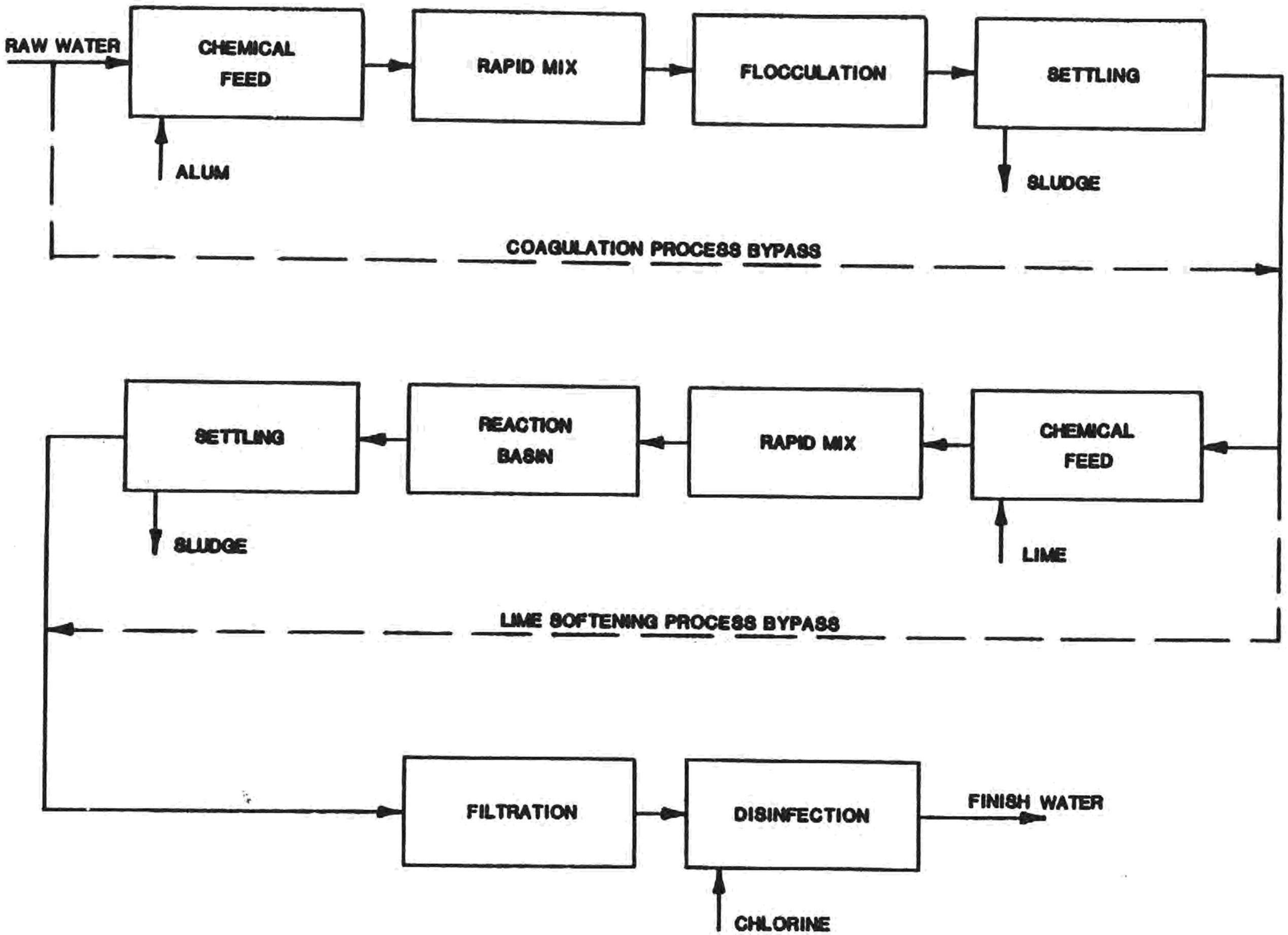
The water then passes to the lime softening process for removal of the hardness present. The steps are the same as those described earlier for the lime softening plant. The water is then passed through the filters and disinfected with chlorine. The finished water is now available for the distribution system.

A schematic plan of this type of treatment plant is shown in Figure 3-4. The raw water from the intake pumps first enters the coagulation unit. This unit combines all of the steps involved in the coagulation process into one structure. Different zones within this structure allow the alum slurry to be fed into the water and mixed to start the coagulation process. Another zone allows a slower mixing for flocculation to occur. The water then enters a settling zone where the floc settles out as a sludge and the water passes through to the next process. The lime softening unit is the same as the one described in Section 3.2 of this report. The sludges from these two units are mixed together and passed through a sludge dewatering unit to reduce the total volume of sludge which needs to be disposed of. A sludge drying basin is required as a backup to the sludge dewatering unit, and also to store the sludge produced during peak flows.

The final clarifying step is to pass the water through the rapid sand filters. This removes any remaining particles from the water and prepares it for disinfection by chlorine addition. After disinfection, the water is ready for either the distribution system through the high pressure pumps, or for storage in the storage tank. The controls for all of the plant operations are located in the operations building. Again, a site of approximately 10 acres is required for this plant.

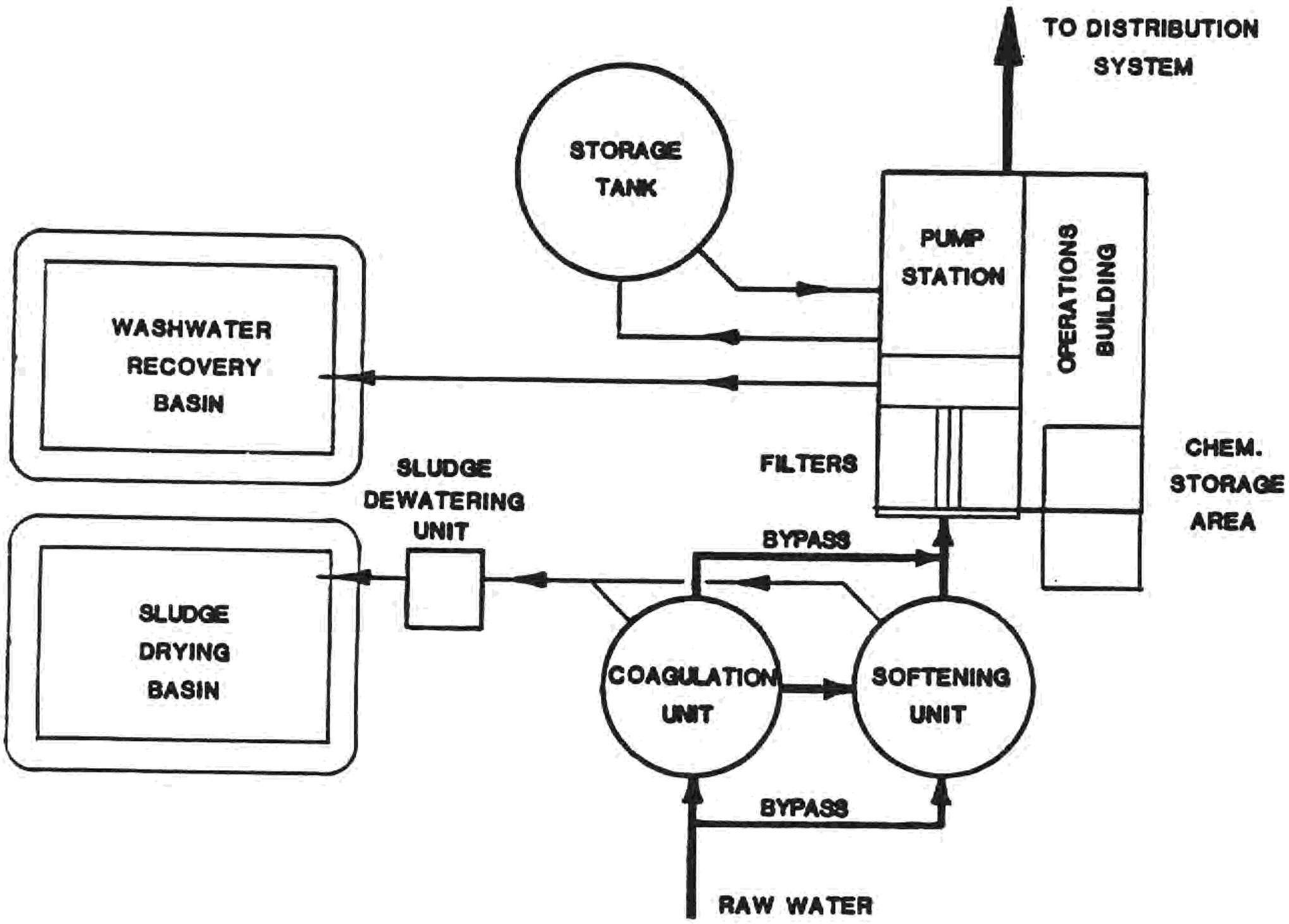
3.3 Reverse Osmosis Plant

The reverse osmosis process is rapidly becoming the standard method of removing dissolved salts from water. By separating two bodies of water which have different salt concentrations with a semi-permeable membrane, water will flow from the less concentrated side to the more concentrated



FLOW DIAGRAM
SURFACE WATER PLANT

FIGURE 3-3



SCHEMATIC SITE PLAN OF SURFACE WATER PLANT

FIGURE 3-4

side to achieve equilibrium. The flow can be reversed by applying a pressure, greater than the osmotic pressure of the more concentrated water, to the more concentrated side. Using this principle the salt concentration in a water can be lowered by passing it under pressure through a semi-permeable membrane.

Figure 3-5 is a flow diagram of a plant which accomplishes this process. The raw water is first passed through cartridge filters to remove most of the suspended solids which would have a tendency to foul the RO membranes. After filtration an anti-scalant is added to the water to prevent the precipitation of compounds present in the water. This precipitation is encouraged by the higher concentrations which occur on the upstream side of the RO membrane and the anti-scalant prevents the precipitation from forming. The water pressure is then increased in the high pressure pumps before it enters the RO unit.

There are two outlets from the RO unit, the desalted product water continues through the rest of the treatment process while the concentrate water, or brine, is disposed of. This brine will be blended with water from the Indian River and then disposed of through an outfall structure in the river itself.

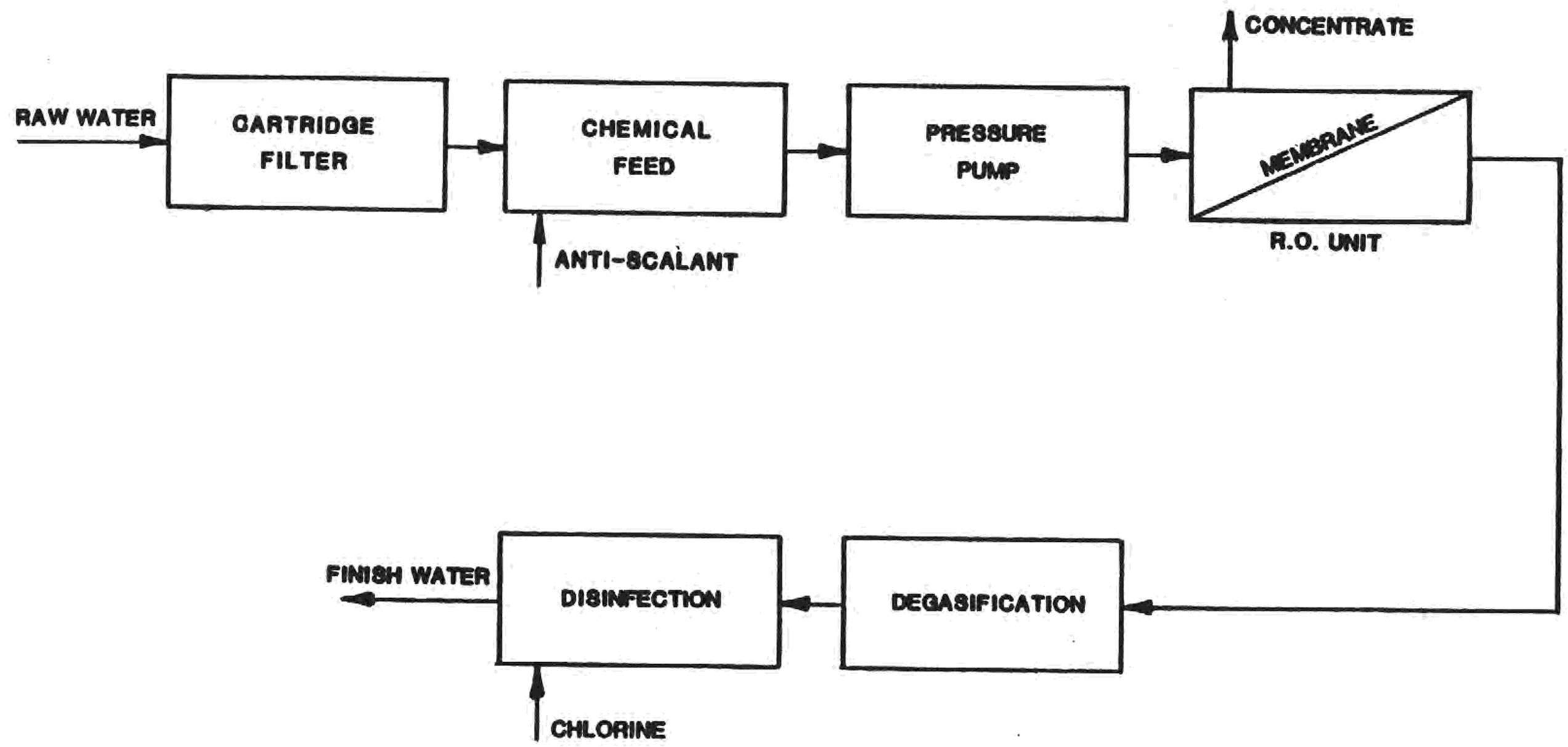
The product water is then stabilized with caustic soda to the proper pH and alkalinity. It is then passed through degasifiers to remove carbon dioxide, hydrogen sulfide and other dissolved gases. Now the water is ready for disinfection with chlorine and for the distribution system or storage tank.

For this report, the RO plant is assumed to achieve a 75% recovery rate and operate at a pressure of 200 psi. These values should be a little conservative and may be exceeded by an operational plant using supply water with the same characteristics.

A schematic plan of the RO treatment plant is shown in Figure 3-6. The raw water enters from the well field and is passed through the cartridge filters. After preliminary filtration the anti-scalant is added and the pressure increased by the high pressure pumps. The water is then ready to be passed through the RO membrane itself. The RO trains are modular in design, permitting great flexibility in designing for future expansions in plant capacity. The product water is then collected and stabilized before going through the degasifiers.

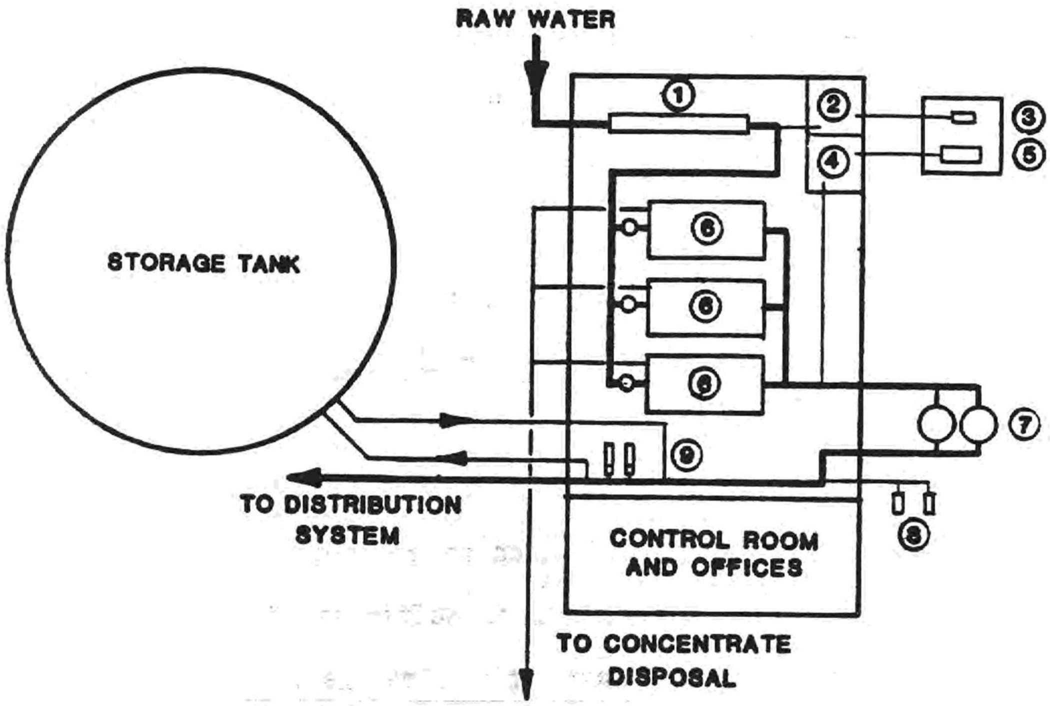
The concentrate water will be piped across AIA to be blended with Indian River water. After blending, the solution will be discharged into the Indian River through an outfall system.

The product water is then disinfected with chlorine and pumped to the distribution system or the storage tank. All of the controls for the different processes are located at the front of the building in the control room and offices.



FLOW DIAGRAM
REVERSE OSMOSIS PLANT

FIGURE 3-5



LEGEND

1. CARTRIDGE FILTERS
2. ANTI-SCALANT INJECTION ROOM
3. ANTI-SCALANT BULK STORAGE
4. CAUSTIC SODA INJECTION ROOM
5. CAUSTIC SODA BULK STORAGE
6. REVERSE OSMOSIS TRAINS
7. DEGASIFIERS
8. CHLORINE INJECTION SYSTEM AND STORAGE
9. HIGH SERVICE PUMPS

SCHEMATIC SITE PLAN
OF
REVERSE OSMOSIS PLANT

FIGURE 3-6

4.0 COST ESTIMATES

4.1 Capital Cost Estimates for the Lime Softening Plant

A capital cost estimate for the lime softening plant was obtained by contacting industry suppliers for current prices of the various components in the treatment plant. The land costs were estimated and kept constant for the various treatment plant alternatives. A breakdown of the capital costs for the lime softening plant is provided by Table 4-1.

4.2 O&M Cost Estimates for the Lime Softening Plant

Operations and maintenance costs for the lime softening plant were taken directly from the 1984 fiscal year records for the existing Martin County Water Treatment Plant. The existing plant operated at an average production rate of 1.3 MGD. The County estimates that the same number of personnel could operate the plant if it's production were upped to 2.5 MGD so the salary and benefits cost for a 2.5 MGD lime softening plant will remain the same. The cost of chemicals and utilities will increase proportionally with an increase in production therefore the values of these figures are increased by a factor of 2.5/1.3, or 1.92. Table 4.2 provides a breakdown of the O&M cost estimates for the lime softening plant.

Capital recovery costs can be included in the yearly operation and maintenance costs to determine the overall costs to produce each gallon of water. Assuming a 30 year life expectancy and a 10% interest rate on the amortized capital costs, a capital recovery factor of 0.10608 will be used. Land costs, since land retains its value, will not be included in the capital recovery calculations. The capital cost estimate, minus land costs, is $3,185,000. Using the capital recovery factor of 0.10608, the capital recovery cost will be $337,865.

TABLE 4-1

LIME SOFTENING TREATMENT PLANT

CAPITAL COST ESTIMATE

1) WATER SUPPLY

A) Eight wells, 150' deep
B) Pumps, motors, controls
C) Electrical service
D) Well field piping

TOTAL	$ 550,000

2) LAND COST FOR WELLS

A) Eight sites at $10,000

TOTAL	$ 80,000

3) WATER TREATMENT PLANT

A) Operations Building
B) Lime storage and feed system
C) Chlorine storage and feed system
D) Filter structure and equipment
E) Softening unit
F) Transfer and filter backwash pumps
G) Washwater recovery system
H) Sludge disposal system
I) Piping
J) Emergency generator
K) Electrical system
L) Sitework
M) Aeration system

TOTAL	$2,325,000

4) GROUND STORAGE TANK

A) 300,000 gallon tank

TOTAL	$ 150,000

TABLE 4-1 (Continued)

LIME SOFTENING TREATMENT PLANT

CAPITAL COST ESTIMATE

5) HIGH SERVICE PUMPING EQUIPMENT

A) 3 - 1,200 GPM and 1 - 500 GPM Pumps

	TOTAL	$ 80,000

6) LAND COST FOR TREATMENT PLANT

A) 10 acres at $25,000/acre

	TOTAL	$ 250,000
	TOTAL CAPITAL COST	$3,435,000

TABLE 4-2

LIME SOFTENING TREATMENT PLANT

O&M COST ESTIMATE

		1.3 MGD	2.5 MGD
1)	Salaries and Benefits	$123,767	$123,767
2)	Chemicals	46,800	89,856
3)	Utilities	75,000	144,000
4)	Office supplies, replacement and miscellaneous	46,164	88,635
5)	Capital Recovery Cost		337,865
	TOTAL O&M COSTS =		$784,123

The O&M costs for a 2.5 MGD lime softening plant total $784,123 per year. To calculate a cost per 1000 gallons of water produced, this number is divided by the total number of gallons produced each year:

$$\text{Cost/1000 Gallons} = \frac{\$784,123}{912,500\ \text{KGAL}} = \$0.86/\text{KGAL}$$

4.3 Capital Cost Estimates for the Surface Water Plant

The capital cost estimate for the surface water plant was obtained from the same sources as the cost estimate for the lime softening plant. Table 4-3 shows a breakdown of the capital costs for the components of the surface water plant.

4.4 O&M Cost Estimate for the Surface Water Plant

Operations and maintenance costs for the surface water plant will be greater than those for the surficial aquifer plant. Approximately two additional operating personnel will be required to run the extra processes, such as the coagulation unit and the sludge dewatering system. Table 4-4 gives a breakdown of the O&M costs for the surface water treatment plant.

The O&M cost estimates for this plant are based on the O&M costs for the lime softening plant plus the additional chemical, replacement and capital recovery costs required by the additional process.

The capital recovery costs are included in Table 4-4, and are estimated with the same capital recovery factor (0.10608) as the lime softening plant. The capital cost of the treatment plant, minus the land cost, is $3,395,000. this gives a capital recovery cost of $360,142 per year.

TABLE 4-3

SURFACE WATER TREATMENT PLANT

CAPITAL COST ESTIMATE

1) WATER SUPPLY

A) Intake Structure
B) Suction Piping
C) Pumps

TOTAL $ 65,000

2) WATER TREATMENT PLANT

A) Operations Building
B) Aeration System
C) Alum Storage and Feed System
D) Clarifying Unit
E) Sludge Disposal System
F) Lime Storage and Feed System
G) Softening Unit
H) Transfer and Filter Backwash Pumps
I) Filter Structure and Equipment
J) Chlorine Storage and Feed System
K) Piping
L) Electrical System
M) Emergency Generator
N) Sludge Dewatering System
O) Sitework

TOTAL $3,100,000

3) GROUND STORAGE TANK

A) 300,000 Gallon Tank

TOTAL $ 150,000

4) HIGH SERVICE PUMPING EQUIPMENT

A) 3-1200 GPM and 1-500 GPM Pumps

TOTAL $ 80,000

5) LAND COST FOR TREATMENT PLANT

A) 10 Acres @ $25,000/Acre

TOTAL $ 250,000

TOTAL CAPITAL COSTS $3,645,000

TABLE 4-4

SURFACE WATER TREATMENT PLANT

O&M COST ESTIMATE

		2.5 MGD
1)	Salaries and Benefits	$173,275
2)	Chemicals	$130,300
3)	Utilities	$140,000
4)	Office Supplies, Replacement and Misc.	$130,000
5)	Capital Recovery Cost	$360,142
	TOTAL O&M COSTS	$933,717

The O&M costs for the surface water treatment plant total $933,717 per year. The cost per 1000 gallons produced will be:

$$\text{Cost/1000 Gallons} = \frac{\$933,717}{912,500\ \text{KGAL}} = \$1.02/\text{KGAL}$$

4.5 Capital Cost Estimates for the Reverse Osmosis Plant

The capital cost estimate for the RO plant is shown in Table 4-5. The component costs were obtained from industry suppliers in this rapidly developing field. With the technology for this process progressing so rapidly, the component costs are being reduced continuously. This makes the RO process more appealing as a choice of water treatment in the future.

4.6 O&M Cost Estimate for the Reverse Osmosis Plant

Operating and maintenance costs for the RO plant were developed using equipment replacement cost estimates provided by the suppliers, personnel requirements estimated from operating plants and utility costs from equipment energy requirements.

Approximately five operating personnel will be required to operate a RO plant of this size. The costs for salaries and benefits, and for all other O&M costs, appears in Table 4-6.

Caustic soda, anti-scalant and chlorine are the major chemicals used in the reverse osmosis treatment process. An estimate of their costs is included in this section.

Caustic soda (NaOH) is added to the product water to raise the pH, resulting in better corrosion control and water stability. An estimated dosage of 5 mg/1 of 50% NaOH will be required for this water. The cost for caustic soda is estimated by:

$$\text{NaOH Cost} = 5\ \text{mg/1} \times 2.5\ \text{MGD} \times 8.34\ \text{lb./Gal.} \times \$0.11/\text{lb.} \times \frac{365\ \text{Day}}{\text{Year}} = \$4{,}186$$

The anti-scalant cost can be estimated in a similar manner. Since the anti-scalant is added upstream of the RO membrane, it will be in solution with 2.5 MGD/75%, or 3.33 MGD, of water.

$$\text{Anti-scalant cost} = 2.5\ \text{mg/1} \times 3.33\ \text{MGD} \times 8.34\ \text{lb./Gal.} \times \$1.08/\text{lb.} \times \frac{365\ \text{Day}}{\text{Year}} = \$27{,}400$$

Due to the effective removal of organics, very little chlorine is required to disinfect water which has been treated by a RO plant. The estimated cost, based on a dosage of 1.0 mg/1, will be:

$$\text{Chlorine Cost} = 1.0\ \text{mg/1} \times 2.5\ \text{MGD} \times 8.34\ \text{lb./Gal.} \times \$0.11/\text{lb.} \times \frac{365\ \text{Days}}{\text{Year}} = \$837$$

Since the RO membranes have a useful life of approximately five years, money should be set aside to replace them. Each element in the RO train will treat about 12000 gallons per day and costs $2,600 per element. From these values, a replacement cost can be estimated:

$$\text{Membrane Cost} = \$2600 \times \frac{2.5\ \text{MGD}}{12\ \text{KGD}} \times \frac{1}{5\ \text{Year}} \times \frac{10^3\ \text{KGD}}{1\ \text{MGD}} = \$108{,}333$$

The cartridge filters used to remove the larger particles present in the water need to be replaced on a regular basis. Assuming a total of four

TABLE 4-5

REVERSE OSMOSIS TREATMENT PLANT

CAPITAL COST ESTIMATE

1) WATER SUPPLY

A) (5) 500 GPM Wells, 900' deep
B) Pumps, Motors, Controls
C) Electrical Service
D) Well Field Piping

TOTAL $ 550,000

2) LAND COST FOR WELLS

A) 5 Sites @ $10,000

TOTAL $ 50,000

3) WATER TREATMENT PLANT

A) Operations Building
B) Chemical Storage and Feed
C) Cartridge Filters
D) Pressure Pumps
E) Membrane Units
F) Degassification System
G) pH Stabilization
H) Chlorine Storage and Feed System
I) Piping
J) Electrical System
K) Emergency Generator
L) Sitework

TOTAL $2,620,000

4) GROUND STORAGE TANK

A) 300,000 Gallon Tank

TOTAL $ 150,000

5) HIGH SERVICE PUMPING EQUIPMENT

A) 3-1,200 GPM and 1-500 GPM Pumps

TOTAL $ 80,000

TABLE 4-5 (Continued

REVERSE OSMOSIS TREATMENT PLANT

CAPITAL COST ESTIMATE

6) LAND COST FOR TREATMENT PLANT

A) 2 Acres @ $25,000/Acre

TOTAL	$	50,000

7) CONCENTRATE DISPOSAL SYSTEM

A) Piping
B) Effluent Mixing Pump
C) Outfall Piping

TOTAL	$	65,000
TOTAL CAPITAL COST =		$3,565,000

TABLE 4-6

RO WATER TREATMENT PLANT

O&M COST ESTIMATE

		2.5 MGD
1)	SALARIES AND BENEFITS	$123,000
2)	CHEMICALS	$ 32,423
3)	UTILITIES	$190,000
4)	MEMBRANE REPLACEMENT	$108,333
5)	CARTRIDGE FILTER REPLACEMENT	$ 3,436
6)	OFFICE SUPPLIES, REPLACEMENT AND MISC.	$ 16,000
7)	CAPITAL RECOVERY COST	$371,280
	TOTAL O&M COSTS =	$844,472

complete change-outs a year, at an average flow rate of 3.5 GPM per equivalent 10-inch length of filter, the cost for filter replacement is:

$$\text{Filter Cost} = \frac{3.33 \text{ MGD}}{1440 \text{ Min/Day}} \times 4 \text{ Replacements/Yr.} \times \frac{1}{3.65 \text{ GPM}} \times$$

$$\$1.30/\text{Cartridge} = \$3,436$$

Capital recovery costs for this plant are estimated using the same parameters as for the other plants. The capital cost, minus the land costs, equals $3,500,000 and a capital recovery factor of 0.10608 result in a capital recovery cost kof $371,280.

The O&M costs for the reverse osmosis treatment plant total $844,472 per year. The cost per 100 gallons of product water will be:

$$\text{Cost/1000 Gallons} = \frac{\$844,472}{912,500 \text{ KGAL}} = \$0.92/\text{KGAL}$$

REFERENCES

1) Data furnished by G.H. Dacy Associates, Inc. 1985.

2) Water Master Plan Phase I September 1984, William M. Bishop Consulting Engineers, Inc.

3) Water Quality & Treatment, Third Edition, The American Water Works Association, Inc.

4) Data furnished by Basic Technologies, Inc. 1985.

APPENDIX A

WATER QUALITY ANALYSES

FOR SURFICIAL WELLS

Date	Wells	Ph	M ALK	Total Hardness	Ca Hardness	Mg Hardness	Fe	Color	Cl
May 23, 1985	1	7.5	212	218			0	20	40
	2	7.0	278	274	260	14	.1	20	48
	3	7.1	270	276	276	0	.11	25	56
	4	7.4	230	216	216	0	.1	20	40
	5	7.4	196	192	176	16	.18	40	38
	6	7.3	212	212	208	4	.11	25	40
	7	7.3	242	250	246	4	.15	20	50
	8	7.2	270	280	270	10	.13	40	65
une 01, 1985	1	7.3	226	220	200	20	.38	20	39
	2	7.4	240	248	232	16	.17	17	33
	3	7.1	268	260	252	8	.24	22	49
	4	7.2	222	204	190	14	.11	23	51
	5	7.3	218	196	190	6	.45	25	50
	6	7.3	216	220	210	10	.16	25	36
	7	7.5	288	306	280	26	.14	17	48
	8	7.2	300	298	268	30	.14	25	53
uly 17, 1985	1	7.2	222	220	212	8	.29	20	44
	2	7.4	248	256	240	16	.17	20	49
	3	7.3	274	280	270	10	.15	17	51
	4	7.4	206	214	200	14	.18	20	48
	5	7.4	212	228	224	4	.21	22	51
	6	7.4	200	210	200	10	.15	17	53
	7	7.2	284	284	268	18	.19	20	45
	8	7.1	288	298	260	38	.13	17	50
st 14, 1985	1	7.3	200	220	200	20	.20	25	40
	2	7.1	260	280	270	10	.20	20	55
	3	7.1	264	280	262	18	.17	20	60
	4	7.4	220	250	230	20	.15	25	50
	5	7.4	220	248	238	10	.25	25	48
	6	7.3	210	240	230	10	.14	20	45
	7	7.4	260	280	268	12	.16	50+	48
	8	7.1	270	300	290	10	.14	20	52

APPENDIX B

GEO TEC inc. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-7280

PRFORM PRIMARY ANALYSIS REPORT

WILLIAM M BISHOP ENGINEERS, INC CLIENT NAME AND ADDRESS

732 NE COMMERCIAL ST

JENSEN BEACH, FL 33457

12710 SAMPLE NUMBER

9-10-84 1145 PJ 9-10 1600 DATE/TIME COLLECTED /BY

ST LUCIE CANAL LOCATION

PARAMETER	STORET NO.	DATE	BY	NBR	RESULT, mg/L
ARSENIC	01002	9-27	MD	35-435	0.006
BARIUM	01007	10-5	MD	57-2	<0.01
CADMIUM	01027	9-12	BM	50-323	<0.0002
CHROMIUM	01034	9-25	MD	35-432	<0.002
LEAD	01051	10-16	MD	57-6	0.007
MERCURY	71900	9-29	BM	50-326	<0.0002
SELENIUM	01147	11-7	MD	57-20	0.004
SILVER	01077	9-27	MD	35-436	<0.002
FLUORIDE	00951	10-2	MD	35-437	0.284
NITRATE-N	00630	9-17	DB	49-356	0.26
TURBIDITY (NTU)	00076	9-11	LC	43-67	3.5

DATE 11-15-84 BY [signature]

ID 06122

GEO TEC inc. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-7280

SFORM SECONDARY ANALYSIS REPORT

WILLIAM M BISHOP ENGINEERS INC CLIENT NAME AND ADDRESS

732 NE COMMERCIAL ST

JENSEN BEACH, FL 33457

12710 SAMPLE NUMBER

9-10-84 1145 PJ 9-10 1600 DATE TIME COLLECTED BY; RECEIVED

ST LUCIE CANAL LOCATION

PARAMETER	STORET NO.	DATE BY NBR	RESULT mg/L
ALKALINITY	00410	9-11 LC 43-86	105.6
CALCIUM	00916	9-18 BM 50-324	50
CHLORIDE	00940	9-18 DB 49-357	71
COLOR	00081	9-11 LC 43-67	70 PCU
COPPER	01042	9-20 BM 50-325	<0.002
CORROSIVITY			-0.83
FOAMING AGENTS	38260	9-11 MR 47-318	0.083
HYDROGEN SULFIDE	00745	9-10 BM 50-326	0.11
IRON	01045	10-3 MD 57-2	0.073
MAGNESIUM	00927	9-18 BM 50-324	9.8
MANGANESE	01055	10-5 MD 57-2	0.006
ODOR	00085	9-11 LC 43-67	1
pH	00400	9-10 PJ 51-95	6.9
SODIUM	00929	9-27 BM 50-325	41
SULFATE	00945	9-16 MR 47-324	44
FILTERABLE RESIDUE	70300	9-17 LC 43-87	362
TOTAL HARDNESS	00900		165
ZINC	01092	10-5 MD 57-2	<0.01

DATE 10-5-84 BY [signature]

LAB ID 86122

GEO TEC

EVERGLADES LABORATORIES, INC. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-4200

M610

POLYNUCLEAR AROMATIC HYDROCARBONS METHOD 610

WILLIAM M BISHOP ENGINEERS	CLIENT NAME AND ADDRESS
732 NE COMMERCIAL ST	
JENSEN BEACH, FL 33457	
12710	SAMPLE NUMBER
9-10-84 1145 PJ 9-10 1600	DATE/TIME COLLECTED BY
ST LUCIE CANAL	LOCATION

PARAMETER	STORET NO.	RESULT ug/L
NAPHTHALENE	34696	<1
ACENAPHTHYLENE	34200	<1
ACENAPHTHENE	34205	<1
FLUORENE	34381	<1
PHENANTHRENE	34461	<1
ANTHRACENE	34220	<1
FLUORANTHENE	34376	<1
PYRENE	34469	<1
BENZO(a)ANTHRACENE	34526	<2
CHRYSENE	34320	<2
BENZO(b)FLUORANTHENE	34230	<2
BENZO(k)FLUORANTHENE	34242	<2
BENZO(a)PYRENE	34247	<2
INDENO(1,2,3,c,d)PYRENE	34403	<1
DIBENZO(a,h)ANTHRACENE	34556	<2
BENZO(g,h,i)PERYLENE	34521	<2

DATE 10-15-84 BY [signature]

LAB ID 8610[illegible]
EL

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M608

PESTICIDES AND PCB — METHOD 608

WILLIAM M BISHOP ENGINEERS	CLIENT NAME AND ADDRESS
732 NE COMMERCIAL ST	
JENSEN BEACH, FL 33457	
12710	SAMPLE NUMBER
9-10-84 1145 PJ 9-10 1600	DATE/TIME COLLECTED BY
ST LUCIE CANAL	LOCATION

PARAMETER	RESULT ug/L	PARAMETER	RESULT ug/L
ALDRIN	<0.005	ENDRIN	<0.01
a-BHC	<0.025	ENDRIN ALDEHYDE	<0.064
b-BHC	<0.015	HEPTACHLOR	<0.005
d-BHC	<0.003	HEPTACHLOR EPOXIDE	<0.07
g-BHC	<0.002	TOXAPHENE	<1
CHLORDANE	<0.03	PCB-1016	<0.2
4,4'-DDD	<0.2	PCB-1221	<0.2
4,4'-DDE	<0.09	PCB-1232	<0.2
4,4'-DDT	<0.2	PCB-1242	<1
DIELDRIN	<0.006	PCB-1248	<1
ENDOSULFAN I	<0.01	PCB-1254	<1
ENDOSULFAN II	<0.008	PCB-1260	<1
ENDOSULFAN SO4	<0.09		

FED.REGISTER VOL 44 NO 233 DECEMBER 3, 1979

DATE 10-15-84 BY [signature]

LAB ID 84109

EVERGLADES LABORATORIES, INC. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-4200

PHENOLS — METHOD 604

WILLIAM M BISHOP ENGINEERS	CLIENT NAME AND ADDRESS
732 NE COMMERCIAL ST	
JENSEN BEACH, FL 33457	
12710	SAMPLE NUMBER
9-10-84 1145 PJ 9-10 1600	DATE/TIME COLLECTED BY
ST LUCIE CANAL	LOCATION

PARAMETER	STORET #	FOUND, microgram/L
2-CHLOROPHENOL	34586	<1
2-NITROPHENOL	34591	<1
PHENOL	34694	<1
2,4-DIMETHYLPHENOL	34606	<1
2,4-DICHLOROPHENOL	34601	<1
2,4,6-TRICHLOROPHENOL	34621	<10
4-CHLORO-3-METHYLPHENOL	34452	<10
2,4-DINITROPHENOL	34616	<50
2,-METHYL-4,6-DINITROPHENOL	34657	<50
PENTACHLOROPHENOL	39094	<50
4-NITROPHENOL	34646	<10

FED.REGISTER VOL 44 NO 233 DECEMBER 3, 1979
FID, SP-1240 DA COLUMN

DATE 9-30-84 BY [signature]

LAB ID 8610

EVERGLADES LABORATORIES, INC. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-4200

OFORM PRIMARY ORGANICS

WILLIAM M BISHOP ENGINEERS INC	CLIENT NAME AND ADDRESS
732 NE COMMERCIAL ST	
JENSEN BEACH, FL 33457	
12710	SAMPLE NUMBER
9-10-84 1145 PJ 9-10 1600	DATE/TIME COLLECTED BY
ST LUCIE CANAL	LOCATION

PARAMETER	STORET NO.	FOUND, mg/L
ENDRIN	39390	<0.00001
LINDANE	39782	<0.000002
METHOXYCHLOR	39480	<0.00007
TOXAPHENE	39400	<0.001
2,4-D		<0.001
2,4,5-TP	39760	<0.0001

METHOD FOR ORGANOCHLORINE PESTICIDES IN INDUSTRIAL EFFLUENTS. EPA 1973
METHOD FOR CHLORINATED PHENOXY ACID HERBICIDES IN INDUSTRIAL EFFLUENTS, EPA 1973

DATE 9-26-84 BY [signature] LAB ID 86109

EVERGLADES LABORATORIES, INC. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-4200

M601

PURGEABLE HALOCARBONS — METHOD 601

WILLIAM M BISHOP ENGINEERS	CLIENT NAME AND ADDRESS
732 N E COMMERCIAL ST	
JENSEN BEACH, FL 33457	
12710	SAMPLE NUMBER
9-10-84 1145 PJ 9-10 1600	DATE/TIME COLLECTED BY RECD
ST LUCIE CANAL	

PARAMETER	STORET NO.	MCL ug/L	RESULT ug/L
BROMODICHLOROMETHANE	32101	*	<2
BROMOFORM	32104	*	<4
BROMOMETHANE	34413		<4
CARBON TETRACHLORIDE	32102	3	<1
CHLOROBENZENE	34301		<2
CHLOROETHANE	34311		<4
2-CHLOROETHYLVINYL ETHER	34576		<4
CHLOROFORM	32106	*	<1
CHLOROMETHANE	34418		<4
DIBROMOCHLOROMETHANE	32105	*	<2
1,2-DICHLOROBENZENE	34536		<4
1,3-DICHLOROBENZENE	34566		<4
1,4-DICHLOROBENZENE	34571		<4
DICHLORODIFLUOROMETHANE	34668		<4
1,1-DICHLOROETHANE	34496		<2
1,2-DICHLOROETHANE	34531	3	<1
1,1-DICHLOROETHENE	34501		<1
1,2-DICHLOROETHENE	34546		<2
1,2-DICHLOROPROPANE	34541		<2
cis-1,3-DICHLOROPROPENE	34704		<2
trans-1,3-DICHLOROPROPENE	34699		<2
METHYLENE CHLORIDE	34423		<2
1,1,2,2-TETRACHLOROETHANE	34516		<2
TETRACHLOROETHENE	34475	3	<2
1,1,1-TRICHLOROETHANE	34506	200	<2
1,1,2-TRICHLOROETHANE	34511		<2
TRICHLOROETHENE	39180	3	<1
TRICHLORFLUOROMETHANE	34488		<2
VINYL CHLORIDE	39175	1	<1

MCL FOR SUM OF STARRED COMPOUNDS IS 100 ug/L

DATE 9-11-84 BY [signature]

LAB ID 861

GEO TEC inc. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-7280

PRFORM PRIMARY ANALYSIS REPORT

WILLIAM M BISHOP ENGINEERS, INC — CLIENT NAME AND ADDRESS

732 NE COMMERCIAL ST

JENSEN BEACH, FL 33457

13440 — SAMPLE NUMBER

10-24-84 1145 PJ 10-24 1600 — DATE/TIME COLLECTED /BY/RECD

ST LUCIE CANAL — LOCATION

PARAMETER	STORET NO.	DATE BY NBR	RESULT, mg/L
ARSENIC	01002	11-5 MD 57-18	0.020
BARIUM	01007	11-19 BM 56-344	0.10
CADMIUM	01027	11-12 MD 57-22	<0.001
CHROMIUM	01034	10-31 MD 57-14	0.005
LEAD	01051	10-25 MD 57-11	0.014
MERCURY	71900	11-16 MD 57-25	<0.0001
SELENIUM	01147	11-7 MD 57-20	0.009
SILVER	01077	11-6 MD 57-18	<0.001
FLUORIDE	00951	10-29 MD 57-12	0.273
NITRATE-N	00630	11-7 DB 49-387	0.23
TURBIDITY (NTU)	00076	10-24 MD 35-443	1.5

DATE 11-15-84 BY [signature]

ID 86122

GEO TEC inc. 1602 CLARE AVENUE • WEST PALM BEACH, FL 33401 • 305/833-7280

STORM SECONDARY ANALYSIS REPORT

WILLIAM M BISHOP ENGINEERS INC CLIENT NAME AND ADDRESS

732 NE COMMERCIAL ST

JENSEN BEACH, FL 33457

13440 SAMPLE NUMBER

10-24-84 1145 PJ 10-24 1600 DATE TIME COLLECTED BY; RECEIVED

ST LUCIE CANAL LOCATION

PARAMETER	STORET NO.	DATE BY NBR	RESULT mg/L
ALKALINITY	00410	10-25 MD 57-3	192
CALCIUM	00916	10-25 MD 57-9	61
CHLORIDE	00940	11-1 DB 47-286	106
COLOR	00081	10-24 CM 35-455	100 PCU
COPPER	01042	11-13 MD 57 24	<0.006
CORROSIVITY			-0.20
FOAMING AGENTS	38260	10-25 MR 47-331	0.10
HYDROGEN SULFIDE	00745	10-25 MD 57-36	<0.01
IRON	01045	11-13 MD 57-23	0.24
MAGNESIUM	00927	10-25 MD 57-7	7.4
MANGANESE	01055	11-13 MD 57 23	0.012
ODOR	00085	10-24 DM	1 T.O.N.
pH	00400	10-24 PJ	7.2
SODIUM	00929	11-2 MD 57 53	67
SULFATE	00945	10-26 DB 47 401	41
FILTERABLE RESIDUE	70300	10-29 CM 35-444	552
TOTAL HARDNESS	00900		171
ZINC	01092	10-26 MD 57 11	<0.1

DATE 10 5 84 BY [signature]

LAB ID 86122

GEO TEC