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SUMMARY OF THE HYDROLOGY OF THE UPPER ETONIA CREEK BASIN

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INTRODUCTION

Major recharge areas within the St. Johns River Water Management District are indicated by closed potentiometric highs on the potentiometric map of the District (Figure 1). The Upper Etonia Creek study area, outlined on Figure 1, is one of these recharge areas. Because of the importance of recharge areas to water resources of the District, a study of the hydrology of the Upper Etonia Creek area was undertaken.

In October 1974, the St. Johns River Water Management District entered into a cooperative agreement with the U. S. Geological Survey that included provisions for a joint study of the hydrology of the Upper Etonia Creek Basin. Although this project was initiated with the support of the U. S. Geological Survey, after July 1975, the project was conducted as a District project exclusive of the cooperative agreement.

During this period from December 1974 through July 1975, measuring points were established and wells were inventoried in the project area. Regular data collection began in July 1975 and continued through December 1976. During this period, staff gages were installed on selected lakes with volunteer observers assisting in the data collection. Water level recorders were installed on selected wells and surface water bodies, and periodic discharge measurements were made on Upper Etonia Creek and its tributaries. An aquifer test was conducted on a well completed in the Floridan aquifer to determine local aquifer characteristics. During 1976, non-recording rain gages were installed at three locations within the project area, and data from

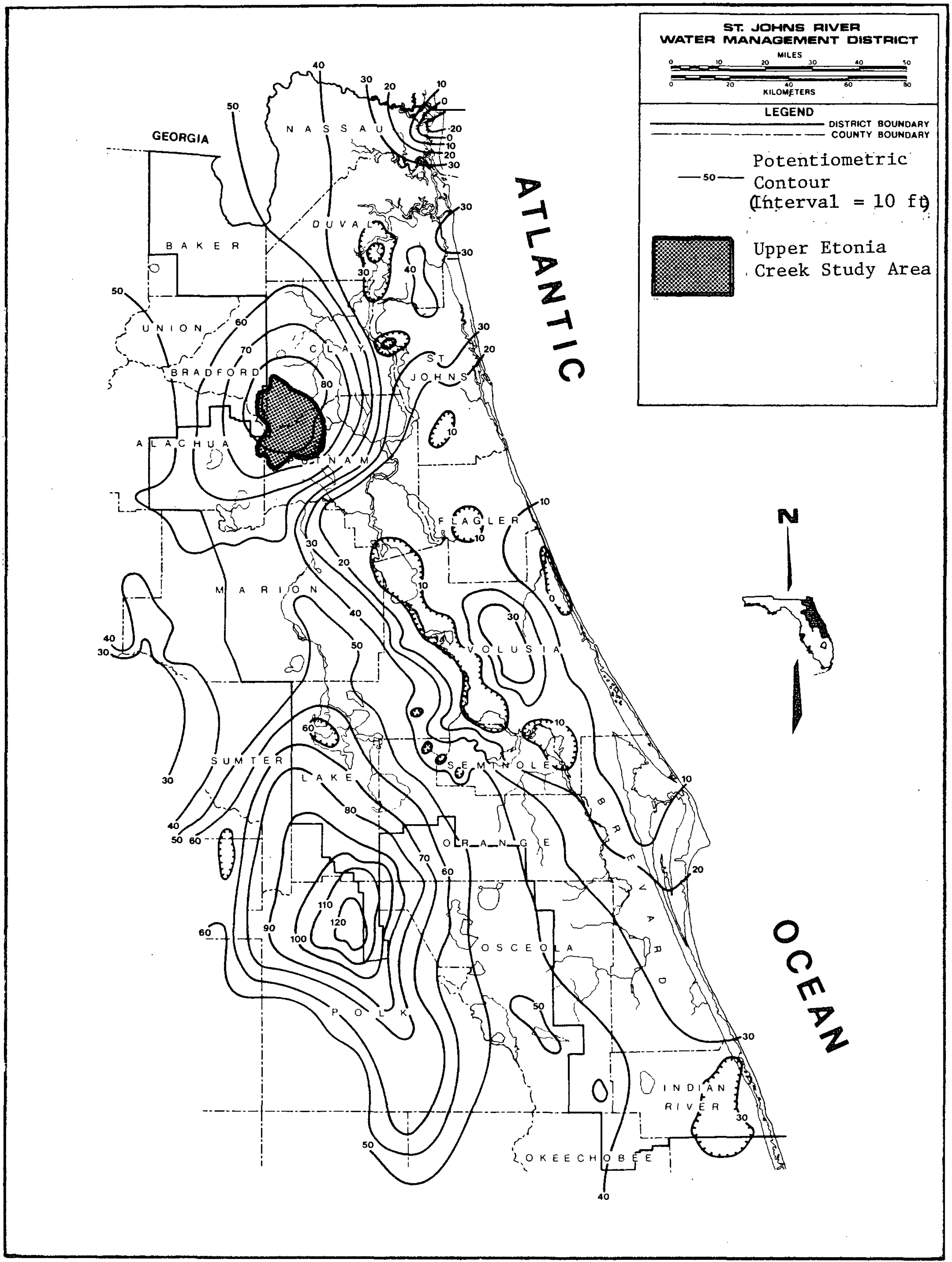

FIGURE 1. -- Potentiometric Surface of the Floridan Aquifer, SJRWMD, May 1974 (Modified from Healy, 1975), Showing the Location of the Study Area

these gages were used to supplement data from National Oceanic and Atmospheric Administration (NOAA) stations nearest to the project area. A monitoring network was established, and data collection has continued to date.

Rainfall, evaporation estimates, evapotranspiration estimates, ground water levels, lake stages, stream discharges, and drainage areas were measured or computed. In the following pages, the most significant findings of the investigation are presented.

PHYSICAL SETTING

PHYSIOGRAPHY

The Etonia Creek Basin lies between 29° 37' and 29° 53' north latitude and 81° 51' and 82° 04' west longitude. The geographic boundary of the project area circumscribes a kidney-shaped area of 165 square miles including parts of Alachua, Bradford, Clay, and Putnam Counties (Figure 1). The community of Putnam Hall is at the approximate center of the project area.

The Upper Etonia Creek Basin is contained within the physiographic division of Florida known as the Central Highlands (Puri and Vernon, 1964). The topography of the basin is shown schematically on Figure 2. Prominent features of the area include the high sand hills in the northwestern part of the area and an elliptically shaped depression, the Florahome Valley, in the eastern part of the area. Elevations range from above 150 feet msl in the northwestern sand hills to below 100 feet msl in the Florahome Valley. Land surface elevation between the two areas is generally between 100 feet and 150 feet msl with significant areas below 100 feet msl.

Numerous solution depressions occur throughout the area, and the lakes in the area have developed within these depressions. The most areally extensive of these depressions is the Florahome Valley that comprises an area of about 40 miles square. Another fairly extensive solution depression is Levy's Prairie which is located in the southwest part of the study area.

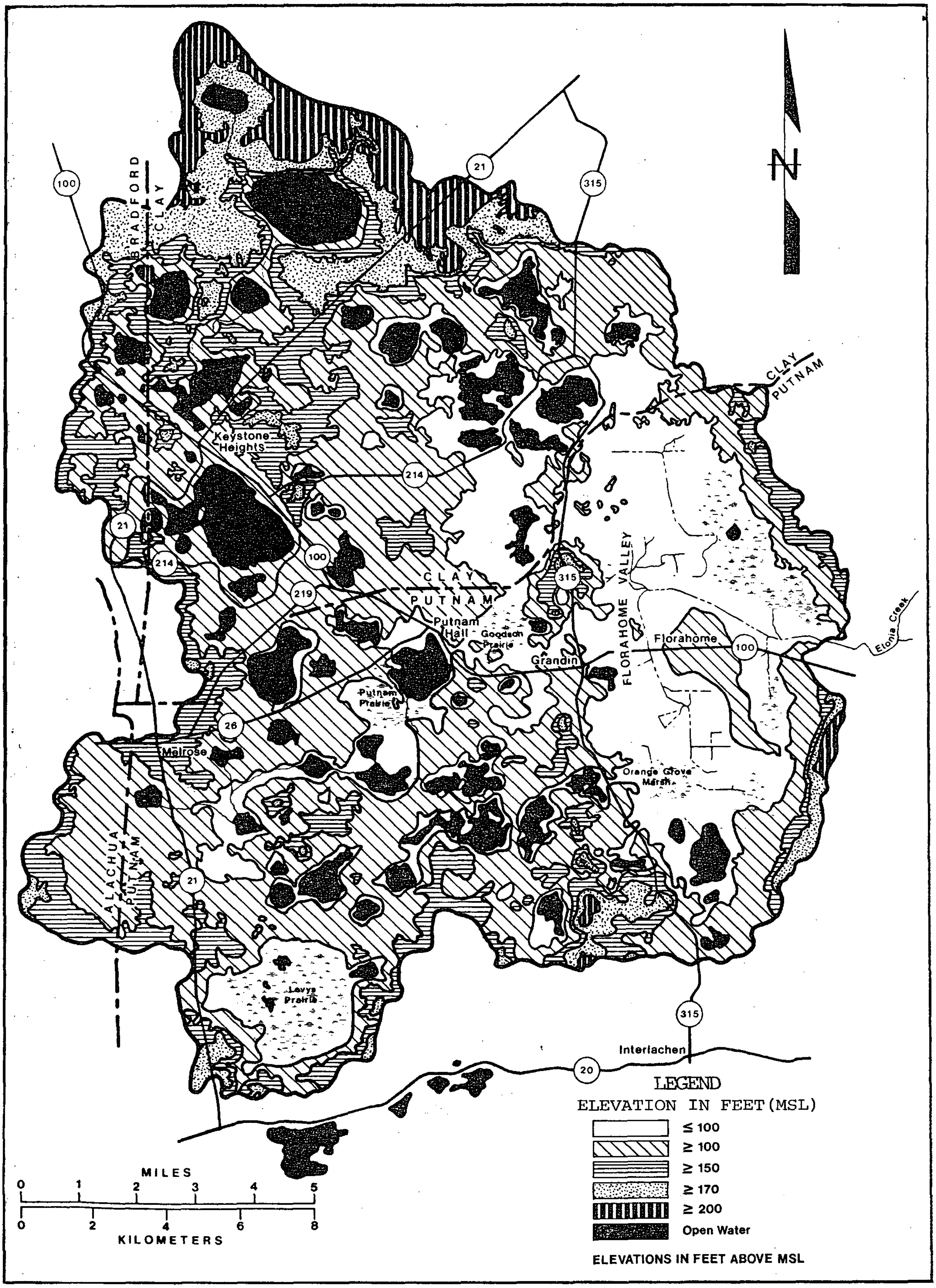

FIGURE 2. -- Topography of the Upper Etonia Creek Basin

CLIMATE

The climate of the study area is classified as humid subtropical. The area lies in a zone of transition between the humid temperate climate of the southeastern United States and the tropical climate of the lower latitudes.

Precipitation

Precipitation within the Upper Etonia Creek Basin occurs primarily as rainfall and is highly variable. The summer rains associated with afternoon thunderstorms have more areal variation than winter and spring rains that are associated with widespread frontal activity. Mean annual rainfall for the area is approximately 52 inches. A plot of yearly, monthly high, monthly low, and monthly mean rainfall at Gainesville for the period 1898-1976 is shown in Figures 3 and 4. Annual rainfall varied from a high of 76.95 inches in 1964 to a low of 32.79 inches in 1917. Monthly rainfall varied from a high of 16.41 inches in July to no rainfall in March. On the average, the dryest month is November, and the wettest month is July. The dry season occurs from late October through May. The wet season occurs from June through September with more than half of the total yearly rainfall normally falling during this four-month period.

Yearly departures from normal rainfall at Gainesville for the period 1940-1978 are shown in Figure 5. The zero departure line represents the normal rainfall of 54.59 in/yr for the 30-year base period. The height of the columns represents the number of inches above (+)

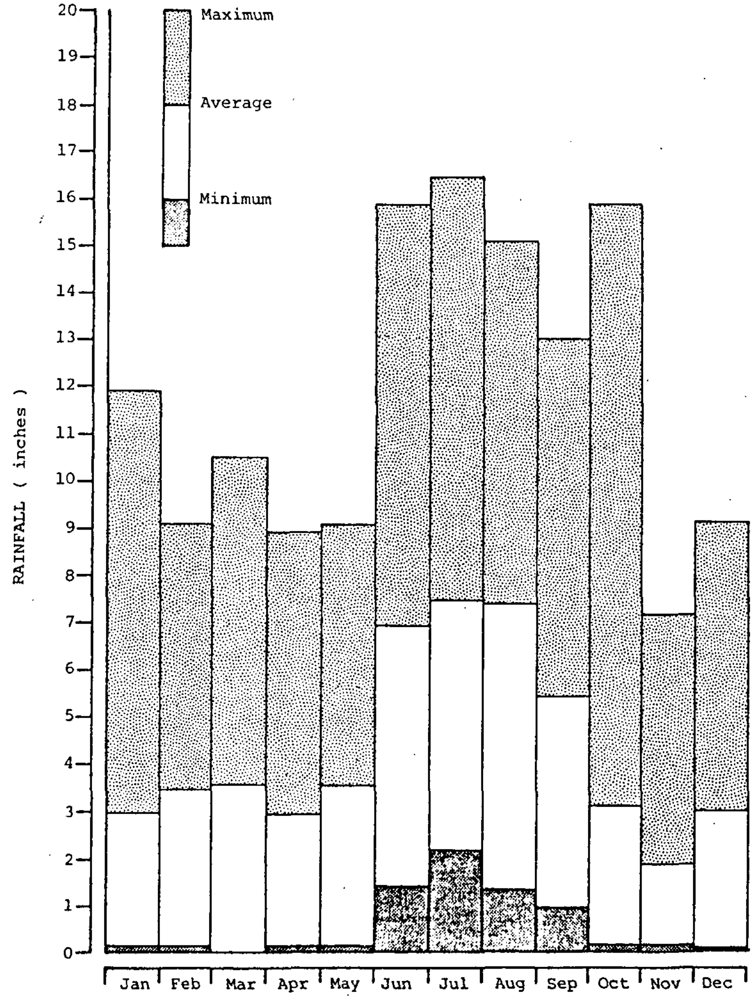

FIGURE 3. -- Average Monthly Rainfall at Gainesville for the Period 1898-1976

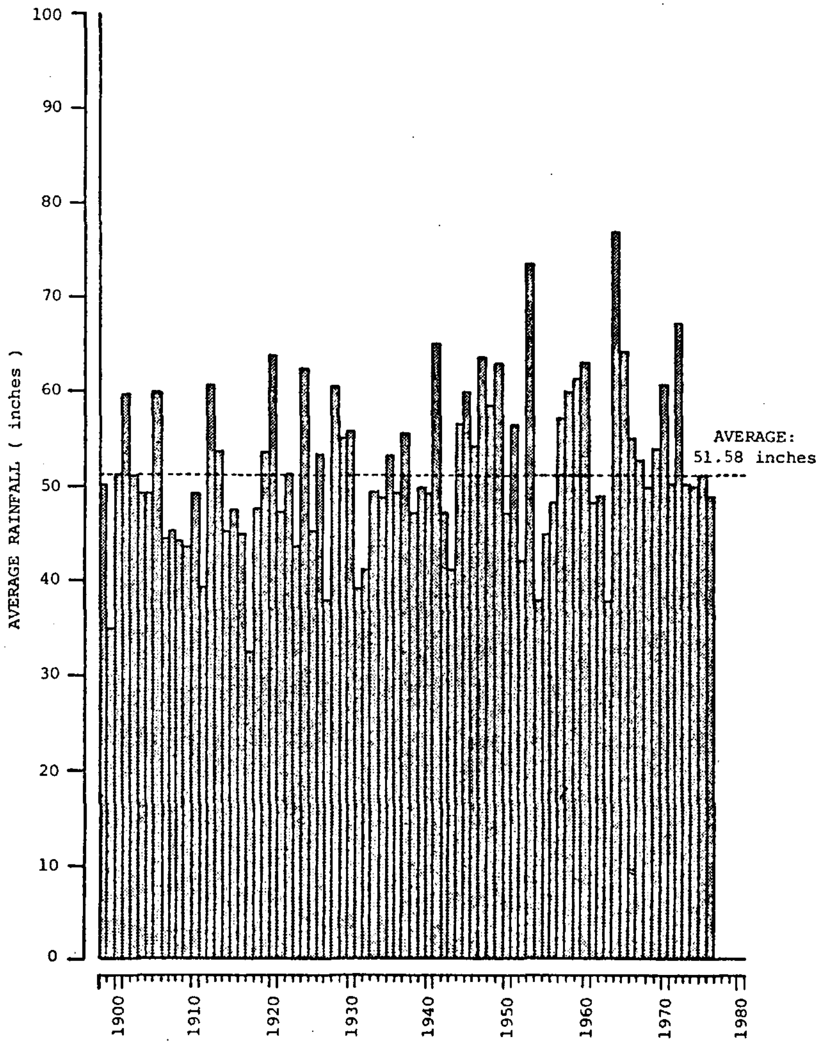

FIGURE 4. -- Average Yearly Rainfall at Gainesville for the Period 1898-1976

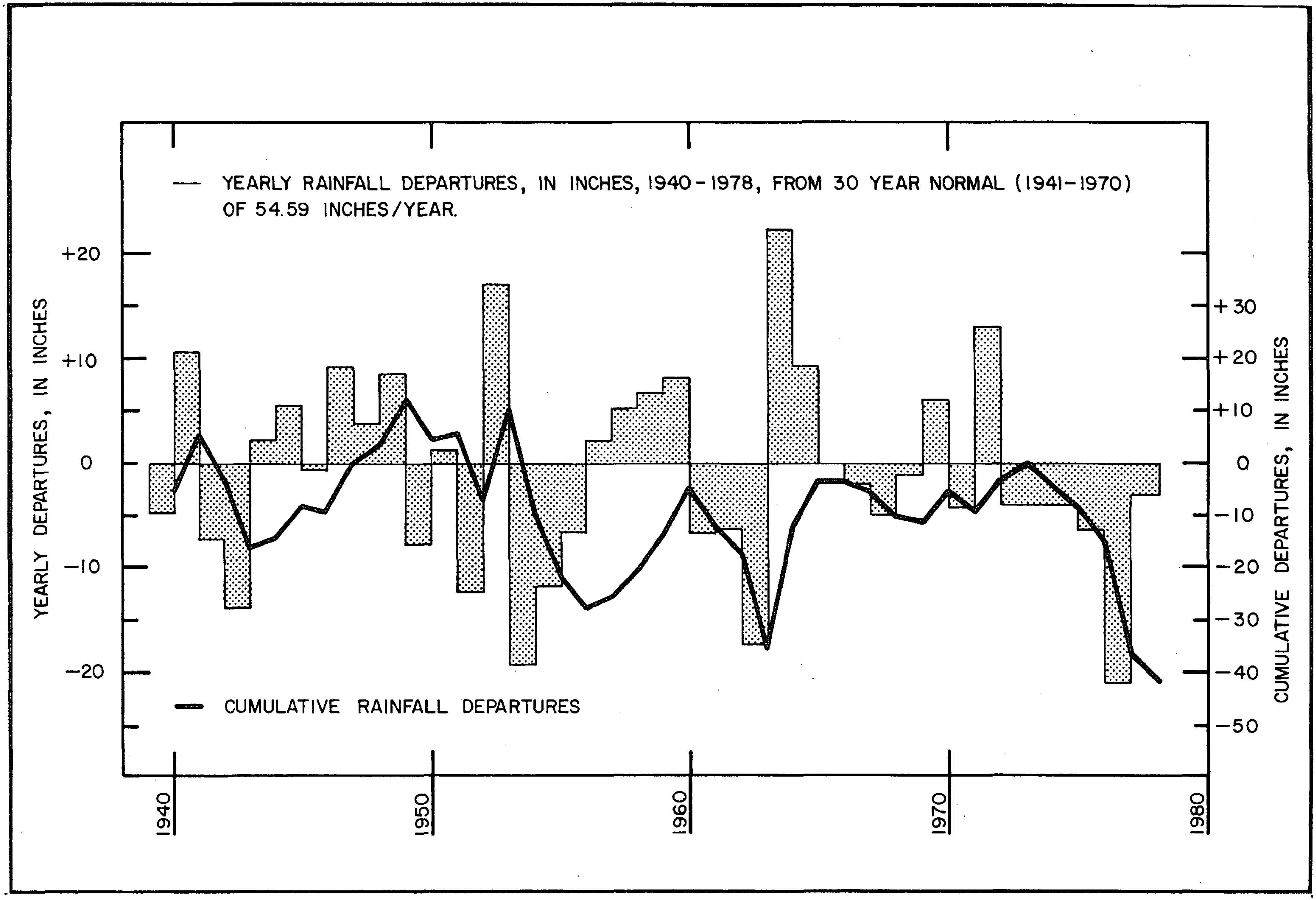

FIGURE 5. -- Departure from Average Rainfall at Gainesville for the Period 1940-1978

or below (-) normal (54.99 in/yr) rainfall that occurred during each year. The heavy solid line, the cumulative rainfall departure, represents the sum of yearly rainfall departures since 1940. Of significance to the study is the downward slope of the cumulative departure curve since about 1973 indicating an absence of surplus (above average) rainfall between 1973 and 1976.

Evaporation

Of the many variables that are involved in the loss of water by evaporation, the most important is the total amount of energy available for vaporization. Richardson (1931) indicates that from 40 to 50 percent of the incoming solar energy is actually used for the process of evaporation. The remaining solar energy is accounted for by losses from absorption and reflectance. The rate of evaporation depends on air-water temperatures, wind movement, and the depth and size of the water body.

Evaporation from a lake surface cannot be measured directly and must be determined by other methods. Kohler, Nordenson and Foxx (1954) describe methods to calculate the evaporation from a lake's surface. The authors derive four equations and suggest the use of each depending on the type of data available. For this study, a combination energy-aerodynamic equation was selected in which representative Class A pan evaporation measurements were utilized. The equation selected for the study is the following:

$$E_o = 0.7 \left(\frac{Qn\ \Delta + E_a r}{\Delta + r} \times \frac{Ep}{Ep'} \right)$$

where

E_o = daily lake evaporation,

Δ = slope of the saturation vapor pressure curve at Ta,

Qn = net radiation exchange,

E_a = daily pan evaporation assuming To = Ta,

E_p = measured daily Class A pan evaporation,

E_p' = computed Class A pan evaporation,

r = factor defined by the equation for Bowens ratio (R),

$R = r \frac{To-Ta}{e_o-e_a}$ where

T_a = temperature of air,

T_o = temperature of water,

e_o = water vapor pressure at water surface,

e_a = atmospheric water vapor pressure.

Direct measurements of solar energy, wind movement, vapor pressure, air and water temperature, and pan evaporation were not made in the project area. Weather data were limited to data collected from two NOAA Bureau Stations: the University of Florida Campus in Gainesville and Jacksonville International Airport.

Estimations of lake evaporation were computed for the years 1954 through 1976 (Figure 6 shows yearly evaporation). Lake evaporation ranged from 54.1 inches in 1967 to 43.4 inches in 1969 and averaged 48.6 inches. Mean monthly lake evaporation varies from 6.1 inches in May to 1.8 inches in December.

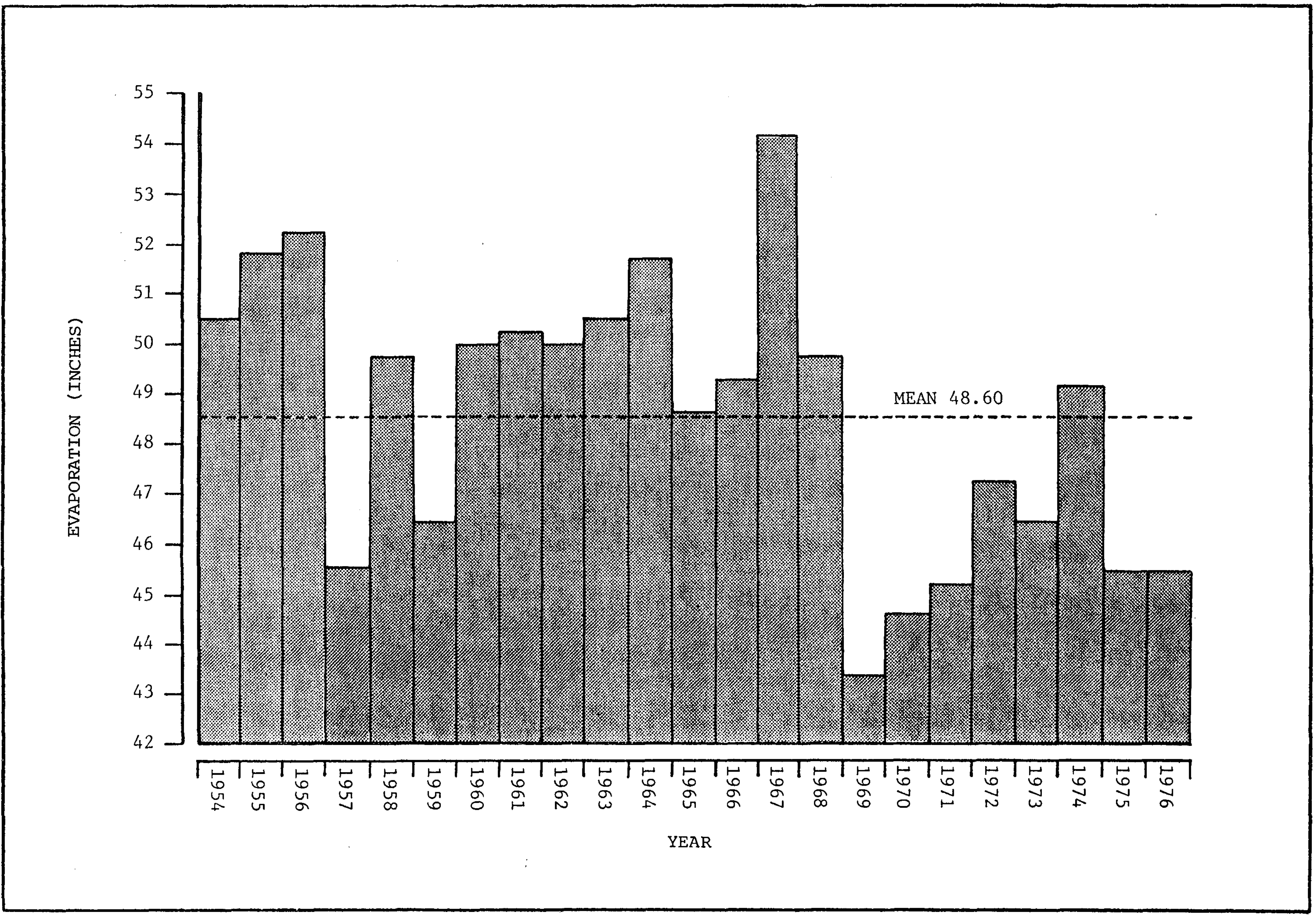

FIGURE 6. -- Annual Evaporation for the Period 1954-1976

Evapotranspiration

Evapotranspiration (ET) is that portion of precipitation which is returned to the air through direct evaporation and transpiration. Because a close relationship exists between evaporation and evapotranspiration, evaporation (Eo) was used as an index to ET.

Annual evapotranspiration can be obtained from the value of annual lake evaporation by multiplying annual lake evaporation by a coefficient that reflects local conditions. The coefficient used in this study is the ratio of annual evapotranspiration divided by annual lake evaporation for the Green Swamp area. The Green Swamp is an area of about 870 square miles of swampy flatlands and sandy ridges approximately 100 miles south of the Upper Etonia Creek Basin.

For the interval 1959-1961, Pride, et al., (1966) calculated evapotranspiration to be 40 inches in the Green Swamp and lake evapotranspiration to be 53.1 inches (at Lake Helen located about one mile southeast of Polk City). The ratio determined is 40/53.1, which gives a coefficient of approximately 0.75. However, this coefficient could be as high as 0.81 if an average lake evaporation of 49 inches (determined by Kohler and others, 1959) is used.

Estimates of evapotranspiration were computed for the years 1954 through 1976. The average ET computed was 36.5 inches, and the range was from 32.5 inches in 1969 to 40.6 inches in 1967.

GEOLOGY

The Upper Etonia Creek Basin is underlain by several hundred feet of unconsolidated to semiconsolidated marine and non-marine deposits of sand, clay, marl, gravel, limestone, dolomite, and dolomitic limestone. A description of the geologic formations occurring in the Upper Etonia Creek Basin is included in Table 1. These sediments range in age from early Middle Eocene to Recent. Formations older than the Eocene Lake City Limestone are not discussed in this report as they are thought to not be a source of fresh water (Clark, et al., 1964, p. 12).

The surficial sands and the sediments that crop out in the upper basin range in age from early Pleistocene to Recent and include unidentified coarse clastics, older Pleistocene terrace sands, and younger marine and estuarine deposits. These surficial deposits consist of varicolored sands and clayey sands and contain some quartz gravel. They underlie the entire project area and vary in thickness from 90 to less than 20 feet. Older deposits occur in the western part of the study area with progressively younger deposits occurring to the east. These clastics overlie the Miocene series.

The Miocene series ranges in thickness from 110 to 180 feet. The principal formation of the Miocene series is the Hawthorn Formation, a shallow marine deposit of clay, sandy clay, and discontinuous lenses of white to gray limestone and phosphatic sandy limestone. Black and amber phosphatic pebbles are mixed throughout this formation. The limestone lenses occur in the Hawthorn at various levels but are concentrated in the basal portion of the formation. The thickness of the

TABLE 1. -- Geologic Formations of the Upper Etonia Creek Basin

Age	Formation Name	Approximate Range in Thickness (feet)	Description of Formation	Aquifer
Pleistocene to Recent	Younger marine and estuarine terrace deposits Older Pleistocene terrace deposits Unnamed coarse clastics	20-90	Varicolored sands, clays, and sandy clays with beds of clay marl and sandy clays. Shell marl and concentrations of shells in some areas. Localized quartz gravel and interbedded thin lenses of clay or kaoline.	Non-artesian
Miocene	Choctawhatchee Formation Hawthorn Formation	110-180	Yellow to cream clay and marl having disseminated phosphatic grains and pebbles. Thin limestone and sand beds with some shells and thick clays, and sand and sandy phosphatic limestone. Dense hard dolomitic limestone in lower portion.	Secondary artesian
Eocene	Ocala Limestone	200-250	Limestone, white, cream, and tan, porous, and fossiliferous. Alternating layers of hard and soft dolomitic limestone in lower portion.	Floridan
	Avon Park Limestone	210	Gray to white, chalky limestone with beds of crystalline dolomite, and tan to dark brown, hard, finely crystalline dolomitic limestone.	
	Lake City Limestone	450+	Gray, tan to brown, finely crystalline dolomite and dolomitic limestone. Intermixed are beds of softer, porous, fossiliferous limestone and seams of peat and lignite.	

Hawthorn ranges from 100 to 150 feet and generally increases from southwest to northeast across the upper basin. The remainder of the Miocene series consists of a shell marl overlying the Hawthorn Formation. Clark, et al., (1964) refer to this sequence as the Choctawhatchee Formation. It has a maximum thickness of 40 feet.

The fresh water yielding, Eocene limestones in the study area consist of the Ocala Limestone, the Avon Park Limestone, and the Lake City Limestone. The Ocala Limestone lies unconformably on the late Middle Eocene Avon Park Limestone and is unconformably overlain by the Miocene Hawthorn Formation. The Ocala Limestone consists of white to cream and tan, porous and fossiliferous limestone. The upper part is a soft, white to cream, chalky, coquinoid limestone that grades downward into alternating layers of crystalline and dolomitic limestone (Clark, et al., 1964). The Ocala Limestone underlies the entire basin and ranges from 200 to 250 feet in thickness. It has been subjected to solution by the circulation of water entering through breaches in the Hawthorn Formation, and numerous features of the basin topography (e.g., lake basins) are a result of the solution activity. Figure 7 shows the approximate elevation of the top of the Ocala Limestone.

The Avon Park Limestone overlies the Lake City Limestone and is of late middle Eocene Age. It underlies the entire project area and is approximately 210 feet thick. The upper part consists of a gray to white, chalky limestone with beds of crystalline dolomite, whereas the lower part consists of brown to dark brown, hard, finely crystalline dolomitic limestone.

The Lake City Limestone lies beneath the Avon Park Limestone and over the Oldsmar Limestone and is early middle Eocene in age. It is

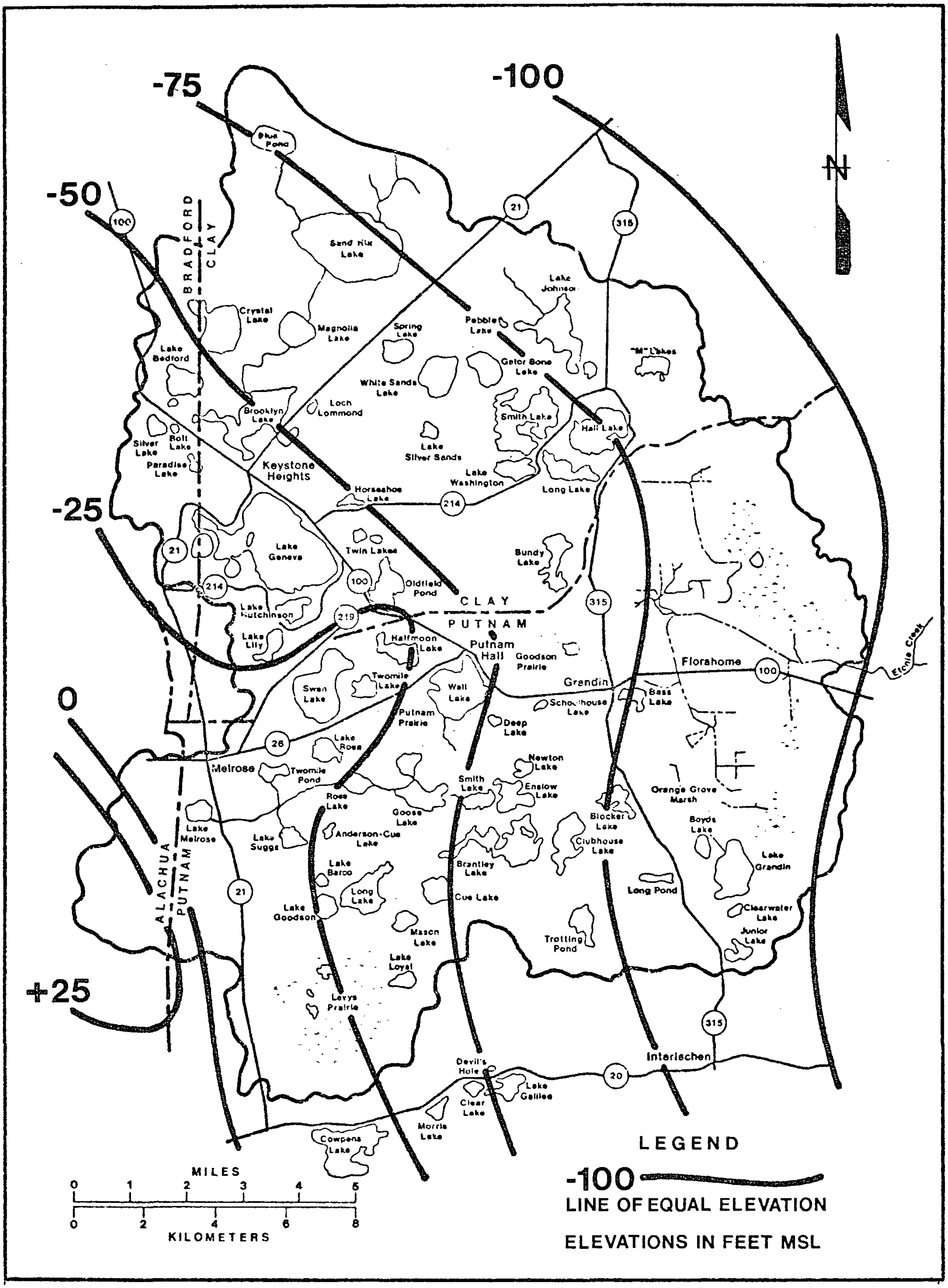

FIGURE 7. -- Structural Contour Map Showing Approximate Elevation of the Top of the Ocala Limestone

the deepest formation from which fresh water is obtained in the area (Clark, *et al*., 1964, p. 12). It consists of tan and gray to brown, finely crystalline dolomite limestone. Beds of softer, porous, fossiliferous limestone are intermixed with the crystalline dolomite. Seams of peat and lignite occur in the upper part of the formation.

HYDROLOGY

SURFACE WATER

Drainage

The study area is comprised of a 165 square mile drainage basin at the head of Etonia Creek (Figure 8). The drainage network for the study area, including lakes, perennial and intermittent streams, and man-made canals is shown schematically in Figure 9. For purposes of discussion, the study area can be divided into two sub-areas; these will be called the western sub-area and the eastern sub-area or the Florahome Valley. The eastern and western sub-areas are approximately separated by a line drawn along SR 315 from the southern study area boundary to the Putnam-Clay County line and then eastward along that line to the eastern study area boundary (refer to Figure 8).

The western sub-area is dotted with numerous lakes most of which are landlocked, and at normal water levels is characterized by interior drainage wherein perennial and intermittent streams terminate in lakes or swamps as opposed to joining together into an integrated drainage network of streams discharging runoff to Etonia Creek. Two lake chains occur in the western sub-area. These are called the Blue Pond chain and the Lake Melrose chain and are located, respectively, in the northwest and southwest part of the western sub-area (Figure 8). Because of the local importance of these two lake chains, a detailed discussion of them is included at the end of the report as Appendix A.

At normal water levels, successive lakes in the upper part of each chain are connected by perennial or intermittent streams. At higher

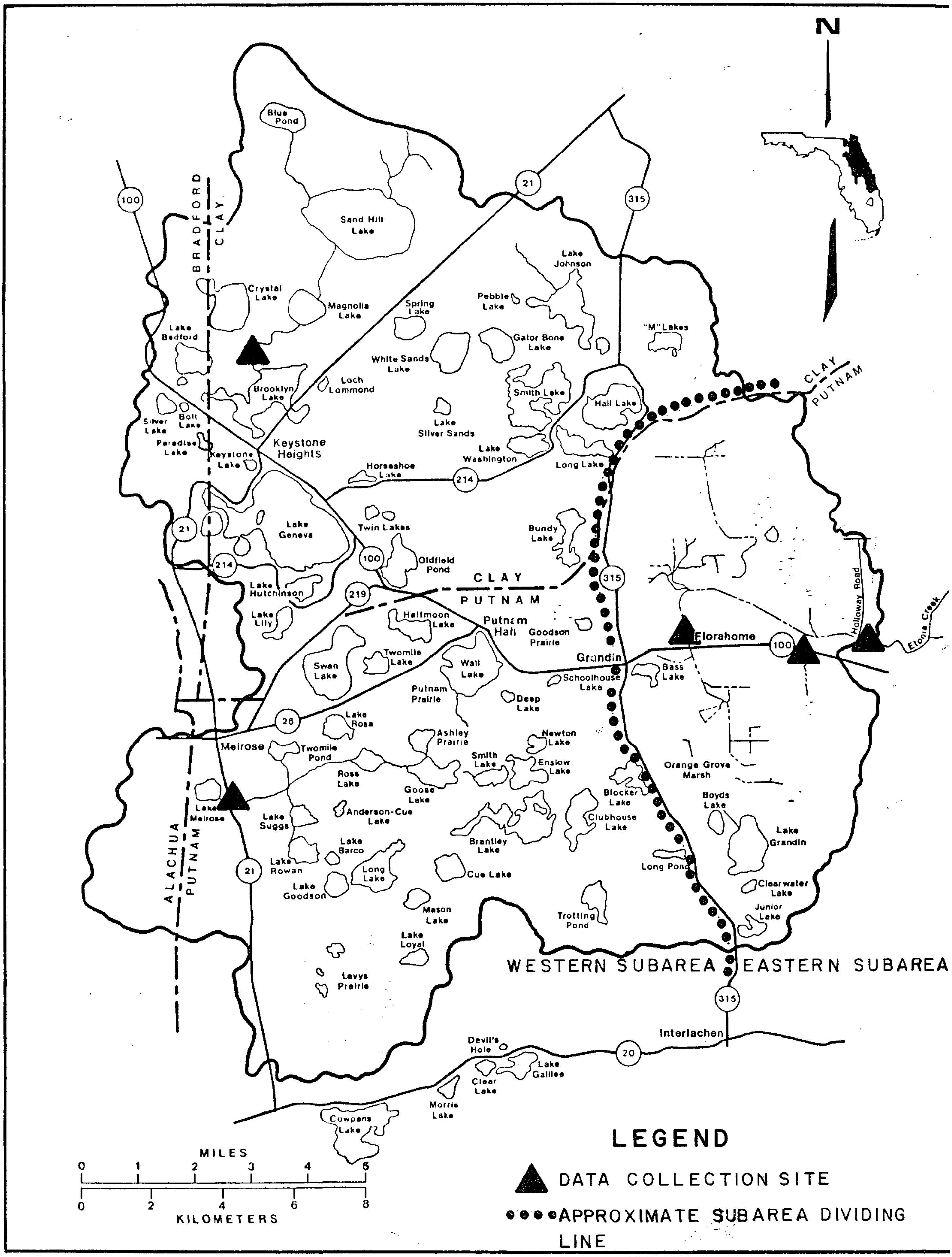

FIGURE 8. -- Surface Drainage Area of the Upper Etonia Creek Basin Study Area Including Data Collection Sites

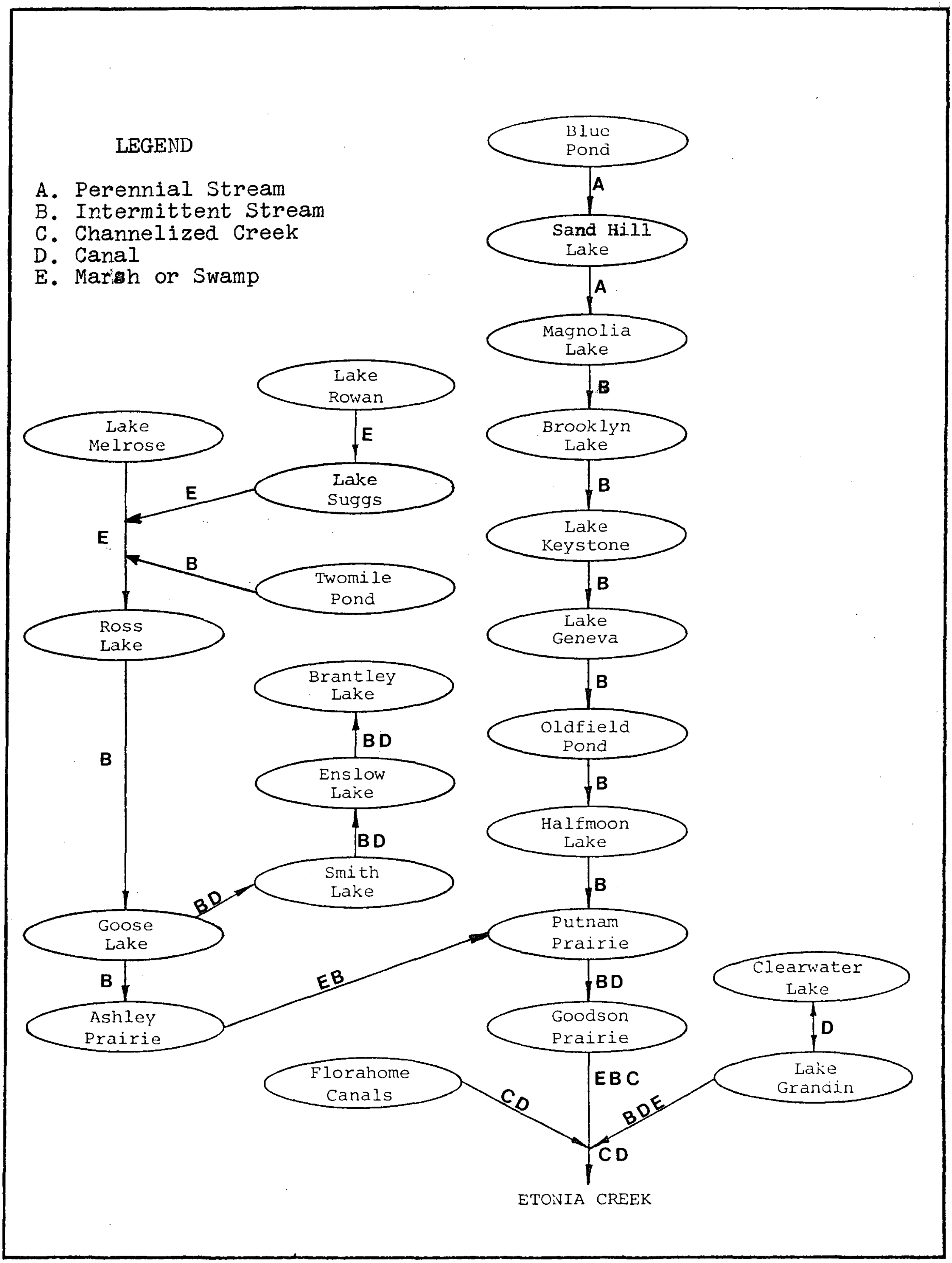

FIGURE 9. -- Upper Etonia Creek Drainage Network

water levels, some lakes may overflow through intermittent courses to lakes at lower elevations. In this manner the Blue Pond and Lake Melrose chain of lakes can overflow through Putnam Prairie and contribute water to Etonia Creek through the Florahome Valley (Figures 8 and 9). However, high water conditions did not occur during the period of the study, and no water was contributed from the western sub-area through the Florahome Valley to Etonia Creek.

A series of man-made canals and channelized creeks drains the Florahome Valley into the headwaters of Etonia Creek. These canals and channelized creeks are apparent on Figure 8 by their linearity and angularity. The canals have lowered the water table sufficiently to prevent long standing water.

From the Florahome Valley, Etonia Creek drains easterly into Rice Creek which subsequently drains into the St. Johns River. The flow of Upper Etonia Creek is derived from ground water seepage from the water table aquifer and overland runoff. Because no overland flow was contributed to the Florahome Valley from the western sub-area during the study, overland flow contributions to the flow of Upper Etonia Creek from the study area were derived from the greater Florahome Valley area.

Discharge of Etonia Creek was measured at the outlet of the Upper Etonia Creek Basin on Holloway Road (see Figure 8). A graphic recorder was installed, and a continuous record of water levels was obtained in conjunction with periodic measurements of discharge. From the discharge measurements, a stage-discharge relation was developed for the station. In all, three rating curves were developed and used during the study period.

Daily mean gage heights were computed from the graphic recorder, and the mean daily flow was determined from the rating curve. Figure 10 is a plot of the resultant mean daily discharge for Etonia Creek at the gaging station, and Table 2 shows average discharge. Mean daily flow of Upper Etonia Creek for 1976 was 9.72 cfs and ranged from a mean daily high of 48.9 cfs to a mean daily low of 3.6 cfs. Mean daily flow was equalled or exceeded only 32 percent of the time (Figure 11). Highest flows occurred during January, June, September, and December. Mean daily flow of 9.72 cfs for Upper Etonia Creek for 1976 translates into 0.80 inches of runoff for each square mile of the 165-mile square drainage area above the gage. Runoff of 0.80 inches per year is low in comparison to the Florida average of 13.6 inches/mi^2/yr (SJRWMD, 1977, p. D-24).

Lakes

Within the study area, there are some 100 lakes. The majority of these lakes are small, steepsided, landlocked bodies of water having a surface area of less than 200 acres. Total combined area of all lakes in the study area amounts to about 10 percent of the total surface area in the upper basin. The basins in which the lakes occur formed as a result of slumping of surficial and underlying sediments into solution cavities in the underlying limestone.

Fluctuations of levels of 62 lakes have been periodically monitored. To provide a quantitative method of comparison of lake level fluctuation in a large number of lakes, fluctuation of levels in 43 lakes in the study area were compared to lake level fluctuations in Swan Lake

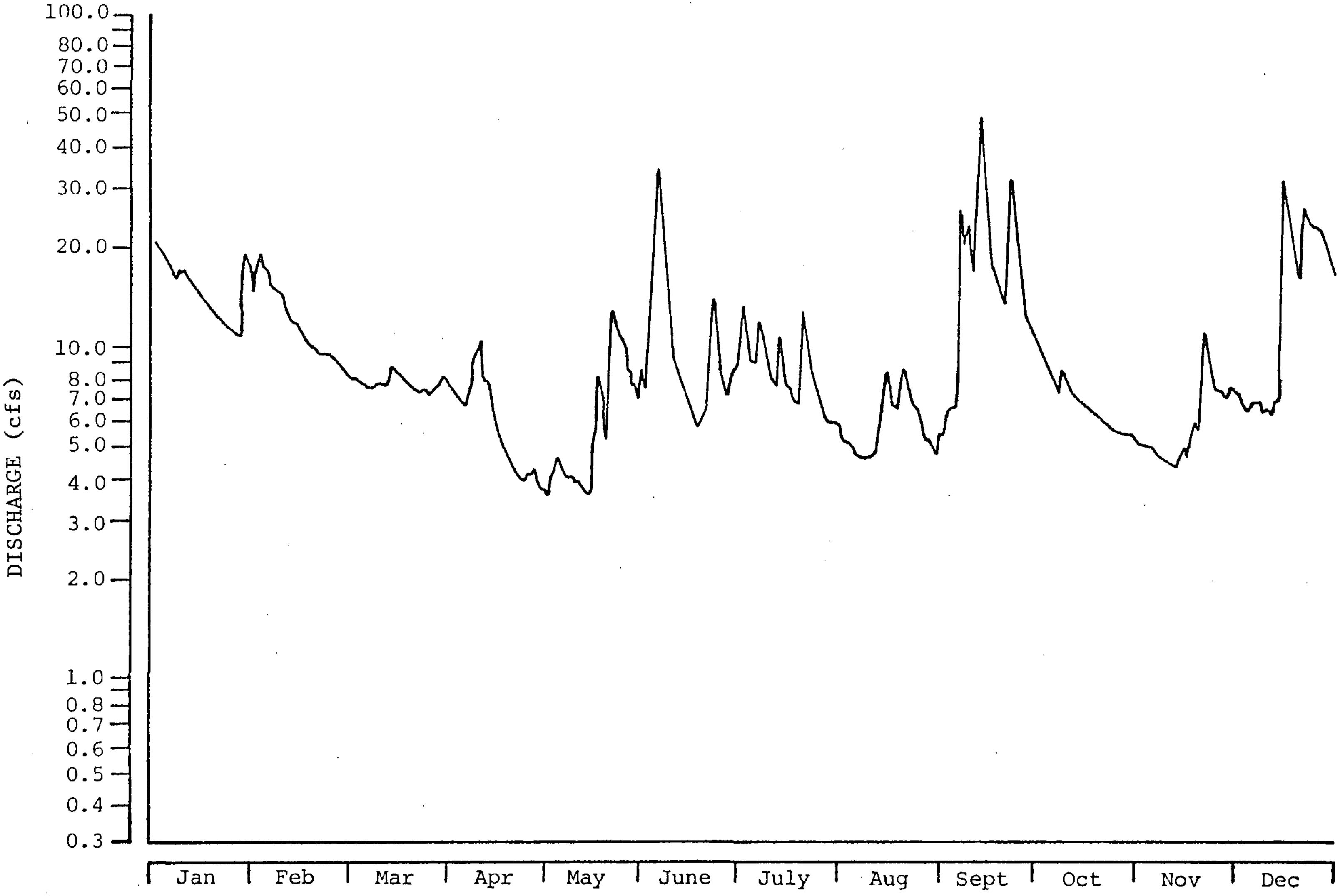

FIGURE 10. -- Mean Daily Discharge Hydrograph for Upper Etonia Creek at Holloway Road, 1976

TABLE 2. -- Average Daily Discharge of Etonia Creek in Cubic Feet per Second for Calendar Year 1976

Month	Monthly Sum	Average Daily Discharge
January	461.34	14.88
February	340.50	11.74
March	239.19	7.72
April	140.57	4.69
May	204.15	6.59
June	324.45	10.82
July	273.03	8.81
August	183.28	5.94
September	538.88	17.96
October	215.89	6.96
November	183.51	6.12
December	443.54	14.31
Total 1976	3549.33	
Average Daily 1976	9.72	
Runoff (Inches)	0.80	

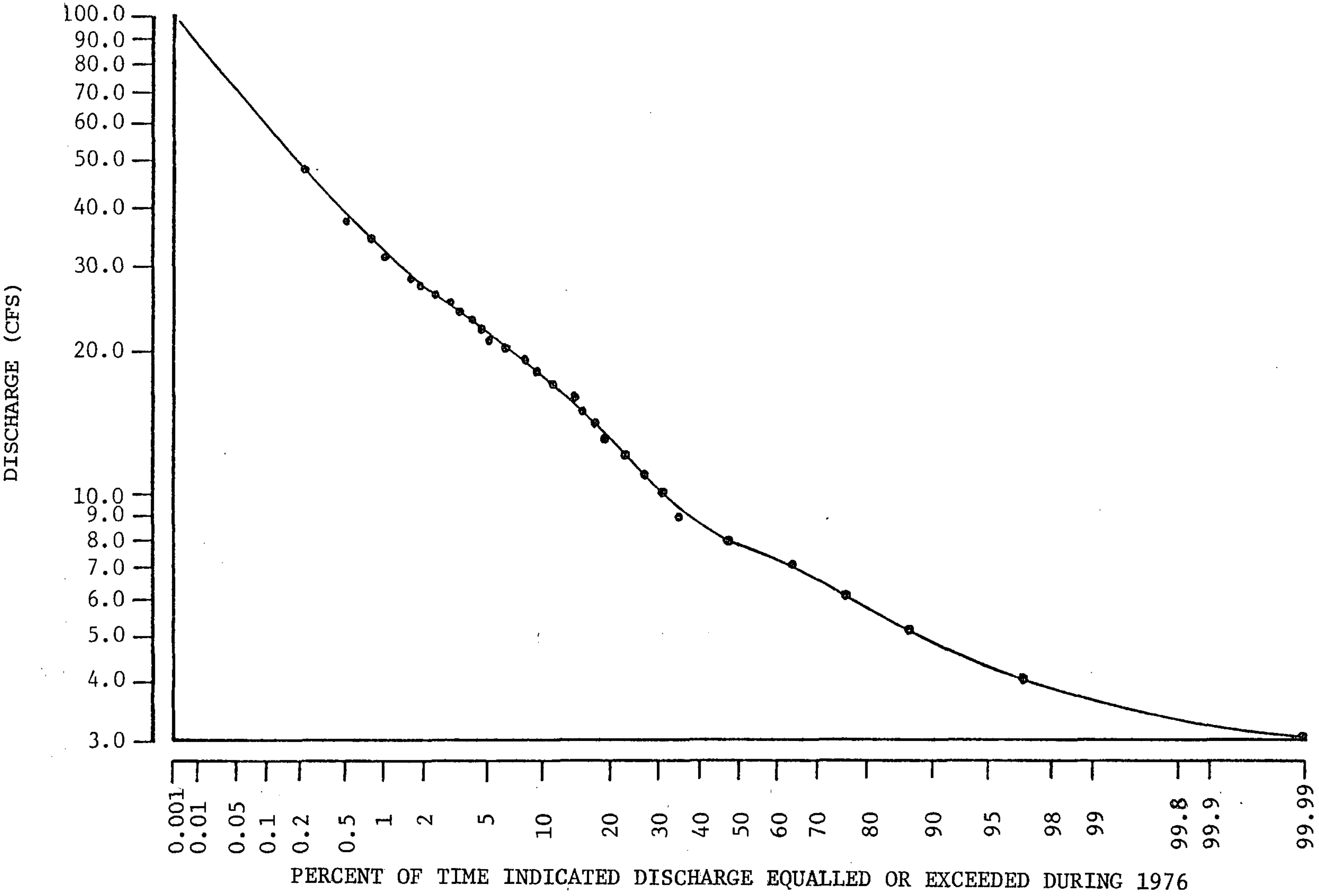

FIGURE 11. -- Flow Duration Curve for Upper Etonia Creek, 1976

by simple linear regression analysis for the period of the study (1975-1976). Correlation coefficients and other parameters pertinent to the analysis are presented in Appendix B. The high correlation coefficients for 37 lakes indicate that they have fluctuated similarly to Swan Lake during the study period (a correlation coefficient of less than 0.90 is considered low). The five lakes with correlation coefficients less than 0.90 are thoughtto represent atypical conditions (e.g., relatively large drainage areas or active surface water inflows and/or outflows). Inspection of the hydrograph for Swan Lake, Figure 12, shows that the level of Swan Lake was declining during the period of the study (1975-1976); the high correlation coefficients obtained for the majority of the lakes in the comparison indicate that they were also declining during the study period.

Examination of hydrographs of lakes in the study area with long term records, Figures 13 through 16, indicates that the lake level decline observed during the study (1975-1976), was part of a longer term decline that took place between 1973 and 1976. As a result of this decline, lake levels in the Etonia Creek Basin approached their historic lowest recorded levels.

Lakes in Florida fluctuate in response to rainfall, evaporation, and surface and ground water inflow and outflow. Comparison of the line showing cumulative departure from normal rainfall at Gainesville since 1940 and the hydrographs of Swan Lake and Lake Geneva (Figure 16) shows that a correlation exist between rainfall and lake stages, and that the lake level declines in the Etonia Creek Basin during the study period can be correlated with below normal rainfall for the years 1973-1976.

FIGURE 12. -- Stage Hydrograph for Swan Lake for the Years 1975-1976

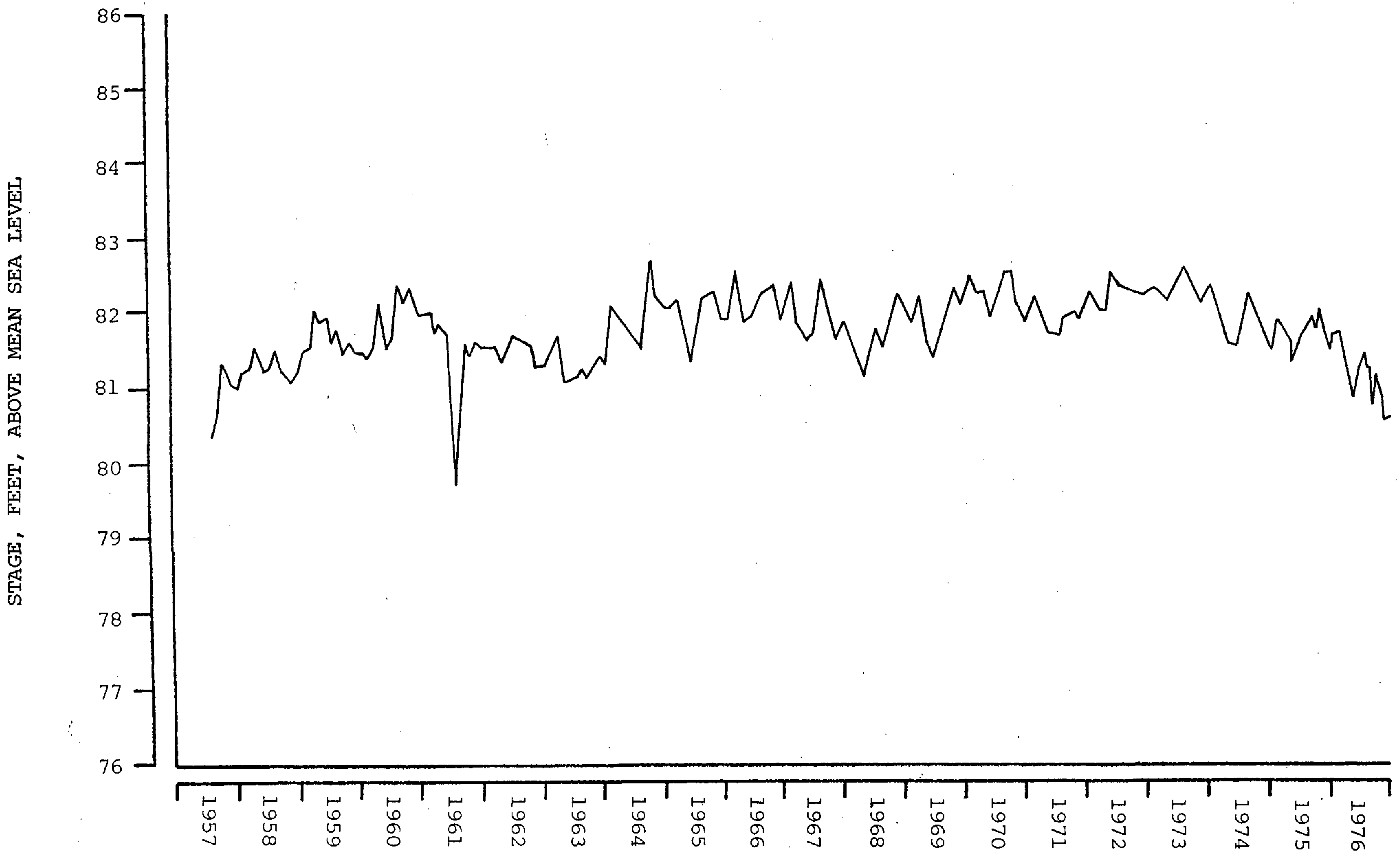

FIGURE 13. -- Stage Hydrograph of Lake Grandin

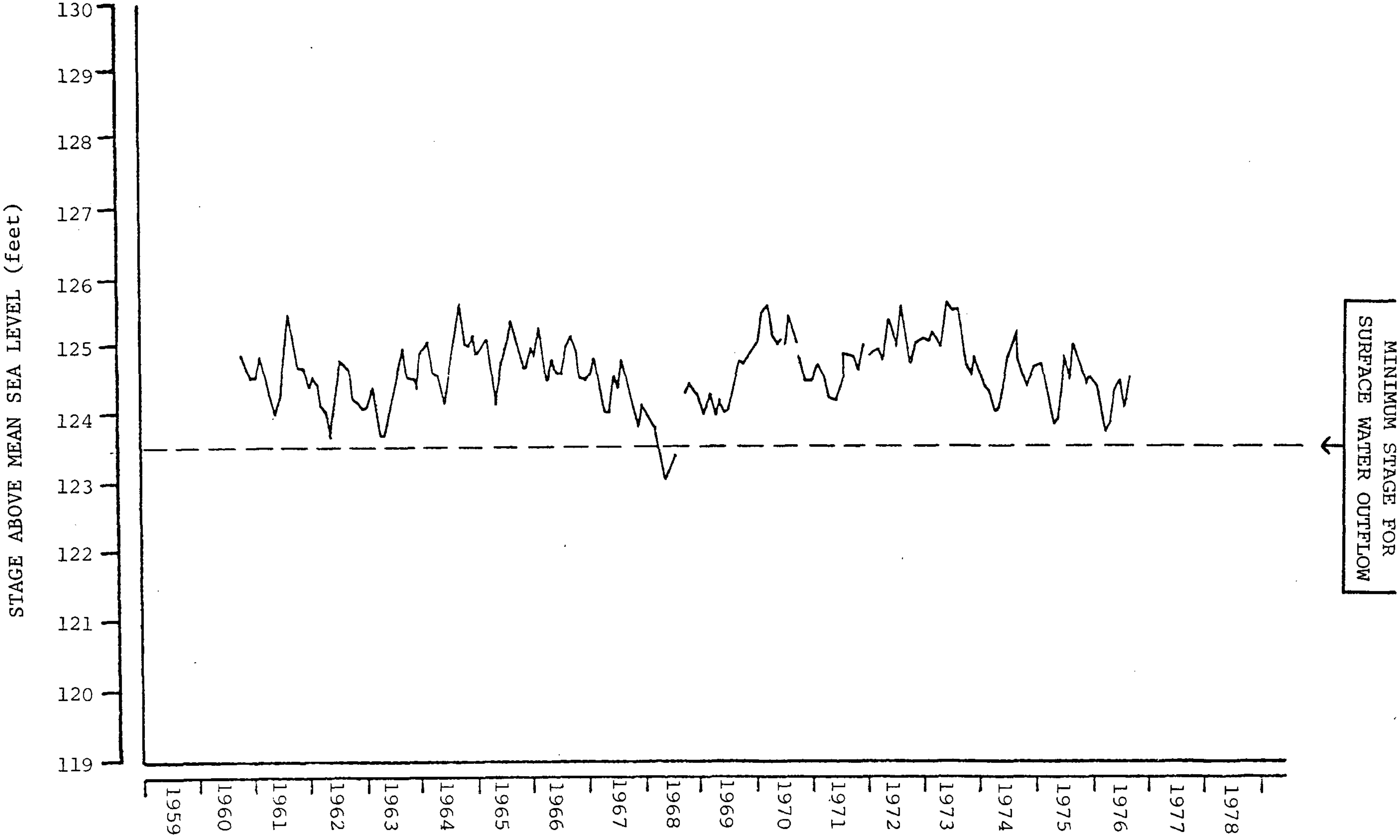

FIGURE 14. -- Stage Hydrograph of Magnolia Lake

FIGURE 15. -- Stage Hydrograph of Brooklyn Lake

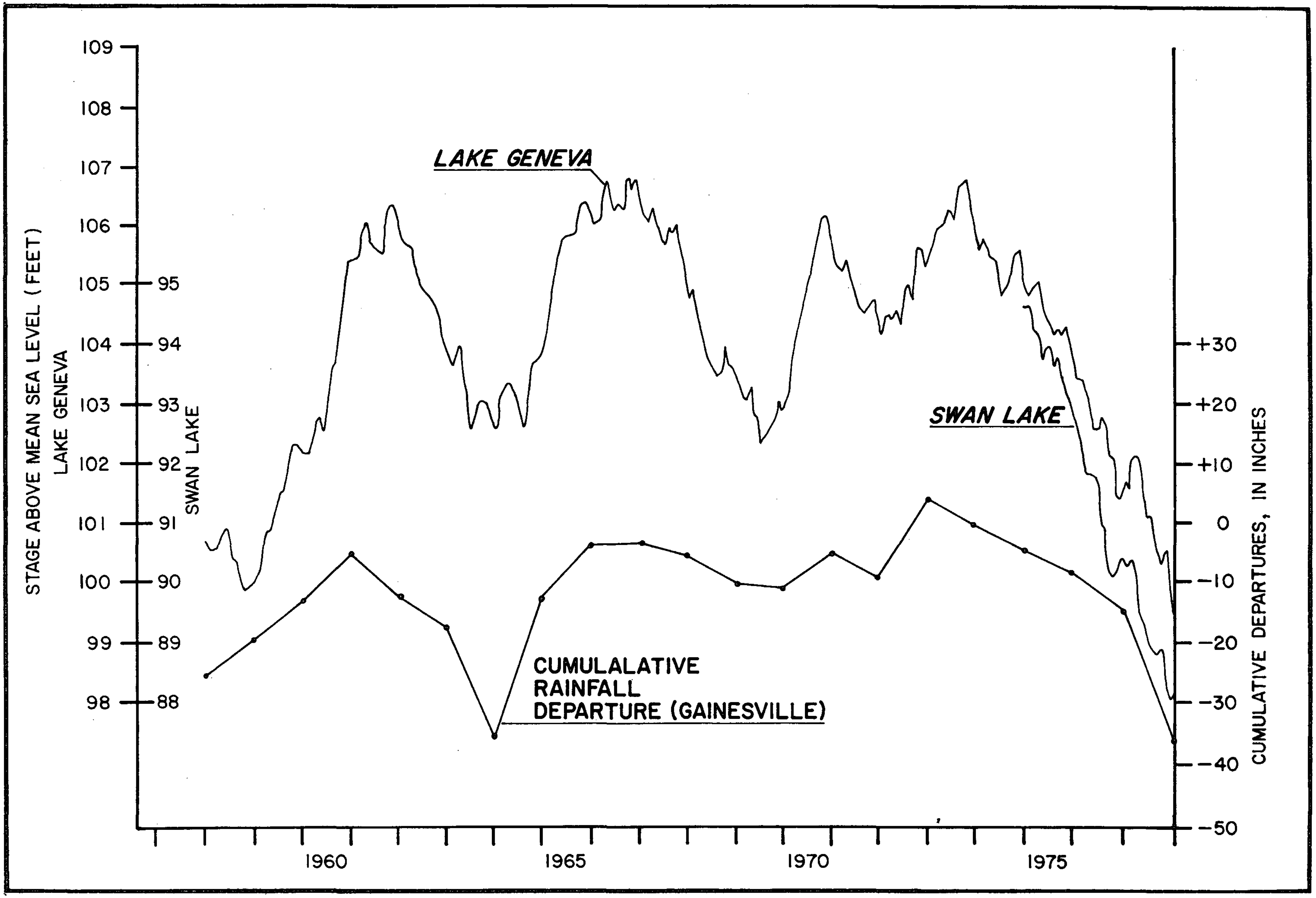

FIGURE 16. -- Stage Hydrographs for Lake Geneva and Swan Lake and Cumulative Departure from Normal Rainfall at Gainesville

Because the net fluctuation due to precipitation and evaporation over the long term is about the same for all lakes in the same general area in Florida (Hughes, 1974), differences in the magnitude of lake level fluctuation are therefore due to local variations in topography and local variations in the permeability and thickness of geologic materials beneath the land surface. An example of a lake that exhibited a large range in fluctuation during the study was Pebble Lake. Pebble Lake showed a net decline of about 10 feet between January 1975 and December 1976 (Figures 17 and 18). This lake has a recorded vertical range of 32.12 feet. The large range in fluctuation in this lake is thought to be due, partly, to the presence of geologic materials with high leakance (permeability/thickness) beneath the lake giving rise to high rates of leakage through the lake bottom and to variations in ground water inflow to the lake.

In general, leakage through the bottom of lakes in the study area is thought to be twice as high as leakage through the materials underlying the areas surrounding the lakes (Yobbi, Pers. Comm., 1979). Thus, the lakes are the most effective areas for recharge in the study area. Possible exceptions to this are the lakes with perennial outflow. The fact that some lakes have perennial outflow indicates that they are receiving more water than can evaporate or leak downward as recharge. A possible explanation for this could be the presence of geologic materials of lower leakance (permeability/thickness) beneath these lakes than is present below other lakes in the study area.

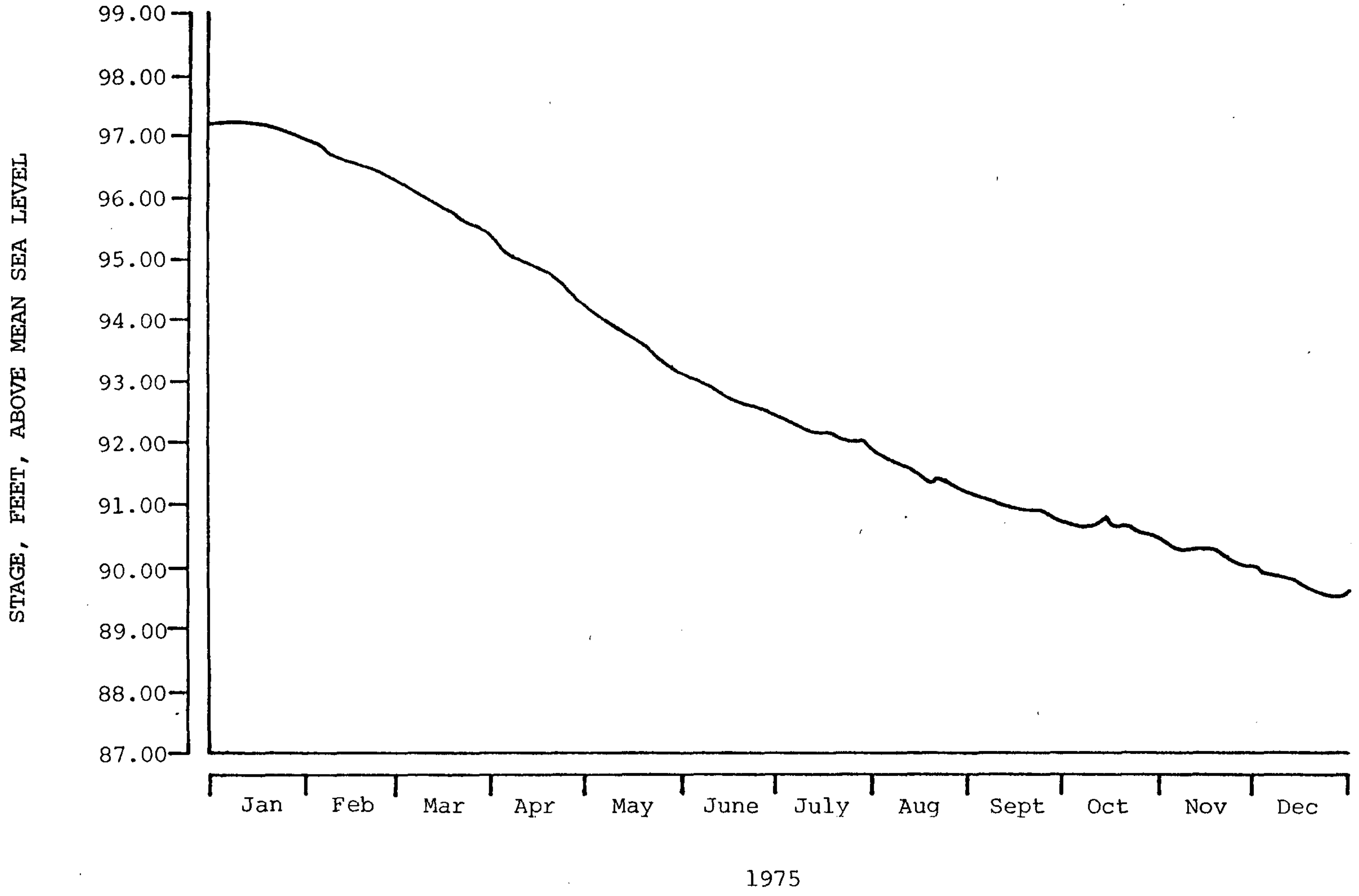

FIGURE 17. -- Stage Hydrograph of Pebble Lake for 1975

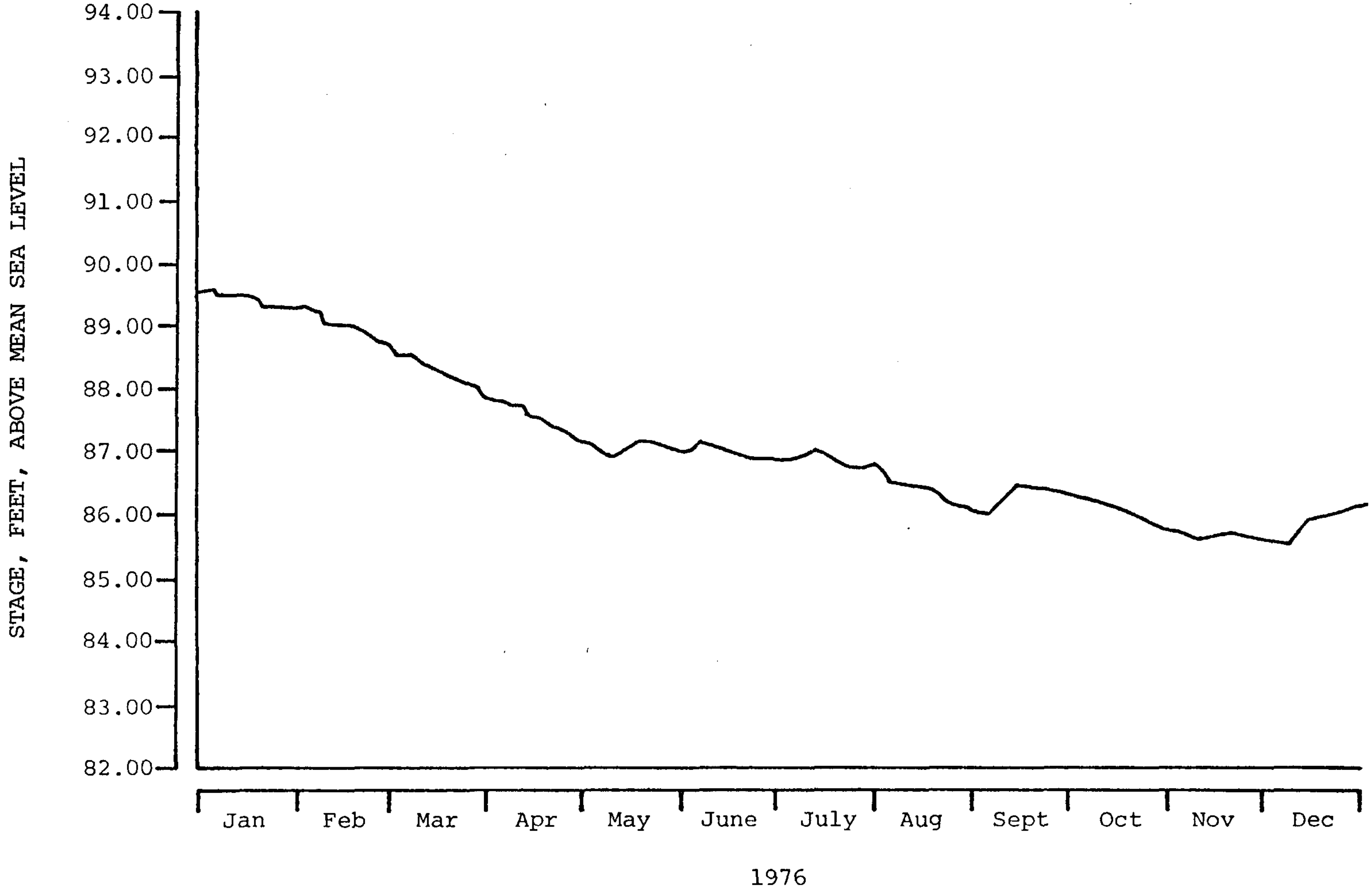

FIGURE 18. -- Stage Hydrograph of Pebble Lake for 1976

GROUND WATER

Ground water occurs in three aquifers within the study area. These are, from land surface downward, the unconfined water table aquifer, the confined secondary artesian aquifer, and the principal aquifer, the confined Floridan aquifer. As is typical in recharge areas, water levels in the study area decrease with increasing depth; this relationship is demonstrated by Figure 19 which shows typical water levels of wells drilled at different depths into the three aquifers.

Water Table Aquifer

The water table aquifer consists mainly of sand and sandy clay beds and varies in thickness from 50 to 130 feet in the study area. The water table generally conforms to topography but with reduced relief and varies in elevation from approximately 70 to 175 feet above msl. The base of the water table aquifer is the top of the confining beds of the Hawthorn Formation or extensive clay layers of the Choctawhatchee Formation where it is present.

Recharge to the water table occurs from rainfall that has not been intercepted by vegetation, removed from the area as runoff, stored in the capillary zone, or utilized in evapotranspiration. Areas, such as the sand hills area located in the northwest part of the study area having thick sections of highly permeable surficial sediments which allow rapid infiltration and downward percolation of rainfall, are characterized by minimum evapotranspiration losses. Such areas generally have low surface runoff, and generally the water table is far

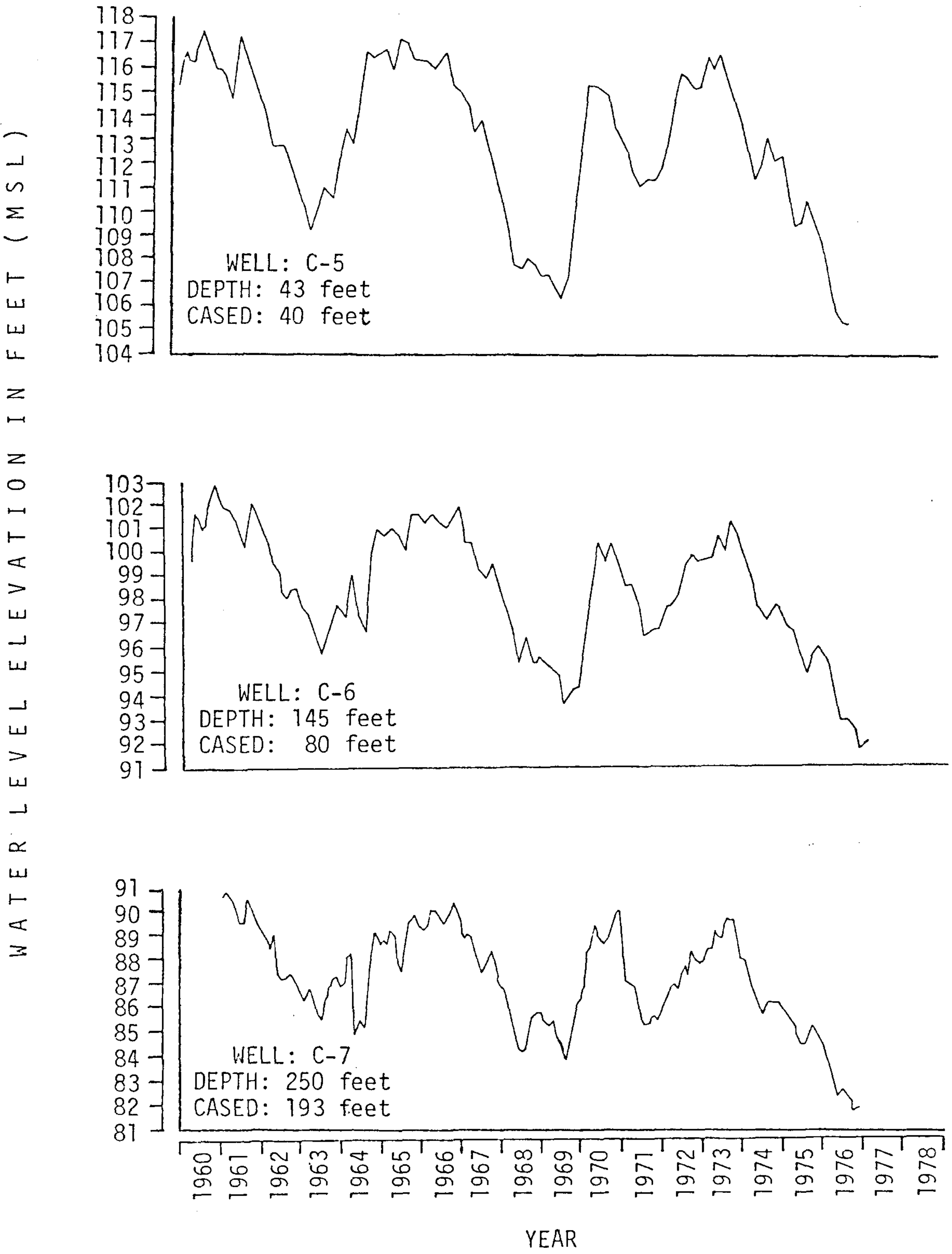

FIGURE 19. -- Hydrographs of Three Wells at the Same Location Showing Water Level Change With Depth

below the root zone, resulting in a greater percentage of rainfall reaching the water table than occurs in areas where these conditions do not exist (Yobbi, Pers. Comm., 1979). Minor amounts of recharge to the water table aquifer occur as a result of irrigation return and from septic systems.

Discharge from the water table aquifer is by evapotranspiration, seepage into lakes and canals, downward leakage into underlying aquifers, and pumpage. Evapotranspiration is low in areas of sand hills due to a deep water table and usually less vegetation. In areas of high water table and thick vegetation, evapotranspiration is much higher.

Ground water seeps laterally into lakes, marshes, and canals where the water table is at a higher elevation than the free water surface. Downward leakage depends on the vertical permeability and thickness of the intervening geologic materials and head differentials between aquifers. Throughout the study area, the water table is generally at a higher elevation than the potentiometric surface of the confined aquifers (Figure 20 and available lake stage data); therefore, leakage into the confined aquifer is possible throughout the study area although the amount varies. Pumpage from the water table aquifer accounted for minimal discharge during the study.

Fluctuations of the water table were monitored in selected wells located throughout the study area during 1975 and 1976. Figure 21 shows water level fluctuations for water table well C-32 located about one mile east of Lake Geneva (Figure 22). In general, fluctuations of the water table in monitored wells were greatest near lakes due

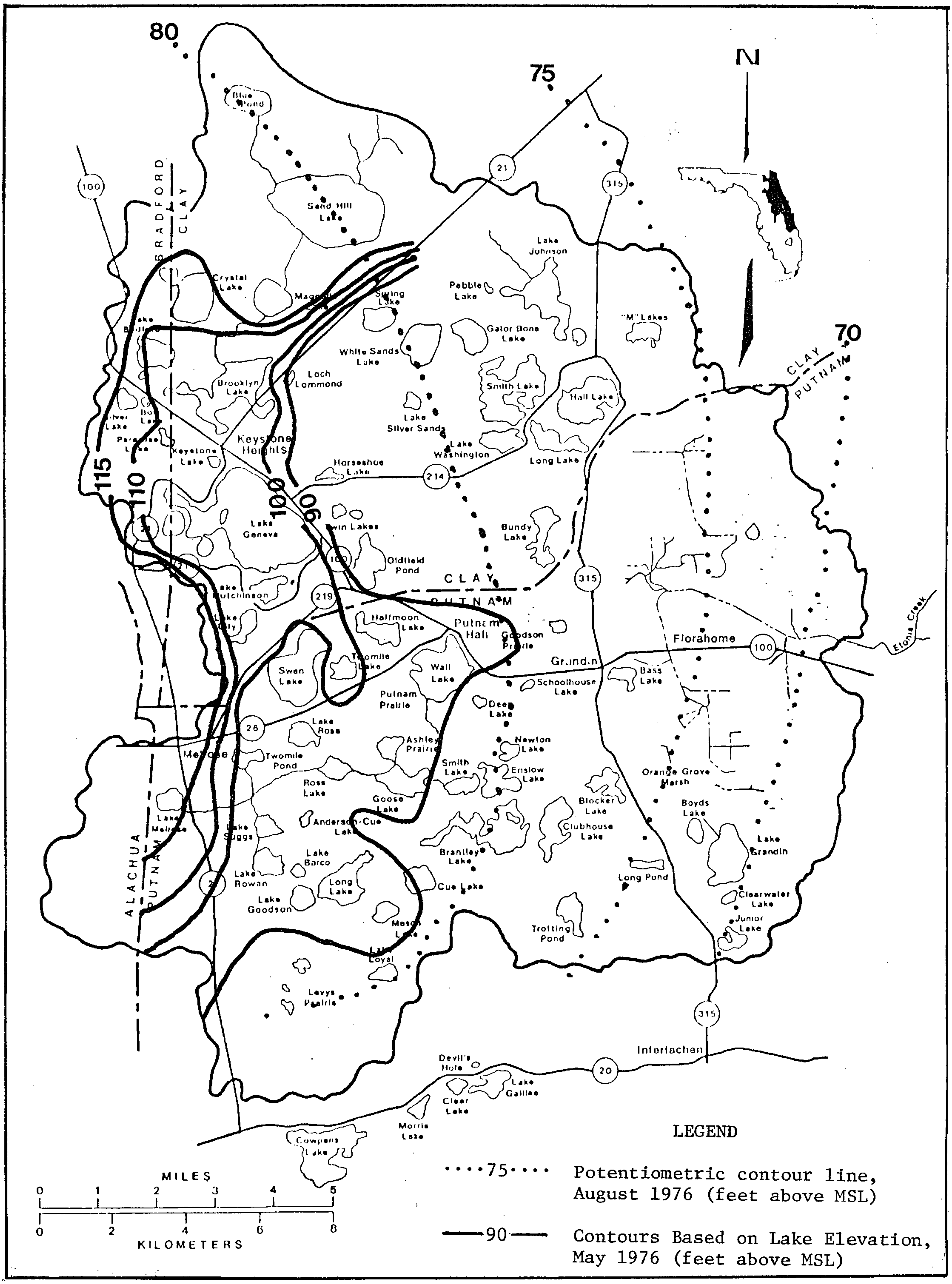

FIGURE 20. -- Relationship Between Potentiometric Surface of the Floridan Aquifer and Lake Surface Elevations, Summer 1976

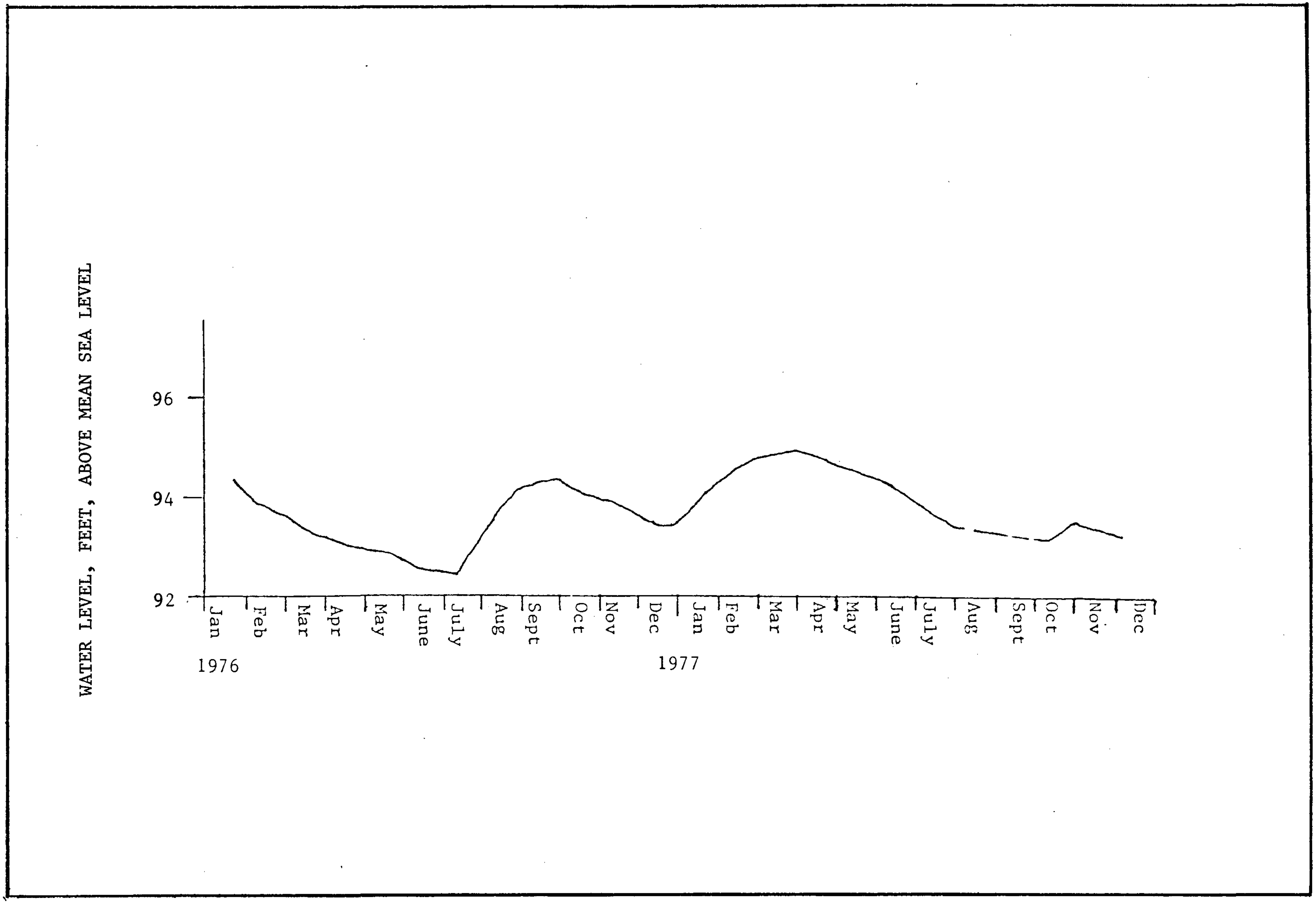

FIGURE 21. -- Hydrograph of Well C-32 (Lake Geneva Well #2)

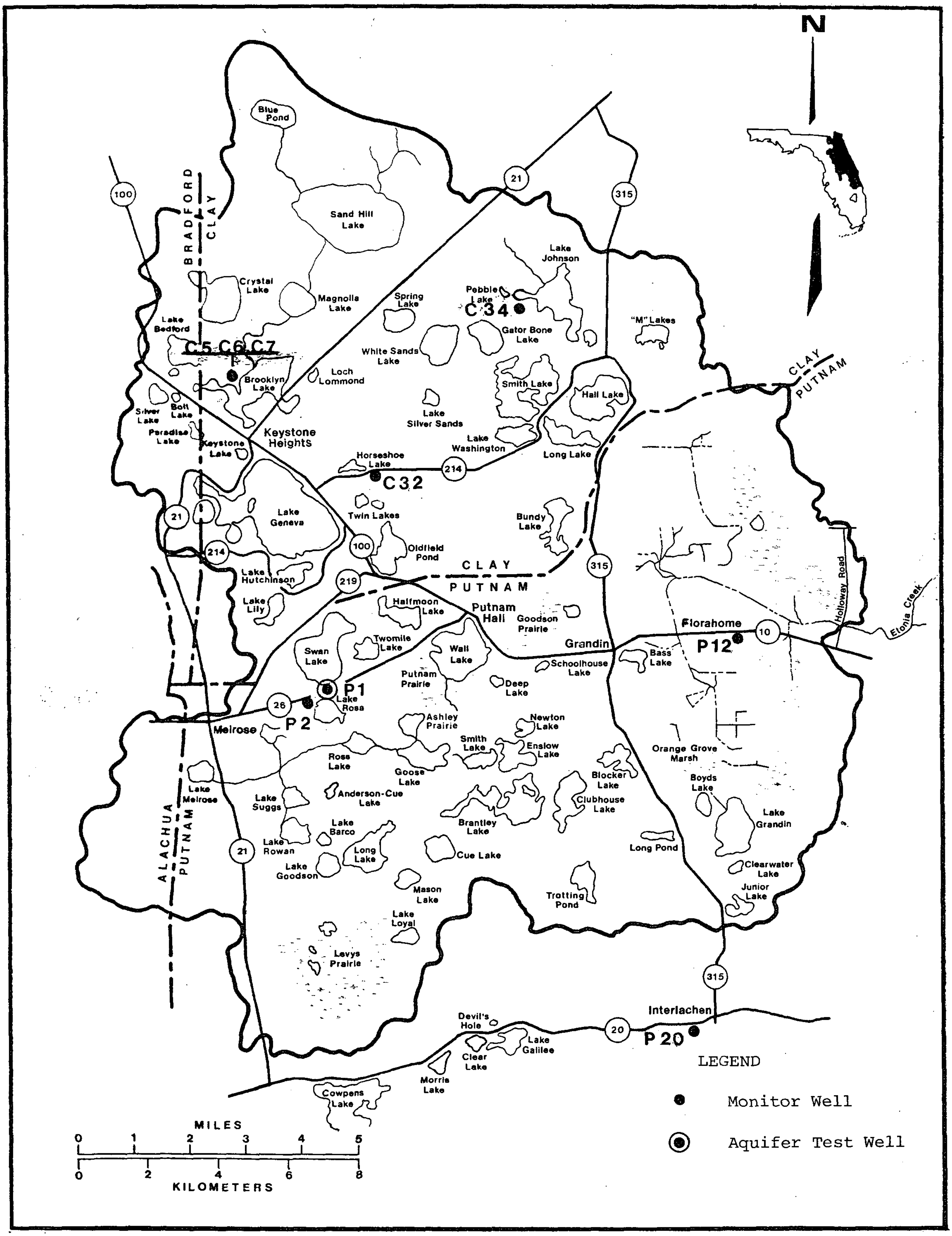

FIGURE 22. -- Location of Selected Monitor Wells in the Study Area

primarily to increased fluctuation in lake levels in response to direct rainfall, runoff, evaporation, and leakage. Away from the influence of lakes, the water table is primarily influenced by recharge from rainfall and leakage to underlying aquifers.

Generally, fluctuations of the water table in response to precipitation within the sand hills would be expected to lag behind areas of shallower water tables. This is due to the relatively thicker section of sand through which the water must percolate to reach the water table in the sand hills area.

Secondary Artesian Aquifer

The secondary artesian aquifer consists of water bearing zones within the Hawthorn Formation. These zones are comprised of alternating sand and limestone beds separated by semipermeable clay layers. The limestone beds range in thickness from a few inches to as much as six feet (Clark, *et al.*, 1964).

Elevation of the potentiometric surface of the secondary artesian aquifer decreases with depth. This is consistent with the statement made earlier that water levels in recharge areas decrease with depth. Generally, wells drilled into the upper parts of the secondary artesian aquifer reflect the elevation of the (higher) water table, although remaining below actual water table heights. Wells drilled into the lower parts of the secondary artesian aquifer reflect potentiometric levels of the Floridan aquifer, although the water levels are higher in elevation than those of the Floridan. Well C-34 located in the southwest corner of Gold Head Branch State Park 0.4 miles northeast of Gator Bone Lake, (Figure 22), reflects the potentiometric head of the lower part of the secondary artesian aquifer. Fluctuation in levels of this well (Figure 23) generally correspond to fluctuations of the Floridan aquifer.

Water is recharged to the secondary artesian aquifer from the non-artesian aquifer and from lakes whose bottoms intersect the Hawthorn Formation. Recharge occurs throughout the upper basin where the water table is higher than the potentiometric surface of the secondary-artesian aquifer and where vertical permeability is conducive to vertical recharge to the Hawthorn Formation.

Water in the secondary artesian aquifer is discharged by leakage to underlying aquifers and by pumpage for domestic use. Clark, et al., 1964, estimated that one-half of the domestic wells in Alachua, Bradford, Clay, and Union Counties are drilled into the secondary-artesian aquifer. It is estimated that this percentage is applicable to the study area.

Floridan Aquifer

The Floridan aquifer is the most extensive water-bearing formation within the State of Florida and the southeastern United States. The aquifer is composed of the basal Hawthorn Formation (where hydraulically connected), the Ocala Limestone, and the Avon Park and Lake City Limestones. Within the Upper Etonia Creek Basin, the aquifer is thought to be semi-confined by clays and sandy clays of the Hawthorn Formation and semipermeable zones within the Oldsmar Formation.

The elevation of the top of the Floridan aquifer is depicted in Figure 24. From a high of +40 feet msl in the southwestern part of

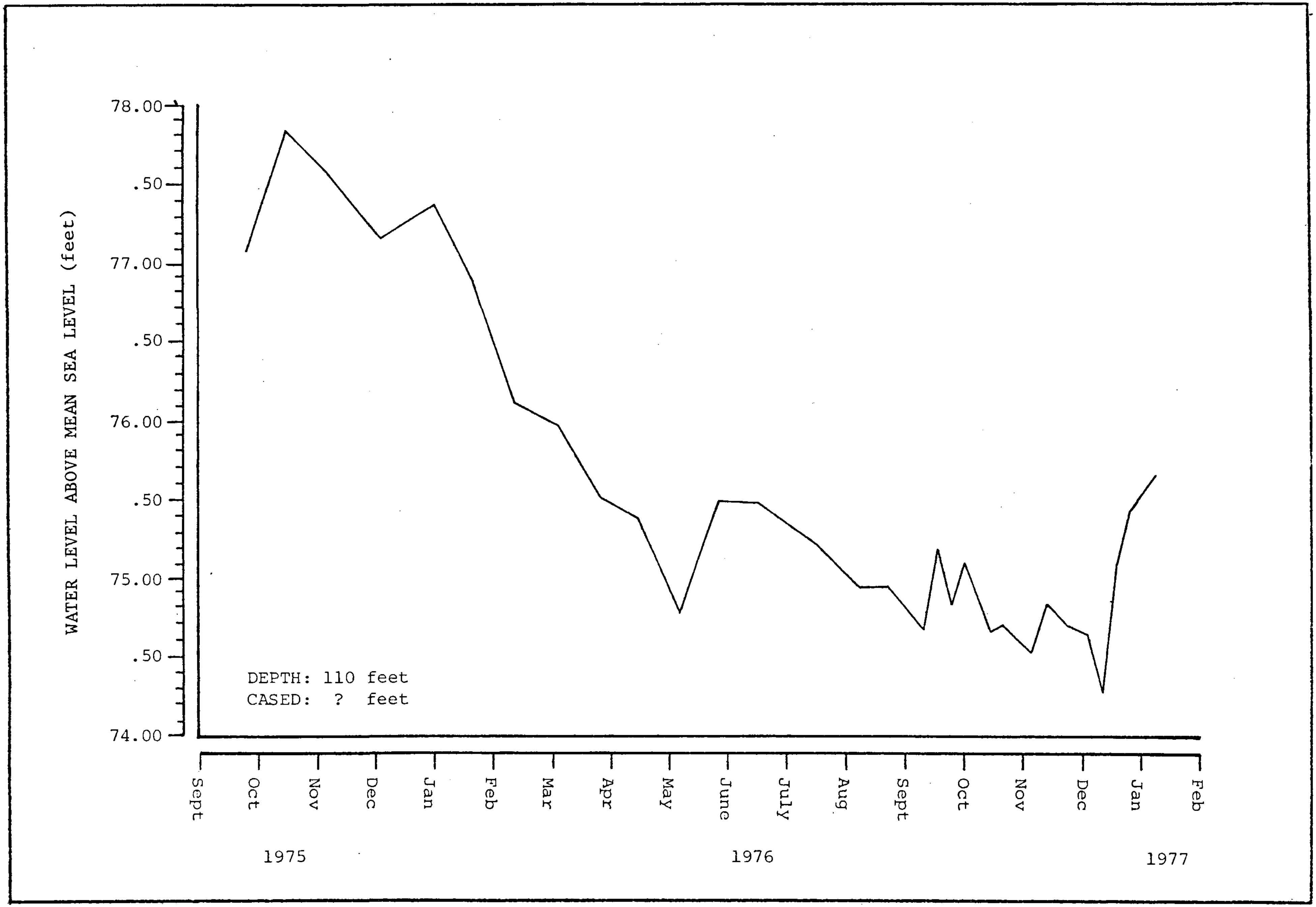

FIGURE 23. -- Hydrograph of Well C-34

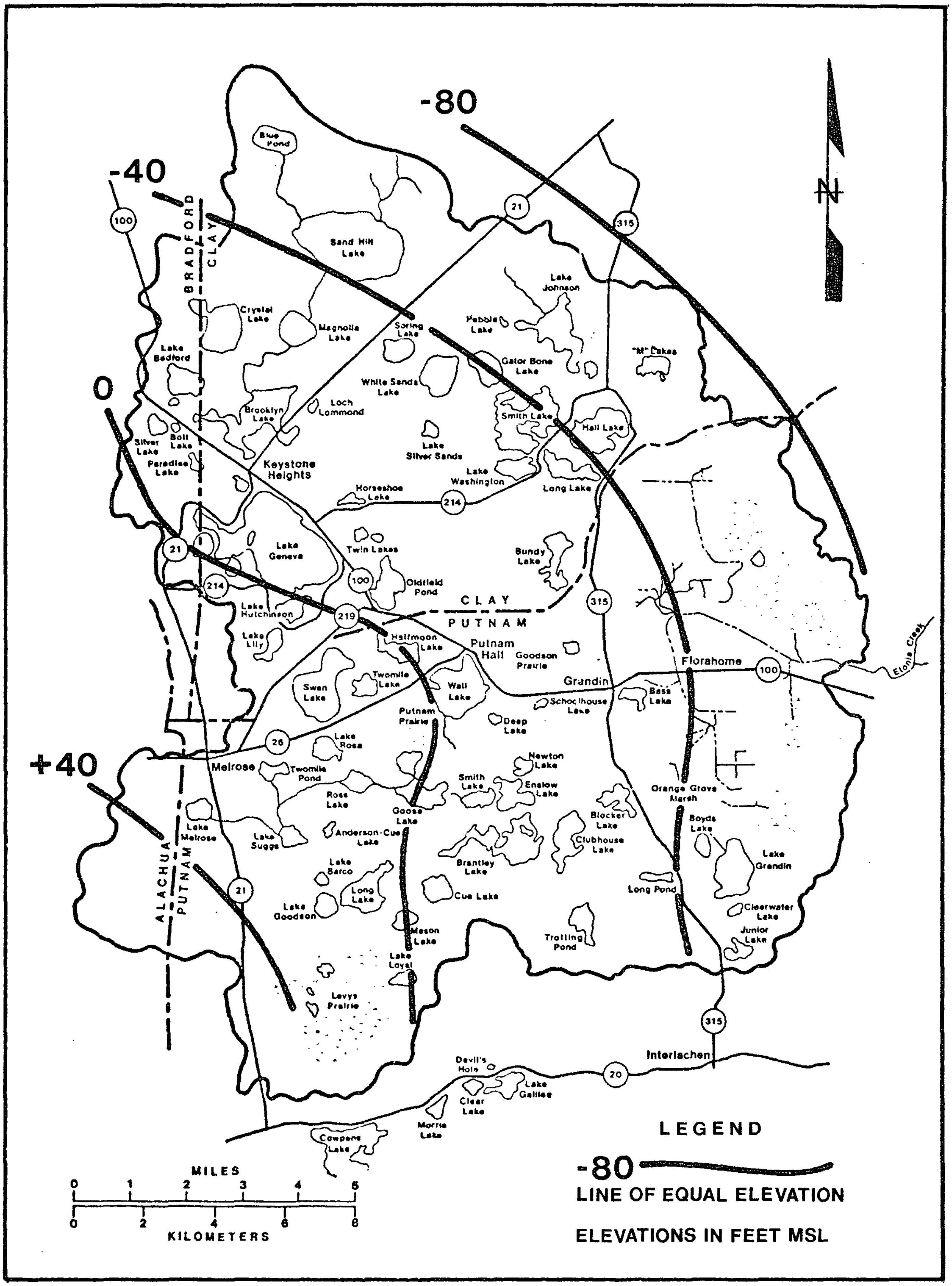

FIGURE 24. -- Contour Map Showing Approximate Elevations of the Top of the Floridan Aquifer

the upper basin, the top of the aquifer dips to the northeast, gradually dropping below sea level. A map of the potentiometric surface of the Floridan aquifer for August 1976 is shown in Figure 25. The map is based upon water level measurements of about 50 wells completed in the upper part of the Floridan aquifer. Natural hydraulic gradients shown by contour line spacing in Figure 25 are gentle, averaging 1 foot/mile. The slope of the potentiometric surface is steepest towards the northwest. The major feature of the map is a potentiometric high centered around Keystone Heights. This configuration of the potentiometric surface indicates that the Floridan aquifer is receiving recharge in this area. Water moves radially from the crest of this high to discharge areas outside the study area.

Water levels in wells within the Upper Etonia Creek Basin have been declining since the end of 1973 to the end of the study period as a result of a deficiency of rainfall. This is illustrated by Figure 26 which shows water level fluctuations in well C-7 and cumulative departure from mean annual rainfall at Gainesville. Well C-7 is located at the northwest corner of Brooklyn Lake near Keystone Heights (Figure 22). The average water level decline of the Floridan aquifer in wells measured in the upper basin during 1976 was 2.3 feet. Long term water level fluctuations of the Floridan aquifer are represented by hydrographs of wells C-7, P-12, and P-20 (Figures 26, 27, and 28). Well P-12 is located near the geographic center of Florahome, and well P-20 is located west of Interlachen (Figure 22). Water level fluctuations in these wells represent water level changes in an area of the Floridan aquifer which is not unduly stressed by development,

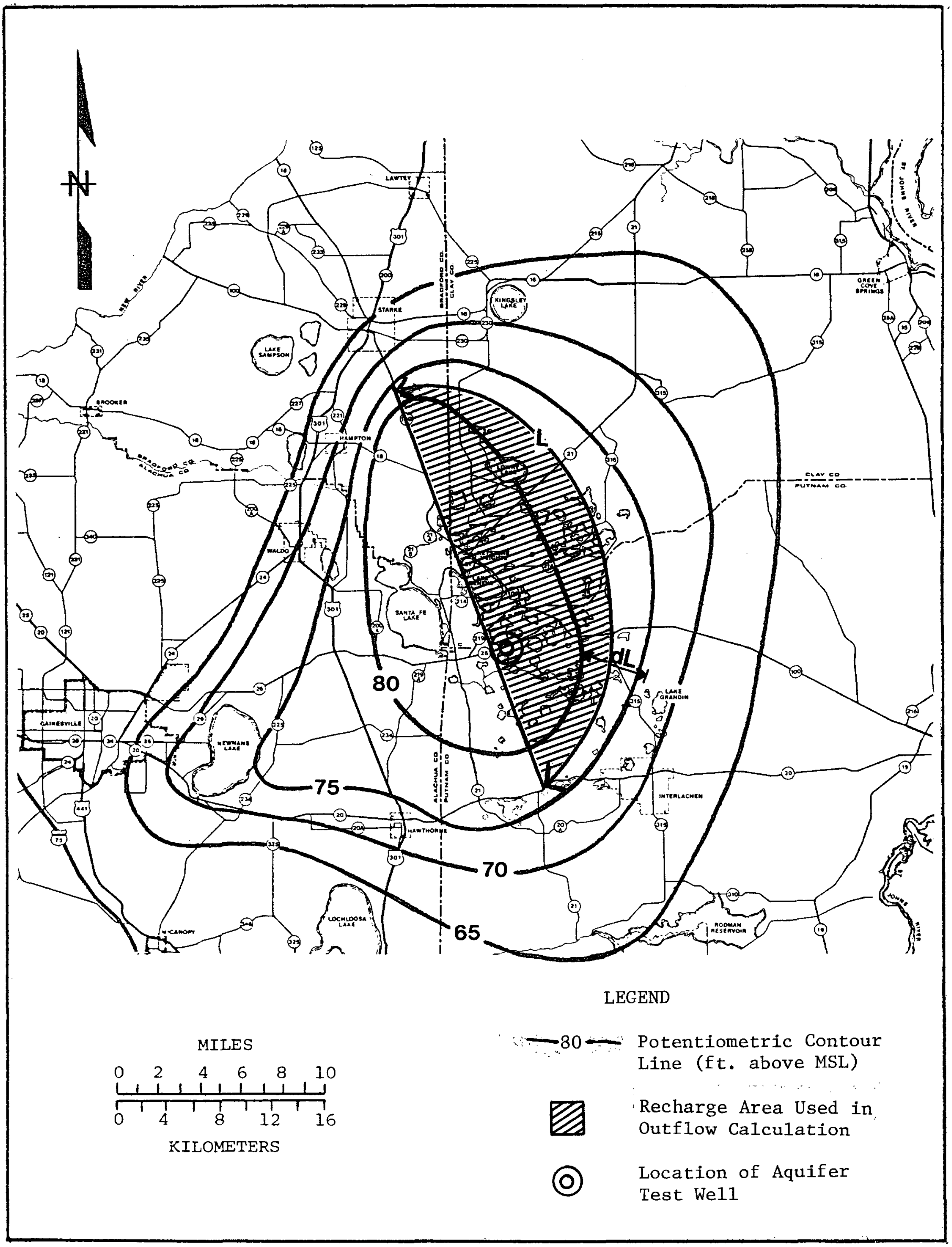

FIGURE 25. -- Potentiometric Surface of the Upper Floridan Aquifer in the Keystone Heights Vicinity, August 1976, Showing Recharge Area Used in Outflow Calculations

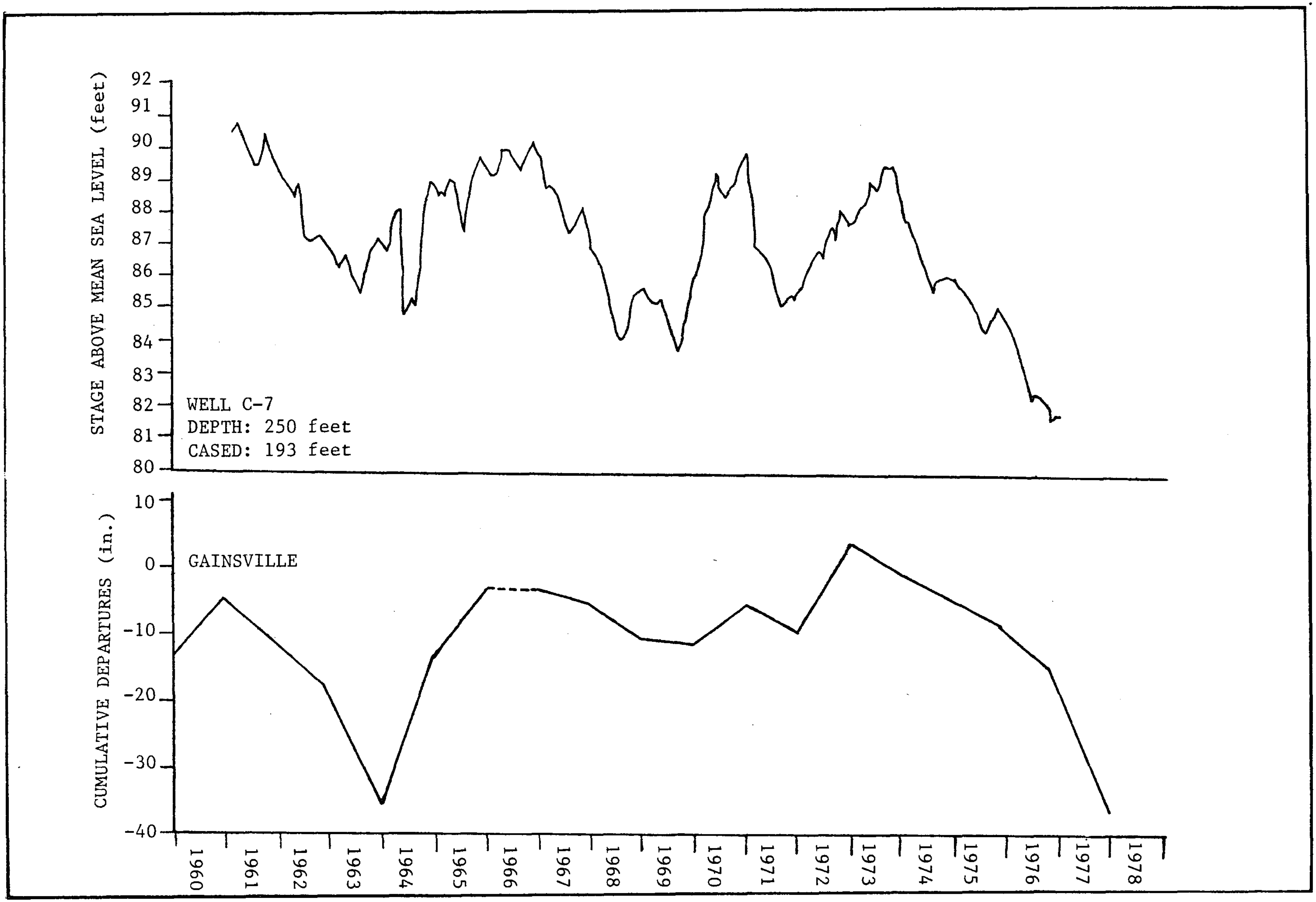

FIGURE 26. -- Hydrograph of Well C-7 and Cumulative Departure from Mean Annual Rainfall at Gainesville

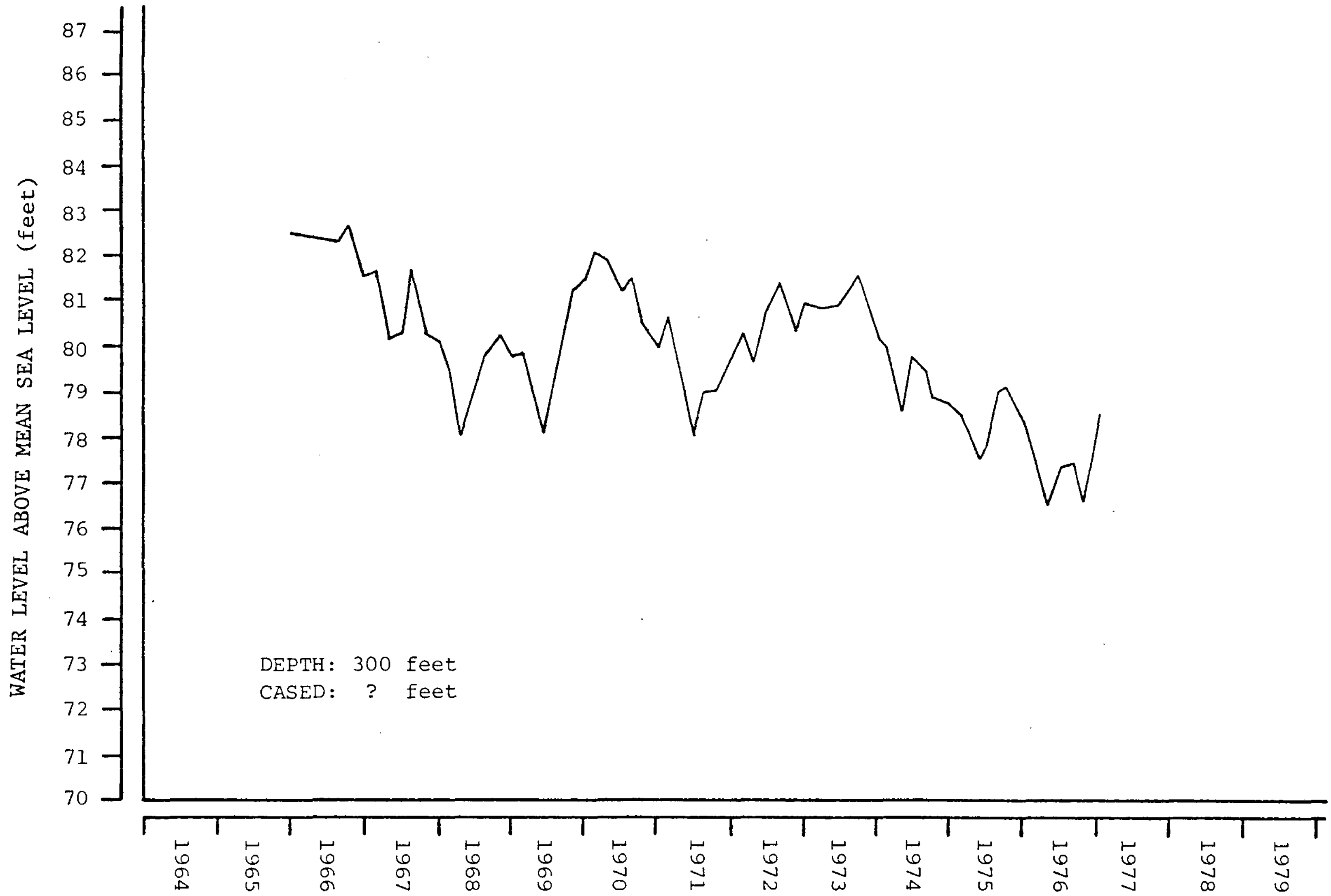

FIGURE 27. -- Hydrograph of Well P-12

FIGURE 28. -- Hydrograph of Well P-20

and variations in levels are thought to be the result of differences in recharge and discharge.

A comparison of water levels in wells C-5, C-6, and C-7 (Figure 19) reveals a pattern in water level fluctuations that is similar to changes in stage elevations of Brooklyn Lake (Figures 19 and 29). The wells penetrate the three aquifers underlying land peripheral to Brooklyn Lake and indicate a hydraulic connection between Brooklyn Lake and lower aquifers.

The Floridan aquifer is recharged by downward seepage from shallower aquifers and surface water bodies which are at a higher elevation than the potentiometric surface of the Floridan aquifer. The quantity of recharge is dependent upon the head difference between the aquifers and the permeability of the intervening geologic materials. Estimates of the amount of recharge to the ground water system are presented in a later section of this report.

Figure 20 shows head relationships between the Floridan aquifer and contours based on lake surface elevations for the summer of 1976. Because of the various degrees of hydraulic connection of lakes with the Floridan aquifer and the fact that the water table is generally assumed to be higher under hills than under depressions, the contours based on lake elevations may represent contours of the lowest points in the water table aquifer. However, comparison of contours based on lake elevations and potentiometric levels in the Floridan aquifer (Figure 20) indicates that a net downward hydraulic gradient exists throughout most of the study area. Examination of available data reveals that all measured lake elevations in the study area were higher than +80 feet msl in May 1976, and therefore based on available

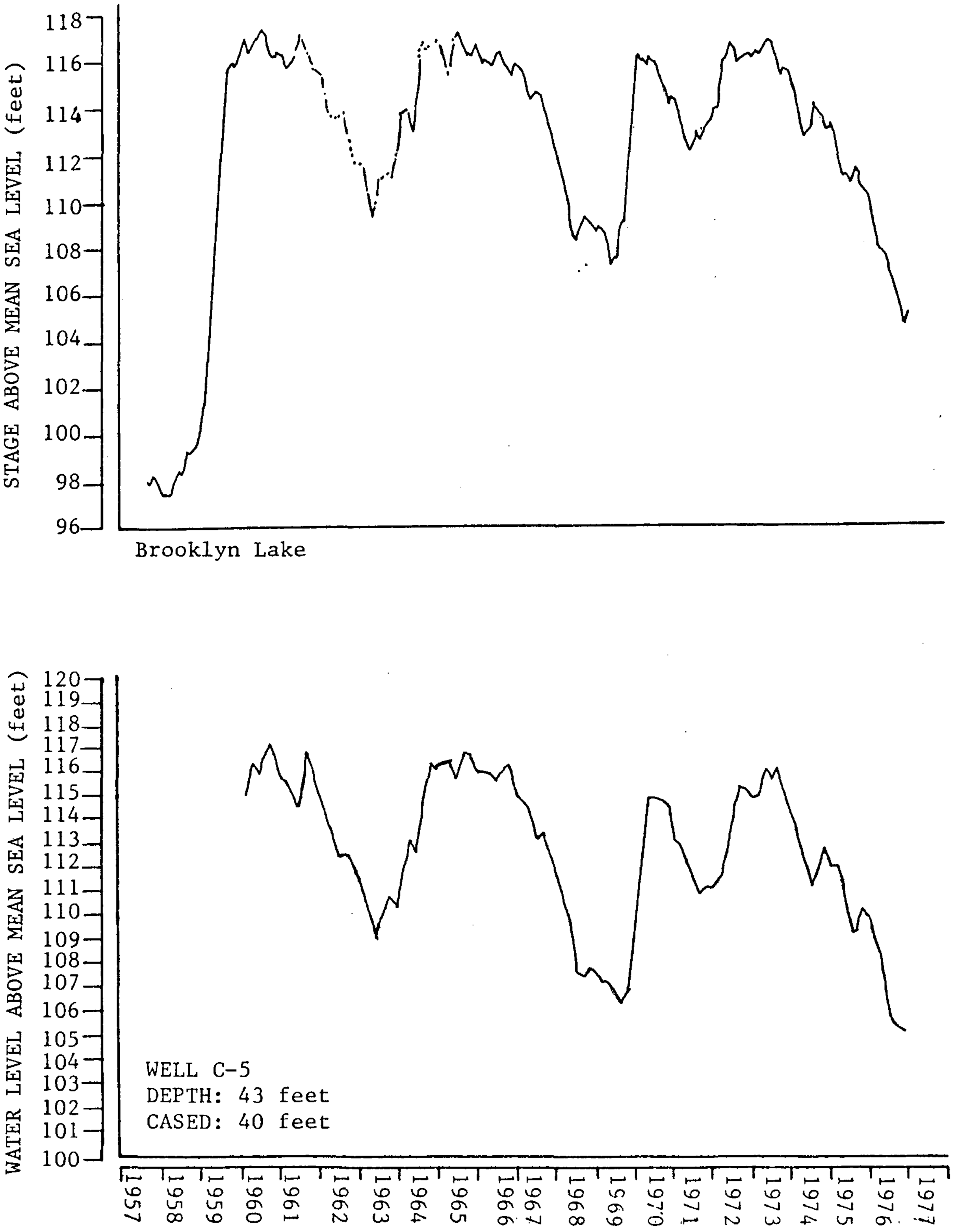

FIGURE 29. -- Hydrographs of Brooklyn Lake and Well C-5

data, a net downward hydraulic gradient exists throughout most of the study area. Higher head differentials exist in the sandhill areas north of Keystone Heights where thick sections of sand mantle the solution depression topography.

For example, the head differentials between the water table and the Floridan aquifer in the vicinity of Sand Hill Lake during the summer of 1976 amounted to about 50 feet. The sands in the sand hill areas are thought to allow rapid percolation of rainfall resulting in an increase of water in storage, thereby increasing the amount of water available for seepage to the secondary-artesian and Floridan aquifers.

Discharge of ground water from the Floridan aquifer in the Upper Etonia Creek Basin occurs through ground water outflow and by pumping. The largest quantity of discharge is by outflow, the movement of water under a hydraulic gradient away from the potentiometric high surrounding Keystone Heights. The largest user of water is industry, accounting for 5 mgd of the estimated 6.4 mgd used. However, this use constitutes only about 6 percent of the quantity of water leaving the basin every day.

To determine aquifer characteristics of the upper Floridan aquifer, an aquifer test was conducted using a well located on the south shore of Swan Lake (Figure 22). The pumped well was a 10-inch diameter drainage well which is 167 feet deep and cased 95 feet to the top of the Floridan aquifer. Water levels in an observation well approximately 2,300 feet southwest of the pumped well were measured to determine the drawdown effect from the pumped well. A few months prior to the aquifer test, the well was pumped to develop it and unclog any channels or flow zones which may not have been previously open.

For the aquifer test, the well was pumped for nine hours at an average rate of 450 gpm. The pumping water level stabilized after six hours of pumping. At the end of the ninth hour, the pump was shut off and the recovery observed. Water levels measured in the observation well at the same time intervals as the pumped well define the time-drawdown curve in Figure 30. As with the pumped well, response to pumping was observed early, but the magnitude was slight due to the large distance between the two wells. The time-drawdown curve indicates gradual declines within the first 40 minutes, showing that the cone of depression was gradually expanding. As with the pumped well, the water level stabilized in the observation well after six hours of pumping. With only one observation well available, only time-drawdown analysis could be made except by using the pumped well as the second observation well.

Analyses of the aquifer test data are presented in Appendix C. The time-drawdown data for the observation well were analyzed by the inflection point method (Hantush, 1956); transmissivity was found to be about 600,000 gpd/ft, and leakance was found to be about 1.0×10^{-2} $gpd/ft^2/ft$. The distance-drawdown data for the pumped well and the observation well were analyzed by a method presented by Hantush (1956); transmissivity was found to be about 1,000,000 gpd/ft, and leakance was found to be 9.4×10^{-3} $gpd/ft^2/ft$. Because of the severe limitations under which the aquifer test was made, the results of the analyses are considered to be only tentative approximations.

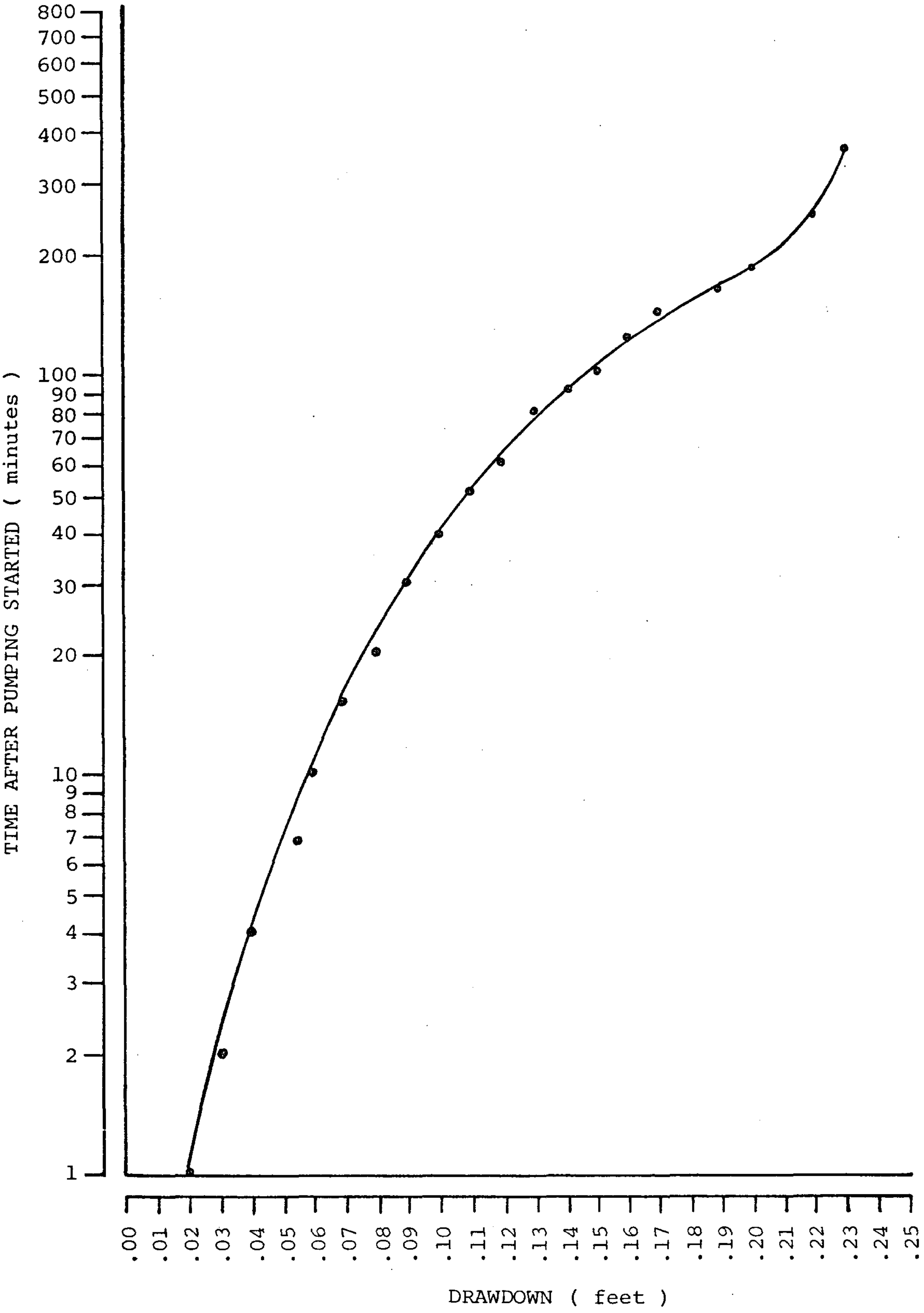

FIGURE 30. -- Time-Drawdown Curve for Observation Well P-2

Recharge to the Ground Water System

In Florida precipitation generally exceeds evaporation (Knochenmus and Hughes, 1976). In the Upper Etonia Creek area, comparatively little water leaves the area via stream discharge except during times of high water levels when some lakes interconnect and flow into Etonia Creek; therefore, significant quantities of water must percolate into the ground water system as recharge.

Within the study area, the Floridan aquifer is recharged by downward seepage from the water table and secondary artesian aquifers and lakes and other surface water bodies that are at a higher elevation than the potentiometric surface of the Floridan aquifer. Recharge to the Floridan aquifer was estimated through the use of a hydrologic budget for the shallow water table aquifer. A hydrologic budget requires balancing the net water input and output of the aquifer. The average annual hydrologic budget for the shallow water table aquifer in the study area may be expressed by the following terms:

INPUT	MINUS	OUTPUT	EQUALS	CHANGE IN STORAGE
P	$-$	$(ET + R + Q + L)$	$=$	ΔS

where

P = precipitation,
ET = evapotranspiration,
R = runoff (streamflow),
L = downward leakage to the Floridan aquifer,
Q = pumpage in the shallow aquifer,
ΔS = change in storage.

From the above equation, the "L" term, downward leakage to the Floridan aquifer, is computed as a residual. For the purpose of this calculation, all ground water discharge from the water table aquifer, with the exception of that going to Etonia Creek which is accounted for in the runoff term, is computed as downward leakage. Then the net recharge to the Floridan aquifer is determined by subtracting pumpage in the secondary artesian and Floridan aquifers from this figure for leakage to the Floridan aquifer.

Components of the hydrologic budget for part of the period of study (1976) were measured, calculated, or estimated as follows:

1. Precipitation was measured at various rainfall stations in and around the Upper Etonia Creek Basin. Rainfall totals within the upper basin ranged from 46.31 to 50.69 inches for 1976. Rainfall totals for 1976 recorded at NOAA stations located in proximity to the upper basin were the following:

Gainesville	48.11 inches
Island Grove	45.10 inches
Jacksonville	50.87 inches
Palatka	45.26 inches
Starke	40.10 inches

The weighted mean rainfall for 1976 was determined to be 47.98 inches.

2. Evapotranspiration was obtained by Penmans formula (discussed previously) and was calculated to be 34.15 inches for 1976.

3. Runoff, which is that portion of precipitation which exits the basin via creeks or streams, consists of waters derived from the flow of water over the surface of the ground (overland flow) to stream

channels, and ground water seepage from the water table aquifer. Runoff was measured at the outflow point of the upper basin by calculating daily mean discharges of Etonia Creek and converting the discharge to inches of runoff. Calculated runoff for 1976 was 0.80 inches.

4. The change in storage in the water table aquifer for 1976 is calculated to be minus 4.60 inches and was estimated from lake level declines.

5. Pumpage from the water table aquifer was assumed to be negligable for 1976.

Thus, the hydrologic budget equation for 1976 is given by:

INPUT	MINUS	OUTPUT	EQUALS	CHANGE IN STORAGE
P	(-)	(ET + R + Q + L)	=	ΔS
47.98	(-)	(34.15 + 0.80 + 0.00 + L)	=	(-) 4.60

from which L = 17.63 inches.

To obtain net ground water recharge, pumpage in the secondary artesian and Floridan aquifers for 1976 must be subtracted from this figure. Estimated ground water pumpage during 1976 within the Upper Etonia Creek Basin was 6.35 mgd. Water users included:

Domestic	0.57 mgd
Agriculture	0.50 mgd
Industry	5.00 mgd
Municipal	0.28 mgd

Pumpage in 1976 is therefore estimated to be 0.81 inches. Net recharge to the Floridan aquifer is then given by subtracting pumpage (0.81 inches) from leakage (17.63 inches) which yields 16.82 inches of recharge to the Floridan aquifer for 1976.

The same approach was applied to the period 1961 through 1966. This time interval was selected because of the availability of rainfall records within the basin, and storage at the beginning and end of the period was equal (Yobbi, Pers. Comm., 1979). Components of the water budget equation for 1961 through 1966 are the following:

INPUT	MINUS	OUTPUT	EQUALS	CHANGE IN STORAGE
P	-	(ET + R + Q + L)	=	ΔS
329.36	-	225.36 - 15.00 - 0.00 - L	=	0.00

from which L = 89.00

Pumpage for the interval 1961 through 1966 in the lower aquifers is estimated to be 3.00 inches. Net recharge to the Floridan aquifer for the period 1961 through 1966 is equal to leakage (89.00 inches) minus pumpage (3.00 inches) or 86 inches for the 6-year period which gives a yearly average recharge to the Floridan aquifer of 14.33 inches.

The internal consistency of the value of recharge to the Floridan aquifer calculated by the water budget method can be appraised by determining the value of transmissivity of the Floridan aquifer necessary to conduct the recharge out of the recharge area and comparing that value with the value of transmissivity obtained from the Swan Lake aquifer test.

To calculate the transmissivity, a flow net was used. In this case, the flow net is the potentiometric contour map of the Floridan aquifer in the recharge area for 1976 (Figure 25). A uniform recharge of 16.82 inches/year was assumed to have occurred over the approximately 100-mile shaded part of the recharge area (Figure 25) and to have been transported out of the area as ground water outflow across the 77.5-foot msl potentiometric contour line that forms the eastern boundary of the shaded area of the figure. Then from the relationship

$$Q = TIL,$$

T is given by

$$T = Q/IL$$

where

T = average transmissivity of the aquifer along the outflow section,

Q = quantity of ground water outflow across the 77.5-foot contour which = 8.0079×10^7 gpd,

I = dh/dl = average change in the potentiometric head per unit length along the outflow section, and

L = length of outflow section.

From the 1976 potentiometric map:

$I = dh/dl = 5$ ft./3 mi. and $L = 26.3$ miles

From the above, T is calculated to be 1.83×10^6 gallons per day per foot; or for 1976 conditions, a T of about 1.8×10^6 gpd/ft for the Floridan aquifer is required to conduct 16.82 inches of recharge out of the recharge area. The value of transmissivity is about 1.8 times larger than the largest tentative approximation value of transmissivity obtained from the Swan Lake aquifer test.

If it is assumed that the value of T obtained from the aquifer test is valid, then a reason must be sought that would explain the disparity between the value of transmissivity obtained from the aquifer test and the value of transmissivity determined by the flow net calculation. This may be found in the fact that the aquifer test approximation of transmissivity applies only to the upper part of the Floridan aquifer, and it is suspected that the Floridan aquifer is much thicker in the study area. Therefore, the transmissivity for the effective thickness of the Floridan aquifer in the study area may reasonably be expected to be some multiple of the value of transmissivity obtained from the aquifer test.

Thus, although the value of recharge is not internally consistent with the approximation of transmissivity obtained from the aquifer test, a plausible explanation has been offered that could explain the disparity. This explanation, however, is dependent on the validity of the assumption that the value of transmissivity obtained from the aquifer test is representative of the interval tested.

RECOMMENDED MONITORING PROGRAM

To fulfill hydrologic data requirements and provide an accurate account of hydrologic conditions within the Etonia Creek area, it is recommended that water levels of the lakes and wells indicated on Figures 31 and 32, taken from the lakes and wells inventoried during the study, be monitored on a routine basis, and that all wells within and around the study area be measured semiannually to provide as complete a picture of the status of water levels in the aquifer around the recharge area as possible.

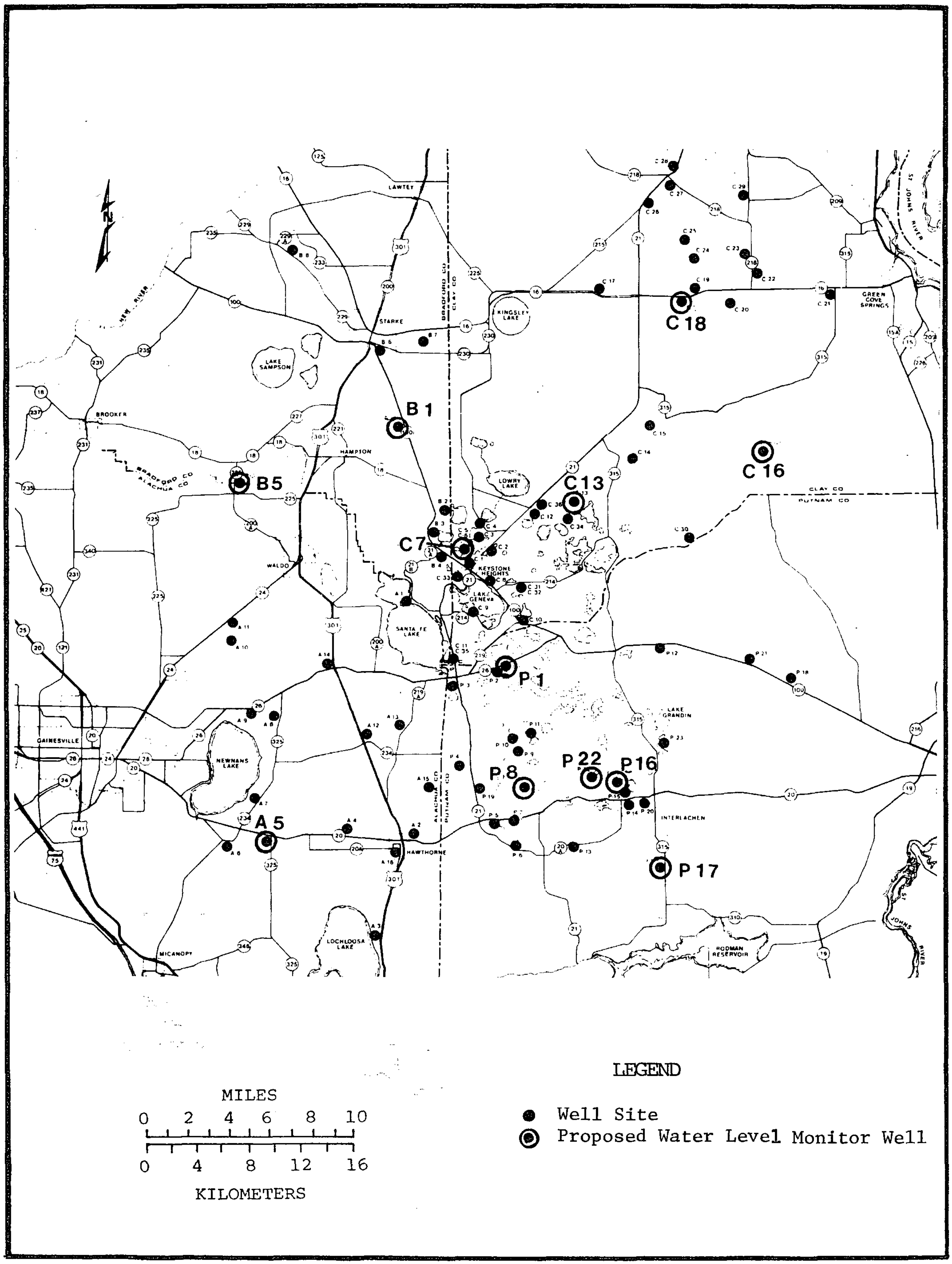

FIGURE 31. -- Well Location Map Showing Proposed Water Level Monitor Wells

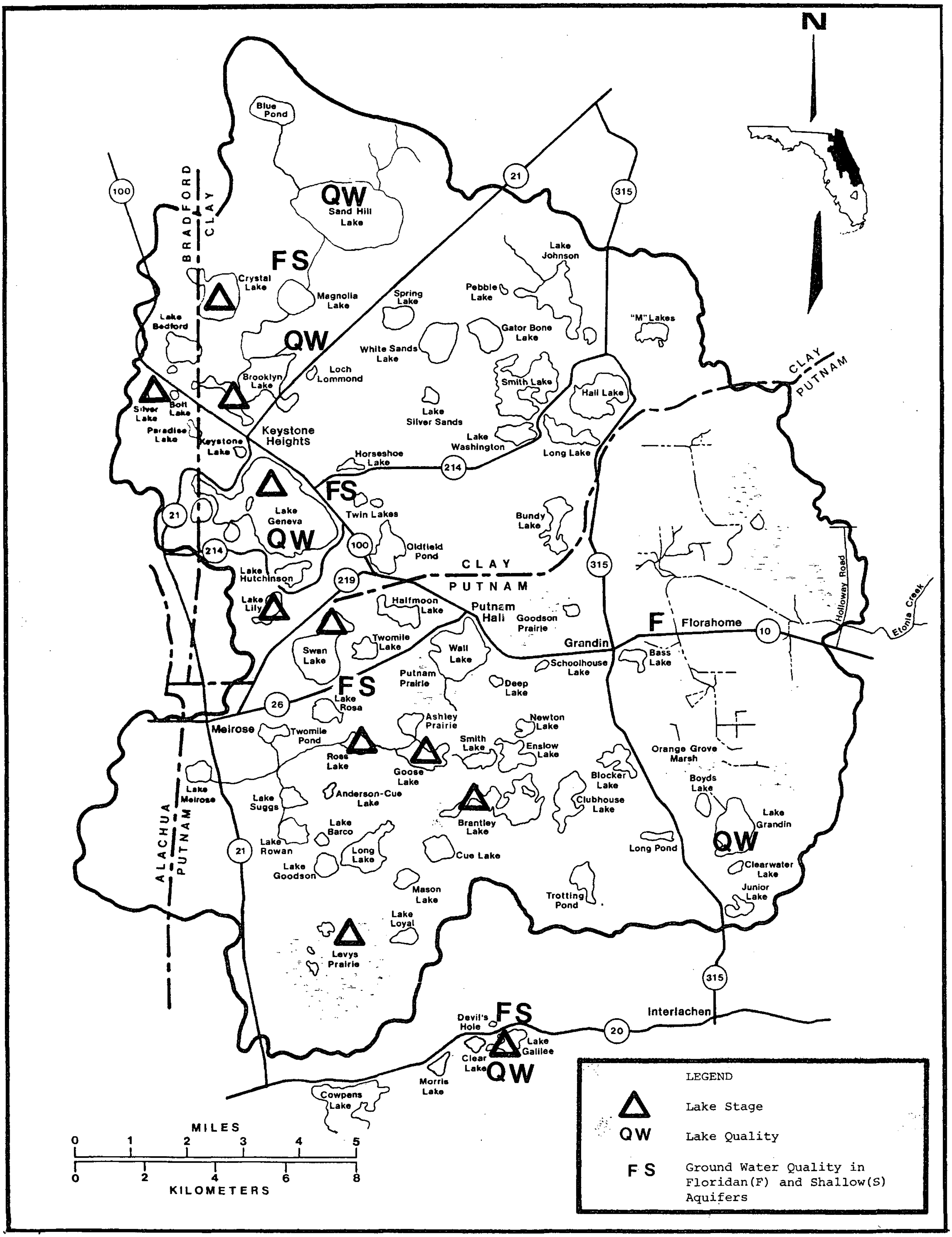

FIGURE 32. -- Proposed Lake Level and Water Quality Monitoring Sites in the Upper Etonia Creek Basin

In addition, it is recommended that chemical analyses be performed on water samples from selected lakes and wells in the study area to monitor the quality of waters in the recharge system. Lakes proposed for chemical quality monitoring are indicated on Figure 32 by the designation "QW", and approximate locations for proposed Floridan and shallow aquifer quality monitoring wells are indicated by the designations "F" and "S", respectively. To institute this program, it is anticipated that most of the shallow wells will have to be constructed; therefore, selection of Floridan wells for water quality sampling will be dependent upon obtaining permission to construct nearby shallow wells.

With regard to sampling frequency, it is recommended that water quality samples be collected semiannually with additional samples to be collected more frequently when conditions warrant a modified sampling frequency.

The above monitoring program is designed to provide the maximum amount of information with the minimum number of monitoring sites. To assure that sufficient information is being obtained, the collected information will be assessed for adequacy of coverage after one year and refinements made in the data collection program if necessary.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. A correlation exists between lake stages and rainfall. Generally, increases in lake stages correlate with above normal yearly rainfall, and declines in lake stages correlate with below normal yearly rainfall.

2. The general decline in lake levels during the period of study (1975-1976) is correlated to a period of below normal rainfall that began in 1973.

3. The following hydrologic parameters were determined for the study area during the study period (1976):

Precipitation	=	47.98 inches
Evapotranspiration	=	34.15 inches
Stream Runoff	=	0.81 inches

4. Recharge to the Floridan aquifer was estimated by using a hydrologic budget calculation. Net recharge for 1976 was estimated to be 16.82 inches. In comparison, an additional calculation based on available data for the period 1961-1966 showed the average net recharge to be 14.33 in/yr.

RECOMMENDATIONS

1. Because significant amounts of recharge to the Floridan aquifer take place in the study area, steps should be taken to insure the following:

A. That detrimental pollution of potential recharge water does not occur;

B. That adequate surface area is maintained for potential recharge to seep into the ground; and

C. That withdrawals of water be limited to an amount that would have minimum detrimental effects on downgradient uses during periods of drought.

2. To help accomplish recommendation 1, the monitoring program described in the text should be implemented.

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APPENDIX A

Discussion of Blue Pond and Lake Melrose Chain of Lakes

BLUE POND LAKE CHAIN

The Blue Pond lake chain, consisting of eight interconnected lakes, flows south and then east, draining an area extending from the northwest corner of the upper basin through Keystone Heights to Putnam Hall. Water level elevations for Blue Pond are available from 1958 through October 1967 (Figure A-1). During this interval, the stage fluctuated between a high of +174.45 on June 1, 1959 to a low of +172.68 feet msl on November 27, 1962 (1.77-foot range). The outlet elevation for Blue Pond is about +173 feet msl (Figure A-2). During the nine years of record, flow from Blue Pond occurred 95 percent of the time.

Surface water flow leaving Blue Pond enters Lowry Lake (Sand Hill Lake). Lake stage information is available from July 1957 through December 1976 (Figure A-3). Lowry's outlet elevation is about +131 feet msl, flow has existed 97 percent of the time; no flow occurred during some months in 1963 and 1968. The range in fluctuation for Lowry Lake has been from +132.73 on September 22, 1964 to +130.74 feet msl on May 26, 1968 (1.99-foot range). Outflow existed throughout 1976.

Magnolia Lake receives flow from Lowry Lake. Its hydrograph is shown in Figure A-4. The outlet elevation for Magnolia Lake is about +124 feet msl, and flow occurred 91 percent of the time. The only substantial interval in which the lake was below its outlet elevation was in January through August 1968. The range in fluctuation for Magnolia Lake has been from +125.87 on September 22, 1964 to +123.08 feet msl on May 25, 1968 (2.79-foot range).

Surface water flow leaving Magnolia Lake enters Brooklyn Lake through Alligator Creek. The approximate outlet elevation of Brooklyn

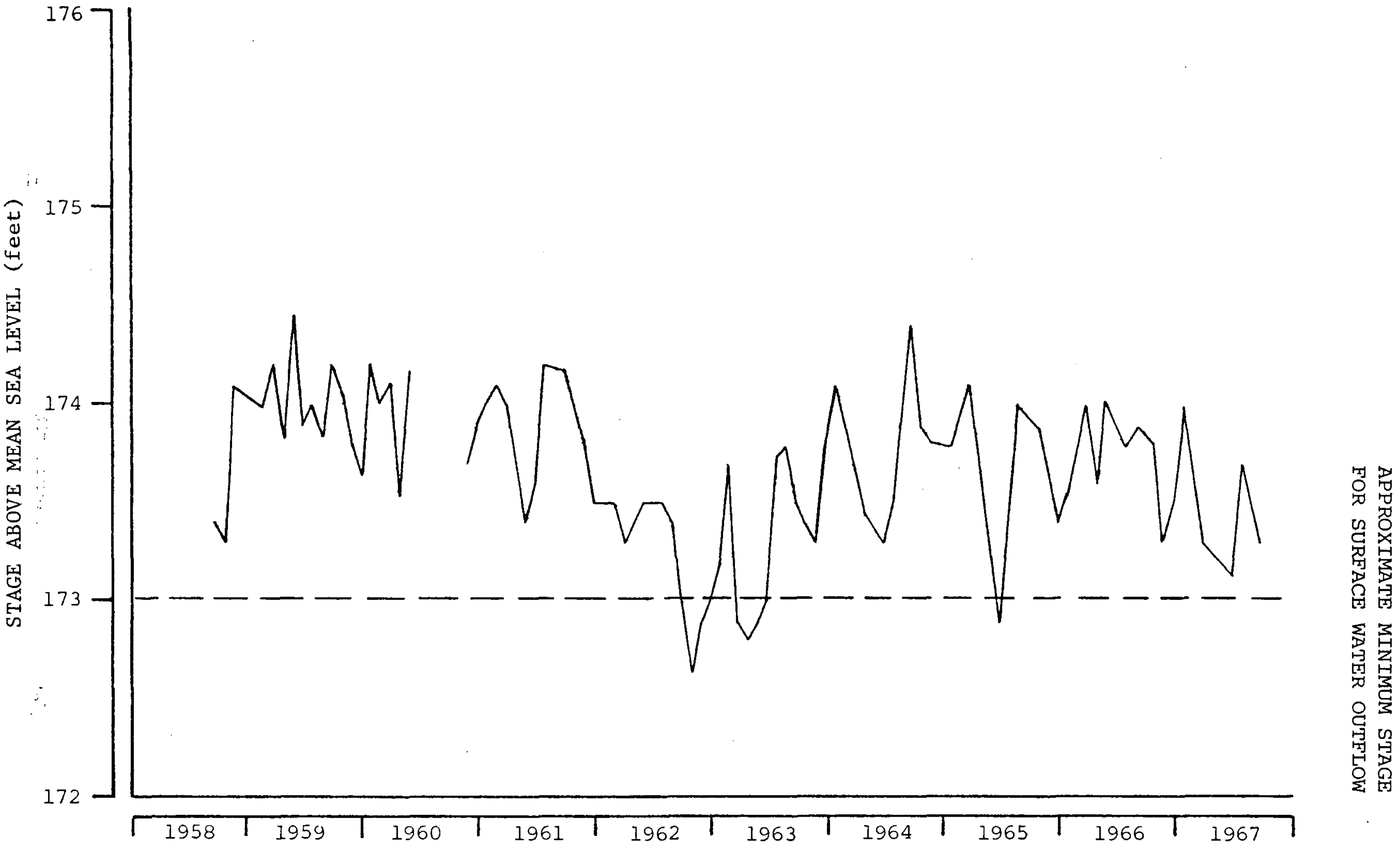

FIGURE A-1. -- Stage Hydrograph of Blue Pond

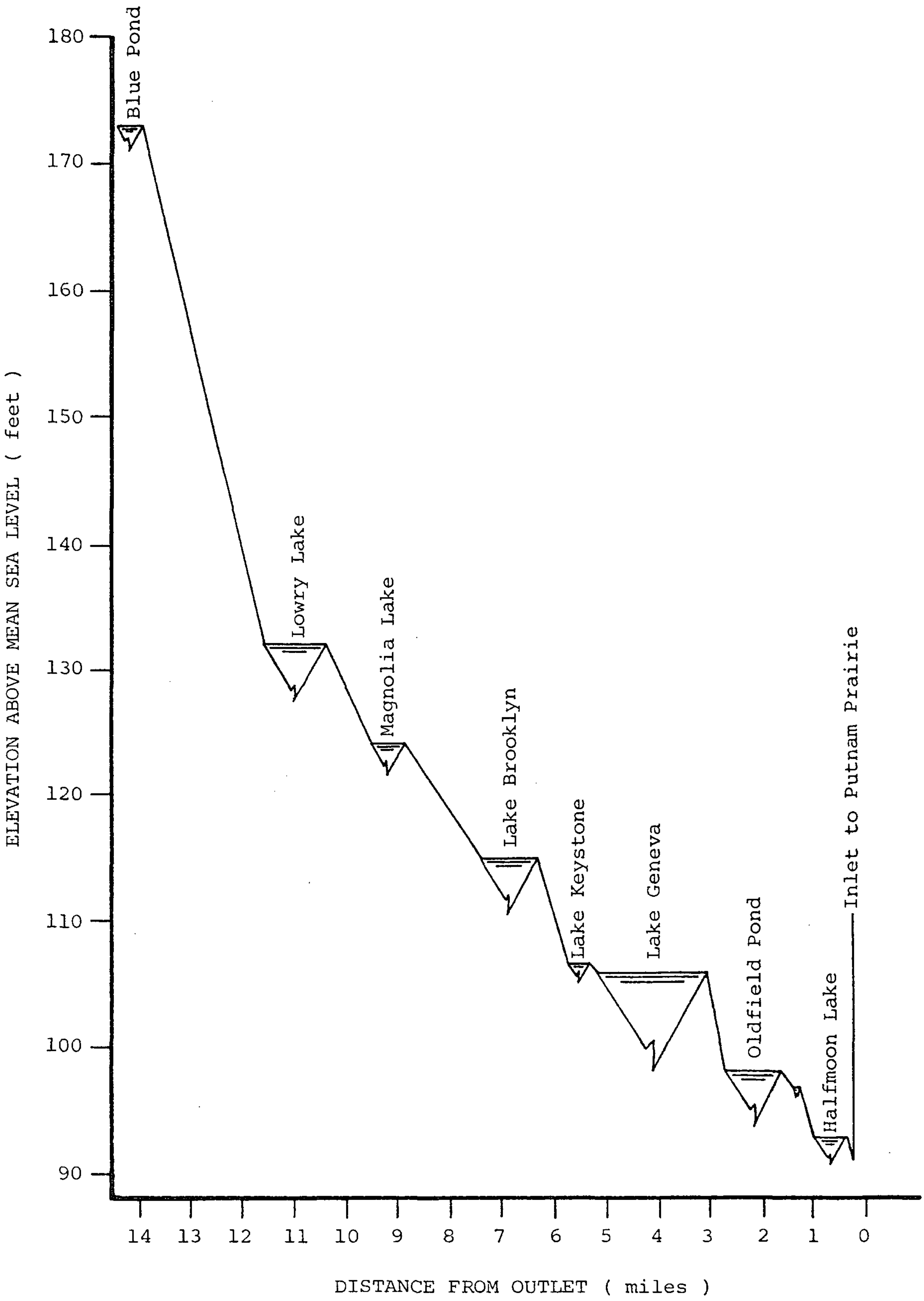

FIGURE A-2. -- Stream Bed Profile from Blue Pond to Putnam Prairie

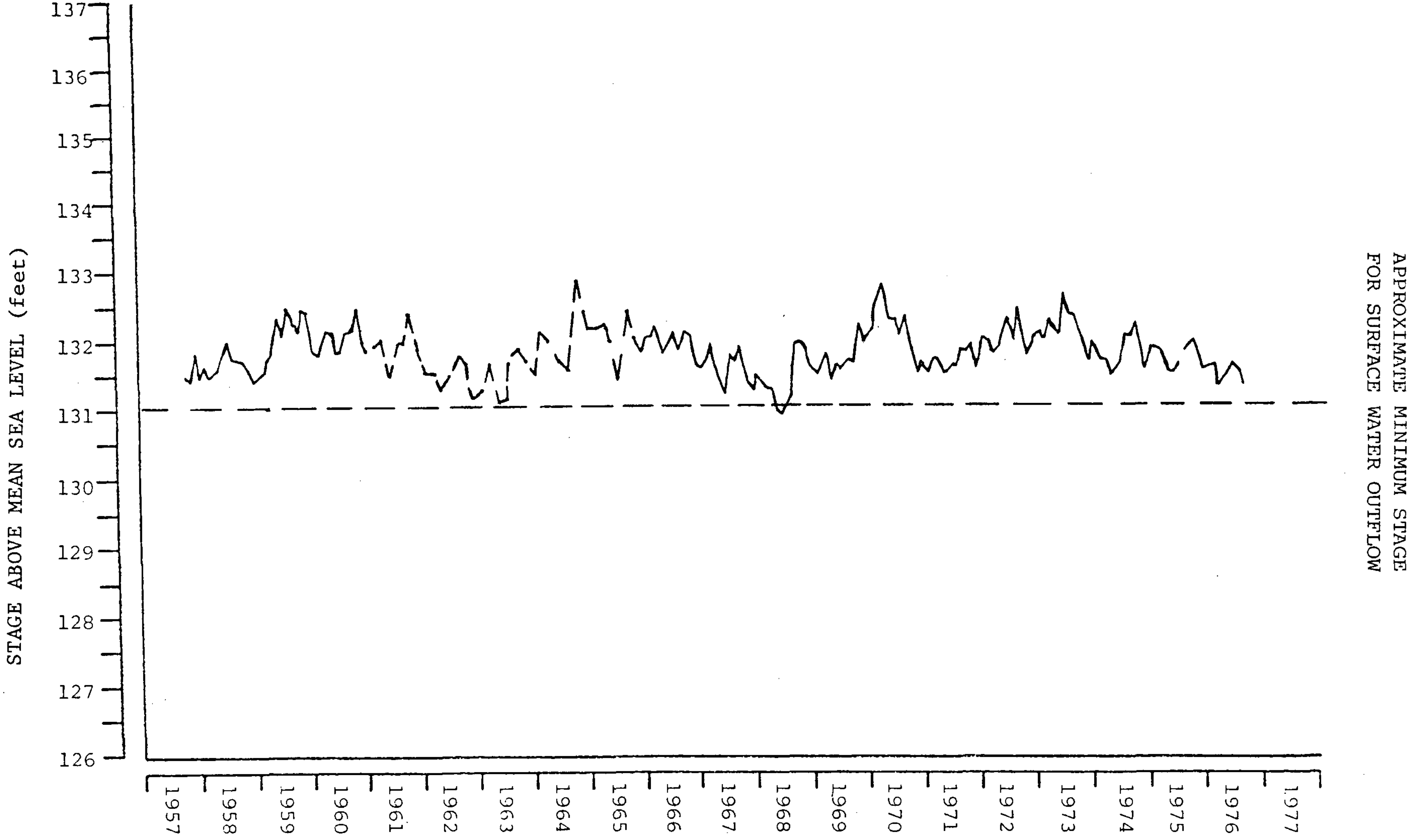

FIGURE A-3. -- Stage Hydrograph of Lowry Lake (Sand Hill Lake)

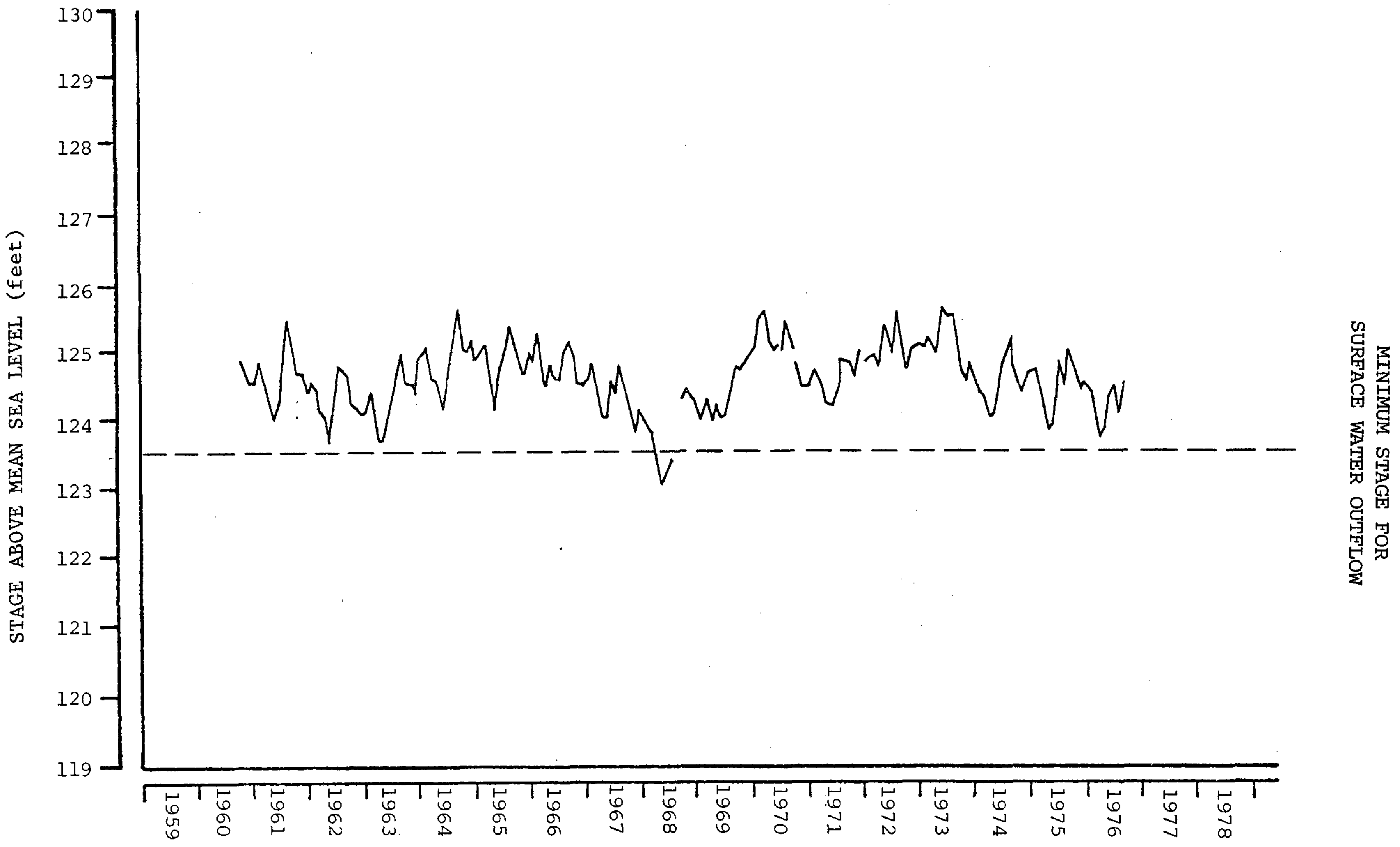

FIGURE A-4. -- Stage Hydrograph of Magnolia Lake

Lake is +115.2 feet msl. Figure A-5 shows the stage hydrograph of Brooklyn Lake. Unlike lakes of higher elevation in this chain, Brooklyn Lake's surface elevation is below its outlet's elevation the majority of time due to high leakance. Outflow has existed only about 39 percent of the time. The stage has ranged from +117.43 on October 1, 1960 to +97.23 feet msl on February 24 and 25, 1958 (20.20-foot range). Brooklyn Lake collects the majority of the overflow derived from the upper three lakes. A flow of 2.1 cfs was measured on October 6, 1976 at Alligator Creek just at the inflow to Brooklyn Lake. Since July 1973, water levels of Brooklyn Lake have been declining, resulting in little or no flow out of the upper four lakes in this part of the tributary.

The fifth lake in the chain is Keystone Lake. As with Brooklyn Lake, no outflow was observed leaving this sub-basin in October 1974. The outlet elevation of Keystone Lake is about +106.3 feet msl, Historical stage records for this lake are not available, but it is expected that outflow from this basin corresponds to the same cycle as Brooklyn Lake, with no flow most of the time.

Next in the chain is Lake Geneva. The approximate elevation of its outlet is +105.8 feet msl. The stage hydrograph of Lake Geneva (Figure A-6) shows that outflow from this basin has occurred about 21 percent of the time. The hydrograph also shows that the elevation of Lake Geneva was +106.21 feet msl on December 23, 1972. Runoff must have occurred during this time, but it ceased in 1974 and was not observed during 1976. Lake Geneva stage has ranged from +107.23 on July 15, 1973 to +99.79 feet msl on October 17 and 18, 1958 (7.44-foot range).

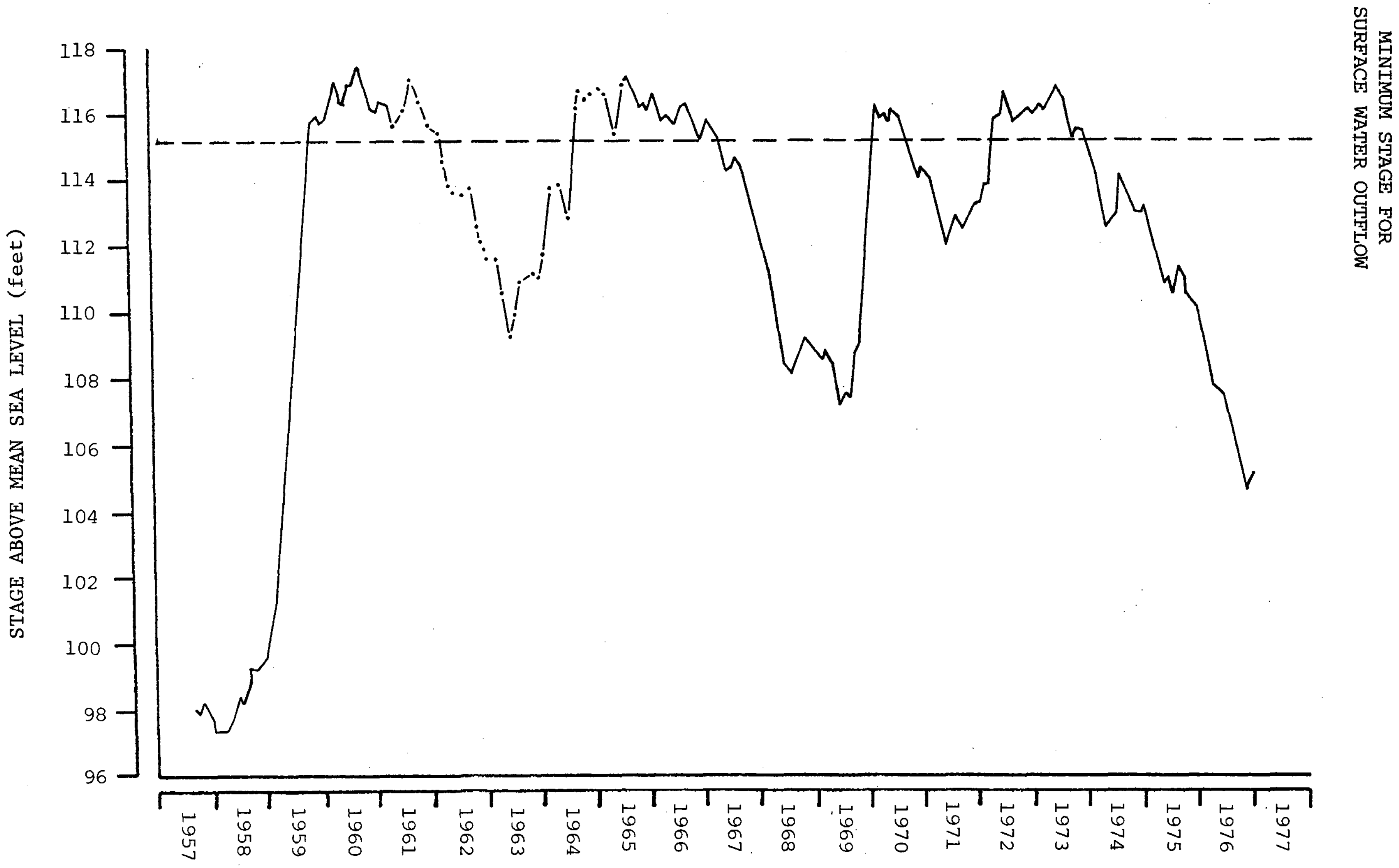

FIGURE A-5. -- Stage Hydrograph of Brooklyn Lake

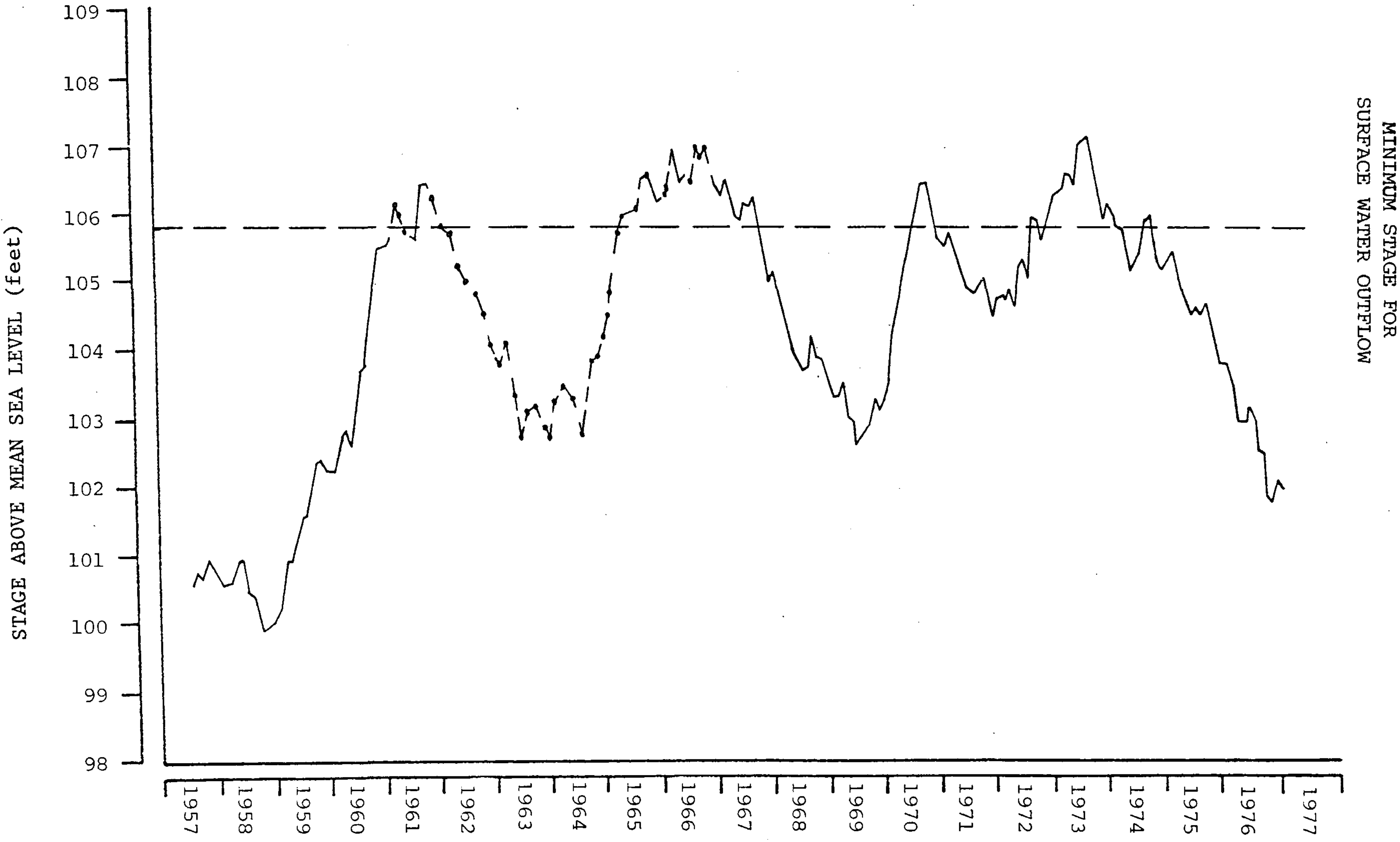

FIGURE A-6. -- Stage Hydrograph of Lake Geneva

The next to last lake in this chain is Oldfield Pond. Its outlet elevation is approximately +97.8 feet msl. Lake levels have not been measured regularly, but it was determined from residents around the lake that the elevation of the lake was approximately +101 feet msl in August 1973. Heavy rains produced high waters, and it was reported that the waters receded at the rate of about one-half inch/day. At that rate of decline, flow would have ceased in December 1973. Oldfield Pond can be considered a closed basin with no flow leaving the basin since December 1973.

Halfmoon Lake is the last lake in this chain. As with Oldfield Pond, Halfmoon Lake was under flood conditions in August 1973 with surface water outflow occurring. Historical records of lake stages are not available for Halfmoon Lake. Measurements of the elevation of Halfmoon Lake during 1973-1975 indicate that the lake elevation fell below the outlet elevation of 92.8 feet msl in February 1974, when it dropped to +92.38 feet msl. Therefore, flow ceased from Halfmoon Lake during this time. Surface water which leaves Halfmoon Lake enters Putnam Prairie through a connecting channel. Putnam Prairie will be discussed with the Melrose chain of lakes.

The surface water flow in this tributary is intermittent, and only the upper three lakes (Blue Pond, Lowry, and Magnolia) exhibit outflow a high percentage of time (94 percent). The lower five lakes receive surface water inflow occasionally and have surface water outflow less than 20 percent of time. Continuous outflow exists within the eight lakes only at extremely high water level conditions. During 1976, surface water flow terminated at Brooklyn Lake.

LAKE MELROSE LAKE CHAIN

The second lake chain has as its headwater Lake Melrose. From Lake Melrose the drainage flows northeast, draining an area in the center of the upper basin extending from south of Melrose to Putnam Hall. This tributary of Etonia Creek has intermittent flow throughout its reaches. As with the Blue Pond chain, the Lake Melrose consists of a series of lakes interconnected by natural creeks or channels (Figure A-7). Six lakes form this branch; four lakes have outlets but no surface water inlets. Three previously landlocked lakes have been connected to this branch by a canal. These lakes do not add flow to Etonia Creek since they are at a lower elevation than the connecting canals.

From September 1975 to January 1977, the elevation of Lake Melrose fluctuated from a high of +104.7 to a low of +102.9 feet msl. A natural creek provides an avenue for discharge from the lake. Runoff from Lake Melrose is limited by a fixed cement weir which has been placed across the creek's channel at the lake's outlet. The elevation of the top of the weir is +103.6 feet msl, but the weir has been disturbed, and the sides bordering the weir have been eroded. This allows water to flow around the weir, and the weir only partially controls flow from Lake Melrose. Flow has been observed in the creek throughout the study period; calculated runoff is 3.4 inches/year. Table A-1 shows the total monthly flows calculated from measurements made downstream from the weir for the calendar year 1976. Information is not available on past water levels of Lake Melrose, but the vegetation along the banks indicates that the water level has been a couple of

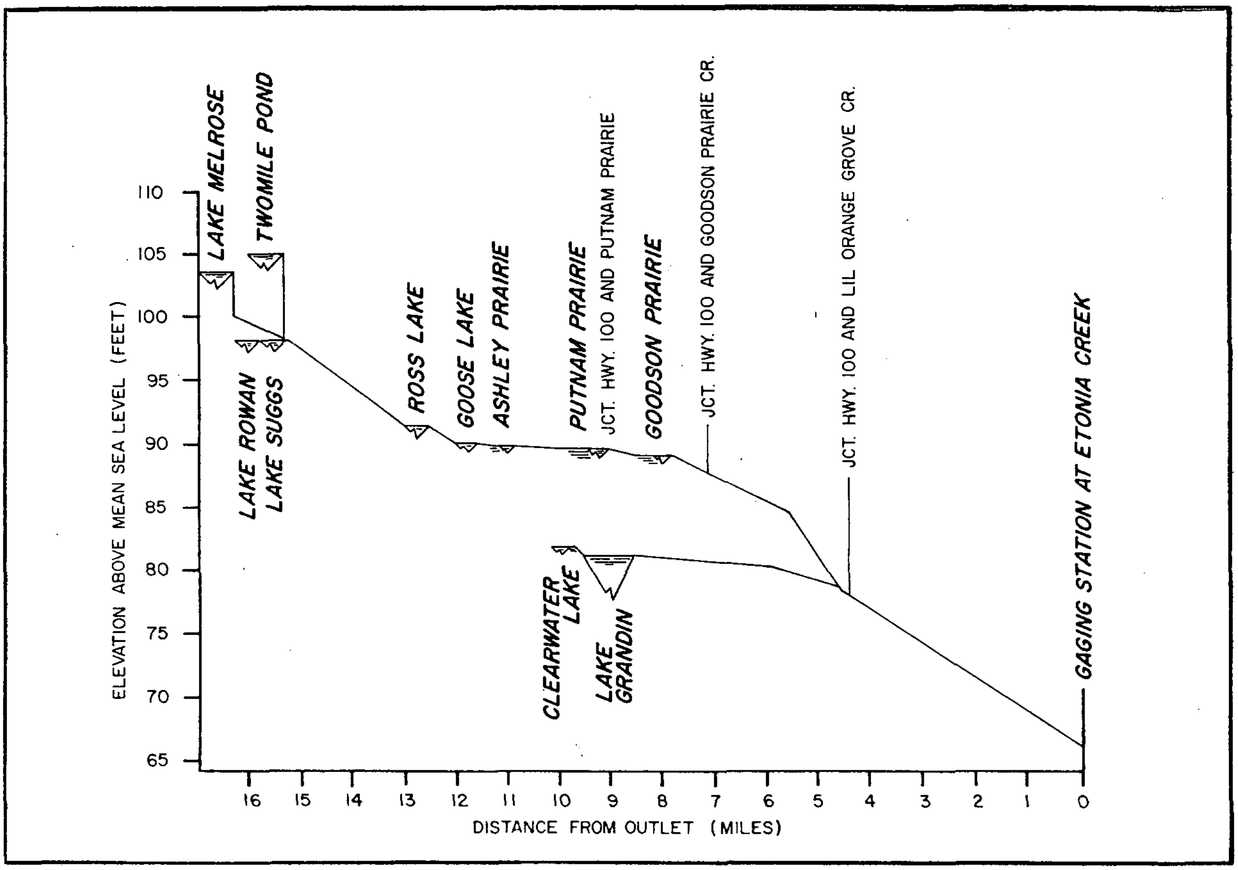

FIGURE A-7. -- Stream Bed Profile from Lake Melrose to Gaging Station at Etonia Creek

TABLE A-1. -- Mean Monthly Stage Elevations of Lake Melrose With Associated Monthly Discharges into Mill Creek During 1976

Month	Lake Elevation		Total Discharge (cfs)
January	103.59		65.1
February	103.45		42.9
March	103.13		19.5
April	103.11		17.7
May	103.40		40.3
June	103.43		75.6
July	103.42		42.5
August	103.26		27.9
September	103.48		48.0
October	103.25		27.0
November	103.13		18.9
December	104.08		200.0
		Total for Year	625.3 cfs
		Runoff	3.4 inches

feet higher than that observed during the study period. It appears that runoff calculated for 1976 is on the low side of the mean with the probable mean runoff in the neighborhood of five inches/year. Surface water from Lake Melrose flows through two box culverts under Florida Highway 21. Approximately one mile downstream from the culverts, outflow from three lakes enters Mill Creek. Two of these lakes, Lake Suggs and Lake Rowan, are marsh-bordered lakes lying in the floodplain on the south side of Mill Creek; during high water, they are connected by sheet flow to Mill Creek. The range of fluctuation for Lake Suggs between September 1975 and November 1976 was 1.2 feet.

The third lake, Two Mile Pond, north of Mill Creek, is above the floodplain of the creek, but has an outflow channel into the creek. The controlling elevation of the outflow is approximately 105+ feet msl. Water levels fell below this elevation in March 1976 and remained below through December 1976, resulting in zero flow contribution to Mill Creek for that period. Two Mile Pond had a range of fluctuation of 3.97 feet between May 1, 1975 and December 10, 1976. Although there are no historical water level records available for this lake, shore line vegetation suggests that the lake has a large range of fluctuation.

Flow from the upper four lakes goes into Ross Lake through Mill Creek. As with the upper lakes, historical water levels are not available from past years; during the study period, flow was seen leaving Ross Lake at all times except during May and June 1976. The outlet control structure for Ross Lake is two box culverts with a base elevation of +91.4 feet msl. Water levels of Ross Lake fluctuated between +93.36 to +90.58 feet msl from September 26, 1975 to December 3, 1976.

The next lake in the Melrose chain downstream from Ross Lake is Goose Lake, a shallow marsh-bordered lake with one inflow from Ross Lake and two outflows. Goose Lake fluctuated between +92.5 feet msl in September 1975 and +89.6 feet msl in January 1977. One outflow, an artificial channel, leads to a chain of three artificially connected lakes--Smith, Enslow, and Brantley--at a lower elevation than Goose Lake. This chain contributes no flow to Etonia Creek and receives flow from Goose Lake only at times of high water. No flow was observed in this chain during the period of study. The other outlet for Goose Lake is through a channel to Ashley Prairie, an open water body in the marsh north of Goose Lake. From Ashley Prairie flow goes through the marsh into Putnam Prairie.

There is no well defined drainage pattern across Putnam Prairie, although there are several bodies of open water on the prairie including Wall Lake. Putnam Prairie receives inflow from the Melrose chain and during high water, the Blue Pond chain. The outflow of Putnam Prairie is through two box culverts under SR 100 east of Putnam Hall into a channel leading to Goodson Prairie. The controlling elevation of the outflow, the base elevation of the box culverts, is less than 89.9 feet msl. Putnam Prairie water level fluctuated from +92.4 feet in September 1975 to +88.1 feet msl in January 1977.

A measurement at the outflow of Putnam Prairie in January 1976 showed 1.2 cfs leaving Putnam Prairie. Although water was observed in the channel between Putnam Prairie and Goodson Prairie in the months following January 1976, the flow was minimal at best, with the Prairie going dry in July 1976. The water level recovered somewhat in December 1976, but flow did not exit from Putnam Prairie at this time.

The last water body in this chain is Goodson Prairie, an extensive marsh area containing one body of open water in the northern part. The remainder of the Prairie acts as a floodplain for the lake and a storage area for high water from Putnam Prairie. Water from Goodson Prairie enters a channelized creek between Orange Grove Lake and Etonia Creek.

Flow was observed at the outlet of Goodson Prairie (two box culverts with the base elevation of +87.1 feet msl) in October 1974; flow ceased in January 1975. The water level of the Prairie subsequently began dropping in elevation with large areas of the Prairie becoming dry and eventually being burned. Elevations of water in Goodson Prairie ranged from +91.4 to +86.6 feet msl from December 1975 to January 1977, with no flow leaving this basin during the project period of 1976. Thus, the Melrose tributary did not contribute any flow to Etonia Creek during the study period, although there was flow between the upper lakes of the tributary.

APPENDIX B

Coefficients of Simple Linear Regression of Lake Stage Data of Swan Lake as a Function of Stage Observations of Forty-Four Lakes

TABLE B-1

COEFFICIENTS OF SIMPLE LINEAR REGRESSION OF LAKE STAGE DATA OF SWAN LAKE AS A FUNCTION OF STAGE OBSERVATIONS OF FORTY-FOUR LAKES

	1975				1976				1975 and 1976		
Lake	*R	*M	*Y_O	*No. of Data Pairs	R	M	Y_O	No. of Data Pairs	R	M	Y_O
Barco	0.7962	1.5480	-43.43	8	0.9716	1.2866	-20.19	19	0.9883	1.2502	-17.05
Bass	0.9586	0.7852	24.25	8	0.5811	0.9930	5.24	22	0.8827	1.2588	-17.68
Bolt	0.9401	0.9221	-12.69	7	0.9962	0.8591	- 5.30	22	0.9970	0.8294	- 1.97
Brooklyn	0.9166	0.4403	44.85	68	0.9902	0.5231	35.37	34	0.9894	0.5554	32.01
Clear	0.7203	1.4211	-24.60	7	0.9749	1.1621	- 2.94	21	0.9910	1.1250	0.05
Cooper	0.7966	0.5332	49.04	9	0.9668	1.1736	- 4.09	19	0.9834	1.0279	7.69
Cowpens	0.8785	0.9714	6.87	8	0.9799	1.2802	-20.76	26	0.9975	1.2830	-20.99
Crystal	0.9405	0.6968	12.60	36	0.9944	1.0530	-28.55	71	0.9952	0.9602	-18.00
Cue	0.9540	1.0487	- 4.10	6	0.9854	1.1026	- 9.08	19	0.9950	1.0925	- 8.17
Enslow	0.9849	0.9684	11.13	8	0.9743	1.1969	- 7.90	19	0.9896	1.0612	3.30
Galilee	0.7452	0.4580	55.58	10	0.9788	1.0996	2.32	24	0.9970	0.8294	- 1.97
Devils Hole Sink	-0.2463	-0.2648	114.39	7	0.9620	1.1407	4.10	23	0.9803	1.1774	1.32
Gator Bone	0.9580	0.6999	33.98	7	0.9414	1.3964	-24.55	25	0.9673	1.0864	1.13
Geneva	0.9782	1.1067	-21.96	40	0.9866	1.5451	-67.54	26	0.9930	1.3162	-43.92

$^{*}R_{75}$ (Correlation Coefficient)
M (Slope of Regression Line)
Y_O (Y Intercept of Regression Line)
Number of Data Pairs (Simultaneous Observations)

TABLE B-1

Sheet 2 of 3

	1975				1976				1975 and 1976		
Lake	R	M	Y_o	No. of Data Pairs	R	M	Y_o	No. of Data Pairs	R	M	Y_o
Goodson Prairie	0.9933	0.8382	17.92	8	0.9216	0.9014	12.56	24	0.9731	0.8174	19.86
Goose	-0.0235	-0.0359	96.90	8	0.9624	1.1403	-12.15	19	0.9706	1.3272	-29.01
Grandin	0.2767	0.8762	22.08	14	0.8822	2.3085	-96.06	28	0.9165	3.0313	-154.53
Hall	0.8666	0.4560	55.54	8	0.9703	1.3286	-16.90	21	0.9643	1.0479	5.94
Heart	0.9035	0.8411	25.45	10	0.9747	1.2839	- 9.97	24	0.9881	1.1181	3.04
Johnson, Big	0.9418	0.3684	60.39	44	0.7468	1.4664	-38.94	32	0.8696	0.8266	18.32
Johnson, Little	0.2173	-0.1013	103.28	35	0.8294	1.6988	252.80	26	-0.8258	-0.7257	160.70
Junior	0.8591	1.0483	0.77	7	0.9291	1.3766	-27.83	26	0.9722	1.2171	-14.08
Lakawana	0.9310	1.0246	5.92	7	0.9769	1.3250	-35.26	25	0.9919	1.3722	-39.74
Long Pond	0.6476	0.6721	34.45	6	0.9870	1.0862	- 2.13	22	0.9926	1.1105	- 4.21
Loch Lommond	0.8299	0.5580	42.64	7	0.9764	1.1079	- 7.29	24	0.9800	0.9880	3.36
Mariner	0.9342	0.6299	47.32	8	0.9791	1.1998	5.93	24	0.9890	1.0503	16.50
Mason	0.2272	0.3147	63.16	5	0.9886	0.9656	0.05	20	0.9919	1.0232	- 5.34
Melrose	0.1439	0.1133	81.81	7	-0.2413	-0.4737	40.26	24	0.1008	0.2857	62.21
Morris	0.8605	1.3253	-21.75	6	0.9748	1.2268	-12.92	19	0.9937	1.1458	- 6.09
North Twin	0.6220	0.5362	37.61	6	0.9961	0.9738	- 8.52	19	0.9963	1.0599	-17.27
Oldfield Pond	0.9631	0.6009	40.26	11	0.9906	1.1129	- 4.66	21	0.9883	0.8870	14.71

TABLE B-1

	1975				1976				1975 and 1976		
Lake	R	M	Y_o	No. of Data Pairs	R	M	Y_o	No. of Data Pairs	R	M	Y_o
Osborn	-0.2988	-0.3363	124.01	5	0.9886	1.2127	-16.82	20	0.9800	1.3900	-32.51
Paradise	0.9742	0.7419	10.03	7	0.9965	0.7856	5.10	21	0.9984	0.7862	5.04
Pebble	0.4579	0.1679	78.29	42	0.9491	0.7961	21.98	32	0.9057	0.3449	61.64
Putnam Prairie	0.0627	0.1562	79.38	13	0.9211	0.8992	10.14	20	0.9459	1.1620	-13.45
Rosa	0.9268	0.9014	5.39	11	0.9940	0.9582	- 0.16	20	0.9977	0.9534	0.30
Ross	-0.0659	-0.0401	97.30	8	0.6773	1.1493	-13.93	20	0.7997	1.5145	-47.10
Schoolhouse	0.9629	1.1082	- 3.09	7	0.8651	1.3029	-19.32	21	0.9601	1.0596	1.25
Silver (Putnam Co.)	0.6062	0.7371	29.71	8	0.9779	1.3490	-22.91	26	0.9867	1.2081	-11.04
Silver Sands	0.9666	1.4024	-20.90	6	0.9886	0.9264	18.02	21	0.9947	0.9044	19.75
Smith (Clay Co.)	0.9391	0.7920	26.12	8	0.9845	1.1586	- 4.93	23	0.9918	1.0700	2.41
Two Mile Pond	0.8416	1.0213	-14.91	8	0.9969	1.1017	-14.42	23	0.9962	1.0097	-13.67
West Twin	0.9594	0.4715	52.62	7	0.9884	1.1657	- 7.03	21	0.9707	0.9039	15.00
White Sands	0.9295	0.5207	48.75	7	0.9686	1.2800	-16.09	27	0.9666	1.0287	4.98
Swan Well	0.8022	0.6564	37.00	44	0.9538	1.1920	- 9.37	26	0.9779	1.0588	1.92

APPENDIX C

Analysis of Aquifer Test Data

INFLECTION POINT ANALYSIS[1] OF DRAWDOWN TIME DATA FROM OBSERVATION WELL FOR AQUIFER TEST AT SWAN LAKE

1. The drawdown data from the observation well are plotted against $\log_{10}$ time (Figure C-1), and the maximum drawdown s_m is estimated (s_m = 0.23 feet).

2. The drawdown at the inflection point is calculated from $s_i = 1/2\ s_m$, and the coordinates are noted (s_i = .115 feet, t = .038 days).

3. The slope of the time drawdown line at the inflection point is computed ($m_i = \Delta\ s/\Delta\ \log_{10}t = 0.144$).

4. Then $e^{r/B}Ko(r/B) = 2.3\ s_i/m_i = 2.3 \times .115/.144$; $e^{r/B}Ko(r/B) = 1.8368$; and from the tables presented by Hantush[1], r/B = .31 and Ko(r/B) = 1.3425.

5. Knowing r for the observation well (r = 2,285 feet), B is calculated from r/B = .31, B = 2,285/.31, B = 7,370.

6. T is calculated from $T = Q \times Ko\ (r/B) s_i 4\Pi$ where Q = 648,000 gpd, T = (648,000 gpd x 1.3425)/(.115 x 4 x Π), T = 601,979 gpd/ft.

7. $K'/b' = T/B^2 = 601{,}979/(7{,}370)^2$

   $K'/b' = .011 \approx 1.0 \times 10^{-2}$ gpd/ft²/ft.

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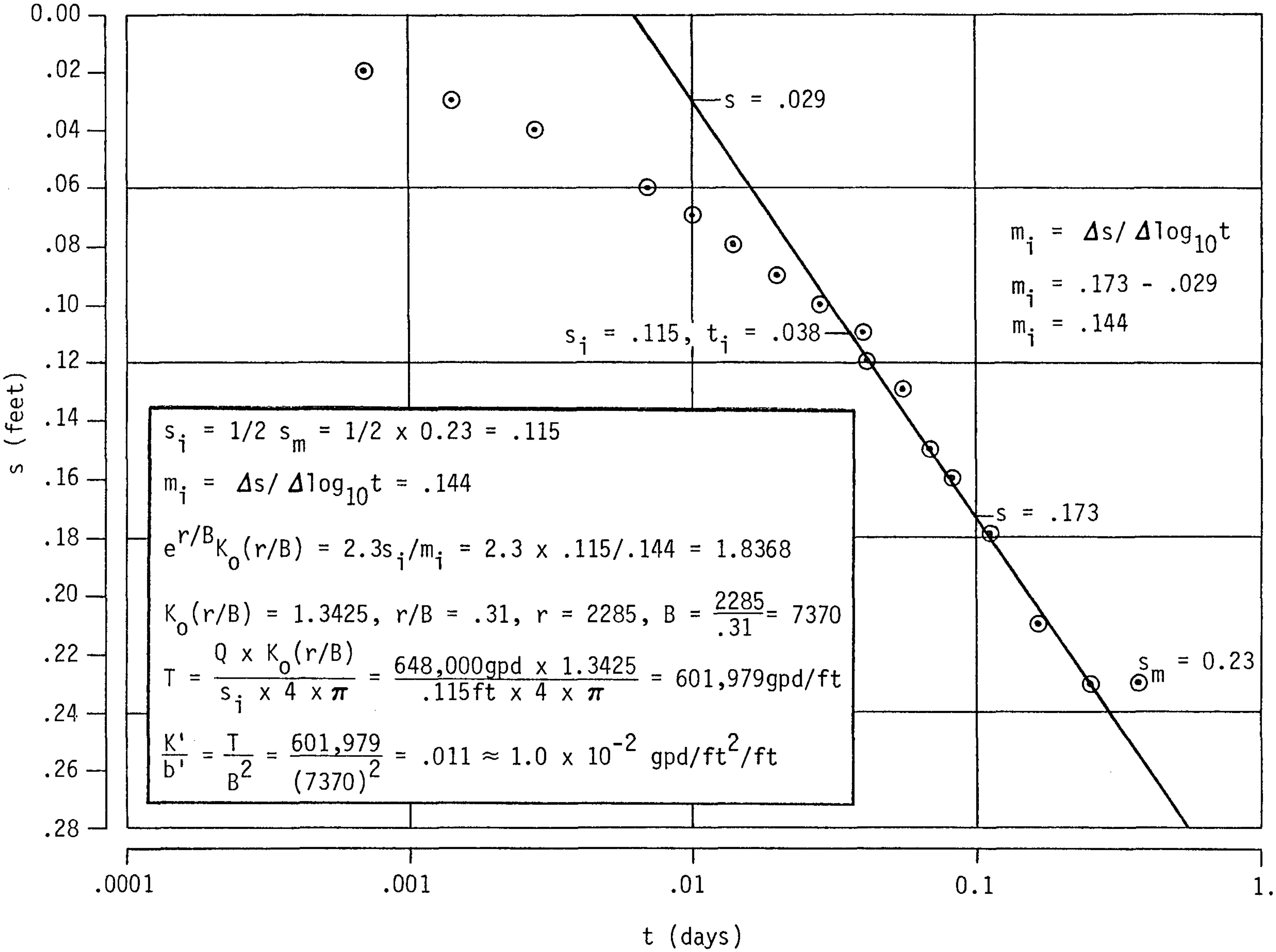
[1] Hantush, M. S., 1956, Analysis of data from pumping tests in leaky aquifers: Trans. Amer. Geophys. Union, Vol. 37, No. 6, p. 706.



$s_i = 1/2\ s_m = 1/2 \times 0.23 = .115$

$m_i = \Delta s/\Delta \log_{10} t = .144$

$e^{r/B}K_o(r/B) = 2.3 s_i/m_i = 2.3 \times .115/.144 = 1.8368$

$K_o(r/B) = 1.3425,\ r/B = .31,\ r = 2285,\ B = \frac{2285}{.31} = 7370$

$T = \frac{Q \times K_o(r/B)}{s_i \times 4 \times \pi} = \frac{648{,}000\text{gpd} \times 1.3425}{.115\text{ft} \times 4 \times \pi} = 601{,}979\text{gpd/ft}$

$\frac{K'}{b'} = \frac{T}{B^2} = \frac{601{,}979}{(7370)^2} = .011 \approx 1.0 \times 10^{-2}\ \text{gpd/ft}^2\text{/ft}$

FIGURE C-1. -- s vs. log t for Observation Well P-2

DRAWDOWN-DISTANCE ANALYSIS[1]
FOR AQUIFER TEST AT SWAN LAKE

1. The maximum drawdown s_m for each observation well, a distance r from the pumped well, is plotted on semi-logarithmic paper with r on the logarithmic scale (Figure C-2).

2. The slope of the plot $\Delta s_m / \Delta \log_{10} r$ is equal to $2.3\ Q/2\ \Pi\ T$.

3. B is equal to $0.89\ r_o$ where r_o is the zero drawdown intercept and $\frac{K'}{b'} = \frac{T}{B^2}$

4. (A) s_m pumped well = 1.10 feet

   s_m observation well = 0.23 feet

   (B) r pumped well = 0.417 feet

   r observation well = 2,285 feet

   (C) Q pumped well = 450 gpm = 648,000 gpd

5. $T = 988{,}352$ gpd/ft

   $\frac{K'}{b'} = 2.35 \times 10^{-3}$ gpd/ft^2/ft

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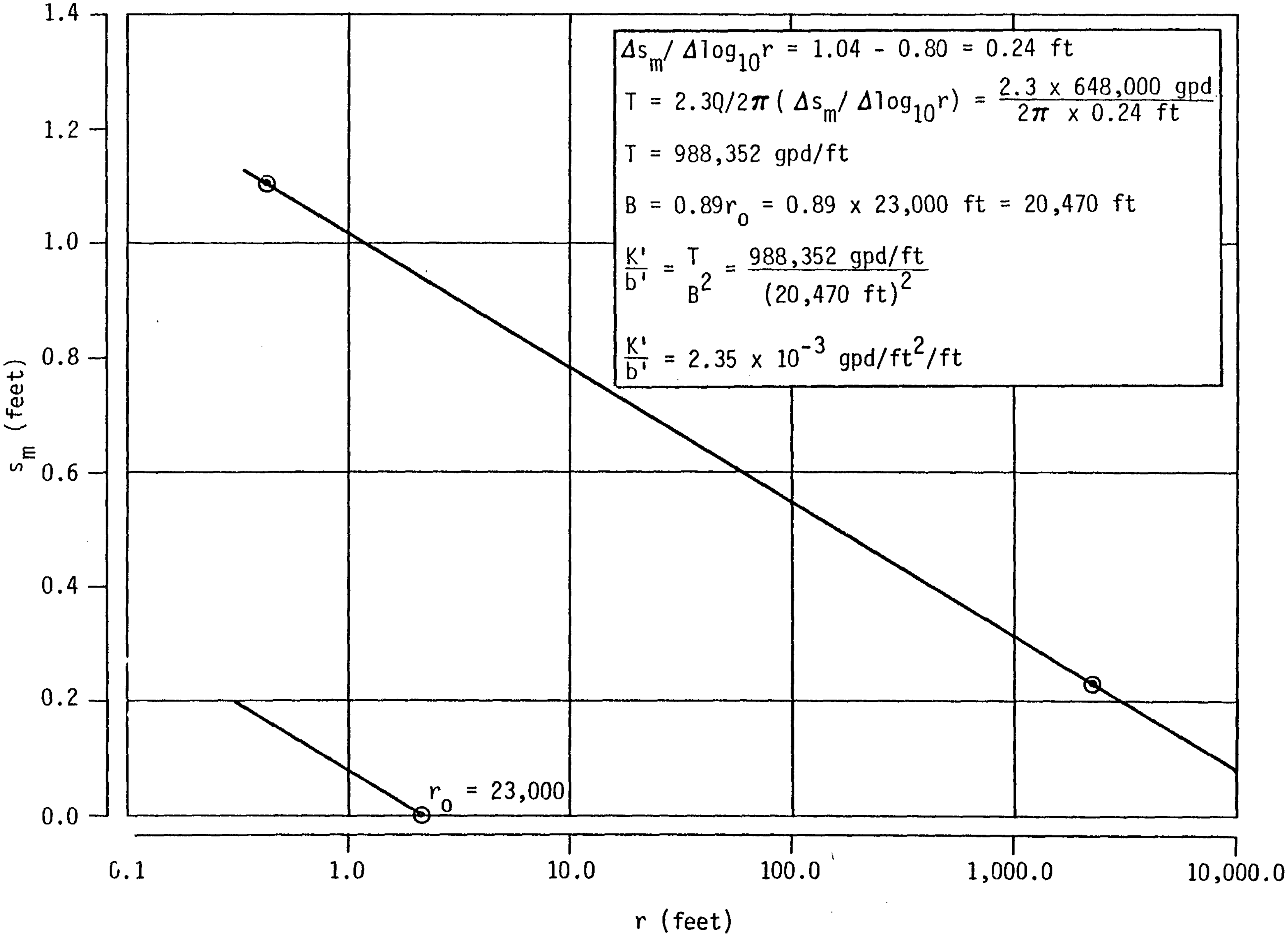
[1] Hantush, M. S., 1956, Analysis of data from pumping tests in leaky aquifers: Trans. Amer. Geophys. Union, Vol. 37, No. 6, p. 703.



$\Delta s_m / \Delta \log_{10} r$ = 1.04 - 0.80 = 0.24 ft

$T = 2.3Q/2\pi\,(\Delta s_m / \Delta \log_{10} r) = \dfrac{2.3 \times 648{,}000 \text{ gpd}}{2\pi \times 0.24 \text{ ft}}$

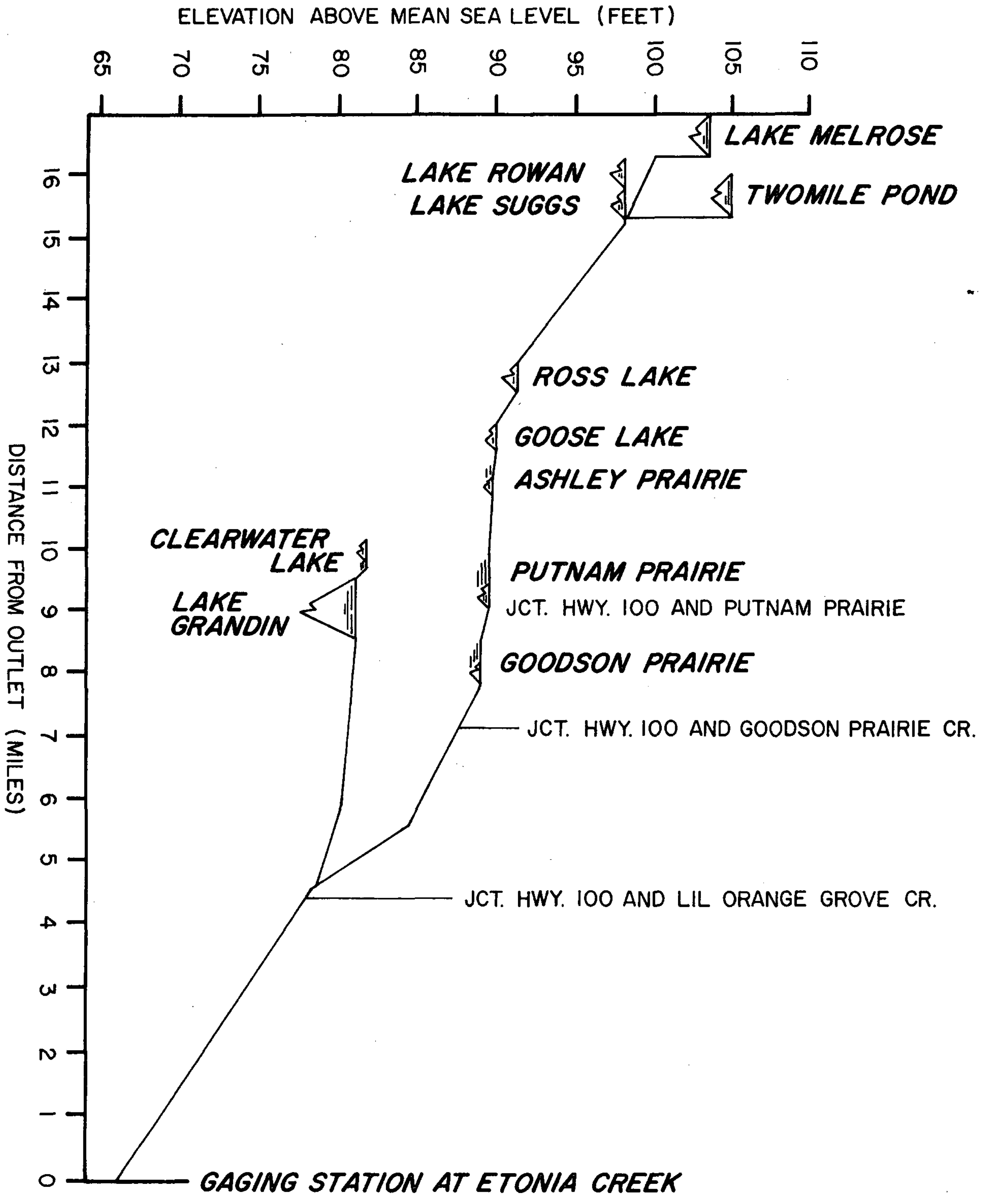
T = 988,352 gpd/ft

$B = 0.89 r_o = 0.89 \times 23{,}000$ ft = 20,470 ft

$\dfrac{K'}{b'} = \dfrac{T}{B^2} = \dfrac{988{,}352 \text{ gpd/ft}}{(20{,}470 \text{ ft})^2}$

$\dfrac{K'}{b'} = 2.35 \times 10^{-3}$ gpd/ft^2/ft

FIGURE C-2. -- s_m vs $\log_{10} r$ for Pumped Well and Observation Well P-2


ELEVATION ABOVE MEAN SEA LEVEL (FEET)
65
70
75
80
85
90
95
100
105
110
DISTANCE FROM OUTLET (MILES)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
LAKE MELROSE
LAKE ROWAN
LAKE SUGGS
TWOMILE POND
ROSS LAKE
GOOSE LAKE
ASHLEY PRAIRIE
CLEARWATER LAKE
PUTNAM PRAIRIE
LAKE GRANDIN
JCT. HWY. 100 AND PUTNAM PRAIRIE
GOODSON PRAIRIE
JCT. HWY. 100 AND GOODSON PRAIRIE CR.
JCT. HWY. 100 AND LIL ORANGE GROVE CR.
GAGING STATION AT ETONIA CREEK