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BUREAU OF GEOLOGY
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Report of Investigation No. 64

HYDROLOGIC CONDITIONS IN THE LAKELAND RIDGE AREA OF POLK COUNTY, FLORIDA

By
Alton F. Robertson

Prepared by
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
THE CITY OF LAKELAND, FLORIDA
and the
BUREAU OF GEOLOGY
FLORIDA DEPARTMENT OF NATURAL RESOURCES

TALLAHASSEE, FLORIDA
1973

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LETTER OF TRANSMITTAL

Bureau of Geology
Tallahassee
June 27, 1973

Honorable Reubin O'D. Askew, *Chairman*
Department of Natural Resources
Tallahassee, Florida

Dear Governor Askew:

The growth of industry, phosphate mining, and citrus production as well as population growth during the last two decades has resulted in an increase in ground-water pumpage from about 11 billion gallons in 1950 to 27 billion gallons in 1970. Declines in artesian water levels due to this pumpage are a subject of concern to water managers.

The purposes of this report are to reveal existing hydrologic data, determine trends of ground-water use, and identify potential problems which may result from these trends.

It is hoped that this investigation will be of significant value to water managers in the development and protection of the fresh-water resources.

Respectfully yours,

Charles W. Hendry, Jr., Chief
Bureau of Geology

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HYDROLOGIC CONDITIONS IN THE LAKELAND RIDGE AREA OF POLK COUNTY, FLORIDA

By
Alton F. Robertson

ABSTRACT

The Lakeland ridge area of this investigation covers about 300 square miles in northwest Polk County in central Florida. The growth of industry, phosphate mining, and citrus production as well as population growth during the last two decades has resulted in an increase in ground-water pumpage from about 11 billion gallons in 1950 to 27 billion gallons in 1970.

Decline in artesian water levels due to this pumpage is most pronounced in the southern part of the area of investigation where water levels have declined 50 feet or more in the last 20 years. These declines may be accompanied by several effects of concern to water managers. The most obvious of these is the necessity to lower pump intakes to prevent the loss of suction. The hazard of upward movement of water of poor quality is also increased by the declines in fresh-water level. Current water analyses, however, have revealed no widespread changes in quality of ground-water that can be correlated with water-level decline.

The water levels of some lakes in the area were lower in June 1970 than in June 1961. For instance, the level of Scott Lake declined about 4 feet. This decline may have been caused, at least in part, by the decline in artesian levels, but rainfall deficiency during the current drought is also a factor. However, not all lake levels declined; the levels at Lakes Parker and Hancock were about the same in June 1970 as they were in June 1961.

Municipal pumpage by Lakeland increased from 1 billion gallons in 1950 to 5 billion gallons in 1970 and may reach 9 billion gallons by 1990, based on the established trend. The greatest drawdown attributed to the city's pumpage in 1970 was about seven feet. This drawdown was centered southwest of Lake Parker. If the additional pumpage required to supply the city's needs for 1990 were drawn from wells south of Lakeland, the greatest drawdown

would be about nine feet and would be centered near Scott Lake. If the additional pumpage were drawn from wells northeast of Lakeland, the greatest drawdowns would be about nine feet, and the center of pumping would shift to the northeast. As a result water levels south of Lakeland would not be significantly affected by the increase in city pumpage.

A widespread zone of solution features in the limestone of the Floridan aquifer occurs at about 450 feet below mean sea level in the northeast part of the area of investigation and at about 650 feet below mean sea level in the south part of the area. Most wells open to this zone yield several thousand gpm (gallons per minute) with relatively small drawdowns.

INTRODUCTION

Lakeland, the largest city in Polk County, has grown from a population of 27 when it was incorporated in 1885, to 41,550 in 1970. The water resources of the area have played an important role in this development.

The production and processing of citrus, which began late in the 1800's, draw upon the water resources both for irrigation supplies and supplies for processing. At present (1970) more than 150,000 acres in Polk County are producing citrus. Polk County's phosphate industry began in the 1800's. Production increased from about 3,000 tons during the first years to over 30 million tons in 1967. Tourism is another economically important industry, which, along with many smaller industries, depends upon the area's water resources for continued growth.

Central Florida is underlain by aquifers that contain large quantities of fresh water. These aquifers supply most of water needs in the Lakeland ridge area. The increased use of ground-water to support agricultural and industrial operations and to supply municipal needs has resulted in a continued decline in ground-water levels in the area.

Changes in land-use patterns in the area that have taken place, or may be expected to take place as the area develops, also have a significant affect on the water resources. For example, as phosphate deposits are depleted, less water will be pumped from the aquifers to support the industrial operations associated with phosphate mining. Industrial water use presently (1970) represents the greatest demands upon the aquifers. Likewise, suburban developments have displayed citrus groves, thus reducing the irrigation requirements.

PURPOSE AND SCOPE

Recognizing the importance of the water resources to the continued development of the Lakeland ridge area and the need for additional technical evaluation to aid in management of the resources, the Southwest Florida Water Management District, the city of Lakeland, and the Florida Bureau of Geology entered into a cooperative investigation with the U. S. Geological Survey, to evaluate current hydrologic conditions in the ridge area.

The specific purposes of this report are to:

1. Review, assemble, and summarize existing hydrologic data to determine the adequacy of these data and the data-collection network for defining present-day hydrologic conditions and for monitoring possible changes in these conditions that may result from possible changes in patterns of water-use.
2. Determine present-day conditions and trends of ground-water quality, the potentiometric surface and water use.
3. Identify problems and anticipated problems resulting from current hydrologic conditions and trends.

The 4-year investigation upon which this report is based began in 1967. It was made by the U. S. Geological Survey under the general supervision of C. S. Conover, district chief for Florida and under the immediate supervision of J. S. Rosenshein, chief of the Tampa Subdistrict.

AREA OF INVESTIGATION

The Lakeland ridge area of this investigation includes about 300 square miles of northwest Polk County in central Florida (fig. 1). The area is marked by a distinct topographic ridge more than 150 feet high that generally parallels the coastline. This ridge begins rather abruptly about 10 miles northwest of Lakeland and extends southeast about 35 miles to the vicinity of Fort Meade.

The Lakeland ridge is the drainage divide between the Peace River basin on the east and the Hillsborough and Alafia River basins on the west (fig. 1). To the north, the Withlacoochee River has its headwaters in the Green Swamp area.

METHODS OF INVESTIGATION

An evaluation of hydrologic data and a comprehensive well inventory, formed a base for expanding the network for monitoring ground-water levels. Included in this network were five continuous water-level recording stations.

Specific conductivity-measuring instruments were installed in a

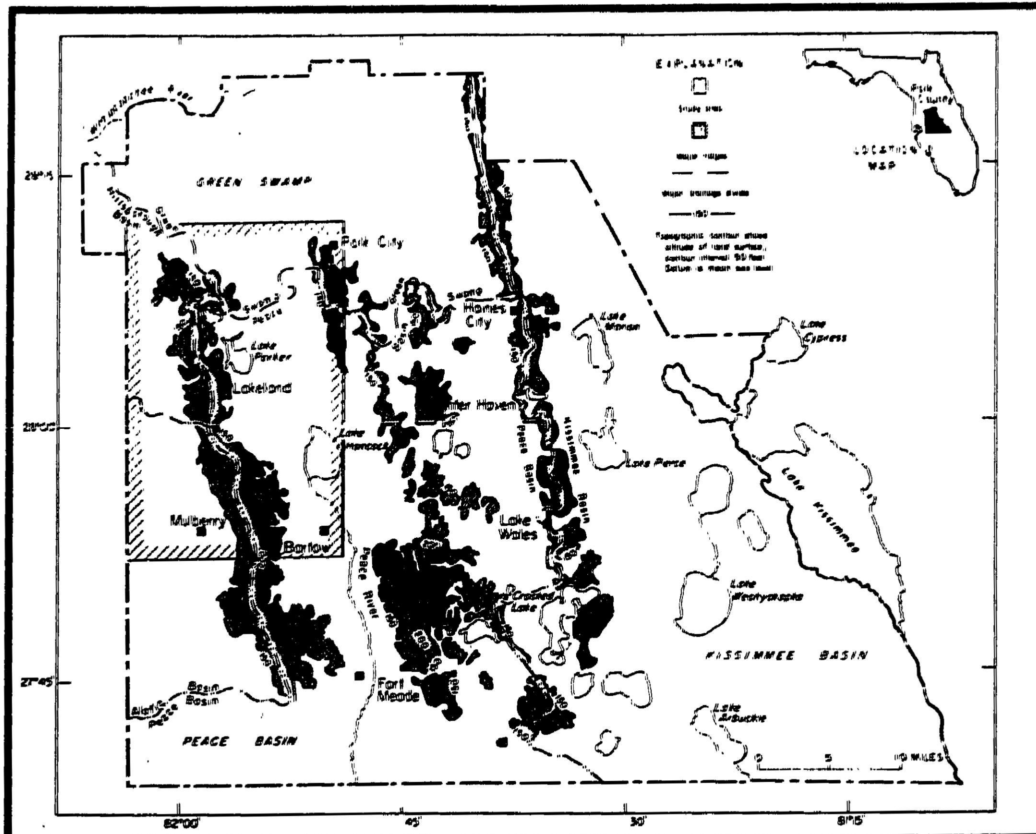


Figure 1. Map of Polk County showing the area of investigation.

well at Lakeland to monitor changes in the quality of the ground water. Twenty wells, which had been sampled for water quality during previous investigations, were again sampled to determine water-quality changes. Water samples were obtained from 16 lake and stream sites to establish the quality of the surface waters.

An inventory of ground-water withdrawals was made for 1970. The owners or managers of industrial enterprises in the area of investigation provided information concerning their water use. Municipal water-use was obtained from the various city water-plant supervisors. Estimates of citrus-irrigation withdrawals were made by establishing a pilot study area, a 300-acre grove. A relation between pumpage and electrical power use was established. This relation provided a basis for computing annual irrigation pumpage from power-consumption records, where direct determinations were not possible.

In a series of packer tests, various intervals in the aquifer were isolated, from which samples were pumped for water-quality analyses. Geophysical logs were run on 10 wells, and geologic data were obtained from 6 wells to extend the geologic coverage of previous investigations.

WELL NUMBERING SYSTEM

For convenience of reference, all wells referred to in this report are numbered serially and referred to serially on the figures and tables of the report. The locations of wells referred to in this report and U.S. Geological Survey surface-water gaging stations in the area of investigation are shown on figure 2.

In addition to the serial numbers used in this report, all the referenced wells are catalogued by the well-numbering system of the Water Resources Division of the U.S. Geological Survey. This latter well number should be used by the reader seeking further information or exact locations of the wells. A cross reference between the serial number of the well used in this report and the Geological Survey number is provided as a part of table 5.

The Geological Survey number used to catalog wells is a 16-character number that defines the latitude and longitude of the southeast corner of a 1-second quadrangle in which the well is located. The first six characters of the well number include the digits of the degrees, minutes, and seconds of latitude, in that order. The six digits defining the latitude are followed by the letter N which indicates north latitude for wells in the northern hemisphere. The seven digits following the letter N give the degrees, minutes, and seconds of longitude. The last digit, set off by

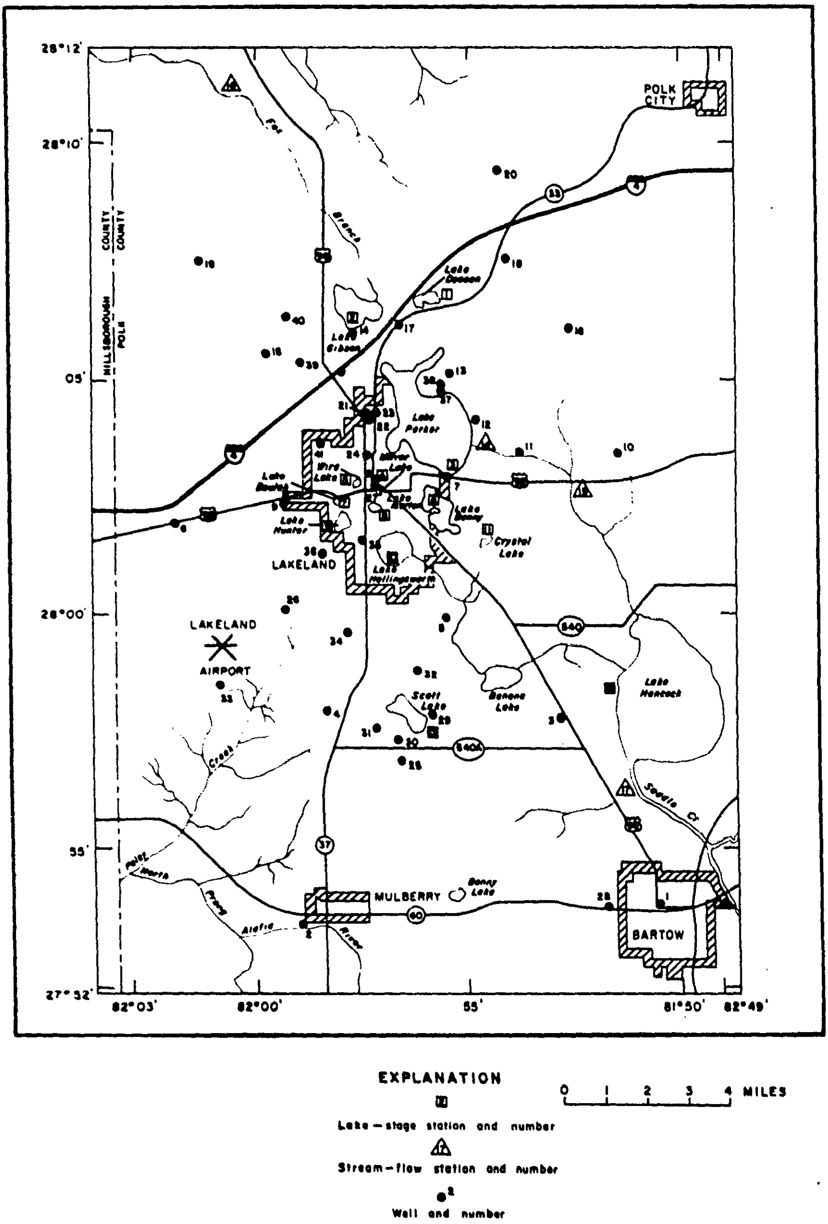


Figure 2. Map showing locations of gaging stations and selected wells in the Lakeland ridge area.

a period from the rest of the number, is assigned sequentially to identify wells inventoried within a 1-second quadrangle.

An example of the well number is illustrated in figure 3. The designation 275134N0815220.1 indicates the first well inventoried in the 1-second quadrangle bounded by latitude 27°51′34″ on the south and longitude 081°52′20″ on the east.

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation to the many citizens of the area, who permitted the sampling of water and measuring of water levels in their wells, and to the well drillers, who provided much helpful information. Appreciation is also

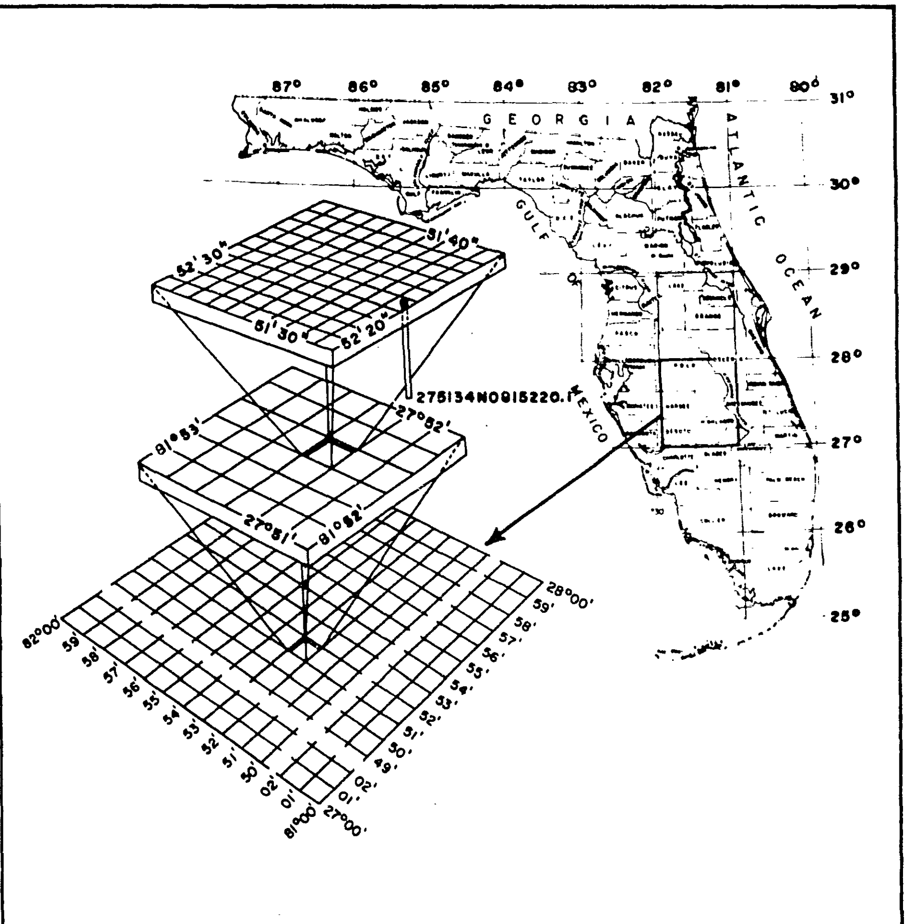


Figure 3. Diagram illustrating the U. S. Geological Survey well-numbering system.

expressed to the city and industry officials, who supplied information on water use and power consumption.

Special thanks are given Mr. Tom Williams, whose cooperation by furnishing information concerning Lakeland's water system and special operation of the wells to provide specific information, was especially helpful.

HYDROLOGIC DATA

The considerable amount of hydrologic data available for the area of investigation can be grouped into two categories. The first of these consists of geologic and hydrologic information gathered as a result of previous investigations in and near the Lakeland ridge area. The second consists of periodic measurements of hydrologic parameters made on a continuing basis.

These hydrologic data and the additional data collected as a part of this investigation are sufficient in general to define the present-day hydrologic conditions.

PREVIOUS INVESTIGATIONS

Various aspects of the water resources of central Florida have been investigated and the results of these investigations published by the Florida Geological Survey and the U.S. Geological Survey. These investigations provide a considerable amount of hydrologic data useful in describing both historical and current hydrologic conditions.

Stewart (1966) provided the most recently published information on the ground-water resources of Polk County. His work drew upon many previous investigations describing the geology and hydrology of central Florida, most of which are cited in the list of selected references in this report. An investigation of ground water in peninsula Florida by Stringfield (1936) provided some of the early data.

The surface-water resources of Polk County were described by Heath (1961), who presented hydrographs and stage-duration curves for 107 gaging stations throughout the county. The chemical quality of the ground water and surface water was discussed by Black and Brown (1951) and Wander and Reitz (1951).

Kenner (1964) provided a map showing depth contours of selected Florida lakes, one of which, Lake Parker, was in the area of investigation. Stewart (1966) made a comprehensive study of the hydrology of Lake Parker and Scott Lake. His evaluation indicated that Lake Parker was underlain by sand and sandy clay and that water from the lake leaked downward through these materials to recharge the underlying aquifers.

The Withlacoochee River basin was described by Pride, Meyer, and Cherry (1966). Streamflow rates and flow-duration curves were given along with the results of chemical analyses of the water. Although highly colored, the water in the streams was low in mineral content.

Menke, Meredith, and Wetterhall (1961) discussed the Hillsborough and Alafia River basins. Streamflow and water quality were described. Both basins had surface water that was more highly mineralized than the surface water in the Withlacoochee basin.

Toler (1967) found fluoride concentrations to be abnormally high in the surface waters of the Alafia and Peace River basins; he discussed the source, amounts, and effects of fluoride in the streams of these two basins.

Other investigations which were made of nearby areas in the state or which provide additional information related to the water resources of the area are listed in the selected references.

MONITORING NETWORK

GROUND WATER

The ground-water level monitoring network in the area of investigation consists of 18 wells measured periodically by the U. S. Geological Survey in cooperation with various state and local agencies. The locations of these wells are shown on figure 2. As a part of this investigation, about 50 other wells were measured to define in greater detail the potentiometric surface of the Florida aquifer, (fig. 8).

SURFACE WATER

The locations of the 18 stream and lake gaging stations maintained by the U.S. Geological Survey in the area covered by this report are shown on figure 2 and listed in table 1. Included in table 1 are the maximum and minimum water levels or flow for the period of record at each gaging station. The most recent (1970) information on these gaging stations is tabulated in "Water Resources Data for Florida," an annual publication of the U. S. Geological Survey. These gaging stations adequately portray the surface-water conditions in the area of investigation.

Table 1. Surface-water gaging stations in the Lakeland ridge area
(msl - mean sea level)

Gaging Station Number (see Fig. 2)	Station Name Lakes	Period of Record	EXTREME OF RECORD: Maximum Gage Height (feet above msl)	Date	Minimum Gage Height (feet above msl)	Date
1	Lake Deeson near Lakeland	1954-60, 1965-67	135.39	9/28/54	122.52	7/31/67
2	Lake Gibson near Lakeland	1954-59	145.1	10/8/57	141.4	7/5/56
3	Lake Parker at Lakeland	1949-69	131.81	8/2/60 9/13/60	127.92	5/24/49
4	Mirror Lake at Lakeland	1954-59	178.72	5/17/57	178.23	10/28/54
5	Wire Lake at Lakeland	1954-60	198.22	7/16/59	194.00	5/1/56
6	Lake Bonny at Lakeland	1954-60	131.92	9/11/59	123.12	7/10/56
7	Lake Beulah at Lakeland	1954-59	180.47	5/15/57	178.23	7/9/56
8	Lake Morton at Lakeland	1954-59	179.54	3/23/59	176.30	3/10/55
9	Lake Hunter at Lakeland	1954-59	162.97	4/17/57	160.95	4/27/56
10	Lake Hollingsworth at Lakeland	1954-59	133.2	5/17/57	131.9	5/1/56 10/21/58
11	Crystal Lake near Lakeland	1951-52, 1954-59	137.24	11/23/59	127.04	6/10/51
12	Lake Hancock near Highland City	1950-51, 1958-69	101.88	9/16/60	93.98	5/23/68
13	Scott Lake near Lakeland	1953-69	169.19	9/13/60	160.50	6/5/68
	Streams		**Maximum Flow (cubic feet per second)**		**Minimum Flow (cubic feet per second)**	
14	Lake Parker Outlet at Lakeland	1955-59	12.2	5/2/57	0	Various occasions
15	Saddle Creek near Lakeland	1955-56	45.2	9/15/55	.38	3/8/56
16	Fox Branch near Socrum	1963-67	685	9/11/64	0	Various occasions
17	Saddle Creek at Structure P-11 near Bartow	1963-67	516	9/13/65	0	Various occasions
18	Peace River at Bartow	1939-69	4140	9/24/47	1.1	4/27/68

HYDROLOGIC FRAMEWORK

The hydrologic framework consists of the natural elements supplying water to the area and the medium through which the water moves. These elements are described in the following sections on the geology and aquifers. All surface water and water in the aquifers are derived from precipitation that either falls on the area or on upgradient areas.

GEOLOGY

The Lakeland ridge area is underlain by several thousand feet of heterogeneous limestone and dolomite. In most of the area these consolidated rocks are overlain by phosphatic clay beds which are, in turn, overlain by surficial sand beds.

Vernon (1951) and many others have described the consolidated rock units present in Polk County. The water-bearing stratigraphic units in this area are: Lake City Limestone, Avon Park Limestone, the Ocala Group, Suwannee Limestone, Tampa Formation, and Hawthorn Formation. These units range in age from Eocene to Miocene and are solution riddled and faulted. The phosphatic clay and surficial material overlying the limestone are described by Cathcart (1966) and others.

The stratigraphic nomenclature used in this report conforms to the usage of the Florida Bureau of Geology. It conforms also to the usage of the U. S. Geological Survey, with the exception of the Ocala Group and its subdivisions and the Tampa Formation.

AQUIFERS

The ridge area is underlain by four aquifers, as described by Stewart (1966); (1) the water-table aquifer, (2) the uppermost artesian aquifer, (3) the secondary artesian aquifer, and (4) the Floridan aquifer. Figure 4 shows the generalized geology and relation of the aquifers.

Permeable zones in the sandy and clayey surficial materials constitute the water-table aquifer, which is used for some domestic supplies but is relatively unimportant as a source of water for other uses. The sand of the aquifer is Miocene and Holocene (in older literature called "Recent") in age.

The pebble phosphate deposits underlying the surficial deposits form the uppermost artesian aquifer. Like the water-table aquifer, this aquifer is used only for domestic and small irrigation supplies.

Limestone of the Hawthorn Formation constitutes the secondary artesian aquifer, which is confined by the clay beds of the

Hawthorn Formation above and the Tampa Formation below. The secondary artesian aquifer is a source of water for domestic and small irrigation supplies.

The water-bearing characteristics of these first three aquifers are not well known, and they are not used extensively as sources of supply.

The Floridan aquifer is the major source of water in the ridge area and is comprised of limestones that range from Eocene to Miocene in age. The Suwannee Limestone underlies most of the Lakeland ridge area and constitutes the uppermost part of the Floridan aquifer in much of the area of investigation. In places, limestone of the Tampa Formation is sufficiently connected hydraulically with the underlying rocks to be included as part of the aquifer.

Where the Suwannee Limestone is not present, the limestone units of the Ocala Group constitute the uppermost part of the Floridan aquifer. The base of the Avon Park Limestone is, for practical purposes, the base of the aquifer, although some wells penetrate the Lake City Limestone. Many wells in the Lakeland ridge area are terminated in cavities in the limestone of the Floridan aquifer. Such wells characteristically yield several thousand gallons per minute with small drawdown.

Cavities in the aquifer develop over a long period of time as the limestone is slowly dissolved by water moving through the aquifer. Fissures and other structural features, which provide preferential flow paths for water, localize solution activity and allow it to proceed more rapidly. Cavities occur at various depths throughout the area. In the northeast part of the area of investigation, many wells penetrate a cavity zone at about 450 feet below msl (mean sea level). This zone of solution cavities is deeper toward the south and west and occurs rather uniformly at about 650 feet below msl in the south part of the study area. Figure 5 shows the approximate depth below land surface to this cavity zone. Although, as a general feature, the zone seems to be continuous, individual wells at any given site may not tap cavities at the mapped depth. At most sites cavities occur at shallower depths, but, on the basis of information supplied from drillers' logs, few cavities occur below the depths indicated on figure 5.

Hydraulic Properties of the Floridan Aquifer

Transmissivity pertains to the water-conducting capacity of an aquifer and is defined as the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

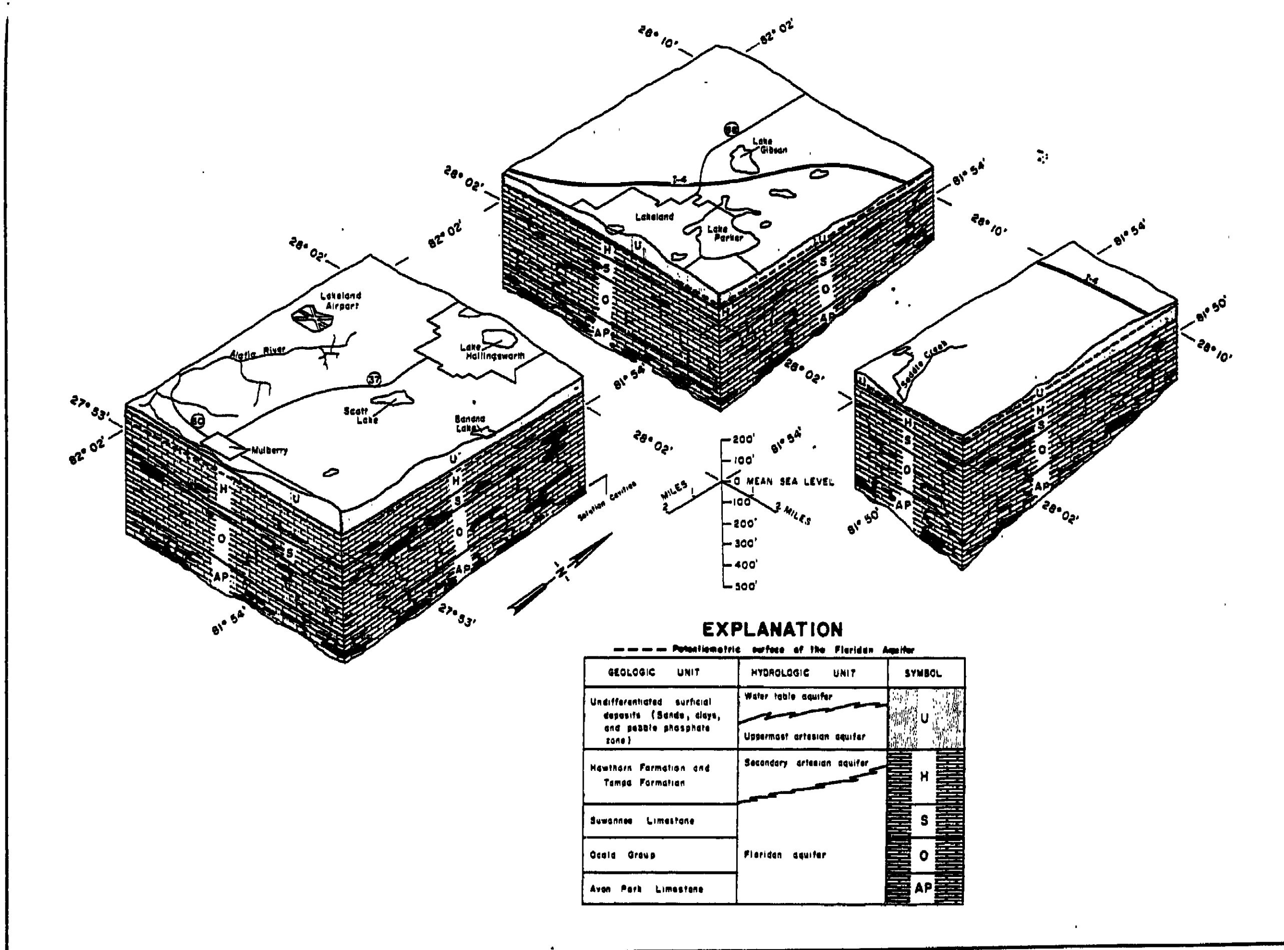
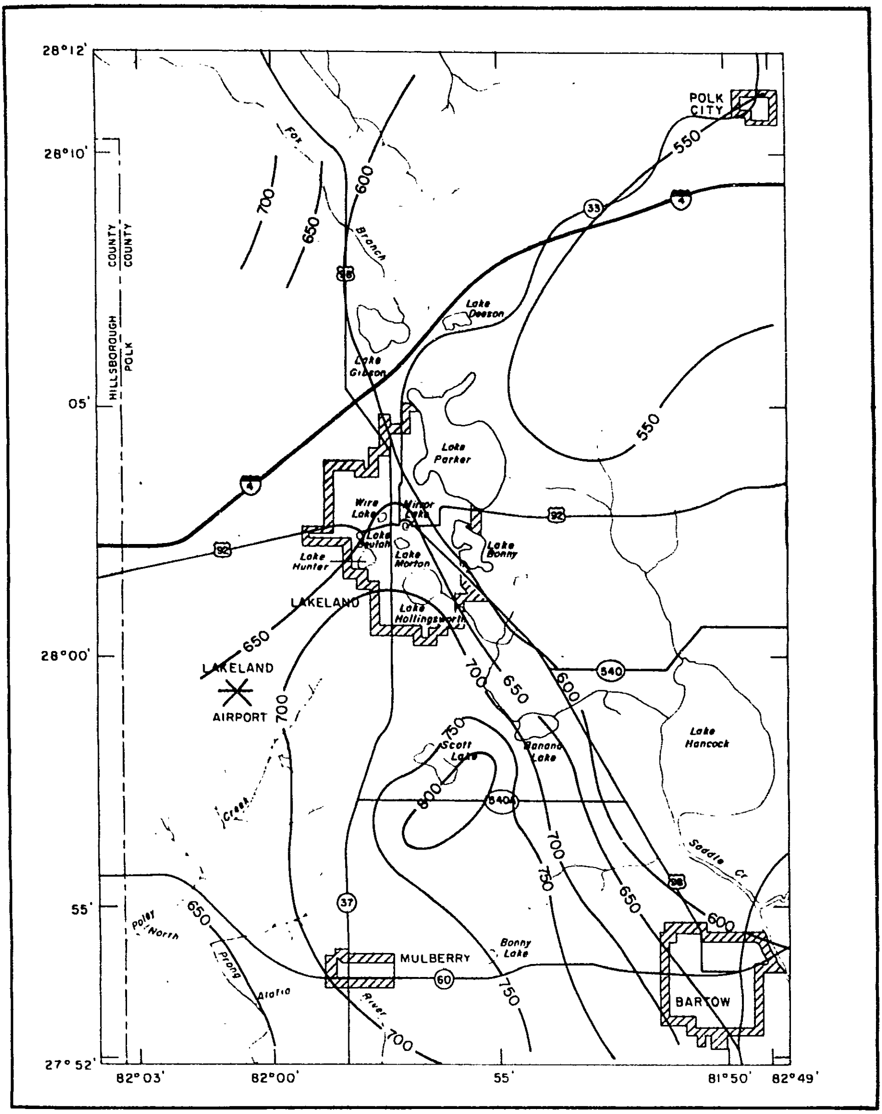


Figure 4. Block diagram showing generalized ground-water geology in the Lakeland ridge area.



EXPLANATION

—— 600 ——

Line of equal depth.
Shows depth to top of solution zone.
Interval 50 feet
Datum is land surface

0 1 2 3 4 MILES

Figure 5. Map showing depth to zone of solution cavities in the lower part of the Floridan aquifer.

The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area per unit change in head.

The specific capacity of a well, that is, the quantity of water the well yields for each foot of drawdown of the water level, can be used as an indication of transmissivity (Brown, 1963, p. 336-338). Stewart (1966) compiled data on the specific capacities of 173 wells in Polk County. These values range from more than 2,000 gpm per ft (gallons per minute per foot of drawdown) to less than 10 gpm per ft in the area of investigation. The specific capacities in some places varied considerably for wells a few hundred feet apart, especially where one of the wells tapped a cavity system. The storage coefficient cannot be determined from specific capacity but the transmissivity can be estimated as suggested by Brown (1963, p. 336-338). Based on the range of specific capacities given above, the transmissivity ranges from 536,000 ft^2/day (square feet per day) to about 2,700 ft^2/day. These values are equivalent to 4,000,000 gpd per ft (gallons per day per foot) and 20,000 gpd per ft in the units formerly used to express transmissivity.

Aquifer tests in which pumping rates are controlled and the resultant drawdowns are measured in observation wells provide a more reliable method for determining transmissivity and storage coefficient. Transmissivity of the Floridan aquifer has been determined in various parts of the State by such tests. Menke, Meredith, and Wetterhall (1961) reported a transmissivity of 29,500 ft^2/day (220,000 gpd per ft) from tests near Plant City, about 10 miles west of Lakeland. The storage coefficient determined from this test was 0.002. Stewart (1966) reported a value of 134,000 ft^2/day (1,000,000 gpd per ft) from tests northeast of Lake Parker, but did not determine the storage coefficient.

As part of this investigation, an aquifer test was made west of Lake Parker. From this test, a transmissivity of 100,000 ft^2/day (750,000 gpd per ft) and a storage coefficient of 0.0009 were determined. These values compare favorably with those recently determined from aquifer tests in Hillsborough and Pasco Counties (J. W. Stewart, oral commun., Jan., 1971; and L. H. Motz, oral commun., July, 1971, both of U.S. Geological Survey).

Transmissivity and storage-coefficient determinations for the Floridan aquifer are applicable over a wide area but may not be applicable for a specific location because of the heterogeniety of the aquifer. However, the values determined in this investigation are probably representative of the area and can be applied to predict drawdowns caused by pumping from the Floridan aquifer.

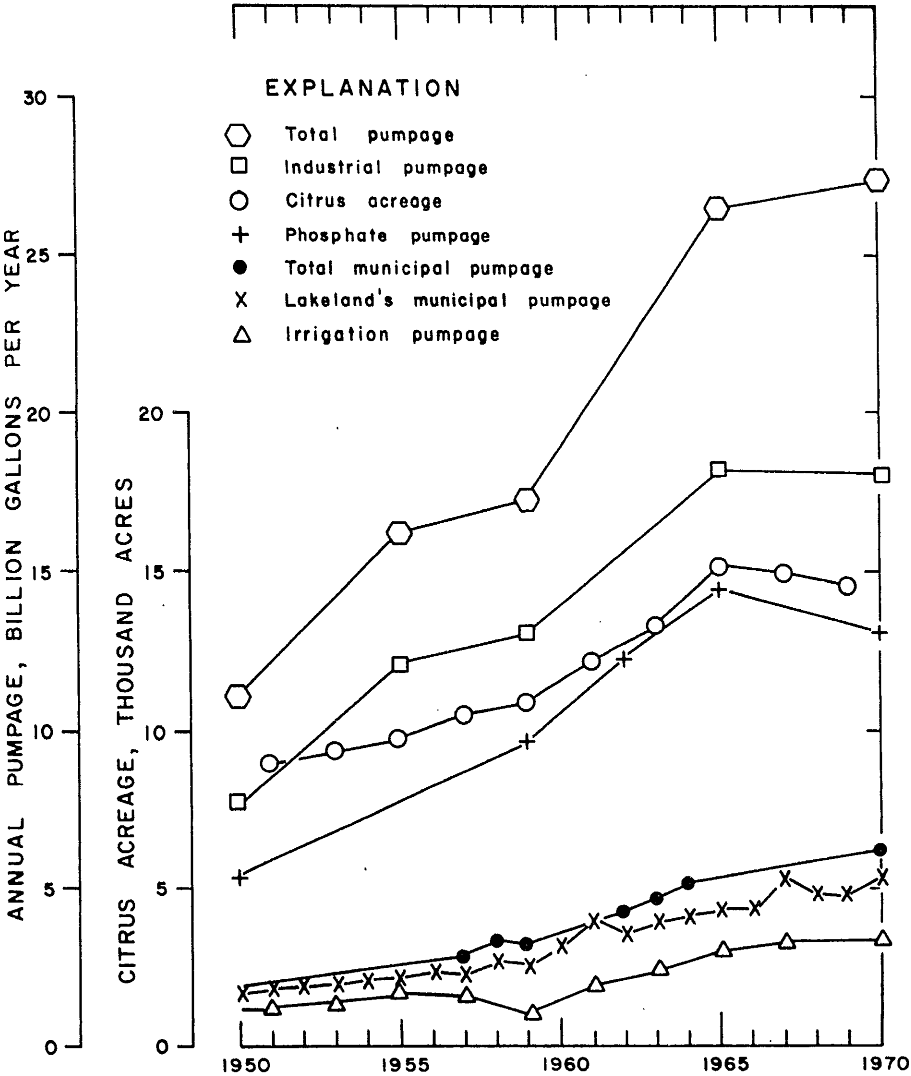


Figure 6. Graph showing industrial, municipal, and irrigation pumpage and citrus acreage under cultivation in the area of investigation, 1950-70.

HYDROLOGIC CONDITIONS AND TRENDS

Ground-water Use

Ground water has historically been the most widely used source of water supply in the area of investigation and in 1970 accounted for about 90 percent of the total water used. Most wells that produce more than 150 gpm (gallons per minute) are terminated in the Floridan aquifer although numerous smaller wells used for domestic and stock supplies are terminated in the shallower aquifers.

Pumpage from the Floridan aquifer in the Lakeland ridge area increased from about 11 billion gallons in 1950 to about 27 billion gallons in 1970. The greatest demand for ground water is for industrial use, principally for phosphate mining and processing. Other industries that require large quantities of ground water are citrus processing plants, ice plants, and commercial laundries. The amount of water withdrawn for industrial use during 1970 was estimated to be 18 billion gallons. This water-use figure was derived from information supplied by various industries and from discharge measurements of selected wells used for industrial supply. Most of Florida's phosphate industry is south of the area of investigation, but five mines are located within this area. Water used by these five mines was estimated to be 25 percent of the water used by all phosphate operations in central Florida. Water supplied to industries through municipal systems is not included in this figure.

Industrial water-use requirements have grown steadily over the last two decades (fig. 6). Estimates of the amount of water pumped before 1970 were adapted from Peek (1951), Stewart (1966), and Kaufman (1967). Industrial water use is generally distributed equally throughout the year, although some seasonal variations in total industrial withdrawals are caused by citrus-processing requirements.

Pumpage of ground water for irrigation varies considerably both annually and seasonally, depending principally upon the distribution of precipitation and the acreage under cultivation. Citrus is the principal irrigated crop. In 1969, about 14,500 acres of citrus were under cultivation in the area of investigation, as compared with about 15,100 acres in 1965. The decrease is principally due to replacement of citrus acreage by subdivision development south of Lakeland. Citrus acreage inventories are not available for years earlier than 1965. Acreage for these earlier years were computed through use of county-wide inventories of tree age and acreage (Florida Department of Agriculture Crop and Livestock Reporting Service, 1970). About 10 percent of the Polk County acreage was within the area of investigation during 1965, 1967, and 1969. Applying this percentage figure to the citrus acreage totals in the county for the last two decades, an estimate of the acreage within the area of investigation before 1965 was obtained (fig. 6). An inventory of citrus irrigation wells indicated that about 70 percent of the acreage was irrigated in 1970.

To determine withdrawals for irrigation, the discharge of many wells were measured and rated against electric-power input to the pump motors. The pumps, whose discharges were measured and rated, were used to irrigate a total of about 2,000 acres. Extrapolation of the unit-acreage water use for these citrus groves to the irrigated acreage in the area of investigation indicated that about 3 billion gallons were withdrawn for irrigation in 1970.

In 1970, most of the water for irrigation was pumped in May, June, August, and December. Little irrigation was done in February, March, September, and October.

The increase in irrigation water use over the last two decades is shown on figure 6. Pumpage figures for the period before 1970 were adapted from Kaufman (1967).

Lakeland is the largest municipal supplier of water in the area of investigation. In 1970, Lakeland's pumpage was 5.23 billion gallons, and the total municipal pumpage was 6.18 billion gallons. Municipal withdrawals for cities in and adjacent to the area are shown in table 2. Total annual municipal pumpage by Lakeland, Bartow, and Mulberry is shown in figure 6 for 1950-1970. For the period that pumpage records were not available for the two smaller cities, their withdrawals were estimated on the basis of Lakeland's pumpage.

Municipal pumpage varies considerably during the year mainly because of higher demands for lawn irrigation during the dry months. The relation of municipal pumpage to precipitation is shown on figure 7.

The trend of increasing water use for municipal supplies will probably continue with population growth. The trend for other water users is extremely difficult to anticipate. The decrease in citrus acreage since 1965 indicates that the irrigation demand has temporarily stabilized and will probably decrease with increasing urbanization. Annual and seasonal precipitation variations, of course, are the principal control on annual water-use demands for irrigation.

Table 2. Municipal pumpage by cities in and near the Lakeland ridge area, 1970

	Million Gallons		Million Gallons
Lakeland	5230	Winter Haven	1685
Bartow	865	Haines City	554
Mulberry	84	Lake Wales	653
Plant City	805	Auburndale	320

Industrial water use may increase as new industries develop. However, this increase will be offset as phosphate deposits in the area of investigation are depleted and the center of phosphate mining moves farther south. In addition, many of the mining operations have increased the use of recirculated water from settling ponds thus reducing their pumpage from the aquifer.

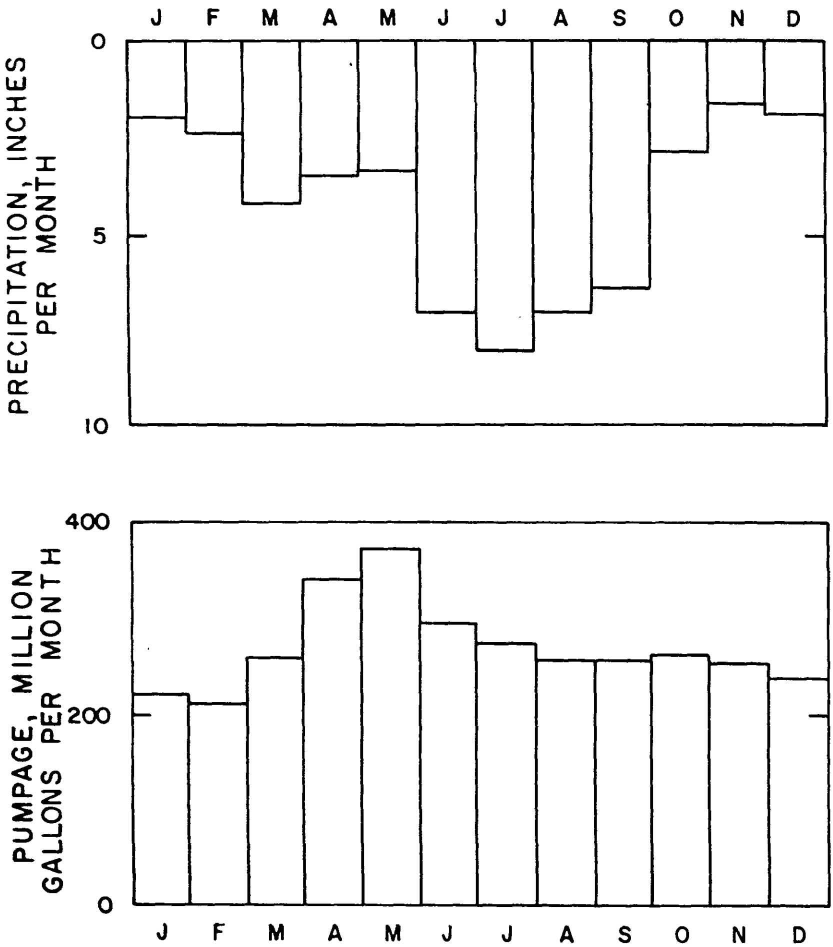


Figure 7. Bar graph of mean monthly municipal pumpage and mean monthly precipitation at Lakeland, Florida, 1950-1970.

THE POTENTIOMETRIC SURFACE OF THE FLORIDAN AQUIFER

The level to which water rises in wells penetrating an aquifer forms a surface referred to as the potentiometric surface. The altitude of the potentiometric surface varies locally in response to variations in both recharge to and discharge from the aquifer.

The potentiometric surface of the Floridan aquifer has been mapped during several previous investigations, which included the area of investigation (Stringfield, 1936; Black, Brown and Pearce, 1953; Stewart, 1966; Pride, Meyer and Cherry, 1966; Healy, 1962; and Kaufman, 1967).

The potentiometric surface was mapped as a part of this investigation in November 1968, near the end of the seasonal water-level recovery, and in June 1969, May 1970, and May 1971, near the end of seasonal water-level declines. The potentiometric surface for May 1971 is shown on figure 8 and reflects the lowest water levels in the aquifer in most of the area during this investigation. The low water levels to the south of the area of investigation are the result of heavy pumpage there.

Changes in the potentiometric surface from the time it was mapped in September 1949 to the measurements made in June 1969 are shown on figure 9. These lowered levels indicate a reduction of the quantity of water in storage in the aquifer. Changes have been greatest in the south part of the area of investigation, where pumpage is greatest. Water-levels have declined there by 50 feet or more. In the northeast part, water-level declines have been generally less than 10 feet.

Pumpage of ground water has resulted in additional water-level declines from those shown in figure 9. Areas where water levels lowered between June 1969 and May 1971 are shown in figure 10.

GROUND-WATER QUALITY

Although the water withdrawn from the Floridan aquifer underlying the Lakeland ridge area is hard, it generally meets the drinking-water quality standards established by the U. S. Public Health Service (1962). Municipal supplies for cities in and near the area are obtained from the aquifer. The water is normally chlorinated and aerated for municipal use.

Lakeland maintains 27 public-supply wells throughout the city and in nearby communities. Some of these wells yield water that contains objectionable quantities of hydrogen sulfide. Hydrogen sulfide imparts an unpleasant taste and odor to water. The gas can be detected by smell in concentrations of less than 1 mg/l

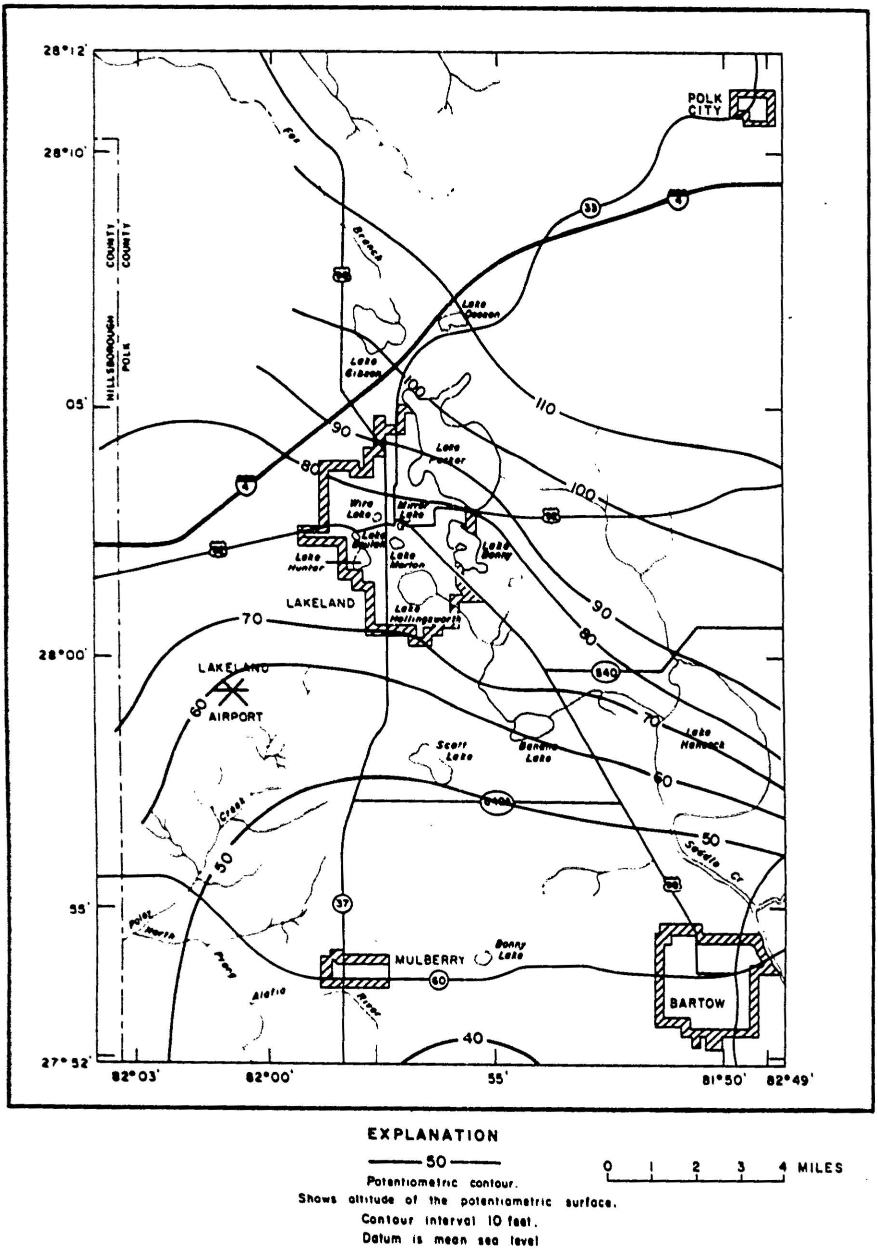
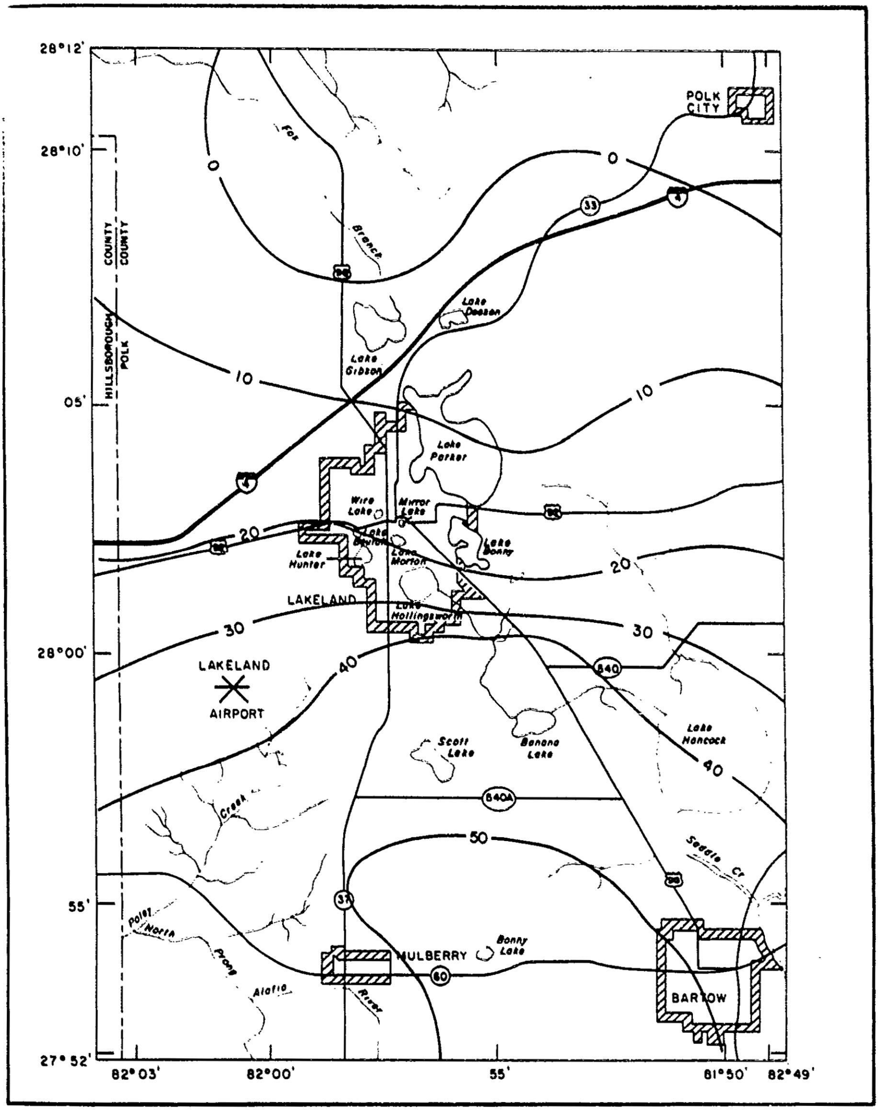


Figure 8. Contour map of the potentiometric surface of the Floridan aquifer, May 1971.



EXPLANATION

0 1 2 3 4 MILES

—— 20 ——
Line of equal water-level decline. Interval 10 feet

Figure 9. Map showing generalized decline in the potentiometric surface of the Floridan aquifer, September 1949 to June 1969.

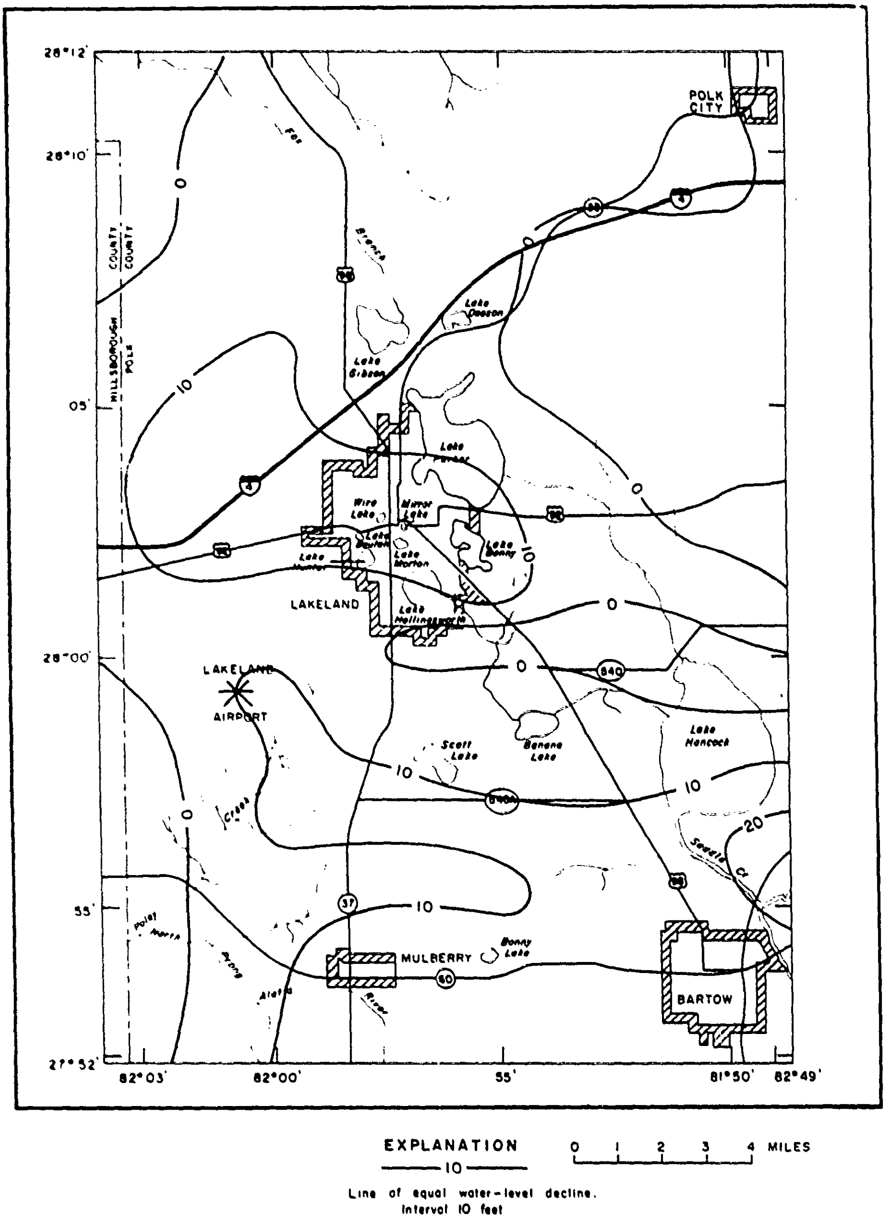


Figure 10. Map showing generalized decline in the potentiometric surface of the Floridan aquifer, June 1969 to May 1971.

milligrams per liter) (Hem, 1959). Hydrogen sulfide is not generally present in water from wells less than about 450 feet deep in the area of investigation; its occurrence may be restricted to certain zones in the geologic section.

Water samples were obtained from two wells drilled about one-quarter mile west of Lake Parker for city supply. One of these wells was drilled to 920 feet below land surface and cased to 660 feet (well 23, fig. 2). The concentration of hydrogen sulfide in this water, as determined by the Lakeland city chemist, was 2.5 mg/l. The second well, drilled about 1,000 feet farther west from the lake, is 650 feet deep (well 21, fig. 2). The concentration of hydrogen sulfide in water from this well was negligible. Because the altitude of land surface for both wells is nearly the same, the gas seems to be present in the immediate area somewhere between 650 and 920 feet below land surface and, therefore, between 150 and 400 feet below the top of the Avon Park Limestone. However, no precise correlation between the occurrence of hydrogen sulfide and depth of wells could be established within the scope of this investigation.

Highly mineralized water containing chloride in concentrations greater than 1,000 mg/l is present near the area of investigation at depths about 1,500 feet below mean sea level (Pride, Meyer, and Cherry, 1966). The depth to this highly mineralized water is related to the level of the less dense fresh water in the aquifer. Declines of the fresh-water levels in the aquifer theoretically would allow the highly mineralized water to move upward, depending upon the amount of the water-level decline and the vertical permeability of the aquifer.

In the area, no wells are accessible that are deep enough to locate precisely the depth to the highly mineralized water. However, based upon the relative densities of fresh water and sea water, about 1 foot of decline in the fresh-water levels would allow the highly mineralized water to move upward 40 feet in a homogeneous aquifer. In central Polk County, south of the area of investigation, water levels declined by 50 feet or more between September 1949 and May 1969 (Stewart and others, 1971). These declines indicate a high potential for upward movement of the highly mineralized water. No such movement was evident in the water samples taken during the investigation. Two possible explanations for the apparent lack of upward movement of the highly mineralized water are (1) insufficient time has elapsed, or (2) the vertical permeability of the lower formations is low. Probably both are involved. Although no data are available to determine the vertical permeability of the rock units underlying the Avon Park

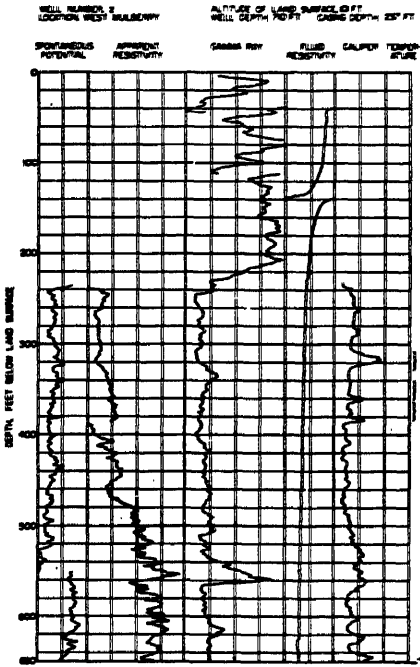
Limestone, observations by Stewart (1966, p. 26-30) indicate that the permeability is low.

A well drilled and properly finished to the depth of the highly mineralized water would allow monitoring of the possible upward movement of this water. Construction of the well to allow simultaneous measurements of the artesian pressure at the depth of the highly mineralized water and artesian pressure in the fresh-water zones of the Floridan aquifer would provide much useful information.

To determine the quality of water at various depths in the Floridan aquifer, a series of packer tests were undertaken. The packer equipment consisted of two inflatable bladders, which could be separated by intervals up to 40 feet. A submersible pump was mounted between the bladders so that, when the bladders were inflated by compressed gas, the isolated zone could be pumped for water samples. Before the tests, geophysical logs were made of the wells. The caliper log, which indicates variations in the size of the borehole, was used as a basis for selecting the depth settings for the packers. Cavity zones within the depth range 27 to 618 feet below msl were selected for sampling. Figures 11, 12, 13, and 14 are geophysical logs of the four wells selected for the tests. Also shown on the figures are the results of chemical analyses of water samples taken at the depths indicated. The fluid resistivity logs indicate little difference in the total mineral content of the water with depth, and the samples taken show no significant difference in the quality of water in the aquifer down through the tested depths. The heterogeneous nature of the aquifer and the results of these tests suggest that water circulates freely within the aquifer through the depths tested.

As a part of this investigation a pump was installed in an unused city supply well 1,200 feet deep near Mirror Lake in Lakeland to obtain periodic water samples for chemical quality analyses (well 24, fig. 2). The pump installation in the well, as shown in figure 15, allows water samples to be taken at two depths in the aquifer, 500 feet and 1,100 feet below land surface. The water at the 500-foot depth is not isolated from the water at the 1,100-foot depth, but water from the two depths differed considerably in mineral content. Chemical analyses for water samples taken from Well 24 are given in table 3. Water from the lower depth emits an odor of hydrogen sulfide; water from the 500 ft depth does not.

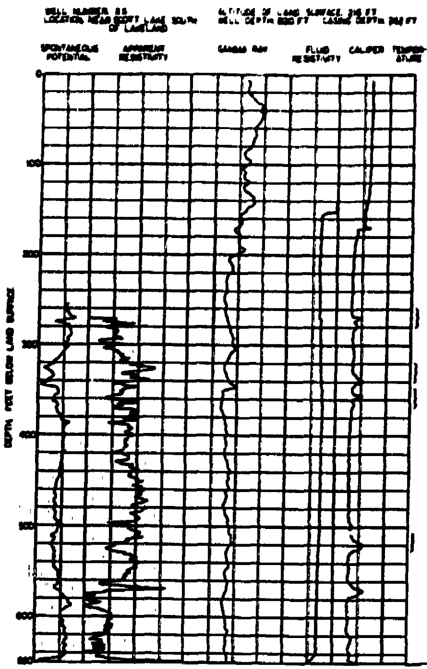
From 1955 to 1962, water samples were collected for analysis from several wells. Some were sampled again in 1969, and their locations are shown in figure 16. The change in water level in the Floridan aquifer between May 1956 and May 1969 is shown in figure



Chemical analyses in milligrams per liter except for pH, temperature (in degrees C), and conductivity (in micromhos)

Zone Sampled, ft	Date	Depth to water, ft	Fe	SO_4	Cl	PO_4	F	Alkalinity	Hardness	Conductivity	pH	Temp.
304-329	8-5-70	40	0	11	9.4	0.05	0	177	154	317	8.5	26.5
346-370	8-5-70	40	0	12	9.0	0	0	179	156	318	8.1	26.5
368-392	8-5-70	40	0	11	9.0	.05	0	178	155	318	8.1	26.5
400-720 Only top packer inflated	8-6-70	39	0	12	9.4	0	0	174	153	318	8.3	27.0
600-720 Only top packer inflated	8-7-70	39	0	11	9.0	.05	0	178	157	320	8.2	27.0

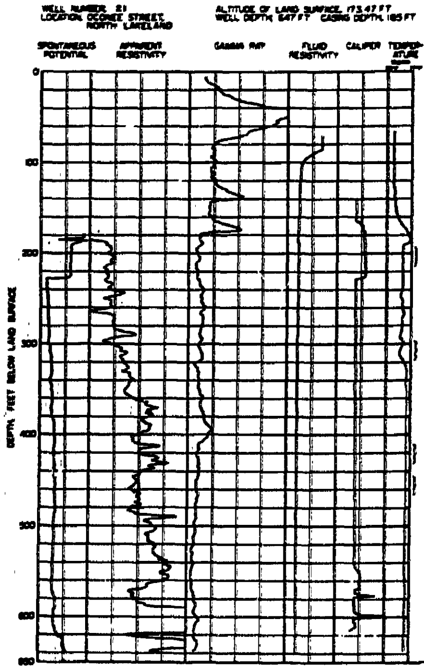
Figure 11. Geophysical logs and water quality at various depths in Well 2.



Chemical analyses in milligrams per liter except for pH, temperature (in degrees C), and conductivity (in micromhos)

Zone Sampled, ft	Date	Depth to water, ft	Fe	SO_4	Cl	PO_4	F	Alkalinity	Hardness	Conductivity	pH	Temp.
260-285	6-15-70	164	0	3.0	8.0	0	0	172	138	260	7.7	24.5
320-345	6-16-70	159	0.05	2.0	8.0	0	0.03	164	131	245	7.6	25.0
345-370	6-16-70	158	.01	2.0	8.4	0	0	183	142	274	7.7	25.0
505-530	6-17-70	157	0	4.0	8.0	0	0	188	150	285	7.7	25.0

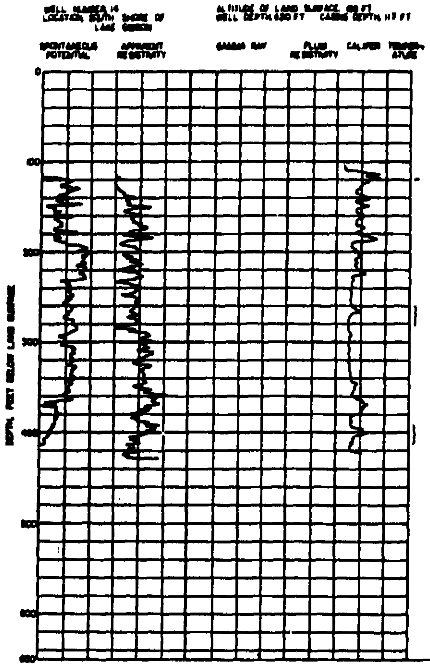
Figure 12. Geophysical logs and water quality at various depths in Well 25.



Chemical analyses in milligrams per liter except for pH, temperature (in degrees C), and conductivity (in micromhos)

Zone Sampled, ft	Date	Depth to water, ft	Fe	SO_4	Cl	PO_4	F	Alkalinity	Hardness	Conductivity	pH	Temp.
At 105 Packers not inflated	4-29-70	82	0.01	4.0	8.0	0.02	0	234	196	354	7.6	25.0
200-225	5-11-70	85	.01	3.0	8.0	.01	0	212	152	315	7.9	26.0
300-325	5-11-70	85	.01	3.0	8.0	.02	0	239	198	360	7.5	26.0
415-440	5-11-70	85	.01	3.0	8.0	0	0	212	153	288	7.8	26.0
450-475	5-11-70	85	.01	3.0	8.0	0	0	242	218	358	7.3	26.0

Figure 13. Geophysical logs and water quality at various depths in Well 21.



Chemical analyses in milligrams per liter except for pH, temperature (in degrees C), and conductivity (in micromhos)

Zone Sampled, ft	Date	Depth to water, ft	Fe	SO_4	Cl	PO_4	F	Alkalinity	Hardness	Conductivity	pH	Temp.
At 120 packers not inflated	7-2-70	59	0	0	7.4	0.20	0.5	194	153	278	7.4	24.5
260-285	7-2-70	59	0	0	9.0	.30	0.4	196	150	326	7.4	24.5
392-417	7-2-70	59	0	0	7.4	.30	0.3	174	140	292	7.4	25.0

Figure 14. Geophysical logs and water quality at various depths in Well 14.

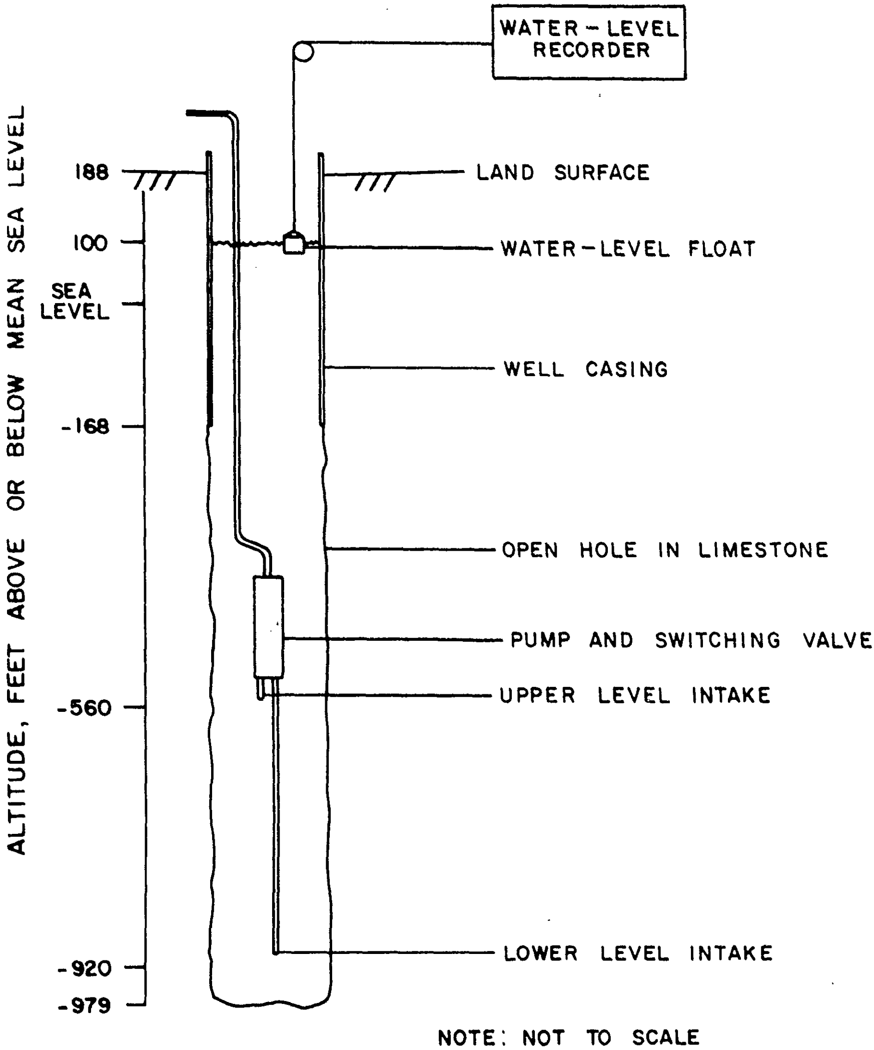

WATER - LEVEL RECORDER
ALTITUDE, FEET ABOVE OR BELOW MEAN SEA LEVEL
188
100
SEA LEVEL
-168
-560
-920
-979
LAND SURFACE
WATER-LEVEL FLOAT
WELL CASING
OPEN HOLE IN LIMESTONE
PUMP AND SWITCHING VALVE
UPPER LEVEL INTAKE
LOWER LEVEL INTAKE
NOTE: NOT TO SCALE

Table 3. Chemical analyses of water samples from Well 24
(Results in milligrams per liter except as indicated. Analyses by U.S. Geological Survey)

Date of sample and depth taken		Water level feet above msl	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$		Specific Conductance (micromhos at 25 C)	pH	Color
														Calcium Magne-sium	Non-carbonate			
3-21-68	500	87.6	20	60	19	6.5	0.9	200	59	14	0.3	0.4	275	229	65	448	7.6	5
	600	87.6	20	52	17	6.6	0.9	188	46	14	.3	.4	247	201	47	408	7.5	5
	720	87.6	19	56	19	6.8	1.0	196	56	14	.4	.2	268	219	58	439	7.6	5
3-22-68	820	87.6	18	104	23	9.4	1.5	270	130	18	.4	.2	449	358	136	700	7.5	20
	1080	87.6	18	98	23	9.7	1.5	260	122	16	.4	.2	424	342	130	650	7.5	15
	1116	87.6	18	106	22	9.6	1.7	264	144	16	.4	.2	462	359	142	700	7.5	20
3-6-70	500	97.9	—	—	—	—	—	—	—	—	—	—	—	—	—	360	—	—
	1150	97.9	—	—	—	—	—	—	—	—	—	—	—	—	—	1610	—	—
4-15-70	500	95.2	—	—	—	—	—	—	—	—	—	—	—	—	—	290	—	—
	1150	95.2	—	—	—	—	—	—	—	—	—	—	—	—	—	1825	—	—
5-18-70	500	95.0	—	—	—	—	—	—	—	—	—	—	—	—	—	980	—	—
	1150	95.0	—	—	—	—	—	—	—	—	—	—	—	—	—	1340	—	—
9-25-70	500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	985	—	—
	1150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2180	—	—
12-28-70	960	91.5	23	430	90	16	2.5	202	1200	26	1.4	6.5	1900	1460	1290	2200	7.9	0
1-20-71	500	92.5	—	—	—	—	—	—	—	—	—	—	—	—	—	440	—	—
	1150	92.5	—	—	—	—	—	—	—	—	—	—	—	—	—	2250	—	—

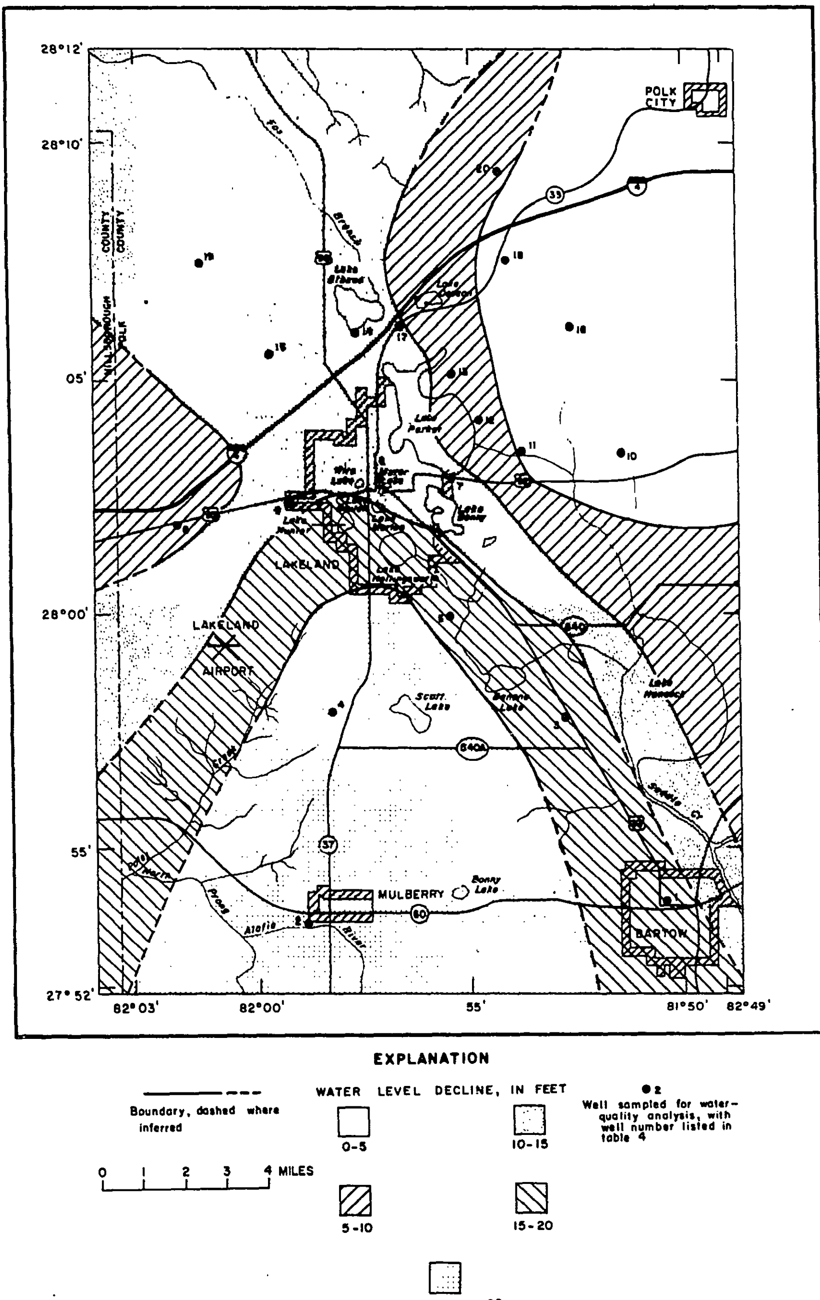


Figure 16. Map showing generalized decline in the potentiometric surface of the Floridan aquifer, June 1956 to June 1969, and locations of selected water quality monitoring wells.

16 for recognition of a possible relation between quality change and water-level change. A comparison of the earlier analyses with those of 1969 (table 4) shows no extensive deterioration of water quality and little correlation between water-quality changes and water-level changes for this period. The specific conductance of water from wells 1, 3, and 18 increased by more than 10 percent. Wells 1 and 3 are within the area where water levels declined 15 to 20 feet, and well 18 is within the area where the water level decline was 0 to 5-foot. However, the specific conductance of water from the other wells throughout the area of investigation either has not changed or has decreased by more than 10 percent. The depths of, and other information about these wells are given in table 5.

Any correlation between water-level declines and quality changes may be overshadowed by other effects, such as inadequate well construction or localized recharge. These effects could allow more rapid downward movement of water into the Floridan aquifer near the well from the water-table aquifer. That such effects have produced rapid downward movement of water into the Biscayne aquifer has been shown by Parker (1955, p. 609).

SURFACE-WATER USE

Surface water in the study area is used principally for recreation. Surface water is also used as a coolant for power plants and for transportation and dilution of municipal and industrial wastes. Two electric-power plants on the shores of Lake Parker pumped about 40 billion gallons from the lake in 1970. The water was returned to the lake at a slightly higher temperature.

Lakeland's municipal sewage-treatment plant discharges into Banana Lake, which discharges into Lake Hancock, and from there flows into Peace River. The discharge from the treatment plant was about 2.37 billion gallons in 1970. Discharge from the plant varies throughout the year in about the same manner as the municipal pumpage.

Bartow's sewage-treatment plants discharge into tributaries of the Peace River. In 1970 the discharge was about 0.4 billion gallons.

STREAMFLOW

The volume of streamflow is dependent mainly upon the amount of precipitation. This relation can be seen in figure 17. Conditions that cause a significant increase in the downward percolation of streamflow through the stream bed may reduce the annual volume of flow. Declines of water levels in the Floridan aquifer have

Table 4. Chemical analyses of water samples from selected wells in the Lakeland ridge area
(Results in milligrams per liter except as indicated. Analyses by U.S. Geological Survey)
(Water level: a, from recorder chart; e, estimated; m, measured.)

Well	Date Sampled	Water level ft. below land surface	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific Conductance (micromhos at 25°C)	pH	Temperature (°C)
1	5-08-59	31e	3.2	0.01	20	11	8.2	0.8	48	54	12	0.2	0.0	—	157	95	56	234	7.4	—
	9-11-69	61e	18	.18	95	24	8.9	1.1	182	174	12	.6	.7	0.05	491	339	190	650	7.6	25.0
	8-4-71	—	16	—	97	25	10.0	1.2	180	200	13	0.3	0.5	—	473	348	201	673	7.0	25.0
2	5-07-59	18a	17	—	46	11	6.8	.8	178	14	8.5	.4	.0	—	191	160	14	326	7.7	26.0
	11-07-69	34a	4.4	.03	20	11	8.4	1.0	112	4.0	6.0	.3	1.1	.2	117	96	4	205	7.3	25.0
3	6-11-56	37e	16	.08	54	11	13	.7	192	8.8	24	.0	1.5	—	227	180	23	396	7.4	—
	9-16-69	55e	14	.54	82	14	16	1.1	260	52	20	.2	.3	—	336	262	49	485	7.5	25.0
4	6-11-56	79m	—	—	—	—	—	—	—	—	—	—	—	.0	178	156	--	299	7.2	—
	4-15-66	101e	—	—	—	—	—	—	—	3.6	7.0	.3	—	—	—	158	—	319	—	—
	9-10-69	104e	16	—	39	12	6.0	.6	180	.0	7.0	.2	.9	.2	176	148	0	290	7.9	25.0
5	6-11-56	33m	—	—	—	—	—	—	—	—	—	—	—	.0	286	216	—	418	7.4	—
	6-9-69	43a	—	0.0	—	—	—	—	—	8.0	10.0	0.3	—	0.1	—	—	—	—	7.3	24.4
	11-07-69	31a	—	0.12	23	4.8	4.1	—	96	0.3	5.0	0.6	—	.2	102	77	0	170	7.8	24.5
6	6-07-66	54e	—	—	—	—	—	—	—	.8	10	.4	—	—	—	150	—	325	—	—
	9-17-69	55e	—	2.4	49	6.1	—	—	—	.4	11	.5	—	—	212	148	—	310	7.6	24.5
7	6-09-56	32e	—	—	—	—	—	—	—	—	—	—	—	.3	237	188	—	383	7.2	—
	9-18-69	37e	16	.48	59	10	8.0	.9	206	.0	10	.3	10	.5	221	188	19	350	8.2	25.0

Table 4. Chemical analyses of water samples from selected wells in the Lakeland ridge area, (cont'd.)

Well	Date Sampled	Water level ft. below land surface	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids	Hardness as $CaCO_3$ Calcium, Magnesium	Hardness as $CaCO_3$ Non-carbonate	Specific Conductance (micromhos at 25°C)	pH	Temperature (°C)
8	3-16-62	—	18	0.01	54	14	6.9	1.0	230	3.6	8.5	0.2	0.2	—	238	192	4	395	7.3	—
	3-25-63	—	—	—	59	13	6.5	1.2	232	10.0	9.0	—	—	0.01	—	202	12	400	7.6	—
	9-18-69	110e	19	0.30	59	14	7.8	0.4	238	0.0	9.0	0.2	12	—	245	205	10	389	7.6	26.0
9	6-11-56	67e	—	—	—	—	—	—	—	—	—	—	—	0.1	211	172	—	322	7.8	—
	9-17-69	73e	—	0.14	41	13	—	—	—	0.1	10	0.5	—	0.05	185	156	—	280	7.9	28.0
10	2-14-55	11e	—	0.06	38	21	—	—	216	7.0	12	—	—	—	214	182	—	366	7.9	—
	11-11-69	7m	22	0.0	40	18	15	0.8	222	4.0	12	1.0	0.6	0.1	225	174	.0	370	8.0	23.5
11	2-15-55	28e	—	0.03	46	21	—	—	237	5.0	10	—	—	—	244	202	—	380	7.8	—
	9-17-69	23e	—	0.48	43	20	—	—	—	0.1	21	0.5	—	0.04	218	190	—	320	8.1	24.0
12	9-26-56	28e	—	—	4.5	28	—	—	260	—	18	—	—	—	280	228	14	435	7.2	—
	9-17-69	29e	—	1.2	33	19	—	—	—	0.1	23	—	—	0.02	214	161	—	310	7.6	23.0
13	12-05-55	27e	—	—	64	12	4.7	—	241	1.0	10	—	—	—	211	209	—	362	7.6	—
	11-09-59	15a	12	1.2	24	7.8	5.2	.5	118	2.0	6.5	0.2	.1	—	115	92	—	196	7.9	—
	11-10-69	20m	16	0.20	63	7.9	5.2	.8	226	0.0	8.0	0.6	1.2	0.2	218	190	5	365	8.0	23.5
14	6-09-56	57e	—	—	—	—	—	—	—	—	—	—	—	—	168	144	—	280	7.3	—
	9-18-69	59e	—	0.48	38	12	—	—	—	0.1	14	0.8	—	0.04	171	145	—	290	7.7	24.5
15	6-11-56	100m	—	—	—	—	—	—	—	—	—	—	—	0.0	151	122	—	239	7.6	—
	9-19-69	110e	—	0.00	30	9.0	—	—	—	0.1	9.0	0.4	—	0.0	142	112	—	200	7.9	24.5
16	6-09-56	86m	—	—	—	—	—	—	—	—	—	—	—	0.1	298	260	—	526	7.6	25.5
	11-10-69	20e	—	0.0	42	15	6.0	—	196	0.0	8.0	0.4	—	—	188	167	6	315	8.2	26.0

Table 4. Chemical analyses of water samples from selected wells in the Lakeland ridge area. (cont'd.)

Well	Date Sampled	Water level ft. below land surface	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids	Hardness as $CaCO_3$ Calcium, Magnesium	Non-carbonate	Specific Conductance (micromhos at 25°C)	pH	Temperature (°C)
17	1-02-56	21m	—	—	32	18	5.2	—	166	1.0	7.0	—	—	—	180	154	—	295	7.8	—
	11-11-69	22m	—	0.01	35	12	3.7	—	174	0.10	4.0	0.3	—	0.6	146	137	0	250	8.1	24.0
18	1-30-56	13m	—	—	50	22	7.9	—	252	1.0	12	—	—	—	236	215	—	412	7.6	—
	11-10-69	18e	22	0.05	60	28	12	0.6	322	0.0	17	0.3	0.1	0.05	306	265	1	566	8.0	23.0
19	6-11-56	52m	—	—	—	—	—	—	—	—	—	—	—	—	141	110	—	223	7.7	—
	9-19-69	61e	—	0.15	26	5.3	—	—	—	0.1	11	0.4	—	—	123	87	—	190	7.4	26.0
20	6-14-62	—	14	0.31	40	4.4	4.8	.5	142	2.8	6.0	0.4	0.2	—	138	118	2	241	8.1	—
	9-19-69	30e	14	0.61	39	5.0	4.7	.3	146	0.0	6.0	0.3	0.0	0.07	147	119	0	240	7.6	24.0

Table. 5. Record of wells sampled for water-quality analyses in the Lakeland ridge area

Well	Well depth (feet)	Altitude (feet)	Casing depth (feet)	Date drilled	Approximate thickness of formation open to well (feet): Hawthorn and Tampa Formation	Suwannee Limestone	Ocala Group	Avon Park Limestone	Latitude-Longitude number
1	121	600	(a)	1904	0	56	173	171	275353N-0815033.1
2	100	710	237	?	0	13	214	246	275326N-0815858.1
3	125	252	90	1936	0	105	57	0	275751N-0815220.1
4	164	325	163	1955	0	0	162	0	275759N-0815813.1
5	122	1220	243	1948	0	0	207	770	275959N-0815525.1
6	137	300	(a)	1940	0	14	86	0	280159N-0820156.1
7	135	746	160	1948	0	90	200	296	280254N-0815525.1
8	201	828	280	1945	0	34	203	311	280246N-0815704.1
9	158	635	114	1951	35	85	226	175	280227N-0815918.1
10	117	193	36	1954	62	95	0	0	280336N-0815128.1
11	123	355	55	1953	55	122	123	0	280325N-0815345.1
12	134	126	78	1953	0	33	15	0	280407N-0815443.1
13	138	311	265	1955	0	0	46	0	280503N-0815528.1
14	158	550	67	1939	51	97	115	220	280559N-0815748.1
15	207	261	203	1954	0	0	58	0	280529N-0815947.1
16	128	1285	375	1950	0	0	0	910	280606N-0815232.1
17	139	103	63	1956	0	40	0	0	280614N-0815636.1
18	135	411	53	1956	17	118	178	45	280702N-0815422.1
19	160	198	88	1952	27	83	0	0	280727N-0820113.1
20	145	140	135	1955	0	5	0	0	280922N-0815412.1
21	173	647	185	1968	—	—	—	—	280416N-0815719.1
22	173	660	198	1969	—	—	—	—	280416N-0815719.2
23	167	920	660	1968	—	—	—	—	280420N-0815707.1
24	188	1167	356	1925	—	—	—	—	280244N-0815708.1
25	216	820	262	1945	—	—	—	—	275646N-0815645.1

[a]Casing depth estimated to be 200 feet.

increased the head differential between the stream levels and the water levels in the aquifer, thereby providing conditions favorable for increasing stream losses. To investigate this possibility, graphs were prepared in which cumulative annual precipitation (an areally weighted mean over the individual basin) was plotted against cumulative annual flows of three streams — Peace River at Bartow, North Prong Alafia River at Keysville, and Blackwater Creek near Knights (fig. 18). Because streamflow is dependent mainly upon precipitation, any significant changes in the streamflow-precipitation relationship, such as increases in stream losses, would be indicated by a change in slope of the graph. No significant changes in this relationship are evident for the period considered, 1951-69. However, the effects of increased losses by downward percolation from the streams may be offset by increased outflow from settling ponds created by mining operations during this period. No data were available to assess this possibility.

Unit-area runoff from six drainage areas in or adjacent to the area of investigation vary considerably. The unit-area runoff for each of the six drainage areas is listed in table 6. The unit-area runoff from the smaller drainage areas upstream from the gaging stations, Peace Creek drainage canal near Alturas, and Lake Lulu outlet near Eloise is much lower than from the four larger drainage areas during 1947-69. These smaller areas contribute significantly more recharge per unit area than the four larger ones. The many lakes in the smaller drainage areas may cause higher evaporation as well as higher unit-area recharge to the shallow aquifers.

LAKE LEVELS

Lake levels in this area respond more rapidly to local precipitation than to any other hydrologic factor, rising during extended periods of above normal rainfall and declining during extended periods of below normal rainfall. This general relation can be seen by comparing mean annual rainfall at Lakeland and Bartow to mean monthly levels of Lakes Parker and Hancock (fig. 19). Although the outflow of these lakes is controlled, long-term trends of mean water level can be defined adequately.

In addition to responding to variations in rainfall, the level of some lakes, for example Scott Lake, also respond noticeably to declines in ground-water level. The hydrograph of mean monthly water level in Scott Lake (fig. 20), indicates that the lake level was about 4 feet lower in June 1970 than in June 1961. On the other hand, the mean water levels in Lakes Parker and Hancock were about the same or somewhat higher in June 1970 than in June 1961. The trend of lowered water levels in Scott Lake follows closely the trend of lowered water levels in the Floridan aquifer during this period. This correlation is apparent from the hydrograph of water levels in well 26 (fig. 20). The well is about 4 miles north of Scott Lake (fig. 2). Stewart (1966) discussed the various influences that affect the water level in Scott Lake and correlated the lake-level fluctuations to water-level fluctuations in the secondary artesian aquifer. Because fluctuations of the water level in the secondary artesian aquifer are closely related to fluctuations of the water level in the

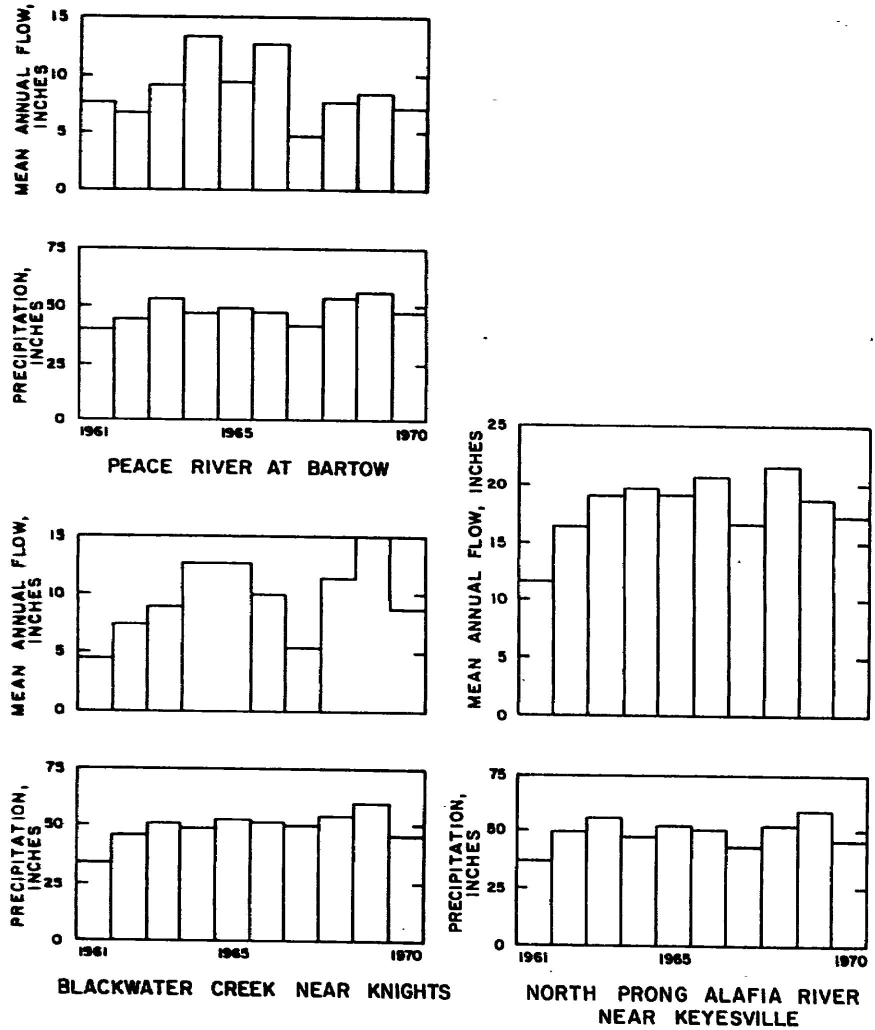


Figure 17. Bar graphs of mean annual flows of the Peace River at Bartow, North Prong Alafia River near Keysville, and Blackwater Creek near Knights, and mean annual precipitation over these basins; 1961-70.

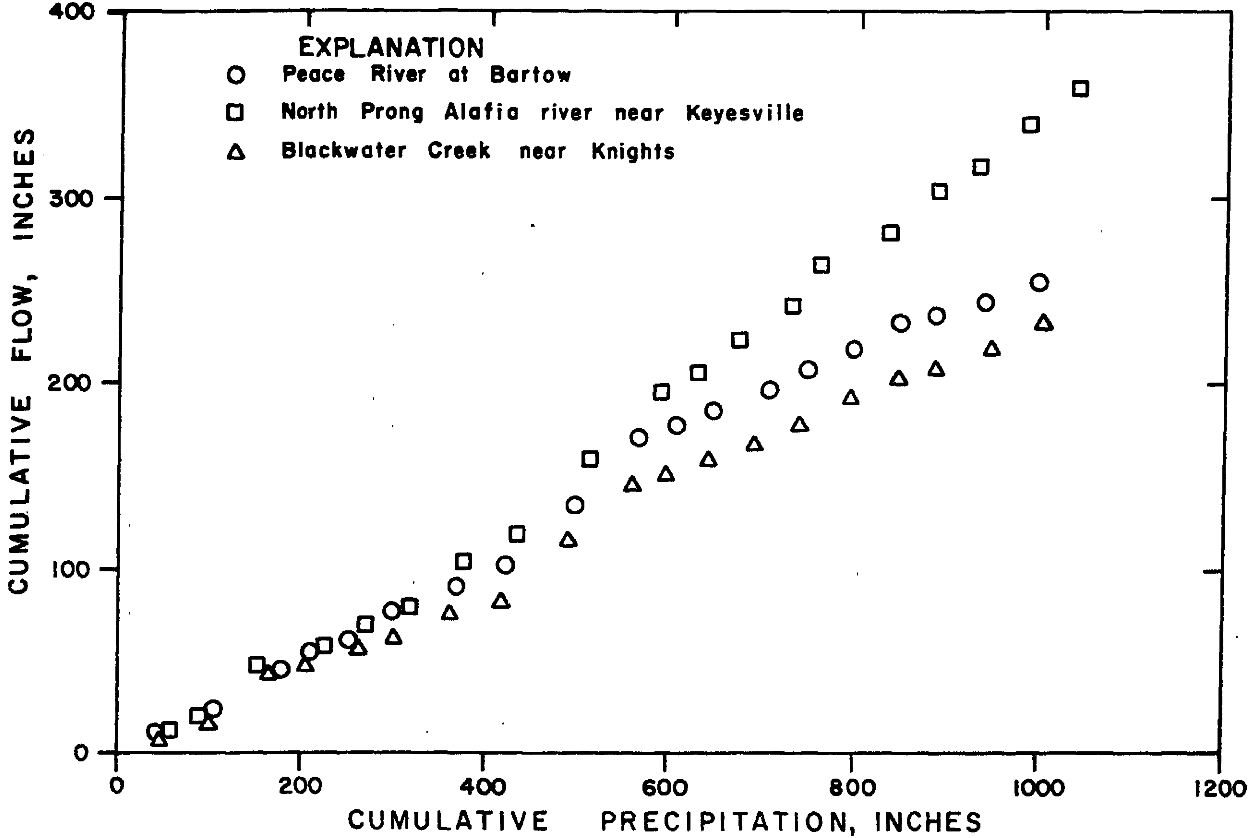


Figure 18. Graphs of cumulative precipitation and flow of Peace River at Bartow, North Prong Alafia River at Keysville, and Blackwater Creek near Knights, 1951-69.

Table 6. Runoff from six drainage basins in and adjacent to the Lakeland Ridge area[a]

Water Year	Area - 160 sq.mi. Peace Creek Drainage canal near Alturas (cfsm)	Area - 23 sq.mi. Lake Lulu Outlet near Eloise (cfsm)	Area - 207 sq.mi. Peace River near Bartow (cfsm)	Area - 253 sq.mi. Peace River near Zolfo Springs (cfsm)	Area - 135 sq.mi. North Prong Alafia River near Keyesville (cfsm)	Area - 110 sq.mi. Blackwater Creek near Knights (cfsm)
1947	1.056	0.543	1.239	3.490	1.370	—
1948	1.312	.878	1.313	2.166	1.370	—
1949	1.031	.573	.796	2.434	1.370	—
1950	.410	.255	.456	1.193	1.370	—
1951	.631	.242	1.089	1.146	.619	0.55
1952	.451	.203	.686	.905	.577	.68
1953	.981	.243	1.204	3.316	1.711	1.45
1954	1.025	.756	1.355	2.873	1.459	1.06
1955	.198	.083	.436	1.094	.822	.42
1956	.081	.048	.376	.750	.574	.38
1957	.462	.447	1.476	1.798	1.600	1.04
1958	.550	.556	1.213	1.952	1.348	.61
1959	1.356	1.447	2.133	3.324	2.740	2.15
1960	1.762	1.652	2.386	3.126	2.740	2.34
1961	.618	.416	.982	1.343	1.074	.51
1962	.195	.163	.449	1.379	1.133	.52
1963	.302	.120	.685	1.596	1.325	.61
1964	.296	.160	.999	1.537	1.488	1.00
1965	.182	.232	.688	1.324	1.237	.78
1966	.483	.865	1.003	1.217	1.703	.85
1967	.26	.27	.396	1.024	1.19	.46
1968	.33	.18	.560	1.822	1.56	.76
1969	.33	.38	.517	1.478	1.22	.86
Mean	.62	.46	.98	1.84	1.37	.90

a In cubic feet per second per square mile.

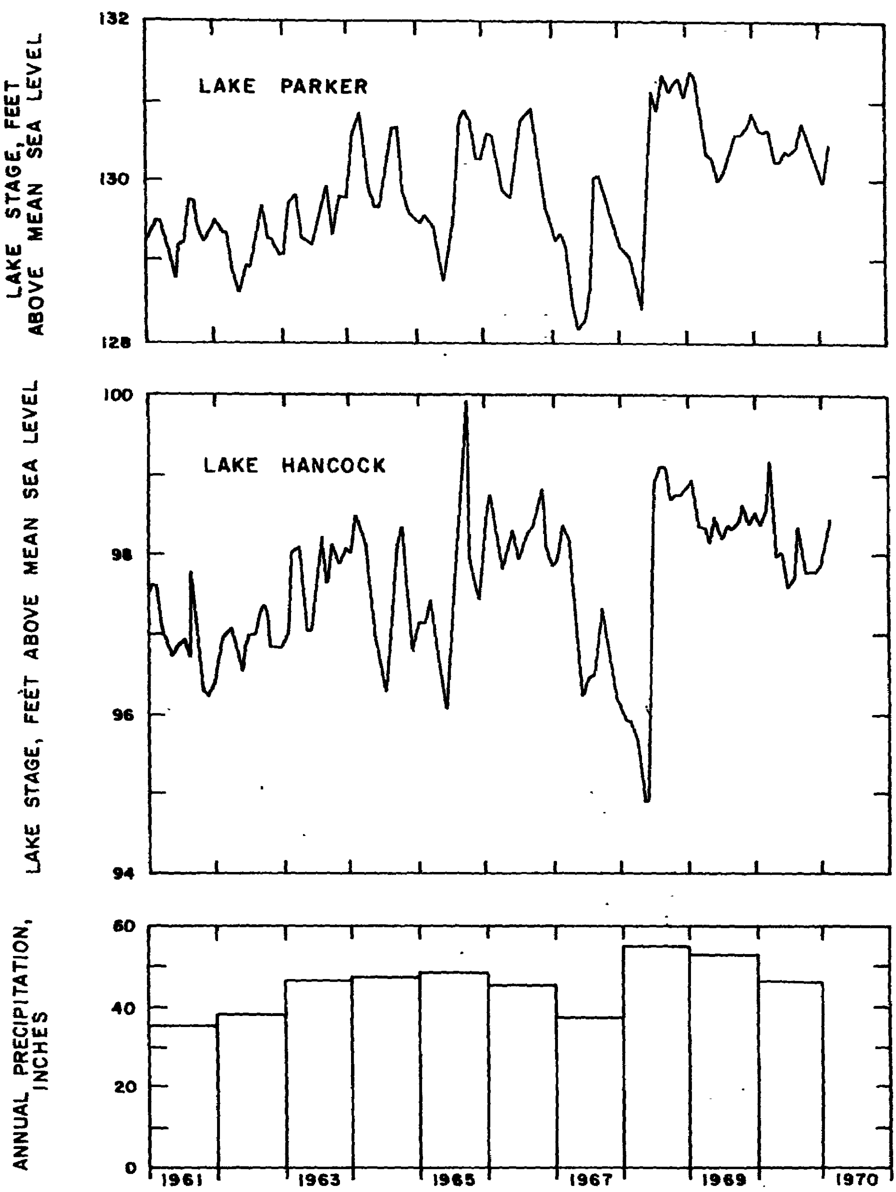


Figure 19. Graphs of mean monthly lake levels of Lake Parker at Lakeland and Lake Hancock at Bartow and bar graph of annual precipitation at Lakeland, 1961 to 1971.

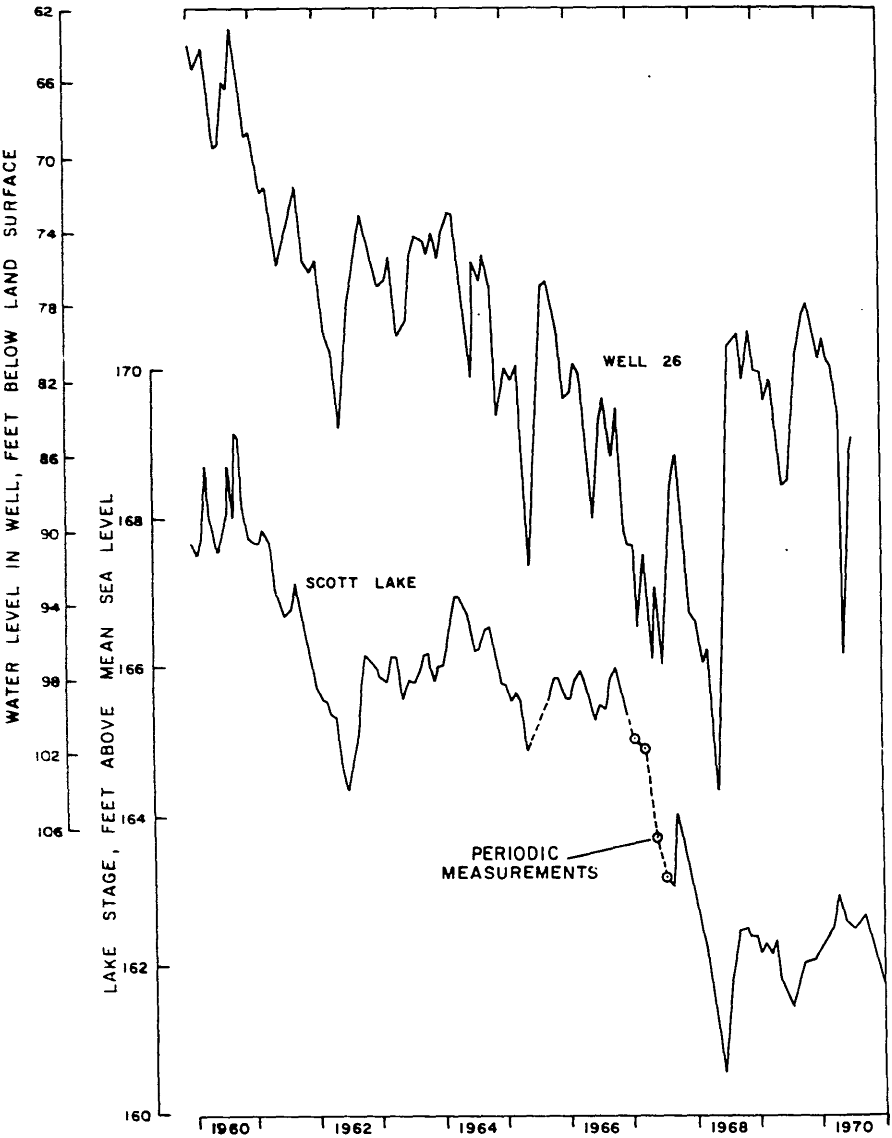


Figure 20. Graphs of water level in Well 26 tapping the Floridan aquifer and stage of Scott Lake near Lakeland, 1960 to 1970.

Floridan aquifer (Stewart 1966), a long-term trend of lowered artesian water levels may result in a long-term lowering of some lake levels.

WATER PROBLEMS

WATER-LEVEL DECLINES

The most immediate effect of declining water levels in wells is loss of suction to pumps, requiring that pump intakes be lowered. Continued water-level declines further increase the potential for upward movement of highly mineralized water. Lowered water levels in the Floridan aquifer increase recharge rates to the aquifer in direct proportion to the head differential between the water level in the Floridan aquifer and the higher water levels in the overlying aquifers. The recharge increase supplied by the overlying aquifers and, ultimately, the water-table aquifer results in some places in the decline of lake levels.

Any increase in the amount of water used likely will be obtained from the Floridan aquifer. Water levels in the aquifer will continue to decline as withdrawals increase. These declines may be modified somewhat if above-average precipitation occurs, reducing the need for irrigation. Some increase in pumpage for municipal and industrial purposes is probable; therefore, continued water-level declines are anticipated.

LAKELAND'S WATER SUPPLY

Lakeland's water supply comes from 27 wells in the city and in nearby communities. Water supplying the distribution system is stored momentarily in small pressure tanks near each well. As additional supplies are needed, new wells are drilled generally near the area of need. Growth of the city has been toward the south, where long-term water-level changes are most pronounced, thus creating the necessity to drill wells near that area.

When a well is pumped, a cone of depression, or lowered water levels, is created in the aquifer and is centered around the pumping well. The shape of this cone of depression is dependent upon the pumping rate and period and the hydraulic characteristics of the aquifer and confining beds. Knowing these characteristics, the shape of the cone can be defined for various rates for any given period of pumping. After steady pumping has continued for a sufficiently long time, the cone approaches an equilibrium condition in which recharge induced into the aquifer is about equal to the pumpage. Under these equilibrium conditions, water-level declines due to steady pumping, cease. However, an increase in pumpage causes additional declines until a new equilibrium condition is again established. When numerous wells are pumped in an area, the individual cones of depression may overlap and interfere with one another, resulting in a complex pattern of drawdown, which becomes more difficult to describe and analyze as the number of wells increase.

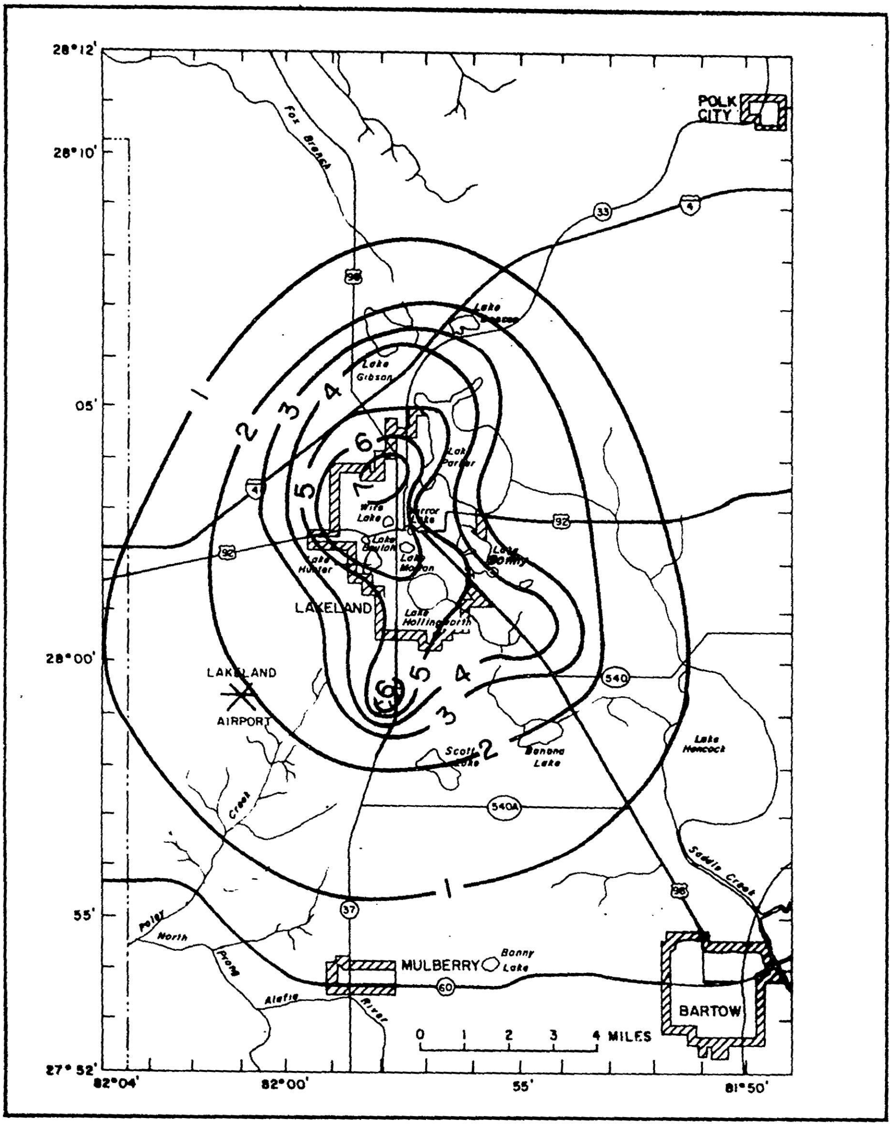
If only those wells pumped for municipal supply by Lakeland are considered, the pattern of drawdown caused by their pumping can be determined with reasonable accuracy. Utilizing the leaky-aquifer method (Ferris and others 1962, p. 110-118) to determine steady-state drawdowns, the cone of depression due to Lakeland's pumpage of 5.23 billion gallons in 1970 was determined (fig. 21). The greatest decline due to the city's pumpage was about 7 feet, southwest of Lake Parker. The cone of depression bounded by the 5-foot decline line was elongated and extended from the north to beyond the south of the city limits. Northwest of Scott Lake the decline was about 6 feet.

To calculate drawdown, transmissivity of 100,000 ft²/day (750,000 gpd/ft) was used because it is assumed to be representative for the Floridan aquifer underlying the area. The yield of each well was taken as the continuous rate which, if maintained for 1 year, would yield the actual quantity of water withdrawn during 1970. Because actual pumping rates and time of pumping varied during the year, the cone of depression shown in figure 21 is an approximation and could not be expected to depict the actual drawdown at any specific time.

The leakage factor used in calculating drawdown was 0.001 gpd/ft³ (gallons per day per square feet of surface area per foot of head difference). This is about 6 inches per year under a head difference of ten feet. Inasmuch as only Lakeland's well system was considered, the drawdown shown on figure 21 is only a part of the total drawdown of water levels in the area, as reflected in the potentiometric-surface map for May 1971, (fig. 8).

To predict the drawdown that could be expected due to future increases in the city's pumpage, the trend of annual pumpage shown in figure 6 was extrapolated linearly to 1990. From this extrapolation, the total annual municipal pumpage in 1980 and 1990 would be about 7 billion and 9 billion gallons, respectively.

Using these projected municipal withdrawals and following the same method as above, the cone of depression resulting from Lakeland's projected pumpage in 1980 and 1990 was determined. The drawdowns shown on figure 22 would occur if the additional pumpage required to meet the projected municipal needs in 1980 and 1990 were equally distributed among five city wells now used



EXPLANATION

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Lines of equal water-leve decline. Interval, 1 foot

Figure 21. Map showing generalized drawdown due to Lakeland's municipal pumpage, 1970.

south of Lakeland. All other wells were assumed to be pumped at the same rate as during 1970. The general pattern of the cone of depression is similar to that of 1970 (fig. 21), but the greatest decline, 9 feet in 1990, occurs near Scott Lake south of Lakeland.

If the additional pumpage for 1980 and 1990 were supplied from wells drilled northeast of Lakeland, the predicted cone of depression due to the city's pumpage would be as shown in figure 23. Again it was assumed that existing city wells would be pumped at the same rate as in 1970. The greatest decline, 9 feet in 1990, occurs northeast of Lakeland near the pumped wells. However, water-level declines south of Lakeland in this case are about the same as in 1970.

The cones of depression in figures 21, 22, and 23 are due only to pumping for Lakeland's municipal supply. Pumping for industrial and irrigation use in and near the area of investigation also produce cones of depression, and the interaction of these drawdowns produce the present configuration of the potentiometric surface (fig. 8). Because most of the industrial and irrigation pumpage is south of Lakeland, water-level changes have been more pronounced there (fig. 10). Municipal wells drilled north of Lakeland to supply increased demands would be more distant from this center of pumping and would experience less interference from other wells. Such a distribution would reduce the amount of further water-level declines south of Lakeland, where industrial and irrigation pumpage are more likely to increase through 1990.

SUMMARY AND CONCLUSIONS

Hydrologic data collected as a part of this and previous studies are sufficient to define in general the present-day hydrologic conditions in the area of investigation. The data-collection network adequately measures artesian water levels and streamflow and lake stages. Changes in the quality of the ground water can be monitored by periodic sampling of selected wells. No observation well is presently available to measure and monitor directly the depth to the highly mineralized water underlying the fresh water of the Floridan aquifer. A well drilled and properly finished to the depth of this highly mineralized water in the area of greatest water-level declines would allow monitoring of the possible upward movement of this water. Such monitoring would warn of possible deterioration from this source before the fresh-water supply is threatened. This well would need to be a multi-zone well to allow simultaneous measurements of the artesian heads in the Floridan aquifer and in the zone containing highly mineralized water.

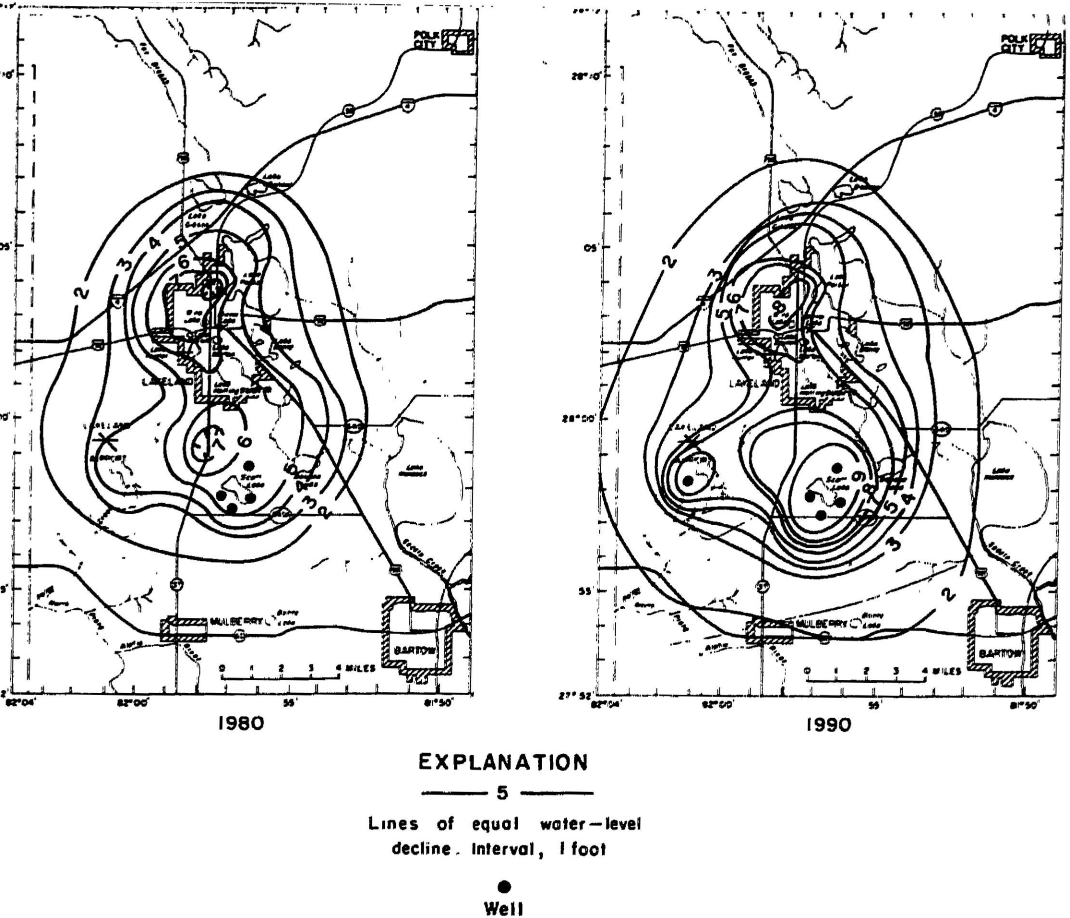
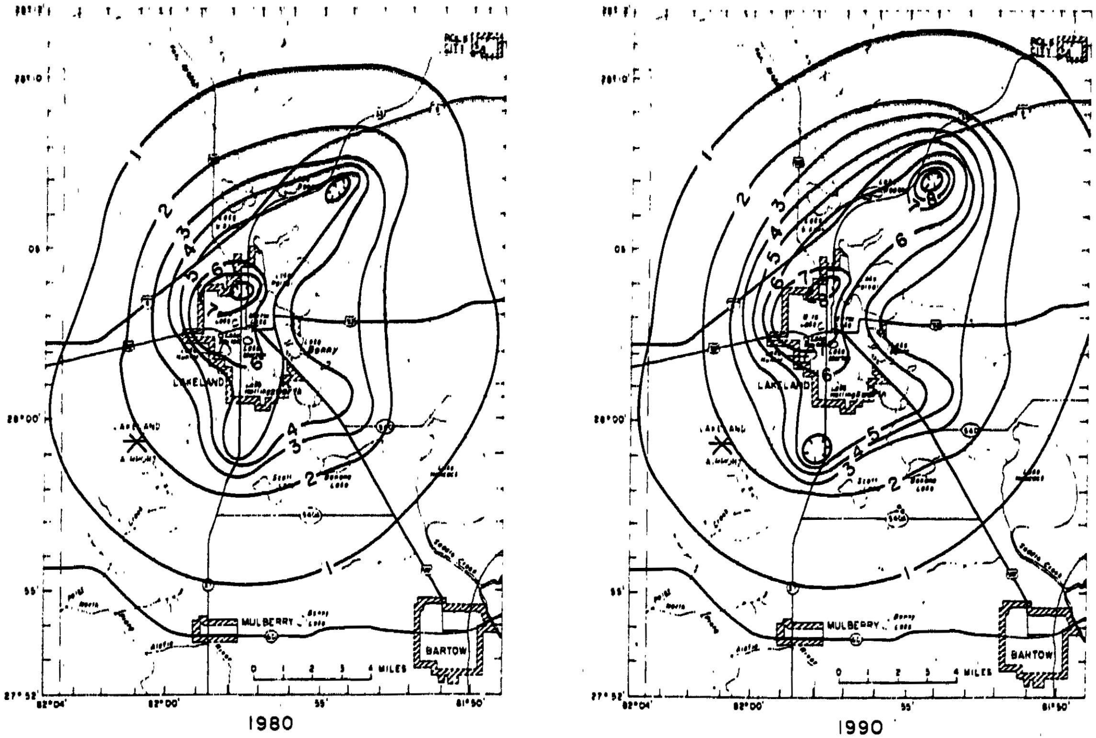


Figure 22. Maps showing predicted generalized drawdown south of Lakeland due to projected municipal pumpage in 1980 and 1990.



EXPLANATION

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Lines of equal water-level decline. Interval, 1 foot

Figure 23. Maps showing predicted generalized drawdown north of Lakeland due to projected municipal pumpage in 1980 and 1990