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HYDROLOGIC INVESTIGATION OF THE POTENTIOMETRIC HIGH CENTERED ABOUT THE CRESCENT CITY RIDGE, PUTNAM COUNTY, FLORIDA

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ABSTRACT

An investigation of the potentiometric high centered about the Crescent City Ridge in southeast Putnam County, Florida was conducted for the 1978 water year (October 1977 through September 1978). The elevation and shape of the underlying limestones, ample precipitation, and the ability of the surficial sand deposits to hold water for eventual recharge to the Floridan aquifer contribute to the formation of the potentiometric high.

The major use of ground water in the area is for irrigation of ornamental ferns and citrus. Largest withdrawals occur in winter with freeze protection application rates reaching .35 inches per hour. These withdrawals produce severe local reductions in artesian levels which occasionally render small domestic wells inoperative. Continued withdrawals by closely spaced, large capacity irrigation wells have the potential to significantly lower the potentiometric surface to induce upconing of poor quality water from deeper zones within the Floridan aquifer.

Ground water flows down gradient from the center of the potentiometric high to the east and west with discharge occurring in Crescent Lake and the St. Johns River. Potentiometric levels range from near 40 along the ridge to approximately 10 feet above mean sea level at the ridge margins. A pump test of the Floridan aquifer produced an average value of 126,000 gal/day/ft for transmissivity and 3.5×10^{-4} for the storage coefficient.

Water quality sampling showed that the Floridan aquifer contains water of excellent quality with chloride concentrations of less than 25 ppm. However, water in the Floridan aquifer near the St. Johns River was found to be of much poorer quality, indicating that the western margin of the ridge is influenced by ground water discharge from outside the area or from deeper within the aquifer.

A water balance for the area was determined for the water year (1978) which included measurements and/or estimates of precipitation (P), evapotranspiration (ET), ground water pumpage (Pu), surface water runoff (R), ground water outflow (Go), and change in storage (ΔS). The water balance equation was expressed as:

$$P = ET + Pu + \Delta S + R + Go$$

or

54 inches = 35 inches + 1 inch + 11 inches + 3 inches + 4 inches.

Total recharge to the Floridan aquifer along the Crescent City Ridge was estimated to be equal to ground water outflow (Go) plus pumpage (Pu) from the Floridan aquifer, or approximately 30 mgd.

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The authors express their sincerest appreciation to the Suwannee River Water Management District for their assistance in the analysis of water samples. Our gratitude is also extended to the many cooperative citizens of the Crescent City Ridge area who willingly opened their property to the investigators. Without their helpful attitude, it would not have been possible to achieve the objectives of this study.

INTRODUCTION

BACKGROUND

Within the Central Highlands of Florida are a number of elongated areas of higher relief capped with a veneer of fine sand. In comparing the physiographic map of northern Florida with the potentiometric map of the Floridan aquifer, it becomes evident that many of these "ridges" coincide with areas of higher potentiometric levels. Potentiometric highs can be associated with recharge to the ground water system, thereby suggesting the ridges as probable sites of resource renewal. However, other factors besides recharge may influence the maintenance of a potentiometric high such as the structure and transmissivity of the aquifer. Also, no recharge will occur as long as the potentiometric surface is near or above the water table most of the time (Knochenmus and Beard, 1971, p. 51). The various factors producing potentiometric highs in areas such as these must be examined in order to determine if an area has any significance as a regional ground water resource. In addition, effective resource planning and management cannot evolve without such knowledge.

PURPOSE AND SCOPE

The purpose of this investigation is to study in detail the potentiometric high associated with the Crescent City Ridge which occupies the extreme southeastern portion of Putnam County (Figures 1, 2, and 3). The ridge axis is oriented in a northwest-southeasterly direction and is flanked by Crescent Lake on its east and the St. Johns River and Lake George to its west. Dunns Creek lies on the northern perimeter of the ridge. Emphasis is placed on the geology and structure of the ridge, aquifer characteristics, the water budget, and water

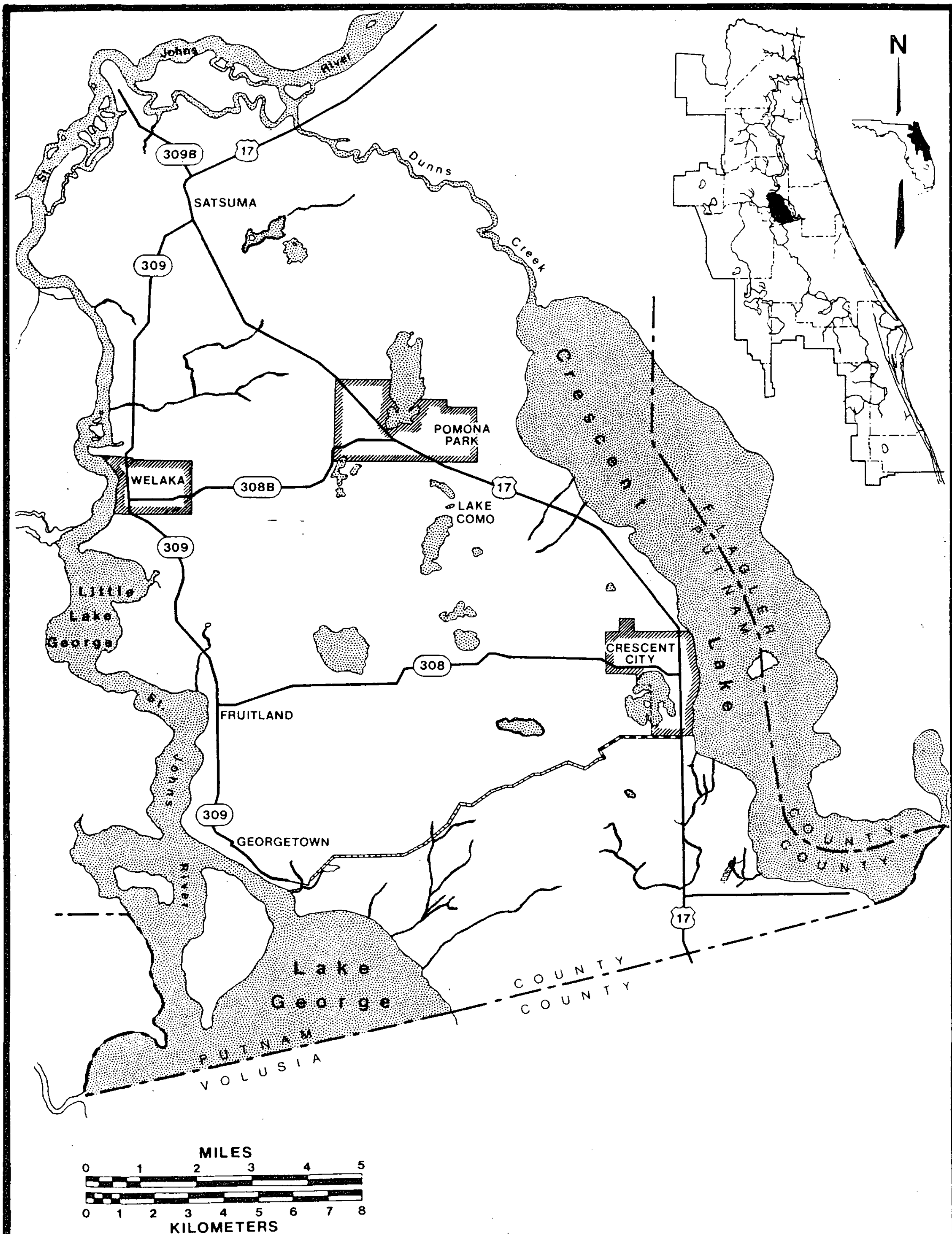


FIGURE 1. -- Map Showing the Location of Study Area

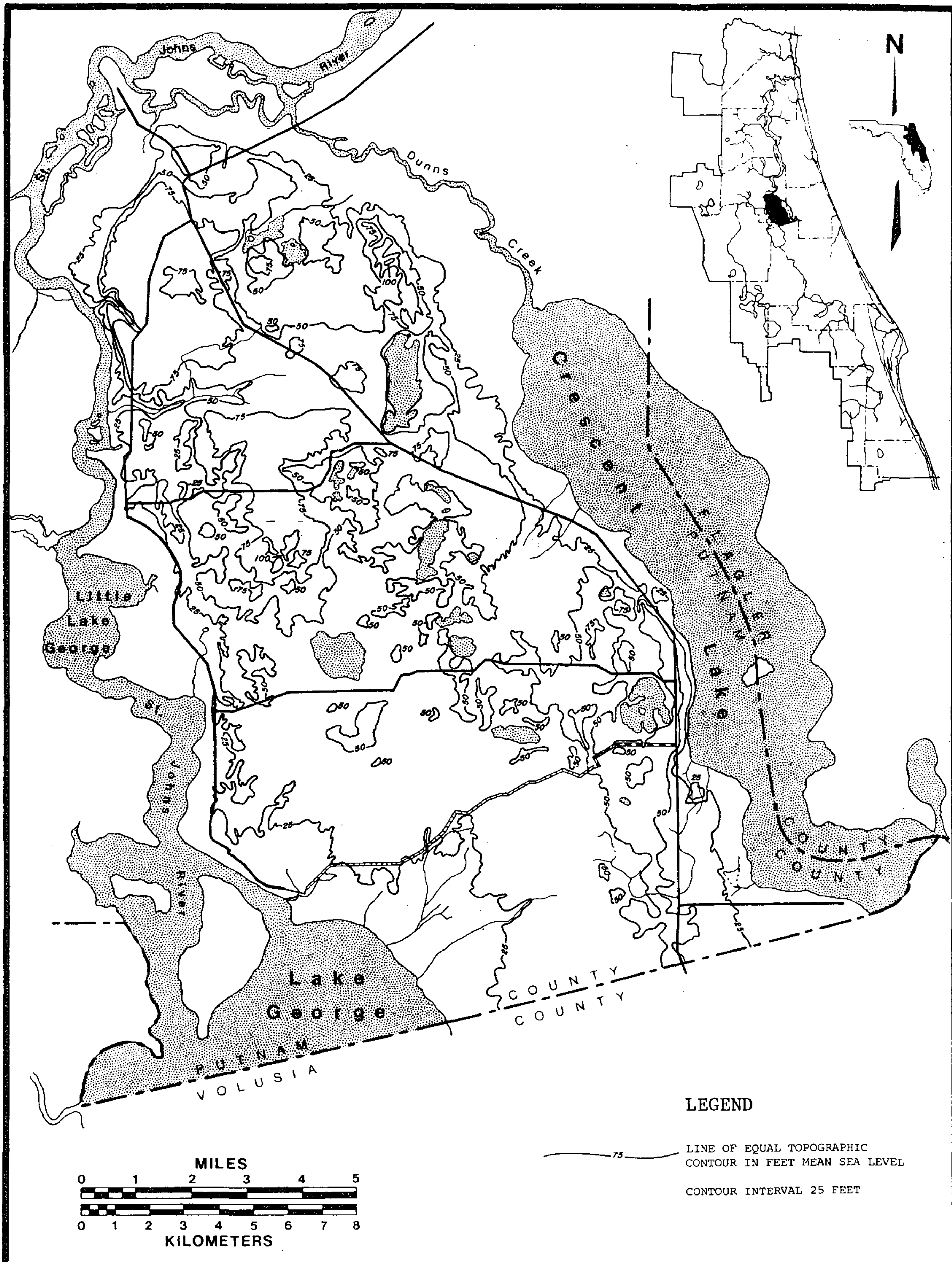


FIGURE 2. -- Topographic Map of Crescent City Ridge

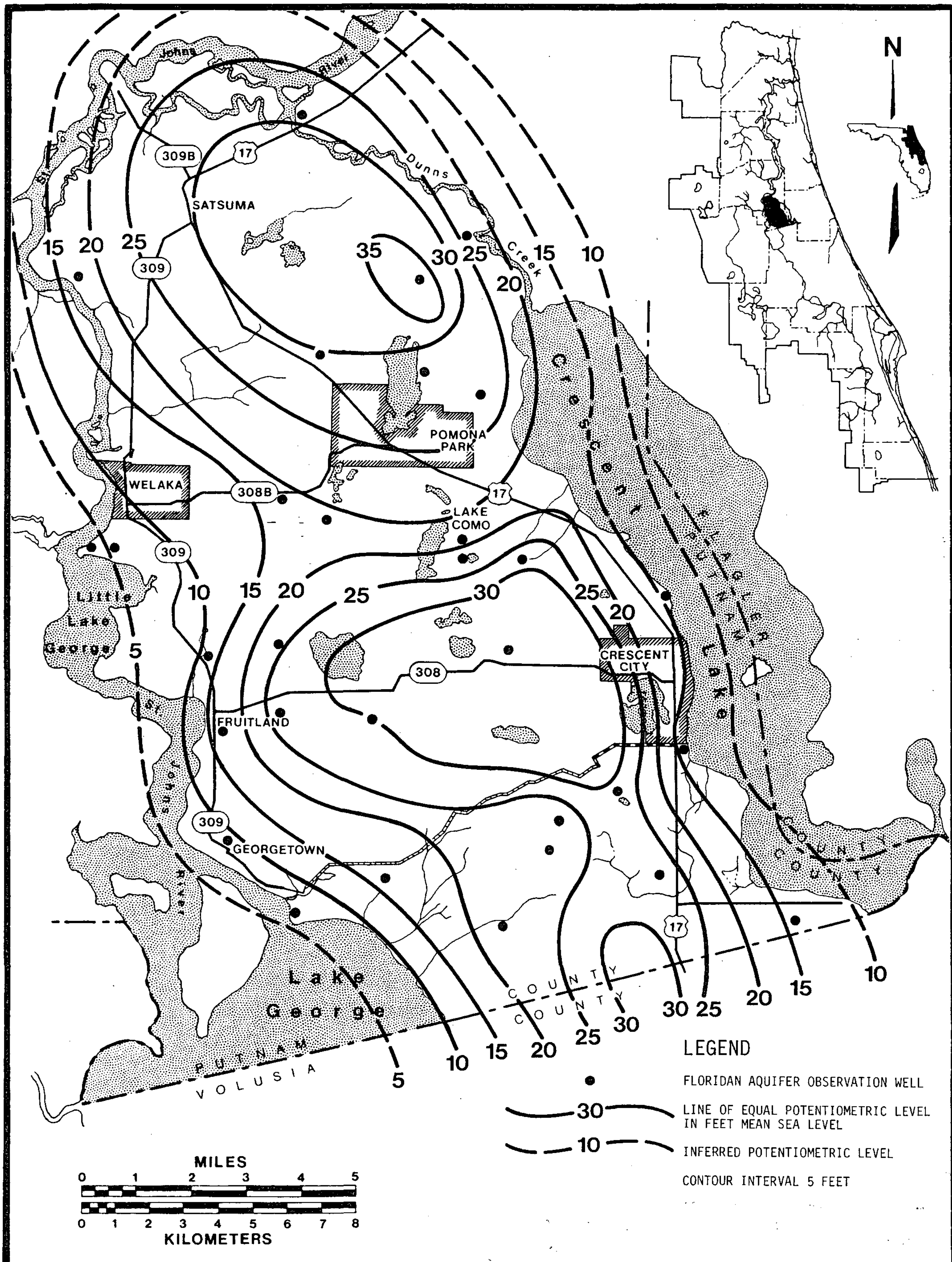


FIGURE 3. -- Map of Crescent City Ridge Showing Potentiometric Surface of Artesian Aquifer for May 1978

quality. Specific knowledge gained from the study of the Crescent City Ridge may be applied to developing a conceptual model for potentiometric highs associated with similar ridges in Central Florida. Conflicting demands for the agricultural, recreational, aesthetic, and domestic uses of water resources are beginning to surface in southeastern Putnam County. Hopefully, this investigation will be used to lead all concerned parties toward better resource management in the area.

PREVIOUS INVESTIGATIONS

A study of the geology and ground water resources of Flagler, Putnam, and St. Johns Counties was conducted by Bermes, Leve, and Tarver (1963), and a further study of the water resources and its relation to the agricultural areas of the same three counties was made by Munch, Ripy, and Johnson (1979). Although both studies cite the Crescent City Ridge as an area of potentiometric high, no detailed work was performed which delineates the quantity of recharge or the mechanism by which it occurs.

White (1958 and 1970) describes the origin and geomorphologic features of the ridges in the Central Highlands as part of his discussion of the geomorphology of the Florida peninsula. Pirkle (1971) describes the surficial sediments of the Crescent City Ridge, and Pirkle (1971) and White (1970) discuss in some detail the origin of the St. Johns River Valley offset between Lake Harney and Palatka. Adams (1976) summarizes some of the previous geologic knowledge concerning the Crescent City Ridge in his thesis about the history of Crescent Lake.

METHODS OF INVESTIGATION

Most of the data for the investigation were collected for the water year October 1, 1977 through September 30, 1978, and are divided into the realms of geologic, surface water, ground water, evaporation, and precipitation data. These data were examined in an integrated way to provide a clearer understanding of the water resources of the area.

Geologic knowledge was derived from the examination of geophysical logs, drillers' logs, drill cuttings, drill cores, and sieve analyses of surficial sediment samples. Twenty-six wells were geophysically logged by the District. Nine wells were drilled by the District's drill rig, and one of these wells was cored from 80 to 157 feet in depth. Surficial sediment samples were collected from two of the wells drilled by the District. These samples were sieved and sand size distribution curves drawn. Drillers' logs from the many private drilling firms were reviewed for lithologic descriptions.

Surface water outflow was monitored by gaging eight major streams draining the ridge, and flow rating curves were derived for two streams in which continuous gage height recorders were installed. Stage elevations were monitored semimonthly on ten lakes, and after each occurrence of rain, at five of these. One lake was monitored continuously by a water level recorder.

Water levels in the artesian aquifer system were monitored in 32 wells. Twenty-seven were monitored monthly, while the remaining five supported continuous water level recorders. Water levels in the unconfined aquifer were measured monthly in a series of six wells drilled by the District across an east-west transect roughly through the center of the ridge. One of these wells supported a continuous water level recorder. Aquifer characteristics were derived from pump test data and flow net analysis. Permeabilities for the unconfined aquifer were derived from grain size distributions for the surficial sand.

Meteorological data, including measured pan evaporation, was obtained from the Gainesville Weather Station. Values of monthly lake and pan evaporation were calculated from this data and applied to the Crescent City Ridge area. Nine rainfall stations were observed, and the average mean rainfall value for the area was calculated based on the Thiessen mean method.

Water samples were collected from 14 artesian wells, five unconfined wells, and four lakes. Samples were analyzed for calcium (Ca^{++}), sodium (Na^{+}), potassium (K^{+}), magnesium (Mg^{++}), iron (total Fe), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), sulfate (SO^{--}), carbonate (CO_3^{--}), fluoride (F^{-}), nitrate NO_3^{-}), sulfide (S^{--}), and total dissolved solids. Water quality composition ratios were plotted on a Piper diagram to determine differences in water quality between and within the aquifers and surface water bodies. The location of all wells, lakes, and rain gages used to obtain data for this study are shown in Figure 4.

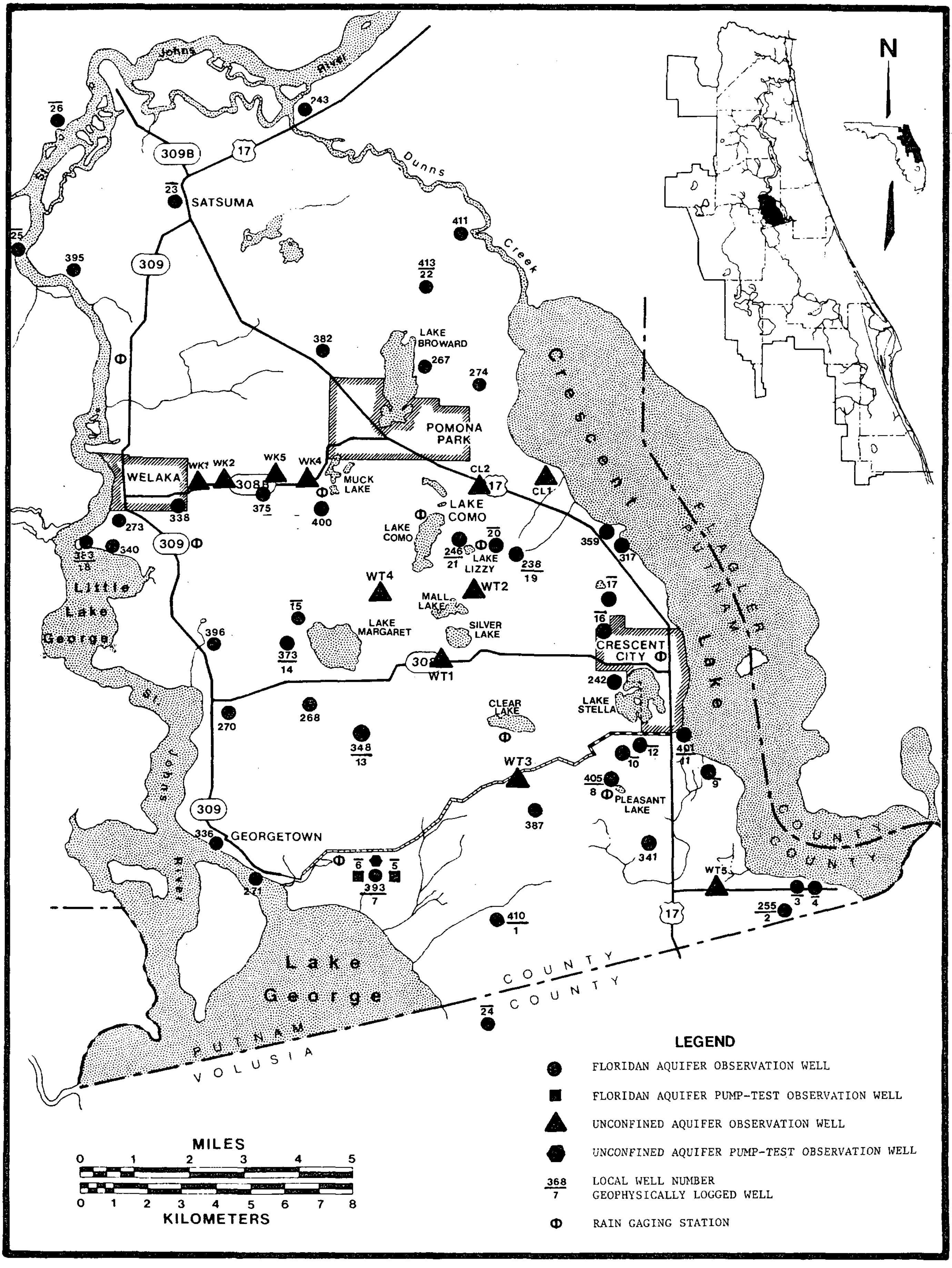


FIGURE 4. -- Map of Crescent City Ridge Showing Locations of All Wells, Lakes, and Rain Gages Used to Obtain Data

GEOGRAPHY

CLIMATE

The Crescent City Ridge lies within the transitional zone between the humid subtropical and humid temperate zones. The area is influenced by polar continental and warm, moist maritime air masses whose interactions produce a climate distinguished by low diurnal and seasonal temperature extremes, high humidity, and high rates of annual rainfall (SJRWMD, 1977, p. 15). The mean annual temperature for the years 1941-1970 at the Palatka Weather Station was 71.3° F., and the average annual precipitation at Crescent City for the same period of time was 54.67 inches.

PHYSIOGRAPHY

Total relief within the study area is approximately 115 feet. The ridge is irregular in elevation, with hills attaining maximum elevations of 120 feet above mean sea level (MSL) and swales between hills having elevations less than 30 feet MSL. Although elevations along the ridge were probably more uniform at one time, solution of the supporting limestone has developed the irregular surface which is present today (White, 1970, p. 113).

Many lakes are grouped throughout the ridge, with most occupying well drained areas of higher relief; however, a few lakes are associated with poorly drained swampy lowlands which occupy areas adjacent to hills where the water table is very close to the surface. During wet periods, swampy lowlands interconnect to allow for surface drainage of the interior portions of the ridge. At drier times, surface runoff occurs mainly at the ridge perimeter where water derived from ground water outflow is collected by streams that flow into the larger bodies of surface water bordering the ridge.

POPULATION AND INDUSTRY

The population of the Crescent City Ridge area in Putnam County is approximately 10,000, with most of the population concentrated along major waterways at the communities of Welaka, Pomona Park, Satsuma, Crescent City, Fruitland, and Georgetown.

Major industries of the area are agriculture (ferns, citrus, and potatoes), forestry, cattle raising, commercial fishing, and tourism. Agriculture, especially the production of ornamental ferns, places the greatest demand on the water resources of the area (see Water Use section).

GEOLOGIC SETTING

FORMATIONS

The sequences of hydrologically significant rock units under the Crescent City Ridge is depicted in Figure 5. The oldest rocks in the column are of Eocene age and consist of the Lake City, Avon Park, and Ocala Group Limestones. Combined, these formations, in addition to the base of the Hawthorn Formation, make up the Floridan aquifer in this area, with the Avon Park Limestone and the Ocala Group being the major fresh water producing units in the artesian aquifer. Data collected from various wells throughout the area indicate that the top of rock of the Floridan aquifer forms a mound which ranges from five feet below MSL at its top to 90 feet below MSL at its base (Figure 6).

The Hawthorn Formation of Middle Miocene age rests unconformably upon the Eocene limestones (Bermes, et al., 1963, p. 30). The Hawthorn Formation in the Crescent City Ridge area consists of hard, green clay with lenses of phosphatic clay, sands, limestones, and coquina. The phosphatic sediments, commonly used to identify the Hawthorn Formation in geophysical logs and well drillings, are thin or absent in the southern half of the ridge. Here, the Ocala Limestone is overlain by green to gray clays and clayey sands of similar appearance to the Hawthorn Formation, but containing little or no phosphate. These non-phosphatic clays were also absent in the portion of the ridge just north of Volusia County. The non-phosphatic clays may be equivalent to the Hawthorn, or they possibly are younger sediments of a different origin. However, it is the combined thickness of both the phosphatic and non-phosphatic clays which comprise the confining unit for the Floridan aquifer in the Crescent City Ridge area (Figure 7). Discontinuous coquina and limestone beds of high permeability found within the Hawthorn Formation form the secondary artesian aquifers.

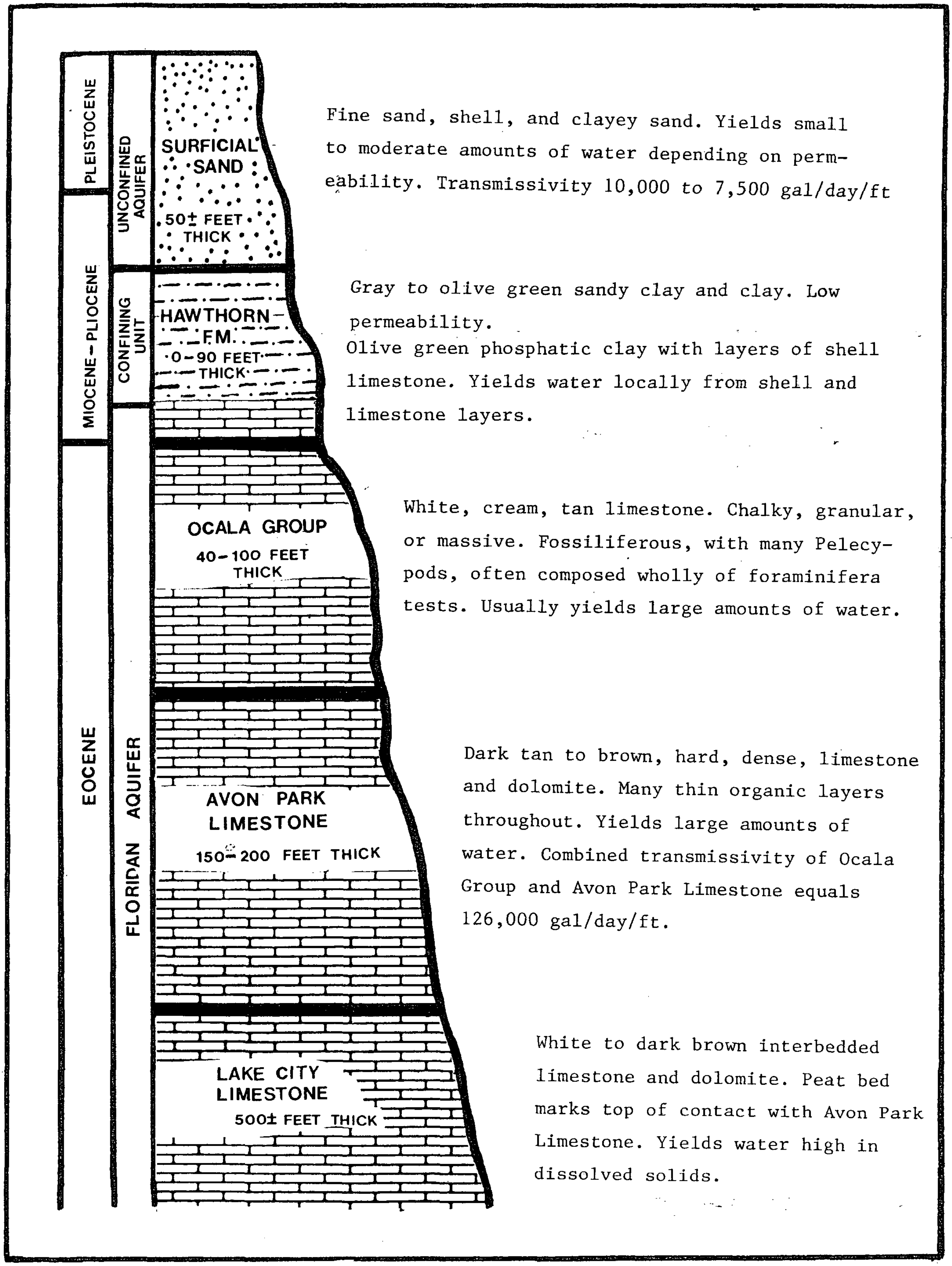


FIGURE 5. -- Idealized Geologic Section of Hydrologically Significant Rock Units Under the Crescent City Ridge

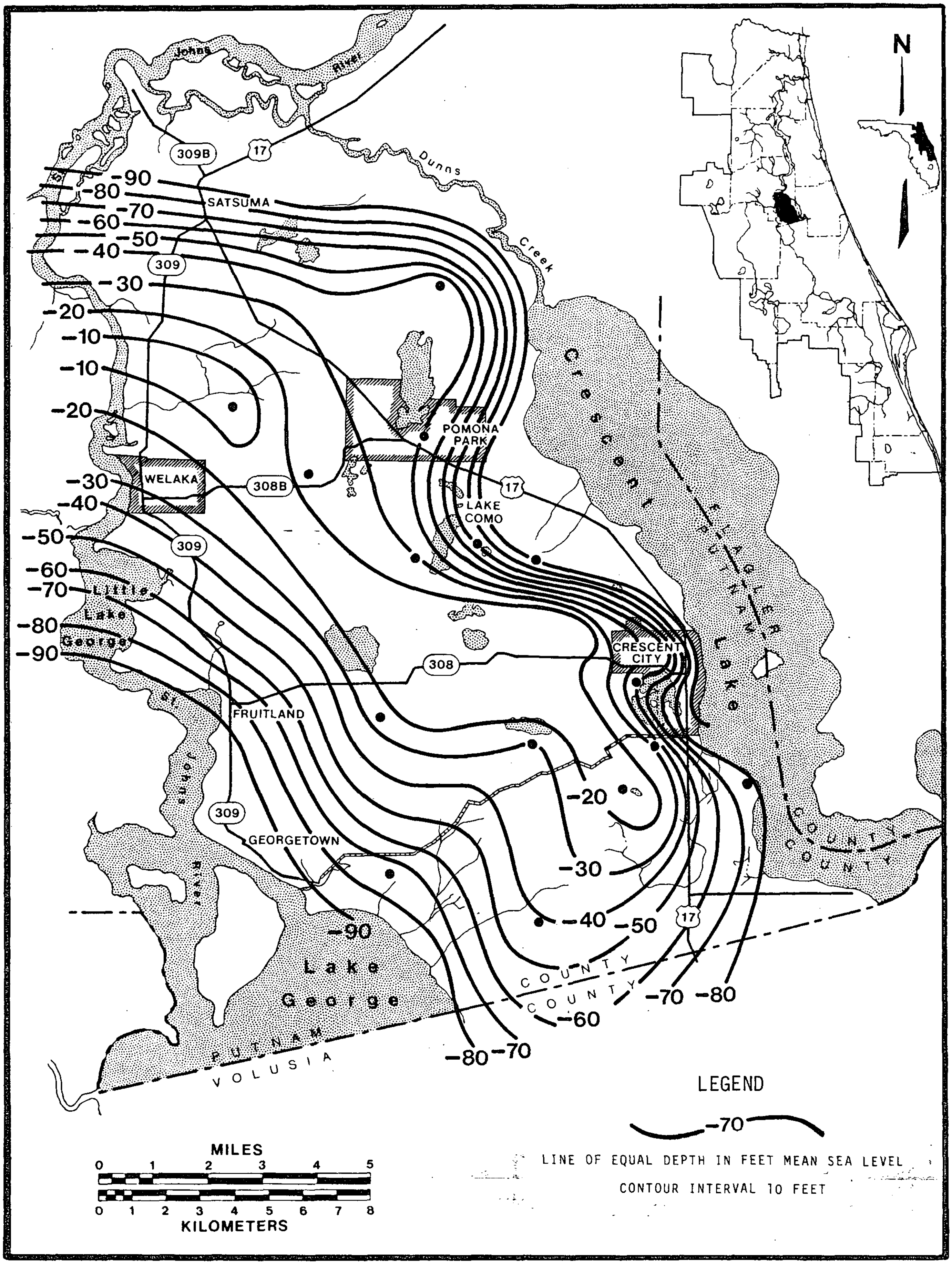


FIGURE 6. -- Map of Crescent City Ridge Showing Elevation of Top of Rock Forming the Floridan Aquifer

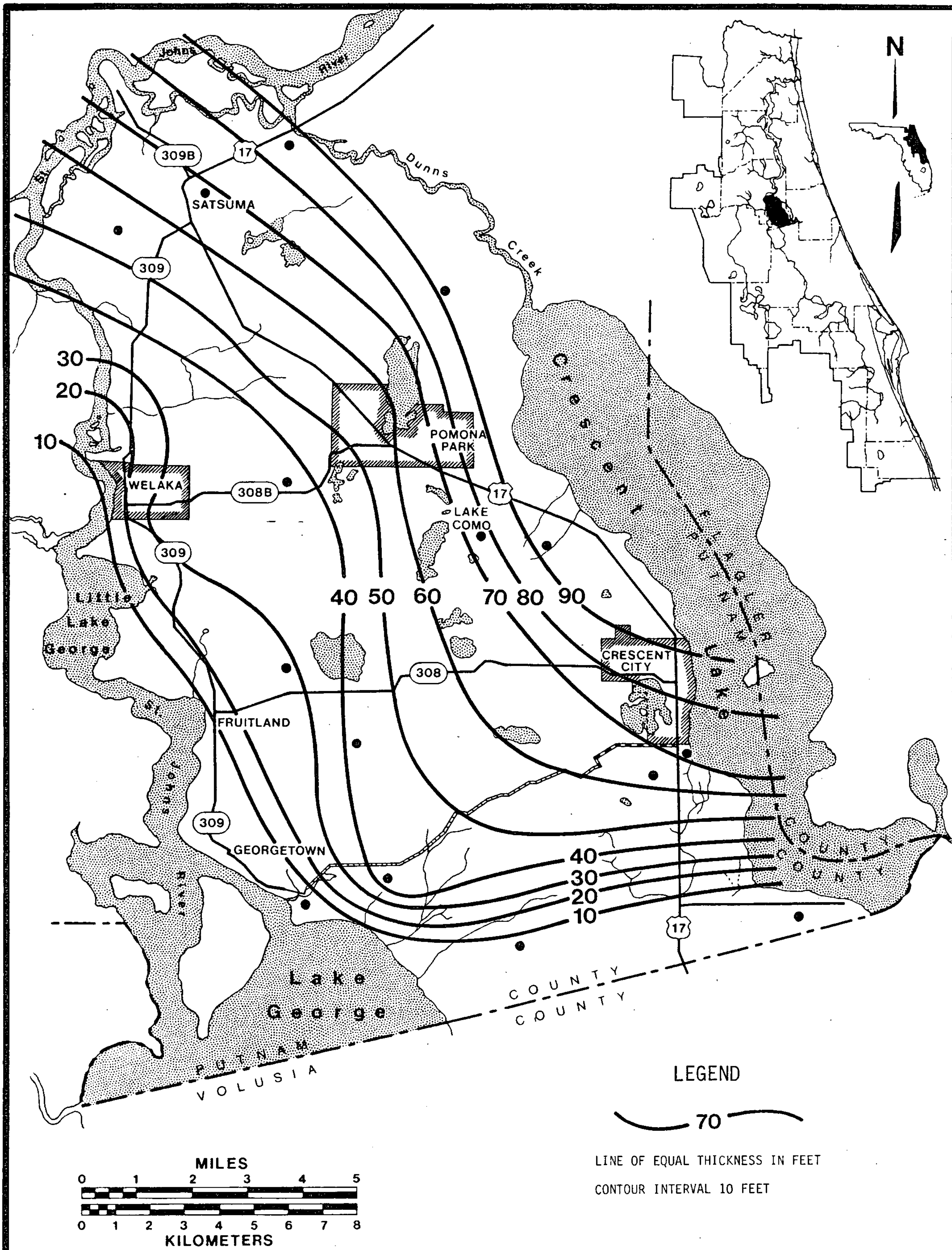


FIGURE 7. -- Map of Crescent City Ridge Showing Thickness of Confining Unit for the Floridan Aquifer

Lying above the confining unit are the unconsolidated surficial sands and clayey sands which make up the upper 30 to 50 feet of the ridge. Sediment grain size analyses of representative samples (Table 1) show that the sands are fine to very fine and well sorted. The grain size distribution data were obtained by sieving composite samples representing the entire thickness of the surficial sand unit. The size distributions and nature of these sediments is consistent throughout the area and compare similarily to size distributions conducted for the same area by Pirkle (1971, p. 43). Various workers seem to agree that the sands form relict shore line features deposited during times of a fluctuating sea level. There is a divergence of opinion as to when these sea level changes took place; however, most authors consider the surficial sediments to have been deposited during the Pleistocene epic. It is the surficial sands which comprise the unconfined aquifer system. Geologic data interpreted from the examination of geophysical logs are summarized in Table 2.

GEOLOGIC HISTORY

The Crescent City Ridge is one of a number of localized areas of elongate ridge-like appearance which rise above broader areas of considerable lower elevations and less relief in the Central Highlands of Florida. This "ridge and valley" system is oriented in a coast-parallel direction as well as parallel with the length of the peninsula (White, 1970, p. 112).

White (1970), in his work on the geomorphology of the peninsula of Florida, has produced the most detailed description of the history of the Central Highlands area. White suggests that the valleys were produced by the differential erosion of a once broad upland area, and the present ridges stand as its remnants.

These "supra-ridges" were somewhat protected from the reduction process by essentially insoluble material deposited in Late Miocene time over a limestone

TABLE 1. -- Mechanical Analyses of Composite Samples Representing the Entire Thickness of Surficial Sands on the Crescent City Ridge

SAMPLE A

Mesh Size No.	Mesh Size Ø	Mesh Size MM	Percent Sand Retained On Mesh	Accumulative Percent Sand
18	0.0	1.00	0.32	0.32
25	0.5	0.71	0.51	0.83
35	1.0	0.50	2.50	3.33
45	1.5	0.35	6.59	9.92
60	2.0	0.25	8.06	17.98
80	2.5	0.177	27.19	45.17
120	3.0	0.125	34.93	80.10
170	3.5	0.088	10.24	90.34
230	4.0	0.063	1.02	91.36

SAMPLE B

Mesh Size No.	Mesh Size Ø	Mesh Size MM	Percent Sand Retained On Mesh	Accumulative Percent Sand
18	0.0	1.10	0.12	0.12
25	0.5	0.71	0.11	0.23
35	1.0	0.50	0.35	0.58
45	1.5	0.35	2.31	2.89
60	2.0	0.25	9.54	12.43
80	2.5	0.177	31.27	43.70
120	3.0	0.125	43.39	87.09
170	3.5	0.088	6.91	94.00
230	4.0	0.063	.48	94.48

TABLE 2. -- Geophysically Logged Wells on Crescent City Ridge and Nearby Areas

Well No.	Latitude/Longitude	Owner	Diameter (inches)	Casing Depth (feet)	TDL (feet)	Elevation (feet)	Elevation of Top of Formations (feet below MSL)				Chloride/Depth (ppm/feet below MSL)
							Hawthorn	Ocala	Avon Park	Lake City	
1	292218/813331	Union Camp	4	81	156	25	-	41	85	-	34/125
2	292247/812843	Wesnofske	6	132	246	12	-	101	181	-	30/228
3	292251/812818	Fredhome	4	120	204	7	-	105	145	-	39/193
4	292254/812814	Fredhome	4	193	240	7	-	86	159	-	30/228
5	292257/813532	McBride *	4	105	190	27	66	78	151	-	60/153
6	292257/813532	McBride *	4	92	174	27	58	70	124	-	50/138
7	292257/813532	McBride **	8	96	186	27	60	74	148	-	50/153
8	292424/813136	Murphy	4	73	147	60	-	15	-	-	20/84
9	292452/813113	Colette	6	109	243	15	-	78	164	-	17/220
10	292505/813113	Newbold	6	80	224	57	-	29	124	-	13/158
11	292508/813027	Colette	6	98	283	3	-	76	163	-	14/272
12	292511/813050	-	8	95	241	63	-	29	103	-	-
13	292524/813553	Phillips	6	82	128	50	+24	16	-	-	4/+50
14	292621/813751	Mansfield	8	73	205	53	20	50	130	-	20/137
15	292628/813733	Eurotropic	8	65	144	45	17	38	94	-	13/90
16	292648/813137	Newbold	8	94	360	66	18	36	134	-	10/274
17	292734/813146	Newbold	8	81	386	65	13	18	108	-	20/300
18	292803/814050	Smith	6	158	167	9	121	148	-	-	60/151
19	292807/813308	Dexter Farms	10	125	425	33	32	95	188	-	-
20	292817/813345	Dexter Farms	10	123	484	65	+3	60	156	397	-
21	292824/813415	Col. Sauls	4	104	144	62	+18	55	-	-	20/73
22	293213/813522	SJRWMD	4	89	182	55	2	35	122	-	-
23	293320/813945	Horton	4	149	206	83	+2	82	-	-	-
24	292012/813210	Martin	10	82	323	25	-	71	115	-	12/175(Volusia Co.)
25	293234/814241	Rodeheaver	4	152	295	18	77	170	-	-	-
26	293419/814156	Thomas	4	90	202	2	75	124	-	-	23/195

NOTES

1. Wells logged as of 4/1/79--compiled by R. Johnson
2. *Test well drilled by SJRWMD for pump test
3. **Pumping well for pump test
4. Well locations are shown in Figure 4

terrain of once extensive relief, and having a coast parallel drainage pattern similar to the one seen today. In the area of the Crescent City Ridge, the insoluble material may be the clays and sandy clays overlying the Hawthorn Formation. For the ridges further west, the Citronelle Formation and the sediments of the Hawthorn Delta are cited. Thicker accumulations filling in the coast-parallel valleys resulted in little limestone solution, while increased solution occurred in the upland areas where the limestones were less protected. Ultimately, a region of inverse topography was developed with the present ridges of protected limestone occupying the areas of former valleys. This theory also explains the coast-parallel distribution pattern for the upland remnants.

Overlying the ridges is a veneer of medium to fine sand. These sands appear in aerial photographs and in the recent NASA ERTS-1 satellite image mosaic as bands of relict beach ridges which are characteristically deposited parallel to a migrating shore line. Pirkle, Yoho, and Hendry (1970, p. 29) believe the beach ridges to be of two types deposited along different shore lines. They found that certain ridges are made up of medium sands deposited on the "supra-ridges" of the western Central Highlands, while others of fine sand such as found on the Crescent City Ridge are associated with the easterly "supra-ridges".

White (1970, p. 113) further believes that the beach ridges of the Central Higlands were formed during one of the higher stands of sea level (150 feet), citing as evidence that solution reduction of the underlying limestone has produced considerable relief along the lengths of the once uniform beach ridges, and that there was no destruction of the lowered areas nor deposition of more recent marine deposits by subsequent rises in sea level. Pirkle, et al. (1970, p. 32) suggest that the beach ridges composed of medium sand are found at elevations commensurate with the 150-foot rise in sea level, while the ridges of fine sand to the east have elevations commensurate with the 100-foot rise in sea level.

ST. JOHNS RIVER VALLEY OFFSET

The St. Johns River makes an abrupt westerly change in its natural course at Lake Harney, flows north along the west flank of the Crescent City Ridge; and at Palatka, it turns abruptly back to the east. This westerly displacement in the course of the river is referred to by White (1970) and others as the St. Johns River Offset.

Pirkle (1971, p. 57) and White (1970, p. 107) suggest that the St. Johns River Valley west of the Crescent City Ridge is an older feature than the upper St. Johns River Valley. According to these authors, the Offset probably originated during some low stand of sea level in Late Tertiary or Early Pleistocene time. Various factors such as limestone solutioning during low stands of sea level and fracturing associated with the Ocala Uplift favored development of the Offset Valley. At that time, the valley was the site of the course of an ancient river which drained the upland areas of Central Florida. Springs associated with fracturing would also help to establish and maintain the ancient valley.

While various authors, Vernon (1951, p. 2), Wyrick (1960, p. 24), Bermes, et al. (1963, p. 35), and Pirkle (1971, p. 44) attribute faulting along with fracturing of the limestone to the formation of the offset course, geophysical logs produced no hard evidence for the existence of faulting in the area. Correlations between several geophysical and geological logs along the western flank of the ridge show large "displacements" in the Eocene Limestone and Hawthorn Formation which are filled in with increased amounts of surficial sediment. These "displacements" appear as anomalies in the overall structure of the area and are considered by the authors to be large solution features. The Florida Bureau of Geology (Tom Scott, 1978, personal communication) believes that localized "displacements" in Eocene and older rock are the result of increased solution associated only with fracturing. Fracturing associated with the Ocala Uplift allowed freer circulation of ground water with a correspondingly greater solution of carbonate rock during the various periods of reduced sea level.

SURFACE WATER

LAKES

Common features of the large ridges of Central Florida are chains of lakes distributed along ridge crests. Of the many lakes located within the Crescent City Ridge, most are small with surface areas less than 200 acres, although several large lakes are prominent. These lakes are Lake Margaret, Lake Broward, Lake Stella, Lake Como, Clear Lake and Silver Lake (Figure 4).

The lakes are of two types: (1) lakes associated with sandy upland areas and (2) lakes of the swampy lowlands located between sandy hills. The nature of each type is controlled by the drainage developed within their respective areas. Areas surrounding upland lakes are well drained, and the lakes have no surface outlets. The deep water table beneath the sandy uplands promotes lateral ground water movement resulting in solution of the underlying limestone and subsequent subsidence of the sand, forming lakes (White, 1958, p. 74).

Lowland areas between sandy hills are poorly drained with water tables close to the surface, resulting in swamps and lakes surrounded by swamps. Lowland lakes have surface outlets which interconnect during times of high water to drain the interior of the ridge.

Lake Levels

Lake levels at ten lakes were monitored throughout the period of this study (October 1977 through September 1978), (Figure 4). Lake Stella was monitored by continuous graphic water level recorder starting in late April 1977. Staff gages were erected at nine lakes and gage heights measured periodically during the period of record. Five of the lakes were monitored after each occurrence of rain and the remaining four biweekly. All ten lakes showed a net gain in stage height for the year. The largest increase was three feet at Pleasant Lake, and the smallest increase of 1.33 feet occurred at Lake Margaret. The average net gain during the year for the ten lakes was 1.85 feet or 22.2 inches.

The greatest factors controlling lake levels on the Crescent City Ridge are precipitation and evaporation. Figure 8 shows a stage hydrograph of Pleasant Lake compared to a graph of accumulated monthly precipitation minus evaporation. The accumulated precipitation minus evaporation curve was developed by plotting differences between average monthly rainfalls over the entire ridge area and calculated adjusted monthly lake evaporation. The resulting monthly values are then plotted being either added or subtracted from the previous month's value.

The graphs clearly indicate that a strong relationship exists between lake levels and precipitation and evaporation for the period of record. Other factors not as strongly effecting lake levels may be surface runoff and ground water seepage to and from the lakes. It must be mentioned that rainfall and evaporation for the year studied fell within "normal" ranges, and other factors may more greatly influence lake levels in future years especially when precipitation falls outside the normal limits.

Lake Levels and the Artesian Aquifer

Although existing data are not adequate to estimate leakance values through lake bottoms into the confined aquifer, it does appear that the lakes studied are well sealed from direct leakage to the artesian aquifer and that leakance values are small. Lake levels on the Crescent City Ridge are above the potentiometric surface by as much as 20 feet in lakes occurring at higher elevations. It is possible that the lake basins are formed by the solution of shell beds

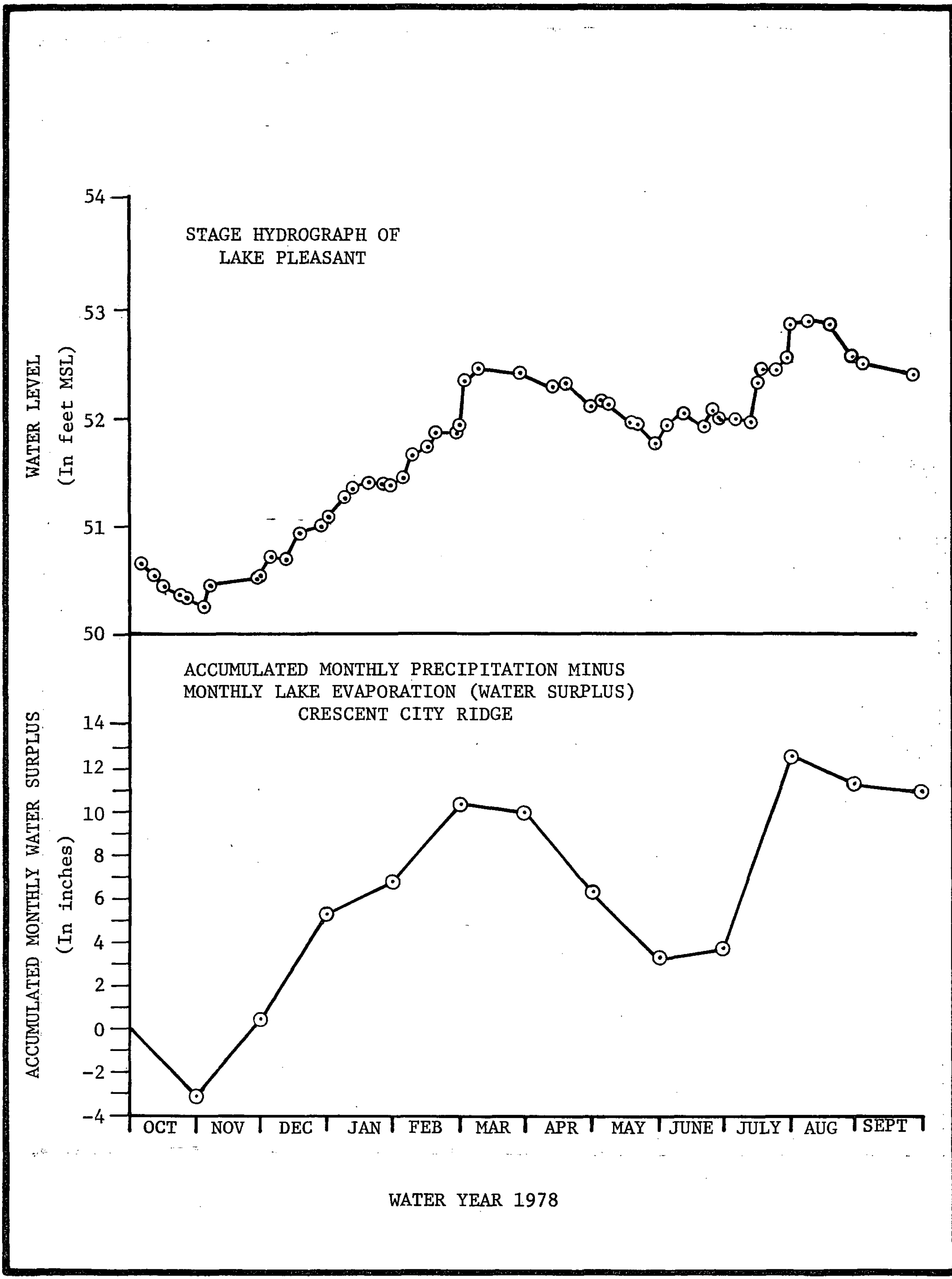


FIGURE 8. -- Stage Hydrograph of Lake Pleasant vs. Graph of 1978 Water Year Monthly Water Surplus at Crescent City Ridge

found in the Hawthorn Formation as suggested by White (1958, p. 74). If this is true, the lakes would be substantially isolated from the Floridan aquifer by the amount of impermeable Hawthorn clay remaining below the shell beds.

STREAMS

Eight identifiable creeks provide the mechanism for runoff from approximately 27,472 acres within the 78,745 acres of the project area. The remaining 65 percent of the designated Crescent City Ridge area is made up of many individual closed drainage basins which have no topographically expressed surface outlets in which surface runoff can be measured (Figure 9). Centered in these closed basins are the majority of lakes which become the receiving bodies for water derived from ground water seepage and overland sheet flow during times of intense rainfall. All of the creeks, with the exception of Beecher Run, derive their base flow from ground water seepage. Beecher Run is continuously fed by artesian waters from the Floridan aquifer, and discharges measured in the Run average 8.91 cfs throughout the year.

Discharge measurements of the eight creeks were made periodically throughout the duration of the study. Continuous graphic water level recorders were installed at Acosta Creek and Beecher Run to measure stage height fluctuations; and from those data, discharge rating curves were developed. Estimates of mean daily flow for the remaining six creeks were determined by comparing flow measurements of individual creeks to the continuous discharge values measured at Acosta Creek. Although continuous records were available for Beecher Run, plots of stage discharge data showed variations from a single curve. These variations may be caused, in part, by the use of Beecher Spring Run as a water supply as well as an outlet for drainage water from fish ponds maintained by the U. S.

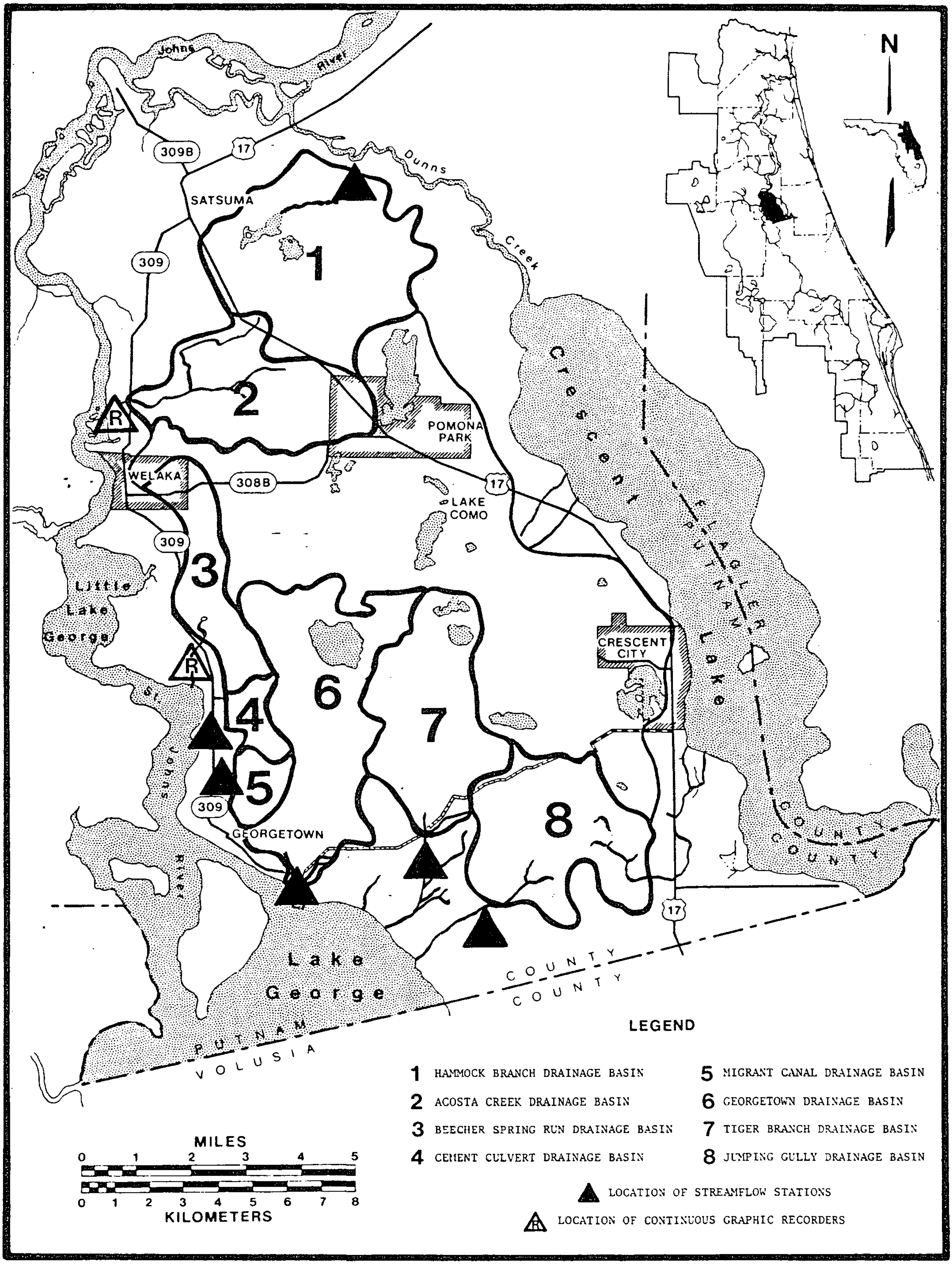


FIGURE 9. -- Map of Crescent City Ridge Showing Locations of Streamflow Monitoring Stations and Respective Drainage Basins

Wildlife Department. This, along with obstructions caused by natural vegetation, made the Run an unreliable source of data for determining relative percentages of flow in the remaining creeks.

Months which showed substantial reductions in flow were April through June; while during the months of December through March, discharges were high due to the above normal rainfall totals. The mean daily flows for individual creeks ranged from 0.18 cfs to 12.03 cfs for the study period. Total monthly discharges from the eight creeks were converted to inches of runoff for each individual drainage basin and for the entire project area. A summary of these data is presented in Table 3. The total calculated runoff from the Crescent City project area is 2.92 inches for the 1978 water year.

TABLE 3. -- Stream Discharge Data, Monthly Discharges and Total Annual Discharge in Inches--1978 Water Year

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Total Basin Runoff in Inches	Drainage Basin Area in Acres	Percent Size of Drainage Basin to Study Area	Runoff Contribution to Entire Study Area in Inches	Mean Daily Discharge for 1977-78 in CFS	High Daily Mean Discharge in CFS	Low Daily Mean Discharge in CFS
Cement Culvert	.03	.29	.7	.99	1.66	.18	--	--	--	.02	.13	.12	4.12	392	.5%	.021	0.19	0.19	0.00
Migrant Canal	.05	.09	.73	4.66	5.08	1.31	.1	--	--	.24	.24	.25	12.75	549	.7%	.089	0.18	7.37	0.00
Beecher Run	4.46	3.37	3.48	2.84	3.76	4.56	3.99	4.74	5.58	5.12	5.85	4.56	52.31	1995	2.5%	1.308	12.03	22.75	3.67
Acosta Creek	.33	.60	1.11	1.29	1.4	.99	.64	.57	.47	.54	1.14	1.06	10.14	3529	4.5%	.456	4.12	12.30	0.60
Tiger Branch	.32	.43	.67	1.00	1.03	.92	.55	.34	.27	.36	.84	.96	7.96	3633	4.6%	.354	3.22	8.45	0.46
Jumping Gully	.07	.11	.21	.45	.76	.46	.03	.0002	.02	.07	.22	.20	2.60	5410	6.9%	.179	1.63	9.99	0.00
Georgetown	.02	.05	.25	.46	.62	.52	.07	.0001	.004	.06	.41	.44	2.90	6772	8.6%	.249	2.28	9.99	0.00
Hammock Branch	.07	.18	.38	.64	.72	.54	.16	.11	.08	.14	.47	.51	4.00	5192	6.6%	.264	2.40	15.00	0.50

TOTAL Runoff = 2.920"
for Entire
Study Area

GROUND WATER SYSTEMS

Three aquifer systems occur in the Crescent City Ridge area--a non-artesian aquifer, a secondary artesian aquifer, and an artesian aquifer. Figure 10 is a generalized representation of the ground water system, illustrating the relationship between aquifers, direction of ground water flow, and areas of recharge and discharge.

NON-ARTESIAN AQUIFER

The non-artesian (unconfined) aquifer consists of fine to very fine sand and clayey sand which comprises the upper 50 feet of the ridge structure. The base of the aquifer is the upper clays and sandy clays of the Hawthorn Formation. The water table occurs at elevations of approximately one to 80 feet above sea level. It is found near the surface in low areas and rises under sandy uplands, conforming to the configuration of the topography, to within a few tens of feet below the crests of the higher sand hills.

Most recharge to the unconfined aquifer occurs directly from precipitation, although some vertical seepage does occur where the water table is lower than the potentiometric surface of underlying aquifers. The volume of recharge from precipitation is the amount of water which is not stored as soil moisture in the unsaturated zone, intercepted by vegetation, or lost to surface runoff and evapotranspiration. Maximum recharge rates occur where the water table is at sufficient depths to allow storage of the infiltrating water and where the permeability is high enough to allow rapid percolation of precipitation through the soil horizon. Generally, prime recharge locations in the study area are further characterized by higher elevations, poorly developed surface drainage, and less dense vegetative communities. Discharge occurs through lateral seepage

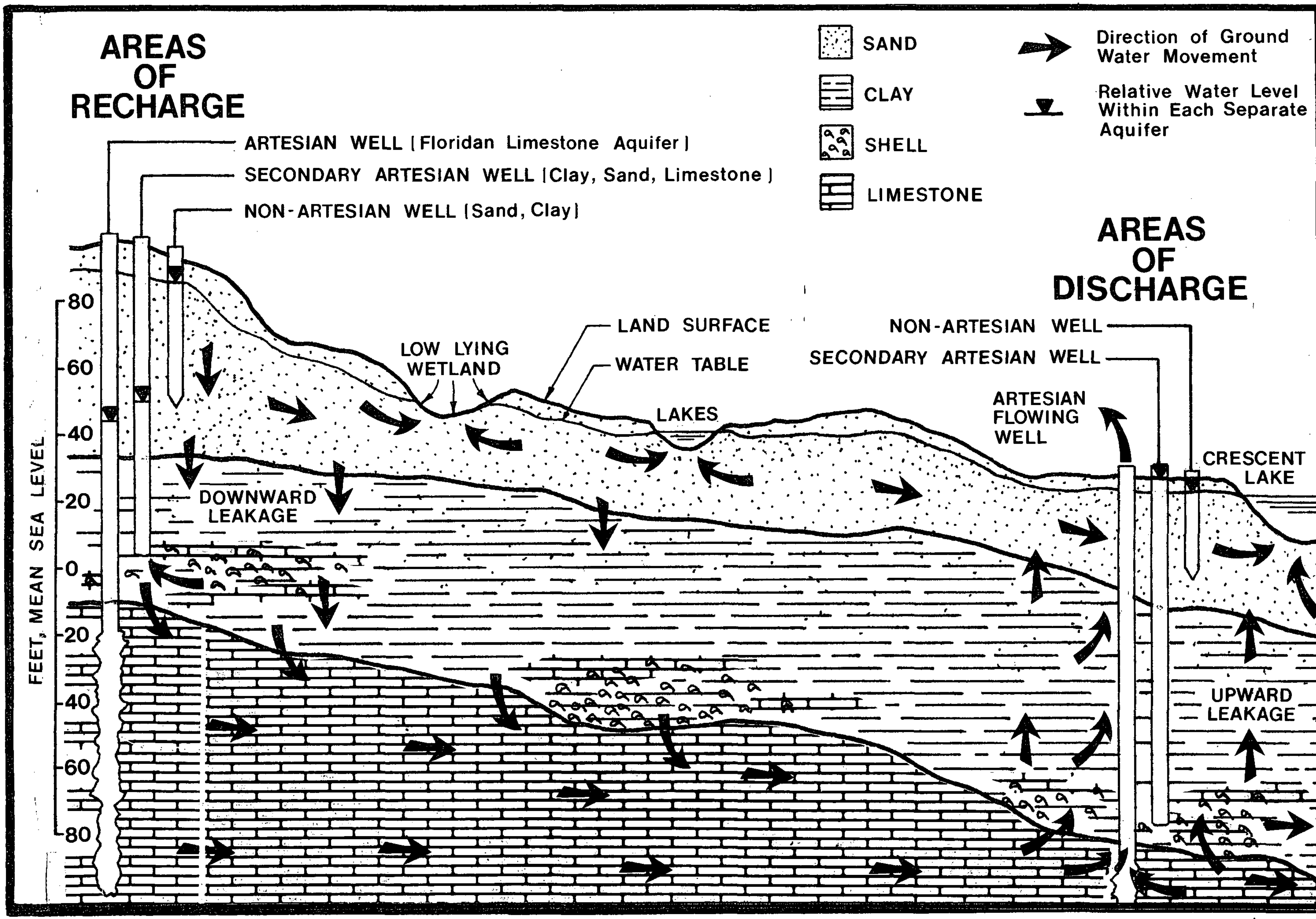
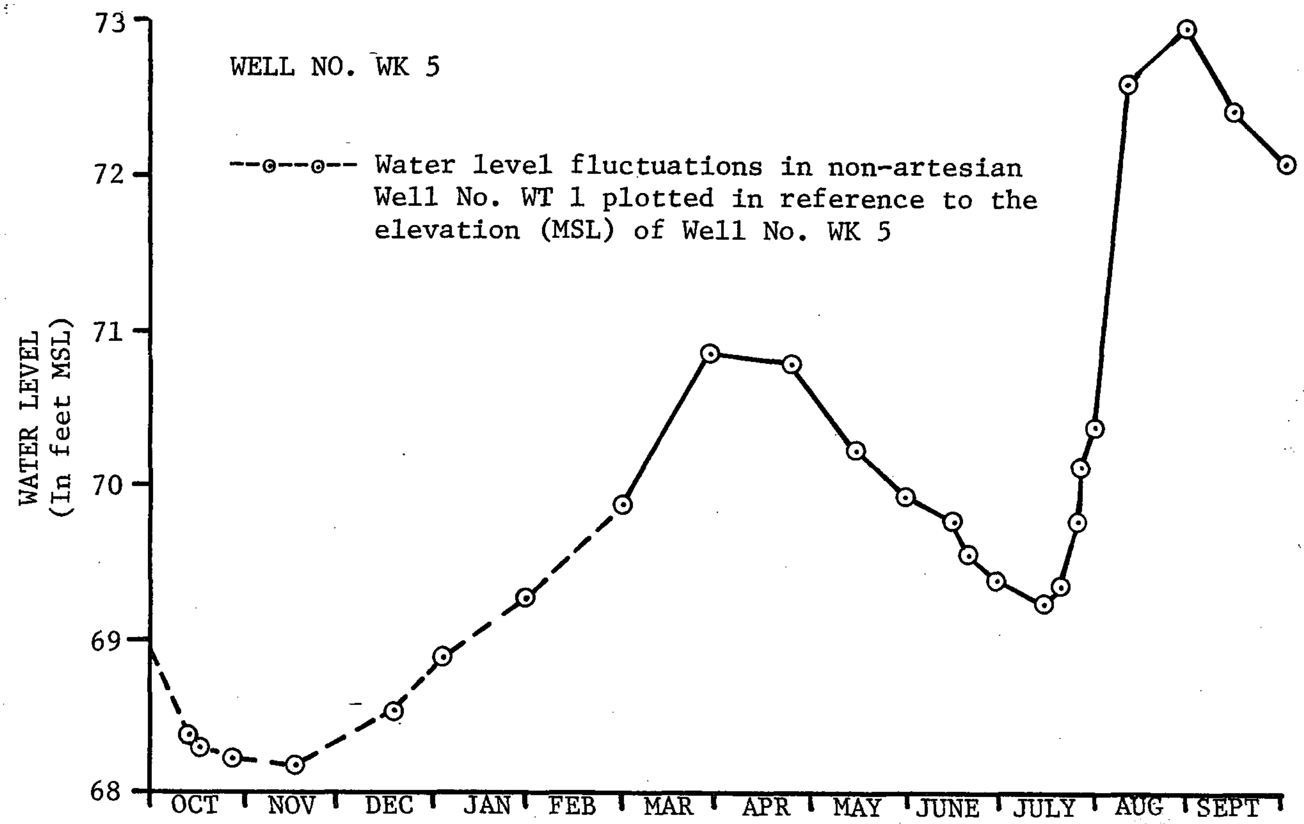


FIGURE 10. -- Diagram Showing Relationships Between Non-Artesian, Secondary Artesian, and Artesian Aquifers on the Crescent City Ridge

into lakes, streams, and swampy areas where ponded water is lost to evaporation and transpiration, vertical seepage into underlying aquifers, and pumpage.

Water yielding properties of the unconfined aquifer are such that the aquifer is only used locally to supply small amounts of water. Permeabilities of sands comprising the aquifer were determined, utilizing grain size distribution curves, with methods developed by Masch and Denny (1966). The average permeability of the two samples is 143 gal/d/ft^2 or 19.1 ft/d, and the average transmissivity is 7,125 gal/d/ft. Field values would probably be lower because the grain size distribution technique does not account for any cementation or consolidation of the natural aquifer, nor does it consider natural particle arrangement, stratification, or directional aspects of permeability (Masch and Denny, 1966, p. 676). The average value of transmissivity could not be correlated with field values reported in the literature for unconfined aquifers, because no previous tests were conducted on aquifers with similar grain size distributions.

Figure 11 compares water level fluctuations in an unconfined aquifer well located on a high sand hill versus the accumulated water surplus for the Crescent City Ridge. The figure shows that the height of the water table is dependent on the amount of surplus water available for recharge, the largest increases occurring after periods having the greatest surpluses. The water table will continue to rise as long as positive net surpluses occur. Increases in water table elevations lag behind gains in accumulated surplus, the lag time depending directly upon the vertical permeability and thickness of sand recharge water must percolate through before reaching the water table. The total net change in water level for water table well WK5 was 37 inches with a total range in fluctuation of nearly five feet. The average net change in water level in wells monitoring the unconfined aquifer for the water year was 36 inches.



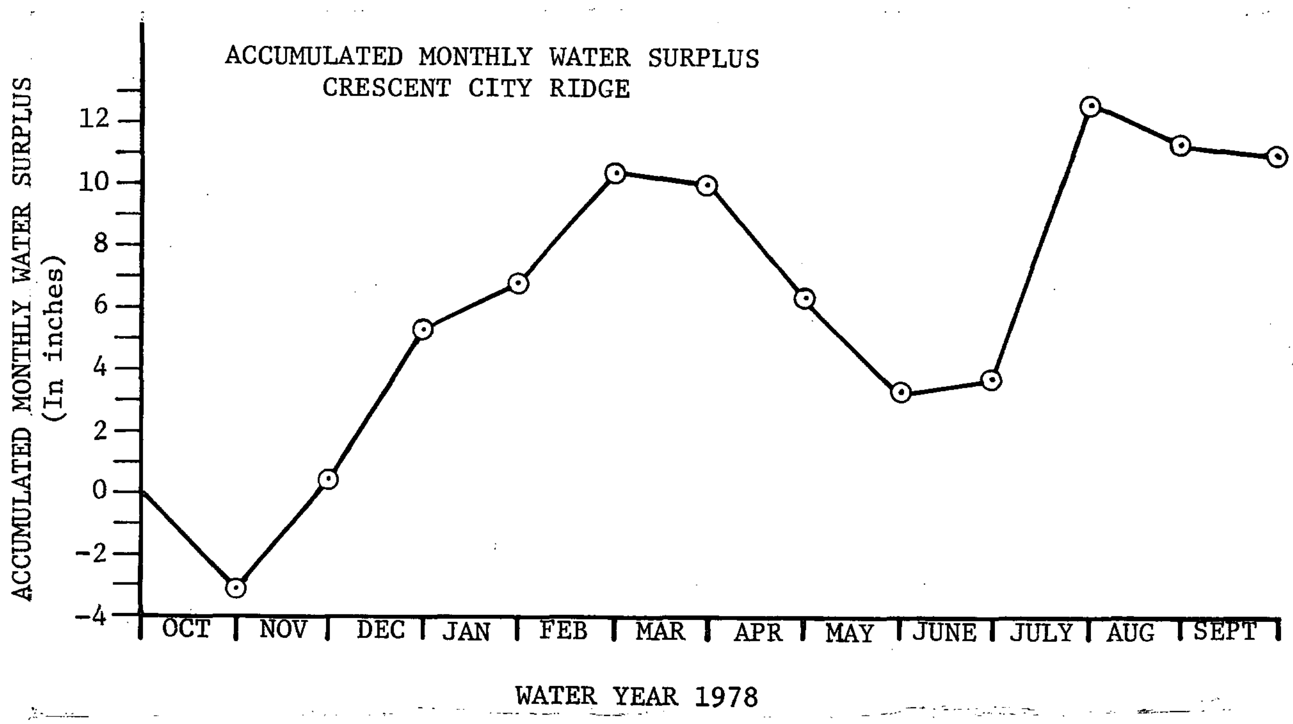


FIGURE 11. -- Graph of 1978 Water Year Monthly Water Surplus at Crescent City Ridge vs. Water Level Fluctuations at Non-Artesian Well WK 5

SECONDARY ARTESIAN AQUIFER

The secondary artesian aquifer consists of permeable shell and soft limestone beds that appear to exist as discontinuous lenses between less permeable clay and sandy clay beds in the confining unit. The aquifer ranges from less than one foot to about 15 feet in thickness (Bermes, et al. 1963, p. 48). A detailed examination of the secondary artesian aquifer was beyond the scope of this investigation. Little has been learned about the secondary artesian aquifer from this study except that zones of high permeability were occasionally encountered in the confining unit while attempting to complete observation wells in the artesian aquifer. It appears that the secondary artesian aquifer is more extensive in this area than previously reported, and that many shallow wells in the area may be drawing water from this aquifer. The secondary artesian aquifer will receive recharge from the overlying unconfined aquifer in recharge areas and from the artesian aquifer in discharge areas (Figure 10). Water in the secondary artesian aquifer appears to be generally of excellent quality.

ARTESIAN AQUIFER

The artesian aquifer in southeastern Putnam County consists of the basal limestones of the Middle Miocene Hawthorn Formation, the Eocene limestones of the Ocala, and the Avon Park and Lake City limestones (see GEOLOGIC SETTING section). These formations form a single aquifer known as the Floridan aquifer which is the major source of fresh water for the Crescent City Ridge area.

Recharge to the Floridan aquifer occurs where the potentiometric surface is lower than the water table (Figures 10 and 12) provided the confining unit is thin or breached. Water is transmitted through the confining unit from the non-artesian aquifer to the Floridan aquifer at a rate depending upon head

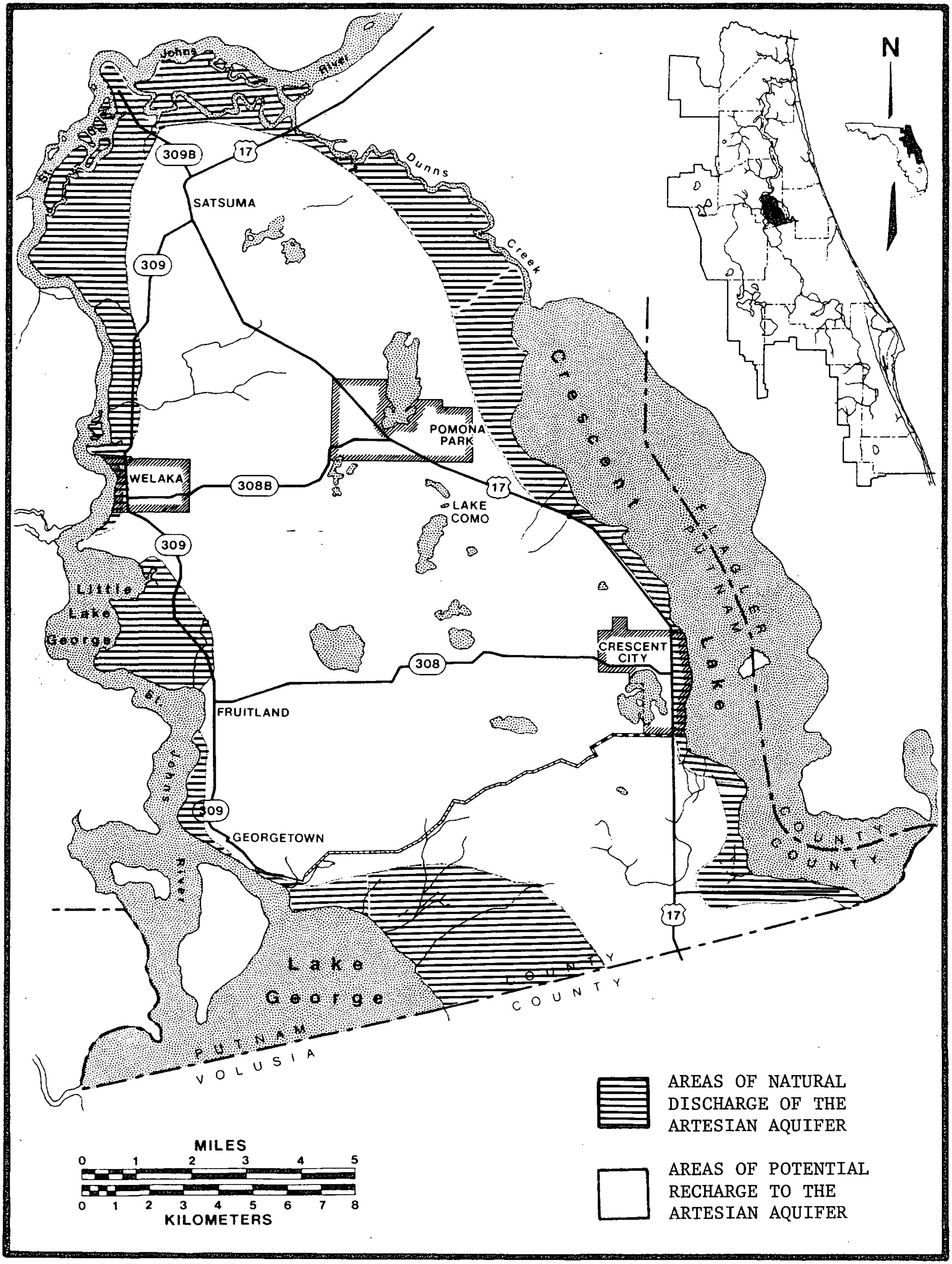


FIGURE 12. -- Map of Crescent City Ridge Showing Areas of Natural Discharge and Recharge to the Floridan Aquifer

differences between aquifers and the thickness and vertical permeability of the confining unit. The high sand hill areas offer the greatest potential for recharge to the underlying aquifers. Their thick layers of sand reduce runoff and evaporation by propagating vertical seepage and storing water for eventual recharge to the Floridan aquifer.

Water in the Floridan aquifer moves in the direction of declining fluid potentials, eventually discharging into overlying aquifers where the potentiometric surface is higher than the water table (Figures 10 and 12). Discharge also occurs through springs and by pumpage. Recharge and discharge rates are discussed in the WATER BALANCE section of this report.

Potentiometric maps (Figures 3 and 13) for the upper Floridan aquifer of the Crescent City Ridge were constructed from water level data collected in May and September 1978. Potentiometric maps for the Floridan aquifer are conventionally prepared in May and September because seasonal water levels are usually at their lowest in May and highest in September.

The potentiometric maps indicate that there are two areas of highest potentiometric levels on the ridge, one north of Pomona Park and another west of Crescent City. These highs are centered around areas where the top of the Floridan aquifer is at a high elevation (see Figure 6) and is covered by a thick section of surficial sand. This is particularly true for the high north of Pomona Park where elevations along an extensive undisected portion of the ridge exceed 100 feet MSL.

The potentiometric maps indicate that the general direction of ground water movement is away from the central axis of the ridge towards the St. Johns River on the west and Crescent Lake and Dunns Creek to the east, with the gradient being somewhat steeper on the east side. Natural discharge takes place along the margins of the ridge as well as areas of artesian flow (see Figures 2 and 12).

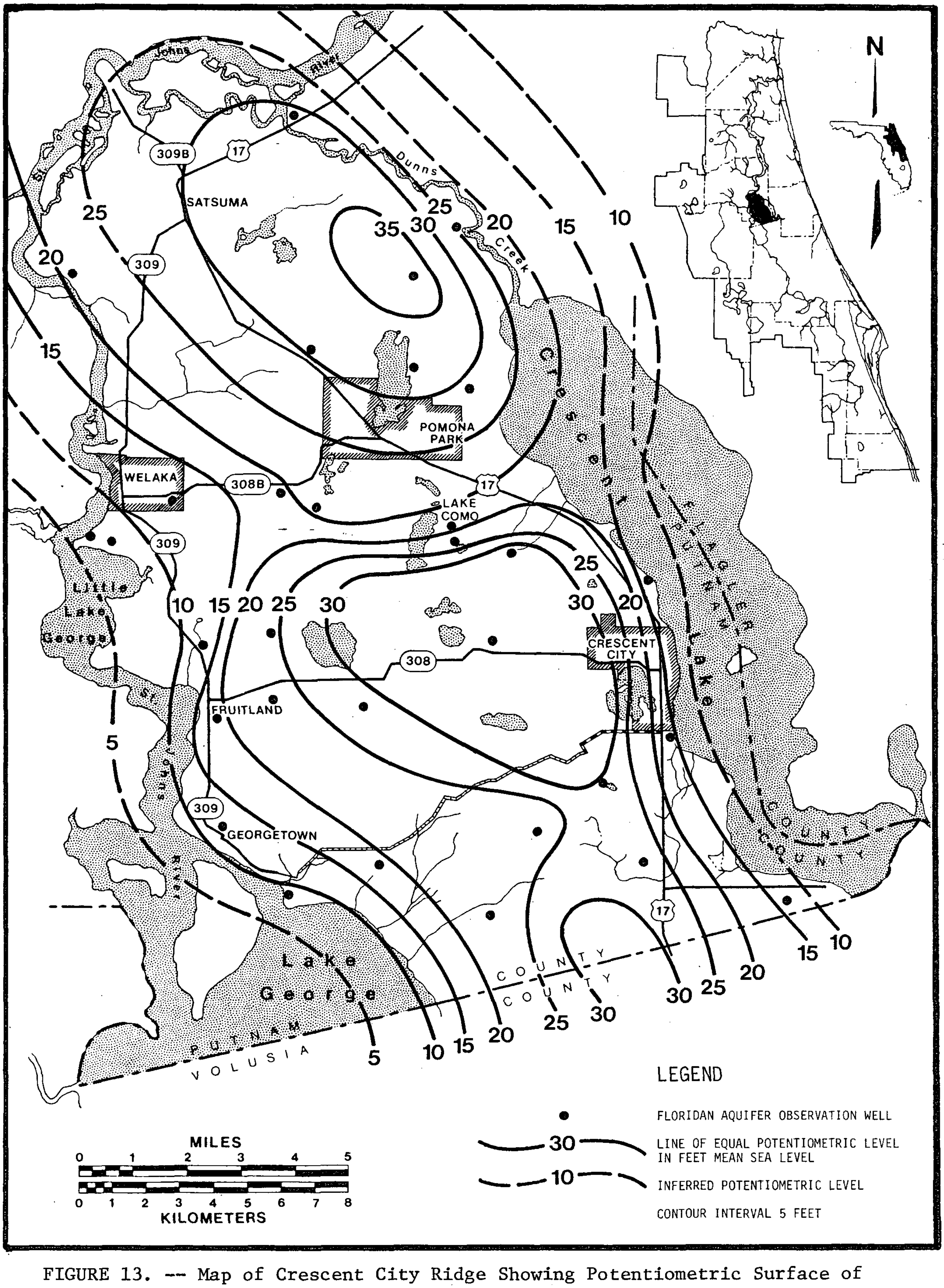


FIGURE 13. -- Map of Crescent City Ridge Showing Potentiometric Surface of Floridan Aquifer for September 1978

Figure 14 is a hydrograph covering a two-year period, 1977 through 1978, for a well completed in the artesian aquifer. The hydrograph shows that water levels fluctuate seasonally. Declining levels occur from mid-March through May when the climate is dry and crop irrigation needs are greatest. The short rapid declines of approximately two feet followed by equally rapid rises occurring in December, January, and February were produced when large volumes of water for freeze protection were withdrawn from nearby wells (see WATER USE section).

The range in fluctuation for the two-year period was 3.36 feet with the highest water level of + 31.34 feet MSL occurring in August 1978 and the lowest of + 27.98 MSL occurring in May 1977. The hydrograph also shows that for the two-year period, water levels were generally on the rise with seasonal highs and lows for 1978 being at higher elevations than for the preceding year.

AQUIFER TEST

A test to evaluate the hydraulic characteristics of the Floridan aquifer in the Crescent City area was conducted in May 1978. The test was performed using an eight-inch diameter pumped well located approximately one mile northeast of Lake George (Figure 2). The test well is 187 feet deep and is cased 22 feet into the Floridan aquifer with 91 feet of open hole. Two observation wells four inches in diameter were drilled to approximately the same depth as the test well. One is located 210 feet west of the test well and the other 450 feet east of the test well, having 82 feet and 85 feet of open hole, respectively. A three-inch diameter well was drilled 50 feet north of the test well and was used to monitor the unconfined aquifer. The three Floridan wells were geophysically logged, and local geologic conditions were determined to be uniform. The geophysical data is summarized as part of Table 2.

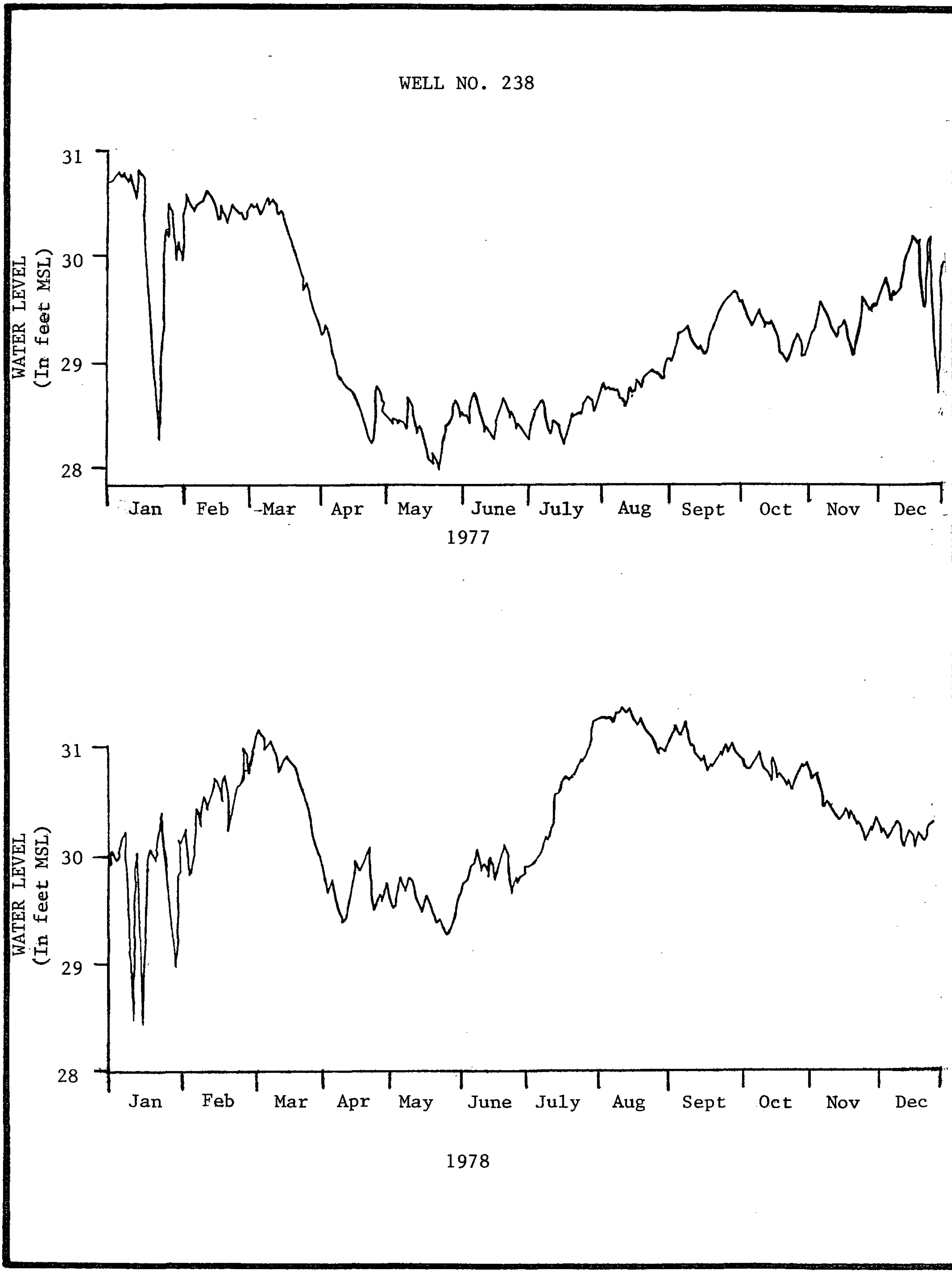


FIGURE 14. -- Hydrograph of Daily Mean Water Levels at Floridan Aquifer Well No. 238 for Years 1977-78

The test well was pumped at a nearly constant rate with an average discharge of 334 gallons per minute (gpm) for 1,900 minutes. The pumping rate was measured by a circular orifice weir attached to the discharge opening of the pump. Water levels in the pumped well and the unconfined aquifer well were measured by wetted chalked steel tape. Digital continuous water level recorders were attached to the two four-inch observation wells for convenient measurements of water level changes, especially for the initial period of the test and during the recovery period. After 1,900 minutes, the pump was turned off and recovery data recorded in the wells with the automatic recording instruments.

Based on available geologic and historical pump test data, it was assumed that the Floridan aquifer in the pump test area existed under leaky artesian conditions. After two hours of pumping, water levels in the observation wells began to stabilize suggesting that the assumptions about the aquifer were correct. However, before equilibrium conditions could be reached, drawdown again began increasing at an accelerated rate in the Floridan observation wells. This condition persisted for another 30 hours before stabilization was achieved. Throughout the test period, no observable change in water level occurred in the non-artesian aquifer.

The Floridan aquifer at the test site did not react as a typically leaky aquifer. Time drawdown data for both Floridan observation wells were plotted on logarithmic paper (Figures 15 and 16). The initial drawdowns follow the Theis-type curve; but after approximately 90 minutes in the 210-foot distance well and 45 minutes in the 450-foot distance well, the curves begin to flatten and resemble the type curves for leaky artesian conditions. However, before stabilization is reached, the curves, once again, begin to rise towards the Theis-type curve.

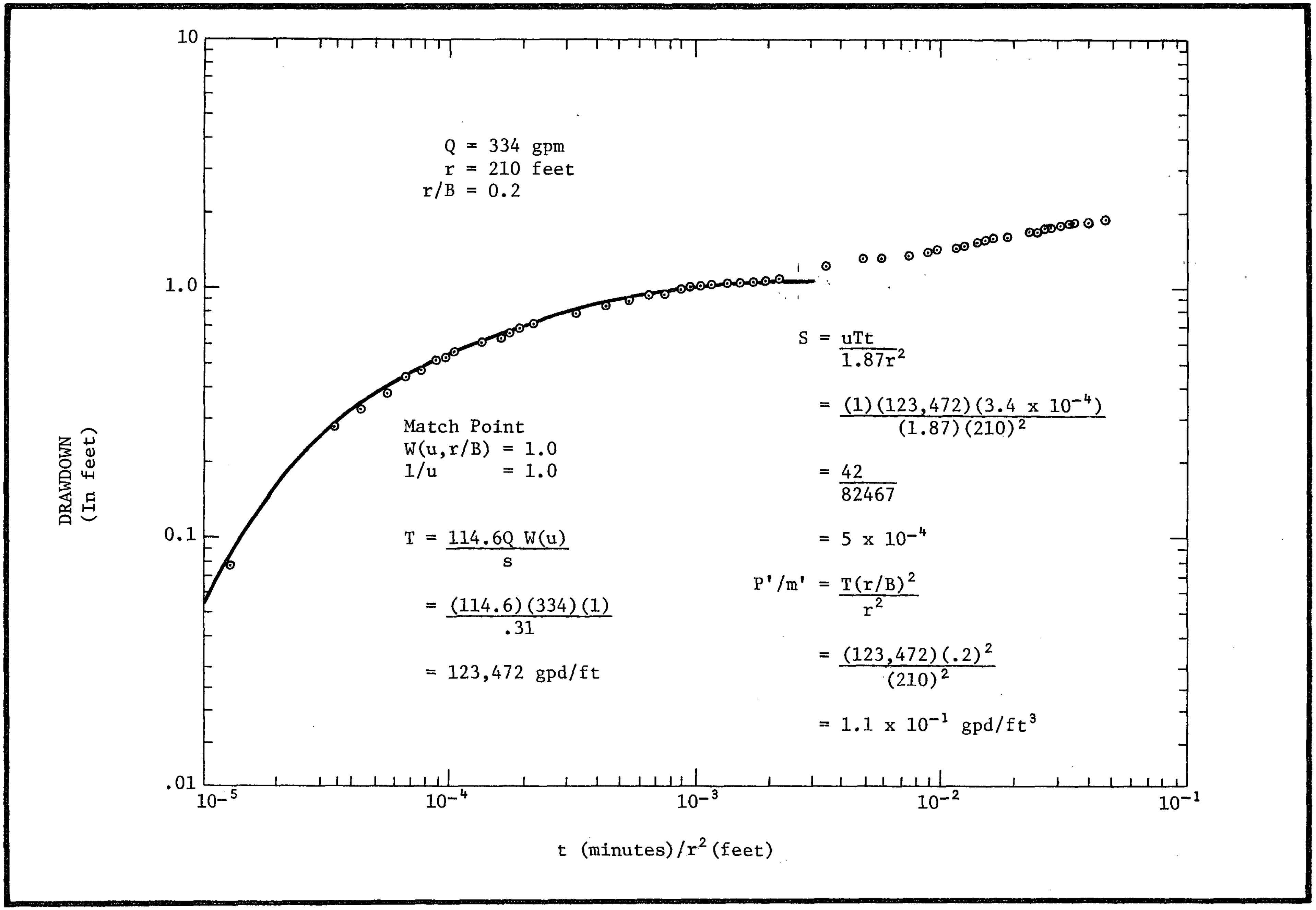


FIGURE 15. -- Drawdown Data and Calculations from Aquifer Test at Well No. 393 for Observation Well 210 Feet from Test Well

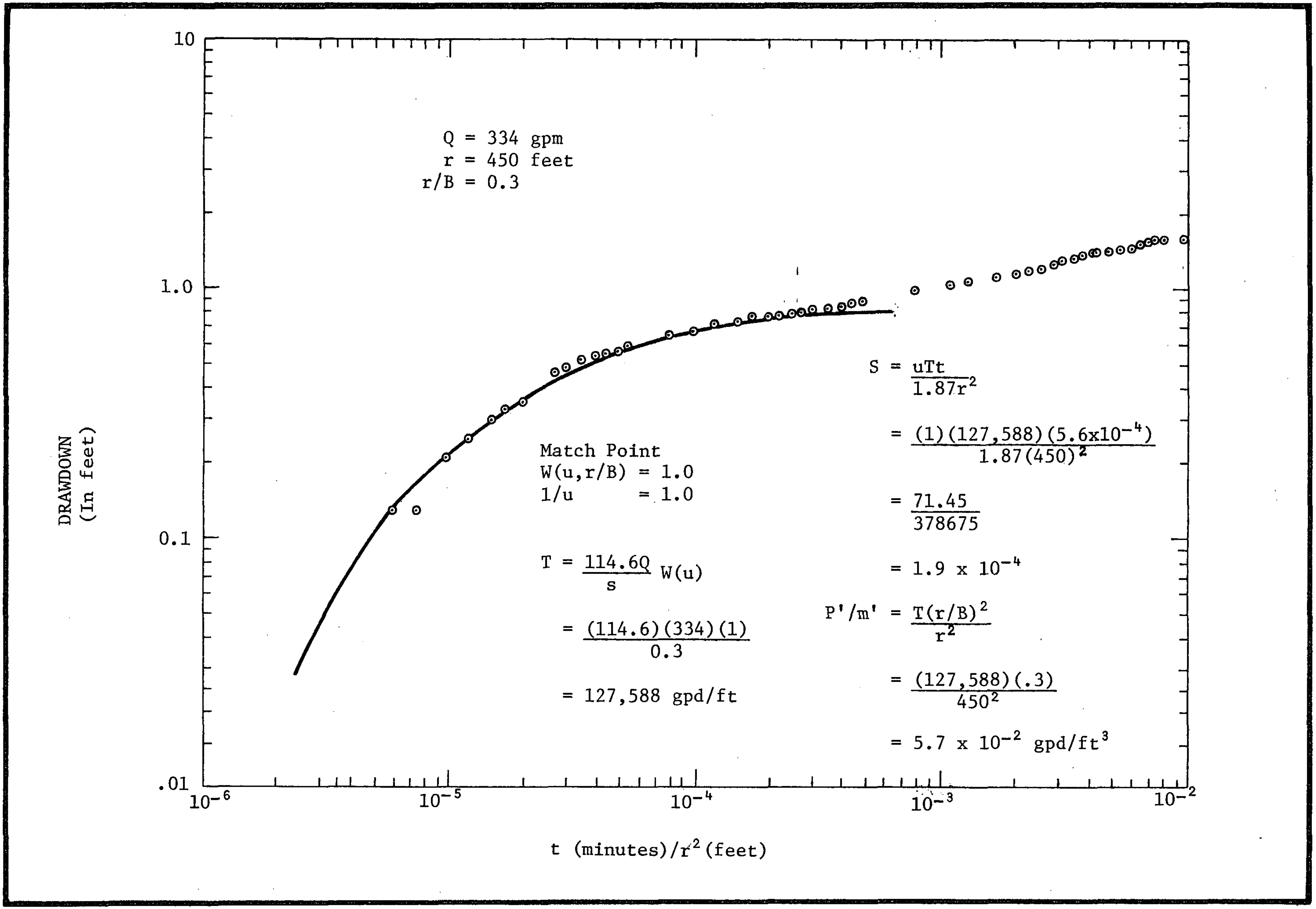


FIGURE 16. -- Drawdown Data and Calculations from Aquifer Test at Well No. 393 for Observation Well 450 feet from Test Well

All portions of both data curves compare closely to the Boulton-type curves which were developed for unconfined and semi-unconfined aquifers exhibiting delayed yield phenomena. These type curves allow separate values for transmissivity and storage to be calculated from the latter as well as the early portions of the time-drawdown curves (Kruseman and DeRidder, 1970, p. 95). However, calculations for storage indicated that the late storage (Sy) to early storage (Sa) ratios are too low for accurate application of the Boulton method (Kruseman, et al. 1970, p. 99). In addition, the geology would make it very doubtful that the Floridan aquifer is semi-unconfined in this area. Therefore, it is more likely that the increased drawdown occurring at a point just prior to stabilization is due to an encounter with an area of lower transmissivity in the Floridan aquifer. No attempt has been made to define the location or extent of the possible boundary. The early part of the drawdown curves have been compared to the type curves for leaky artesian aquifers. Calculations for transmissivity and storage are shown on Figures 15 and 16. The average value of transmissivity for the Floridan aquifer at the test site is 126,000 gal/d/ft, and the average value for the storage coefficient is 3.5×10^{-4}. The values of leakance are in the order of 1×10^{-1} gal/d/ft^3.

FLOW-NET ANALYSIS

The average transmissivity of the Floridan aquifer for the Crescent City Ridge can be estimated by constructing a flow net (Figure 17) and using the following equation:

$$T = \frac{Qn}{IL}$$

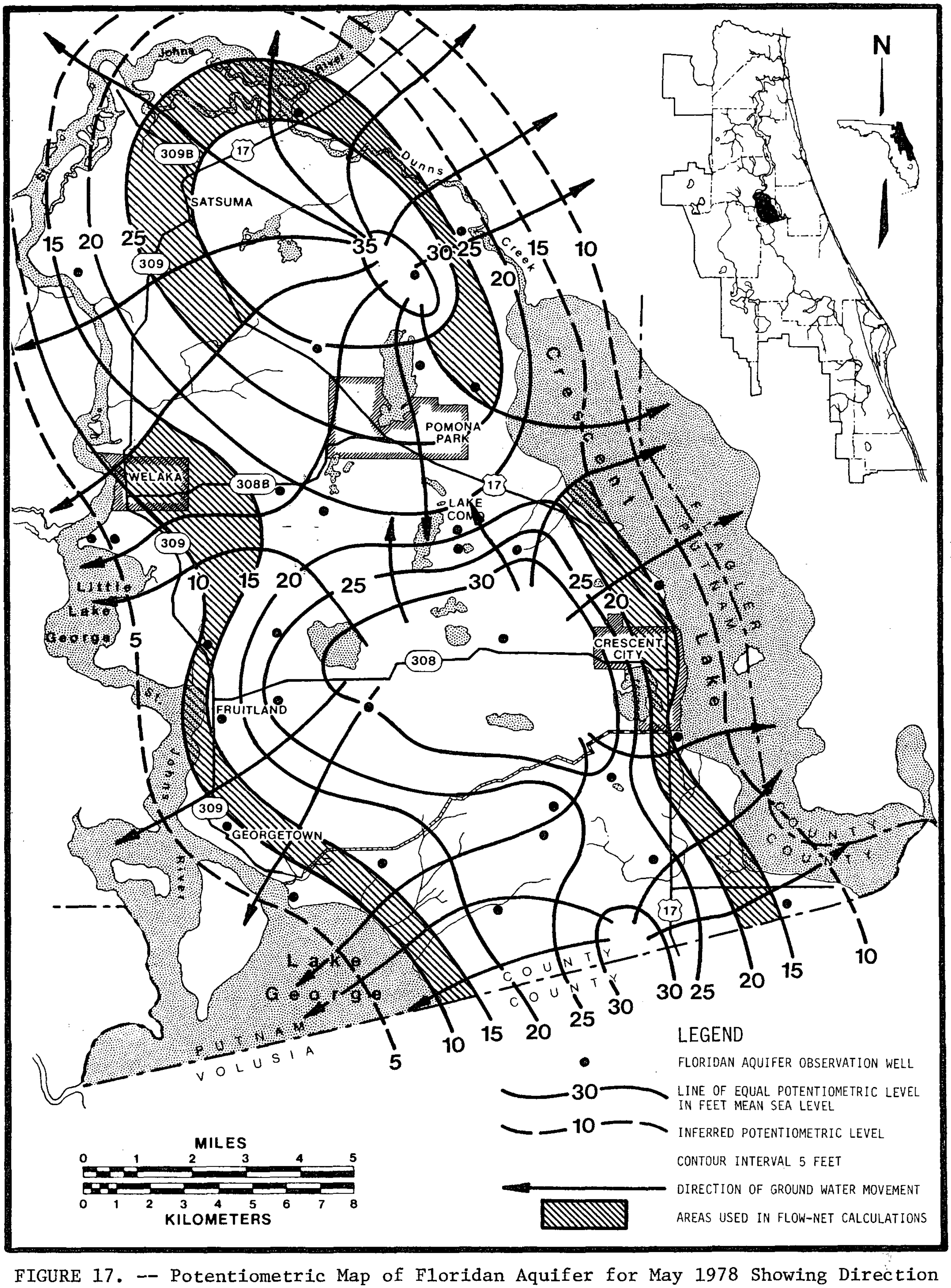


FIGURE 17. -- Potentiometric Map of Floridan Aquifer for May 1978 Showing Direction of Ground Water Flow and Areas Used for Flow Net Calculations

where

Q_n = rate of flow of water through cross section of aquifer in gpd

T = coefficient of transmissibility in gpd/ft

I = hydraulic gradient (ft/mi)

L = average width of cross section of aquifer (mi)

Assuming a discharge rate of 30 mgd (see WATER BALANCE EQUATION section), an average value of transmissivity will be 120,000 gal/d/ft. This value is in reasonable agreement with the value obtained from the pump test described above.

WATER USE

Water use within the Crescent City Ridge area is divided into two major categories: (1) domestic water use, including rural and municipal along with those quantities needed for livestock and (2) irrigation for the production of ornamental plants and citrus.

Domestic Use

Most water for rural domestic use is acquired from the Floridan aquifer through small individual wells and from several small private utilities whose connections each number less than 120.

For the determination of the rural water use, population estimates for the study area were provided by the Putnam County Chamber of Commerce. These estimates are based upon United States Post Office information which provides the current number of boxholders and route deliveries for the area covered by each office. The number of family units served by each office is multiplied by the average household size (2.6 persons/household) to estimate population. From data collected for the Water Resource Management Plan, Phase I, St. Johns River Water Management District, the average domestic rural water use was estimated at 100 gallons per capita per day. By applying this average per capita use to the estimated population of each area, rural domestic water use can be calculated as summarized by Table 4. As a result of the estimation method used, water use figures of Table 4 include the water provided by the small private utility supplies. In addition, the Crescent City municipal system supplies water to approximately 770 connections in the city limits and is the largest system within the study area using an estimated 0.2 mgd.

Ground water withdrawals for livestock in the study area are negligible, with most livestock (mainly cattle) getting water from creeks, lakes, and ponded water throughout the year.

Irrigation Requirements

Essentially, all water used for irrigation is derived from the Floridan aquifer. Approximately 100 wells ranging in size from four to eight inches in diameter, utilizing large capacity centrifugal or turbine pumps, provide irrigation for ornamental ferns and citrus groves. In some specific cases, it has been observed that surface water from ponds or lakes was also used as an irrigation source. Estimates of water use are based on personal communications with the county agricultural agent and individual grove and fernery operators.

Ferneries

The largest use of irrigation water is for the production of ornamental ferns. Ferns are best grown in areas where natural shade of oak hammocks can

TABLE 4. -- Estimated Domestic Water Use in the Crescent City Project Area

Localities	Units Served	Estimated Population	Water Use (MGD)
Crescent City	1423	3640	0.37
Crescent City Municipal	770	2002	0.20
Georgetown	330	858	.09
Lake Como	250	650	0.07
Pomona Park	442	1149	0.12
Satsuma	150	390	0.04
Welaka	486	1264	0.11
TOTALS	3851	9953	1.00

be obtained. Some large commercial ferneries utilize a manufactured cloth supported by cement poles to artificially create the 60 to 70 percent shade necessary for optimum growth.

For the 600 acres of ferns grown throughout the year in this area, an average application rate of approximately 150 gallons per minute per acre was recommended by the county agricultural agent. Duration of pumping during a week is estimated at three hours. Yearly ground water withdrawals from the Floridan aquifer for the production of ferns, including freeze protection, is estimated to be 52 inches or 2.3 mgd. During winter months, when it becomes necessary to protect ferns from freezing, pumps may run at a day's length at an application rate of almost .35 inches per hour or approximately 137 mgd. Freeze protection is a method by which water is continuously applied to the plants during below freezing temperatures to prevent extensive crop loss. When the air temperature at the level of growth falls below freezing, water supplied to the foliage and stems freezes and gives off heat. This heat is supplied by the change in state of water from a liquid to a solid. The heat created by this physical change in state maintains the existing temperature (30-32°F.) of leaves and branches as to not cause any damage as long as a continuous application of water is maintained (Harrison and Conover, 1970, p. 4).

Citrus

Presently, there exists approximately 2,700 acres of citrus groves within the project area. These groves are located in well drained sandy soils along the perimeter of the ridge and in the central sand hill areas. From information obtained from the County Agent, only 1,167 acres of groves are irrigated with an average application rate of 15 inches per year per acre of water. At this rate, it is estimated that the quantity of water withdrawn from the Floridan aquifer for citrus irrigation is 1.3 mgd.

WATER QUALITY

The chemical character of natural water is affected by atmospheric, soil and rock environments, and as ground water by topography, mineralogy, and transmissivity of the hydrologic system (Back and Hanshaw, 1965, p. 72). Precipitation contains small amounts of dissolved atmospheric gases, particularly carbon dioxide, which enhance the solvent properties of water. Concentrated in soils are inorganic and organic substances as well as carbon dioxide which further mineralize the water. Additional mineralization occurs in the rock environment, depending upon the mineralogy, solubility, porosity, and permeability of the rock as well as the distribution, and exchange capacity and selectivity of the clay minerals (Back and Hanshaw, 1965, p. 74). Therefore, water entering the hydrologic system as recharge at potentiometric highs is usually less mineralized than water leaving as discharge at potentiometric lows.

Water quality of aquifers and lakes in the Crescent City area was inventoried in order to establish base line data. Bermes, et al., 1963, and Munch, et al., 1979, sampled water over a three-county area, including Putnam County; however, sampling of the ridge area was not extensive.

Water samples were collected from five shallow wells screened in the unconfined aquifer, 13 wells in the confined aquifer, and four lakes (Figure 4 and Table 5). Alkalinity, pH, and specific conductance were measured at each site at the time of collection. Chloride, fluoride, sulfate, and sulfide concentrations were determined at the District's laboratory. Potassium, magnesium, calcium, sodium, and dissolved iron concentrations were analyzed by using atomic

TABLE 5. -- Water Quality Analysis Data from Selected Samples of Wells and Lakes Located on the Crescent City Ridge

Sample Name	Source or Aquifer	Specific Conductance (microohms)	Chloride (Cl^-)	Bicarbonate (HCO_3^-)	Carbonate ($CO_3^=$)	Sulfate ($SO_4^=$)	Sulfide ($S^=$)	Fluoride (F^-)	Calcium (Ca^{++})	Magnesium (Mg^{++})	Sodium (Na^+)	Potassium (K^+)	Total Iron (Fe)	Nitrate (NO_3^-)	pH
243	Floridan	238	24.0	112	-	3.0	1.3	.12	19.5	8.6	9.4	.85	<.10	<.005	7.85
411	Floridan	155	17.0	56.5	15.0	3.0	1.0	.16	14.1	3.7	6.8	.53	<.10	.16	8.30
413	Floridan	125	12.0	59.0	23.0	7.0	.24	.16	14.5	1.2	5.0	2.64	<.10	.05	8.60
317	Floridan	291	20.0	150	-	2.0	.32	.09	31.3	7.2	9.1	.78	<.10	<.005	7.70
255	Floridan	370	24.5	188	-	1.0	.90	.13	43.3	7.6	10.6	2.29	<.10	.022	7.15
238	Floridan	265	12.0	157.2	-	0.0	.10	.13	33.8	3.8	3.5	.59	.65	.028	7.60
410	Floridan	445	36.5	234	-	0.0	.37	.12	49.8	11.2	16.8	1.5	<.10	.831	7.35
393	Floridan	650	57.5	287	-	1.0	.38	.14	59.7	14.5	25.3	1.09	1.21	.221	6.95
246	Floridan	212	14.0	114.5	-	0.0	.15	.09	25.6	3.4	5.4	.53	<.10	<.005	7.70
373	Floridan	218	14.0	119	-	0.0	.18	.15	24.6	4.4	5.4	.44	.21	.70	7.70
271	Floridan	875	157	281.8	-	8.0	2.22	.12	60.7	18.4	60.2	1.69	<.10	.362	7.20
395	Floridan	920	260	107	2.0	35.0	1.17	.36	37.3	25.6	97.9	2.17	<.10	.028	8.10
383	Floridan	5600	1795	190	-	45.0	.18	.33	172	83.5	984	21.71	.59	.11	7.20
WK1	Unconfined	142	20	25.5	-	30.0	2.13	.03	15.3	.5	4.9	.64	<.10	.146	6.55
CL1	Unconfined	62	14.0	4.0	-	15.0	.20	.04	1.4	.70	3.7	.93	.98	.165	5.02
WT5	Unconfined	50	9.5	-	-	22.0	.06	<.02	3.6	<.5	2.1	1.82	.21	.757	4.60
WT3	Unconfined	68	25.0	2.0	-	5.0	.11	<.03	<1.0	.90	9.5	.24	.16	.395	5.20
WT4	Unconfined	33	13.0	1.0	-	4.5	.04	.02	<1.0	.50	3.9	.15	<.10	.271	5.30
Lk. Broward	Lake	-	16.5	19.5	-	16.0	.07	.04	2.6	1.7	7.4	1.91	<.10	.04	7.10
Crescent Lk.	Lake	-	99.0	35.5	-	34.0	.22	.09	16.8	7.3	44.9	2.28	.47	.346	7.70
Lk. Stella	Lake	-	36.0	14.5	-	67.5	.02	.07	11.5	7.6	17.7	6.96	<.10	.171	7.60
Clear Lake	Lake	-	18.5	-	-	19.0	.06	.08	1.3	1.9	9.1	1.29	<.10	.059	3.55

NOTE: Sample locations are shown on Figure 4.

absorption methods at the Suwannee River Water Management District. Nitrate concentrations were determined at the University of Florida. Data from the various analyses are listed in Table 5.

Composition ratios for all samples were plotted on a Piper diagram to determine differences in water character between and within aquifers as well as surface water bodies (Figure 18). The diamond on the diagram is divided into six sub-areas, each representing a distinct type of water depending on the dominant percentages of either alkaline or alkalide cations and weak or strong acid anions (Piper, 1953).

Points representing water quality data from Floridan wells plotted in three sub-areas of the diamond. All but three Floridan wells produced water characterized by the dominance of alkaline earths (calcium and magnesium) and weak acids (bicarbonate and carbonate) as indicated by the tight cluster of points occupying that sub-area. Two wells, 395 and 383, produced water dominated by strong acids (sulfate and chloride) and alkali (potassium and sodium). The remaining Floridan well, 271, contained water in which no anion-cation pair exceeded 50 percent.

Table 5 shows that wells 271, 395, and 383 are much more mineralized than the other Floridan aquifer wells and plot left to right, respectively, across the Piper diagram as water quality becomes worse. Those wells are located along the western margin of the ridge in close proximity to the St. Johns River (Figure 4). Floridan water along both sides of the river is high in chloride concentration (251 to greater than 1,000 ppm) with the area affected by this water expanding with depth toward the center of the ridge (Bermes, et al., 1963, Figures 33 and 34). The regional potentiometric map (Figure 19) indicates that the St. Johns River receives ground water from northwest Putnam County and eastern Marion County as well as from the Crescent City Ridge. It

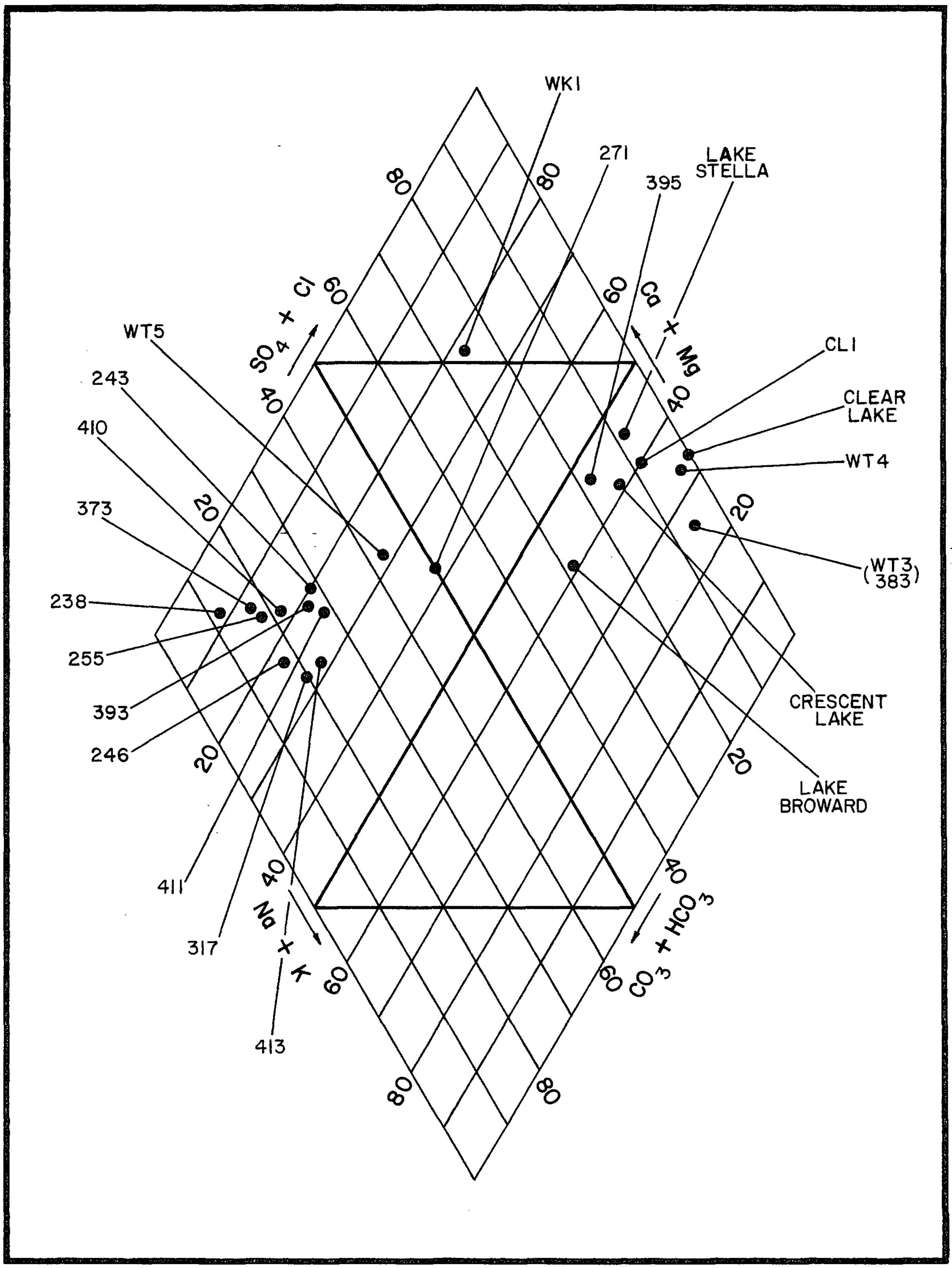


FIGURE 18. -- Piper Diagram Showing Composition Ratios of All Water Samples Collected from Wells and Lakes

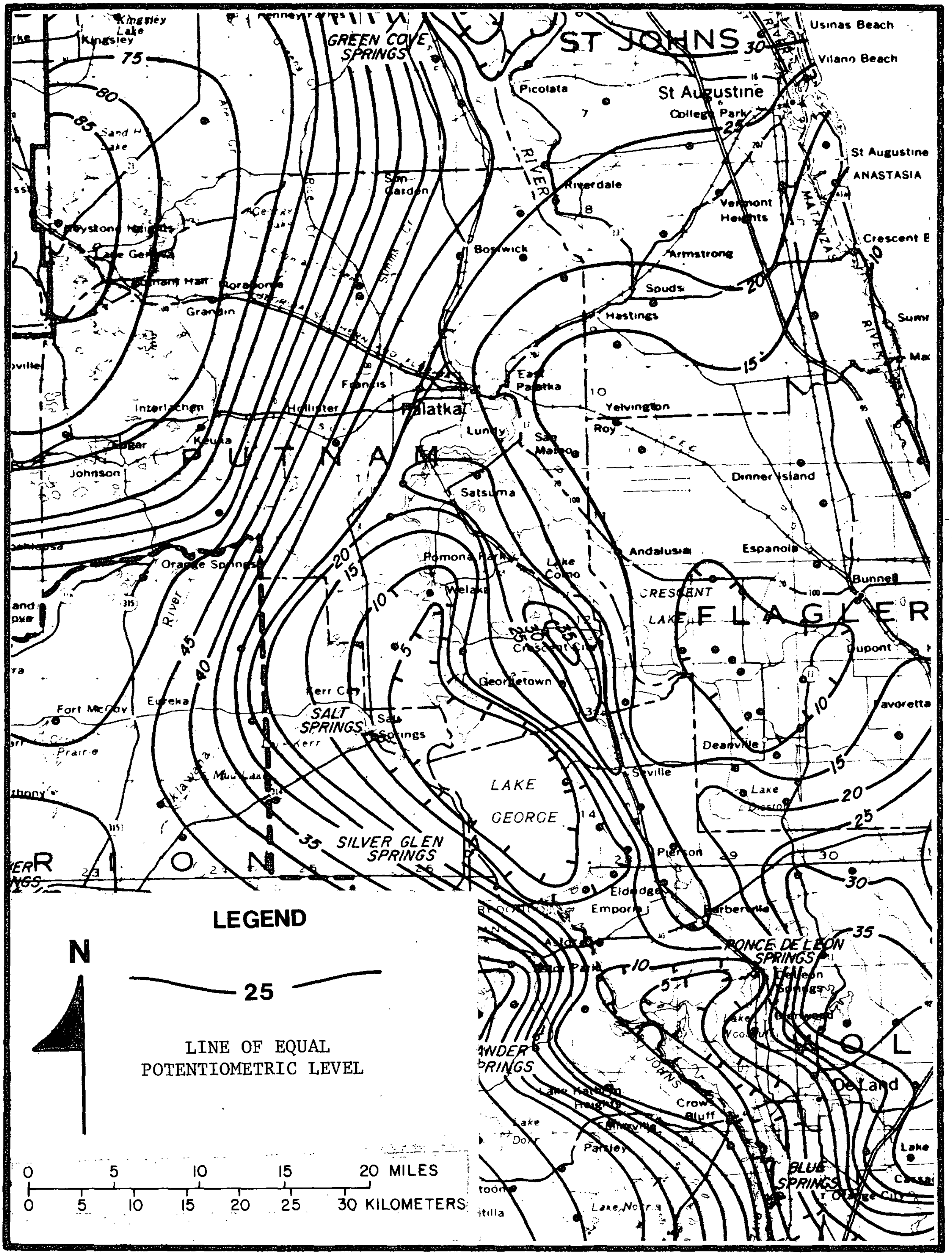


FIGURE 19. -- Map Showing Regional Potentiometric Surface of Floridan Aquifer in Immediate Vicinity of Crescent City Ridge (After Watkins, Laughlin, and Hayes, 1978)

appears then that water from wells along the western margin of the ridge is greatly affected by the poorer quality water from the west. Fracture zones along the river may contribute to additional upwelling of high chloride water from deeper in the aquifer.

Only five wells in the unconfined aquifer could be sampled, making it impossible using the Piper diagram to clearly determine trends in the character of unconfined water. However, the diagram does show that the character of water from the unconfined aquifer differs significantly from most of the samples taken from the Floridan aquifer. Table 5 better illustrates this difference. Water from the unconfined aquifer is much less mineralized, particularly with regard to bicarbonate, chloride, and cations. Sulfate, dissolved iron, nitrates, and pH are higher in the unconfined aquifer.

Points representing lake samples cluster in the right corner sub-area of the diamond along with three of the points representing the unconfined aquifer. This sub-area indicates water dominated by strong acids (sulfate and chloride) and alkali (potassium and sodium). However, the lake water is much less mineralized than Floridan water having similar ironic ratios (Table 5).

WATER BUDGET ANALYSIS

PRECIPITATION

The long term average annual rainfall at the Crescent City Weather Station for the years 1896 through 1976 is 52.73 inches. The normal annual rainfall, average annual rainfall for the period 1941 through 1970, is nearly two inches greater at 54.67 inches (Table 6).

The amount of rainfall varies seasonally, with 53 percent of the average annual rainfall occurring during the wettest one-third of the year. The months June through September are the wettest, each averaging about seven inches. November through April receive the least amount of rain, averaging from slightly below two to approximately three and one-half inches. May and October are transitional months, averaging slightly over four inches each, but have large variations in extremes (Figure 20 and Table 6). Deviations from the long term trends result from summer droughts, tropical storms or hurricanes in late summer and early fall, or from numerous polar fronts during the winter. Wet years average about half again as much precipitation as dry years. The wettest year on record was 1974, with 74.47 inches recorded; and the driest year was 1962 during which only 39.59 inches were recorded.

A more accurate precipitation value for the study area was determined by establishing eight rainfall stations in addition to the NOAA Station at Crescent City (Figure 2). Seven of the stations were established prior to the 1978 water year, and one station was established two months into the water year. The Theissen Polygon Method was used to calculate monthly weighted averages which may be compared to the historical monthly means (1896-1976) at the Crescent City Weather Station (Table 6).

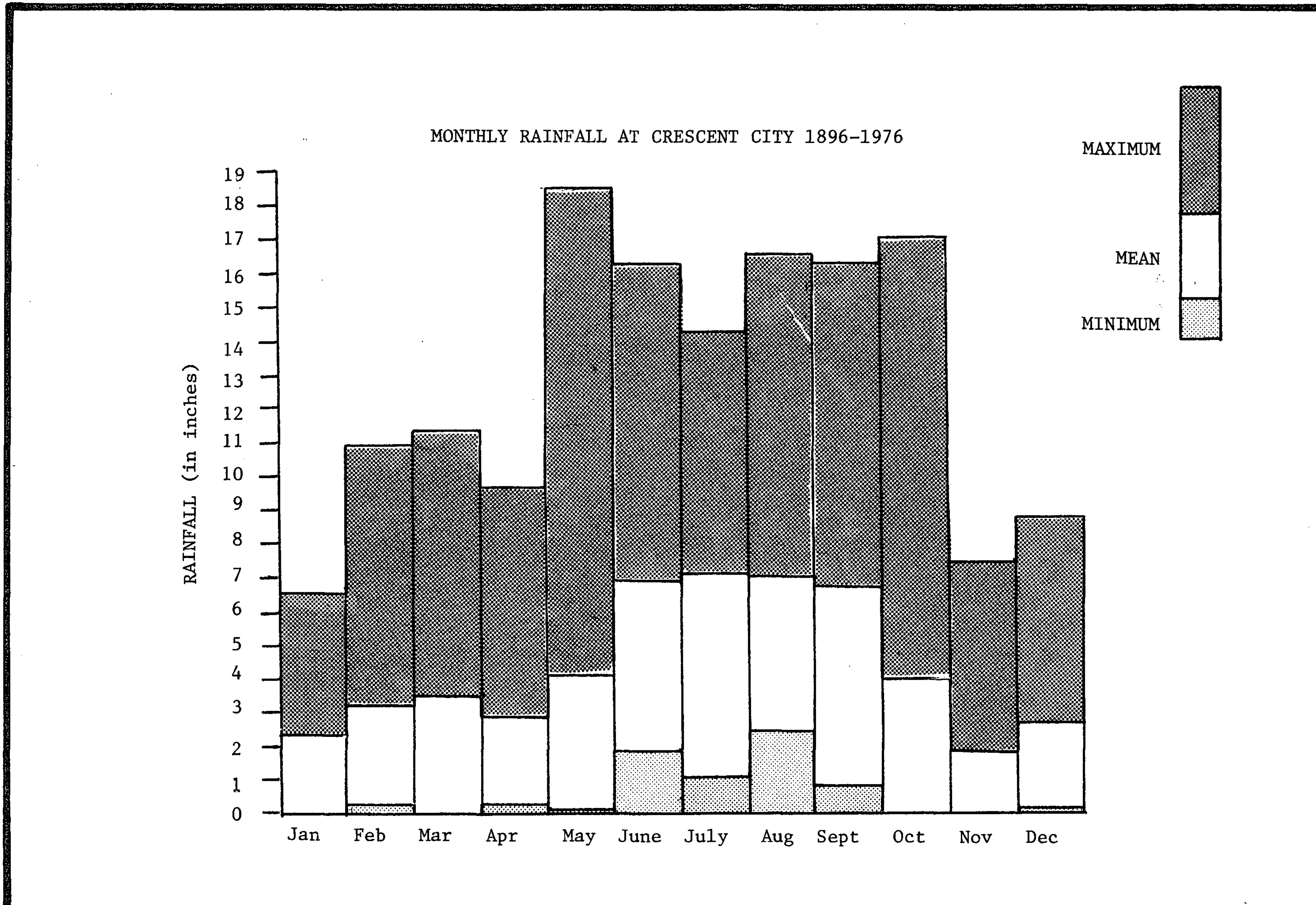


FIGURE 20. -- Bar Graph of Long Term Monthly Rainfall at Crescent City NOAA Weather Station

TABLE 6. -- Rainfall Data from Rain Gages Located on Crescent City Ridge

	Water Year 1978												
Station Name	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	TOTAL
Welaka	0.27	5.82	5.75	3.59	5.19	2.66	1.99	2.18	5.09	10.20	5.95	2.73	51.42
Muck Lake	0.23	6.51	5.94	3.47	4.93	3.99	2.15	2.94	5.05	15.42	5.17	2.31	58.11
Lake Lizzy	0.35	4.81	6.60	3.22	5.01	2.57	1.98	1.66	4.74	14.11	4.51	1.53	51.09
Clear Lake	0.36	4.51	6.74	3.24	5.35	3.55	1.35	1.92	6.89	14.04	4.13	2.30	54.38
Georgetown	-	-	6.25	3.08	5.23	3.89	1.04	1.66	6.28	13.26	3.27	3.84	47.8
Pleasant Lake	0.37	5.47	6.27	3.44	5.37	4.08	1.45	1.44	5.11	9.57	2.58	2.80	47.95
Crescent City	0.33	4.71	6.11	4.16	4.93	5.41	1.80	1.67	5.86	15.05	2.00	2.59	54.62
Lake Como	0.08	5.11	6.66	3.15	5.14	2.39	2.42	2.67	4.59	15.55	5.36	1.96	55.08
Nashua	0.33	5.64	6.31	3.55	5.46	3.01	2.82	3.79	6.59	12.67	3.02	4.63	57.82
Theissen Weighted Average	0.30	5.37	6.31	3.42	5.20	3.43	1.96	2.41	5.76	13.50	3.07	2.89	53.62
Mean 1896-1976 Crescent City	4.03	1.90	2.72	2.39	3.23	3.48	2.91	4.13	6.43	7.14	7.11	6.76	52.73
Normal 1941-1970 Crescent City	4.52	2.04	2.54	2.38	3.44	3.90	3.16	3.45	6.39	7.65	7.54	7.66	54.67

NOTE: Rain gage locations are shown in Figure 4.

The weighted average rainfall of all nine stations for the 1978 water year was 53.62 inches, about one inch above the long term average, but below normal for the Crescent City Weather Station by the same amount. Although the total rainfall for the year was within the normal, individual monthly averages were atypical. Normally wet months of August, September, and October were very dry with only .30 inches recorded in October. Normally dry winter months were marked by rainfall approaching twice normal.

EVAPORATION

Evaporation is the change in state of a liquid substance to a gas. This change takes place only when there is available energy to provide the latent heat of evaporation and with sufficient air movement to remove the accumulated vapor building up at the air-liquid interface. Energy for evaporation at the earth's surface is supplied by the sun. However, only 40 percent of the total incoming radiation reaches the earth's surface, the remainder is lost through reflectance and atmospheric absorption (Gray, McKay, and Wigham, 1970, p. 3.1 and 3.17). Other factors affecting evaporation include wind conditions, relative humidity, atmospheric pressure, air-water temperatures, and size and depth of water bodies (Gray, et al., 1970, p. 3.39, and Yobbi and Chappell, 1979, p. 9). Evaporation is a major component of the hydrologic cycle, a process which returns approximately 75 percent of the total annual precipitation back to the atmosphere (Gray, et al., 1970, p. 3.1).

Lake Evaporation

Evaporation from shallow water bodies can only be estimated by indirect methods. The most convenient methods are those which allow evaporation to be estimated from either standard meteorologic data or by direct measurement from a Class A evaporation pan (Gray, *et al.*, 1970, p. 3.26). Both methods were utilized for this study; however, climatological and pan evaporation data were not collected within the study boundaries. Data from the University of Florida's Agronomy Farm Weather Station, Gainesville, Florida, located approximately 50 miles to the west, was used and applied to the Crescent City area.

Kohler, Nordenson, and Fox, (1955, p. 16), derived equations for which meteorological measurements of solar radiation, wind movement, dew point temperature, and air temperature as well as measured pan evaporation may be used to estimate evaporation from lake surfaces and Class A evaporation pans. The Kohler, *et al.* equations are usually solved graphically. However, Lamoreux (1962) reduced these equations to mathematical expressions which are adaptable to computer use and for which input data are expressed in readily available terms. Individual monthly pan and lake evaporation values were estimated using the computerized Kohler, *et al.* equations and summed to produce an estimated annual lake evaporation value of 43.03 inches (Table 7).

Evapotranspiration

Evapotranspiration is the combined process by which water is transferred from the earth's surface to the atmosphere by evaporation and transpiration by plants (Jensen, 1974, p. 207). Evapotranspiration is effected by the same factors which effect evaporation as well as by soil and vegetative conditions (Gray, *et al.*, 1970, p. 3.39).

Potential evapotranspiration (PET) is a measure of evapotranspiration, assuming that water is always made available to the soil. However, actual evapotranspiration (AET) will be less than PET due to periods when lost soil and plant moisture is not immediately replaced. AET values are also effected by land use

TABLE 7. -- Monthly Measured Pan Evaporation and Calculated Pan and Lake Evaporation Values at Gainesville, Florida--Water Year 1978

Month	Measured Pan Evap. (inches)	Calculated Pan Evap. (inches)	Calculated Lake Evap. (inches)	*Adjusted Lake Evap. (inches)
Oct.77	4.77	4.75	3.35	3.35
Nov.	3.31	3.07	1.96	2.12
Dec.	2.44	2.67	1.65	1.50
Jan.78	2.88	2.78	1.81	1.88
Feb.	2.61	2.50	1.67	1.74
Mar.	4.75	3.44	2.69	3.71
April	7.85	7.18	5.30	5.78
May	7.58	7.34	5.34	5.50
June	7.02	6.57	4.84	5.18
July	6.51	6.02	4.39	4.74
Aug.	5.85	6.49	4.77	4.29
Sept.	5.86	5.69	4.00	3.24
TOTAL	61.43	58.50	41.77	43.03

$$* \text{ Adjusted Lake Evaporation} = \frac{\text{Measured Pan Evap.}}{\text{Calculated Pan Evap.}} \times \text{Calculated Lake Evap.}$$

and vegetative community patterns (Dohrenwend, 1977, p. 189). Ratios of AET to PET for various locations in Florida have been calculated by Dohrenwend, (1977); and based on his data, a AET/PET ratio of 0.81 was determined for the Crescent City Ridge area.

Although PET may be calculated in various ways, lake evaporation is frequently used as an equivalent measure (Jensen, 1974, p. 69). Using the relationship of AET/PET = 0.81 and substituting the value of annual lake evaporation for PET, then the annual AET for the Crescent City Ridge area is determined to be 34.85 inches.

WATER BALANCE EQUATION

The water balance equation is based on the principle of conservation of matter. When applied to hydrology, it means that the total input of water to a natural area during any period of time will be equaled by the total output plus a net change in water volume stored within the area. The water balance for the Crescent City Ridge during the 1978 water year is expressed by the equation:

$$P = ET + R + Pu + \Delta S + GO$$

where

P = precipitation

ET = evapotranspiration

R = runoff (streamflow)

Pu = ground water pumpage (Floridan aquifer)

ΔS = change in storage (unconfined aquifer and surface water)

Go = ground water outflow (Floridan aquifer)

With the exceptions of the change in storage (ΔS) and ground water outflow (Go), components of the water balance were measured, calculated, or estimated as explained in previous sections.

Change in Storage

The change in storage (ΔS) represents the volume of water either gained or lost from surface waters and aquifers during a given length of time. Ideally, ΔS is determined as the residual in the balance equation for a period in which the net change in storage is small. However, the period of record represents a time of greatly increasing water levels in lakes and aquifers following a substantial period of declines. This results in an abnormally large change in storage for the year which can be estimated from lake and water level data.

The average net change in lake stage height for the ten lakes monitored for the 1978 water year (+ 22.2 inches) was used as an estimate for the net change in storage for the wetland portions of the ridge. The net change in storage for the normally dry portions of the ridge was estimated from the average net change in the elevation of the water table (+ 36 inches) monitored in the shallow observation wells, multiplied by the specific yield of the surficial sand (20 percent). The specific yield was estimated from the grain size distributions for the surficial sand. Wetland areas occupy 22 percent of the ridge; therefore, the total net change in storage for the 1978 water year equals:

$$\begin{aligned} \Delta S &= (.22)\ (22.2'')\ +\ (.78)\ (.20)\ (36'') \\ &= 4.88'' + 5.62'' \\ &= 10.50'' \end{aligned}$$

Ground Water Outflow

The component of the water balance represented by ground water outflow (Go) was left as the residual of the water balance equation. The large change in storage (ΔS) and insufficient knowledge of aquifer characteristics suggested that ground water outflow could better be estimated in this manner. When all components are expressed to the nearest inch, ground water outflow becomes 4 in/year or 24 mgd.

In summary, the water balance equation for the Crescent City Ridge for the 1978 water year is:

$$P = ET + R + Pu + \Delta S + Go$$

where

P = 54 inches

ET = 35 inches

R = 3 inches

Pu = 1 inch (Floridan aquifer)

ΔS = 11 inches (unconfined aquifer and surface water)

Go = 4 inches (Floridan aquifer)

Recharge to the Artesian Aquifer

Although it is recognized the ground water outflow consists of water derived from the unconfined as well as the confined aquifer system, it is believed that the unconfined aquifer contributes only a small percentage to the total outflow. Therefore, for the purposes of estimating recharge to the confined system, the following equation may be used:

Average recharge = ground water outflow (Go) + pumpage (Pu)

= 4 inches + 1 inch

= 5 inches

or a recharge rate of approximately 30 mgd.

SUMMARY

The sand hills, lakes, and marshes of the Crescent City Ridge occupy the area between Crescent Lake and the St. Johns River in southeast Putnam County. The ridge is underlain by formations of Eocene Limestone forming an elongated high which parallels the present axis of the ridge. Overlying the Eocene limestones are Miocene limestones, clays and sandy clays which form a wedge of sediment that thickens to the east. Fine to very fine Pleistocene marine sands and clayey sands blanket the entire ridge, with hilly areas standing as remnant beach ridges deposited during the 100-foot rise in sea level. The St. Johns River flows north along the west flank of the ridge following the channel of an older river. This portion of the river has been termed the St. Johns River Valley Offset.

Ground water occurs in three aquifers within the ridge: non-artesian, secondary artesian, and artesian. The Eocene limestones and the basal Miocene limestone comprise the Floridan aquifer which is the area's major source of fresh water. The Miocene clays act as the confining layer in which discontinuous beds of permeable shell and limestone form secondary artesian aquifers. Secondary artesian aquifers supply some fresh water, but their extent of development remains uncertain. The Pleistocene marine sands are of low permeability, 143 gal/d/ft, and are used locally to supply small amounts of water.

The largest use of water in the Crescent City Ridge area is for irrigation. Approximately 600 acres are planted in ornamental ferns which require 150 gallons per minute per acre during a three-hour weekly pumping period for optimum growth. Freeze protection application rates reach .35 inches per hour, and pumps may be run up to a day in length. Approximately 2,700 acres of citrus are grown in the area of which 1,167 acres are irrigated. The Floridan aquifer supplies

2.7 mgd of fresh water for irrigation, and an additional one mgd is withdrawn for domestic use through private wells, a few small public utilities, and one larger municipal system.

Potentiometric pressures within the Floridan aquifer form a localized high with water level elevations ranging from five feet to 38 feet above MSL. Recharge occurs by the infiltration of precipitation through the sand hills with discharge occurring naturally at the ridge margins where the potentiometric surface is higher than the water table and through pumpage of wells. Water levels in all aquifers fluctuate seasonally with lowest levels usually occurring in May and highest levels in September. Large volumes of water are withdrawn from the Floridan aquifer in winter for frost and freeze protection which produce rapid localized short term declines in water level. A pump test of the Floridan aquifer produced a value for transmissivity of 126,000 gal/d/ft and a storage coefficient of 3.5×10^{-4}. A value of 120,000 gal/d/ft for the transmissivity of the entire ridge was determined by flow net analysis.

Water quality in the Floridan aquifer is generally good. Most Floridan wells produce water low in chlorides and other dissolved solids; however, wells sampled near the St. Johns River are relatively high in chlorides (157 ppm to 1,795 ppm), suggesting that the west flank of the ridge is influenced by ground water movement from outside the area or from deeper formations.

Lakes are associated with sandy uplands as well as low, swampy areas. Water to lakes is supplied from direct precipitation, ground water seepage, and surface runoff. Lowland lakes interconnect at times of high water to form part of the internal surface drainage system of the ridge. Lake levels are most greatly affected by evaporation and precipitation and do not appear to be affected by present withdrawal rates from the artesian aquifer. Lake levels increased for the 1978 water year with an average rise of 1.85 feet in the ten lakes monitored for this study.

The Crescent City Ridge contains many individual closed drainage basins with no topographically expressed surface water outlets. Eight creeks drain 35 percent (27,472 acres) of the ridge's 78,745 acres. Discharge for the creeks was measured periodically, and the average daily mean flow for individual creeks was determined by comparing periodic discharge measurements to continuous discharge recorded at Acosta Creek. Total calculated runoff from the project area for the water year was 2.92 inches.

An annual water budget for the 1978 water year was determined based on measured, calculated, or estimated values of precipitation, runoff, evapotranspiration, ground water pumpage, change in storage, and ground water outflow. The area received 54.6 inches of precipitation for the water year which is the weighted average of nine rainfall stations distributed throughout the ridge.

Evapotranspiration of 34.85 inches was calculated from data collected at the Gainesville Weather Station. The change in ground water storage of + 10.50 inches was estimated from net water table and lake level changes. Ground water outflow (Go) was calculated as the residual. The water balance equation for the Crescent City Ridge for the 1978 water year is expressed as:

$$P = ET + Pu + \Delta S + R + Go$$

or

54 inches = 35 inches + 1 inch + 11 inches + 3 inches + 4 inches

Recharge to the Floridan aquifer along the Crescent City Ridge was estimated to be equal to the addition of ground water outflow (4 inches) and exported water (1 inch) from the Floridan aquifer, or approximately 30 mgd.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The presence of the Crescent City Potentiometric High can be attributed to several factors: (1) structure of the bedrock high formed by the Eocene Limestone which underlies the area, (2) the occurrence of ample amounts of precipitation, and (3) the ability of the overlying sand and clay deposits to store and transmit water to the artesian aquifer. Regional potentiometric maps show that the area influenced by the high is confined primarily to the physical boundaries of the Crescent City Ridge. Ground water from the high flows principally to the east and west with natural discharge occurring to Crescent Lake and the St. Johns River.

Water high in chlorides and other dissolved solids is found in wells penetrating the Floridan aquifer near the margin of the ridge along the St. Johns River. Bermes, et al. (1963) show that below 200 feet in the Floridan aquifer, the area affected by this water expands towards the center of the ridge. This indicates that the rate of recharge is not great enough to completely flush saline water from the lower part of the aquifer.

Present annual rates of ground water withdrawal appear to fall within the limits of the Floridan aquifer to supply fresh water. However, the concentration of large, deep irrigation wells, particularly in a belt between Crescent City and Fruitland, is rapidly increasing. An overdraft by these closely spaced high capacity wells has the potential to significantly lower the local potentiometric surface to induce upconing of saline water from lower zones of the aquifer.

Another problem arising from severe local reductions in artesian levels has already been experienced near Crescent City as well as under similar conditions in the Pierson area of Volusia County. As drawdowns in water levels expand around high capacity irrigation wells in the Floridan aquifer, water levels in shallow domestic wells drop far enough to render those wells inoperative. The most critical time for such problems to occur is in winter when intensive pumping for freeze protection of ornamental ferns takes place. Problems will be further complicated during years of deficient rainfall.

This investigation has left some questions unanswered which are suggested for additional study. Avenues for further research are: (1) better definition of aquifer characteristics for the unconfined, secondary artesian, and artesian aquifers, (2) determination of areal extent and development of secondary artesian aquifers, (3) investigation of drawdowns occurring around large capacity irrigation wells during times of peak water withdrawals, (4) continuous monitoring of water quality in irrigation wells throughout the duration of an intensive pumping period, and (5) a more accurate determination of the areal distribution and quality of the poor quality ground water associated with the St. Johns River.

RECOMMENDATIONS

The Crescent City Ridge area is experiencing growth which may bring about the need for supervised local water management. The use of ground water is growing yearly due to the expanding amount of acreage tied to the production of ornamental ferns as well as to the many people who are finding the area an attractive place to settle.

As part of a water management plan, the authors recommend that the St. Johns River Water Management District continue to monitor "key wells and lakes", establishing a regional monitoring network for the Crescent City Ridge area. Several wells currently being monitored and for which long term records exist are now planned to be incorporated into the District's Observation Well Network (DOWN).

At this time, insufficient data have made it impossible to estimate drawdowns incurred at ferneries during freeze protection. However, a project planned for the 1980 water year will provide data on water quality as well as water level changes occurring in the Floridan aquifer from extreme ground water withdrawals. This knowledge will enable us to predict drawdowns as well as to help fern growers establish optimum well spacings for large irrigation wells that will minimize drawdowns as well as any possible degradation of water quality. Additionally, we will be able to design specifications for small domestic wells which, when followed, will enable those wells to produce water even under extreme localized drawdown conditions. Such domestic well specifications will help local officials expand their criteria for water well construction permitting in the Crescent City Ridge area.

Land use planners, when designing development plans, should consider that some areas, particularly along the St. Johns River, are known to have poor quality ground water. Accurate knowledge as to the areal extent of this mineralized ground water will assist in planning for future population growth and land development.

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APPENDIX

TABLE A1--SUMMARY OF WELL DATA

WELL NUMBER	WELL OWNER	AQUIFER	DATE OF INITIAL READING	ELEVATION OF MEASURING POINT	HIGH READING	HIGH DATE	LOW READING	LOW DATE	MEAN	NET CHANGE WATER YR 78
413	SJRWMD	FLA	03/08/78	54.33	38.79	10/03/78	36.98	06/29/78	37.76	+1.81
410	SJRWMD (UNION CAMP)	FLA	06/30/78	25.00 *	23.90	07/28/78	22.60	06/30/75	23.39	+1.30
317	NEWBOLD	FLA	07/01/75	9.58	17.58	03/02/78	14.48	06/29/78	16.64	+1.27
271	LEROY MALUDA	FLA	03/17/75	5.00 *	11.85	10/03/78	9.30	05/17/76	10.26	+1.32
267	PARKER	FLA	03/17/75	46.08	28.72	03/29/78	26.00	05/25/77	28.60	+0.90
274	RANDY MALPHURS	FLA	03/17/75	25.00 *	28.70	08/29/78	23.87	05/25/77	76.92	+2.00
255	WESNOFFSKE FARMS	FLA	03/14/75	10.00 *	16.20	09/17/75	13.90	06/28/78	15.22	+0.11
238	DEXTER FARMS	FLA	05/05/77	37.37	31.26	08/03/78	28.44	07/21/77	29.96	+1.90
242	D. GAUTIER	FLA	03/17/75	52.39	30.62	07/31/78	27.77	05/17/76	29.25	+1.37
270	PAUL CHAMBERS	FLA	03/17/75	28.80	18.47	10/03/78	16.31	05/04/77	17.58	+1.37
246	COL. SAULS	FLA	03/17/75	49.75	19.81	08/30/78	15.73	07/28/77	18.46	+1.86
405	MURPHY	FLA	09/22/77	62.43	30.57	07/28/78	28.00	05/31/78	29.23	+1.40
375	J.P. DEAN	FLA	04/08/77	79.17	18.94	08/29/78	14.52	06/28/78	16.90	+2.61
340	CROWN UTILITIES	FLA	03/17/77	21.59	8.57	10/03/78	6.71	02/28/78	7.23	+1.39
383	L. SMITH	FLA	04/14/77	11.66	6.05	10/03/78	3.98	04/14/77	4.96	+1.57
373	LEE MANSFIELD	FLA	04/14/77	56.63	24.83	07/31/78	22.67	09/15/77	23.77	+1.30
268	PHILLIP HUNTER	FLA	03/17/77	37.57	27.30	07/31/78	25.75	09/16/77	26.58	+1.25
411	SJRWMD	FLA	01/30/78	6.76	23.05	10/11/78	20.76	05/30/78	22.12	**
341	UNDETERMINED	FLA	03/17/77	65.17	29.13	03/01/78	25.87	03/17/77	27.40	+1.36
338	HENRY WIGGINS	FLA	04/07/77	30.97	14.59	02/28/78	8.41	10/26/77	10.76	+1.80

TABLE A1--CONTD.

WELL NUMBER	WELL OWNER	AQUIFER	DATE OF INITIAL READING	ELEVATION OF MEASURING POINT	HIGH READING	HIGH DATE	LOW READING	LOW DATE	MEAN	NET CHANGE WATER YR 78
387	H.L. BARKER	FLA	04/14/77	41.00 *	24.94	07/31/78	21.30	04/14/77	23.19	+1.48
336	J.W. HUTCHENSON	FLA	09/15/77	20.00 *	13.71	01/03/78	12.02	01/04/78	13.00	+1.45
401	COLLETTE	FLA	05/02/77	2.00 *	18.80	03/01/78	14.13	09/16/78	16.90	+2.87
393	PARADISE LAKES	FLA	04/25/77	23.00 *	16.47	07/28/78	14.40	04/25/77	15.43	+0.99
400	GEORGE ZEAGLER	FLA	05/02/77	99.39	21.29	08/29/78	17.86	05/02/77	19.51	+2.45
382	DAVE MAIN	FLA	04/13/77	64.82	30.32	08/29/78	28.16	04/13/77	29.41	+1.46
395	MRS. HAMILTON	FLA	05/02/77	5.00 *	21.75	10/03/78	16.97	10/31/77	20.75	+1.97
396	U.S.FISH & WILDLIFE	FLA	04/13/77	7.93	12.09	10/03/78	10.83	05/30/78	11.30	+1.04
359	BYRON BUTTLER	FLA	03/23/77	10.00 *	14.04	10/03/78	11.70	03/23/77	12.54	+2.19
348	BILL PHILLIPS	FLA	03/17/77	40.00 *	30.04	03/17/77	28.51	10/27/77	29.28	**
243	R.C. FOX	FLA	03/17/75	8.00	32.09	07/21/78	28.30	06/28/78	30.25	+1.73
273	CRABTREE	FLA	03/17/75	24.03	5.99	03/28/78	4.35	07/21/77	5.28	**
CL1	SJRWMD	UNC	01/31/78	32.40	29.00	07/31/78	28.35	01/31/78	28.66	**
CL2	SJRWMD	UNC	01/31/78	74.12	53.70	08/29/78	50.50	06/28/78	52.22	**
WK1	SJRWMD	UNC	01/31/78	23.35	15.14	03/29/78	13.32	06/28/78	14.31	**
WK2	SJRWMD	UNC	01/31/78	54.07	37.73	03/29/78	35.77	06/28/78	36.74	**
WK4	SJRWMD	UNC	02/28/78	88.19	69.05	08/29/78	65.29	05/30/78	66.20	**
WK5	SJRWMD	UNC	02/28/78	96.21	72.36	08/29/78	69.27	02/28/78	70.27	**
WT1	SJRWMD	UNC	09/19/77	61.00 *	36.98	02/28/78	35.33	11/15/77	35.83	**
WT2	SJRWMD	UNC	10/06/77	57.00 *	44.60	10/06/77	41.59	11/15/77	42.55	**
WT3	SJRWMD	UNC	10/17/77	46.00 *	36.73	02/01/78	34.58	11/15/77	35.36	**
WT4	SJRWMD	UNC	10/20/77	50.00 *	36.22	01/03/77	34.94	12/01/77	35.40	**
WT5	SJRWMD	UNC	10/20/77	43.00 *	39.54	02/01/78	37.66	10/20/77	38.50	**

* ELEVATION OF MEASURING POINT ESTIMATED FROM TOPOGRAPHIC MAP

** DATA NOT AVAILABLE FOR COMPLETE WATER YEAR

WELL LOCATIONS SHOWN ON FIGURE 4

TABLE A2 --SUMMARY OF LAKE DATA

LAKES	OWNER OF SITE	DATE OF INSTALLATION	ELEVATION OF REFERENCE MARK	HIGH READING	HIGH DATE	LOW READING	LOW DATE	MEAN	NET CHANGE WATER YR 78
MUCK LK	FORESTER	08/12/77	26.75	33.43	09/06/78	29.63	11/04/77	31.14	+3.02
LK BROWARD	WELLS	08/31/77	35.41	39.96	08/15/78	37.85	10/27/77	38.73	+1.25
LK LIZZY	TOY	08/31/77	38.14	43.96	08/14/78	41.19	08/31/77	42.50	+1.77
MALL LAKE		08/03/77	33.41	39.03	08/15/78	36.23	11/04/77	38.85	+1.82
CLEAR LK	DELANY	08/31/77	30.88	36.90	08/14/78	34.03	11/04/77	35.28	+2.18
PLEASANT LK	MURPHY	08/04/77	46.59	52.87	08/10/78	50.25	11/04/77	51.64	+1.74
LK STELLA	GAUTIER	04/18/77	35.45	40.13	08/15/78	37.63	11/04/77	38.78	+1.54
SILVER LK		08/31/77	31.81	38.29	08/15/78	34.64	11/04/77	35.81	+2.79
LK MARGARET		08/04/77	30.57	35.34	08/15/78	33.47	11/04/77	34.15	+1.08
LAKE COMO	AUTH	06/15/77	32.59	37.84	08/13/78	35.45	11/02/77	36.28	+1.33

LAKE LOCATIONS SHOWN ON FIGURE 4