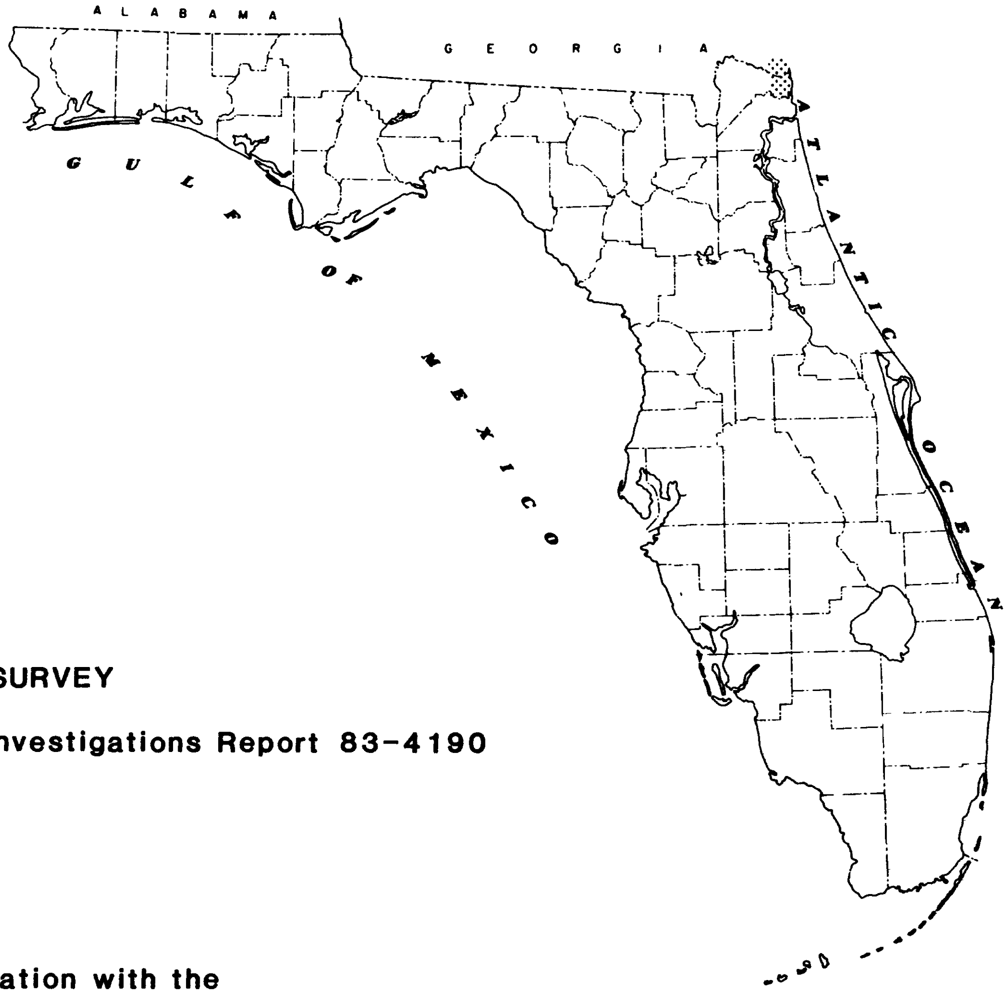
# IMPACT OF DEVELOPMENT ON AVAILABILITY AND QUALITY OF GROUND WATER IN EASTERN NASSAU COUNTY, FLORIDA, AND SOUTHEASTERN CAMDEN COUNTY, GEORGIA




U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4190

Prepared in cooperation with the

OCEAN, HIGHWAY, AND PORT AUTHORITY

Nassau County, Florida

## CONVERSION FACTORS

For those readers who may prefer to use International System (metric) units rather than inch-pound units, the conversion factors for terms used in this report are listed below:

| Multiply | By | To obtain metric unit |
|---|---|---|
| inch (in) | 25.40 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day ($m^2/d$) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second ($m^3/s$) |
| million gallons per square mile ($Mgal/mi^2$) | 1461. | cubic meter per square kilometer ($m^3/km^2$) |
| foot per second (ft/s) | 0.3048 | meter per second (m/s) |
| cubic feet per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| degrees Fahrenheit (°F) | 5/9 (°F-32) | degrees Celsius (°C) |

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called NGVD of 1929, is referred to as sea level in this report.

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By David P. Brown

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1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

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# IMPACT OF DEVELOPMENT ON AVAILABILITY AND QUALITY OF GROUND WATER IN EASTERN NASSAU COUNTY, FLORIDA, AND SOUTHEASTERN CAMDEN COUNTY, GEORGIA

By David P. Brown

## ABSTRACT

The primary source of water in Nassau County, Florida, and Camden County, Georgia, is ground water from the Floridan aquifer. The aquifer consists of upper, middle, and lower water-bearing zones of permeable limestone and dolomite separated by semiconfining beds of hard, massive dolomite and limestone of low permeability, all of which are confined above and below by leaky confining beds. Development of the aquifer is limited to the upper and middle zones, at depths of 530 to 1,000 feet and 1,200 to 1,700 feet below land surface. The transmissivity of the upper zone ranges from 20,000 to 50,000 and that of the middle zone 40,000 to 60,000 feet squared per day. The lower zone, about 2,000 to 2,100 feet below land surface contains very saline water with chloride concentrations exceeding 8,000 milligrams per liter. Water levels in a monitor well open to the lower zone do not appear to be affected by pumpage changes within the upper and middle zones.

Development of the Floridan aquifer has been principally for industrial supply and occurs primarily in the Fernandina Beach-St. Marys area in the coastal part of the study area. Pumpage increased from about 30 million gallons per day in 1940 to about 91 million gallons per day in 1980. The pumpage, primarily from the upper zone, has resulted in (1) a long-term decline in the potentiometric surface of about 25 feet in the western part of the study area to more than 100 feet near the major pumping centers in the coastal part of the study area; (2) an increase or decrease in head differences between the surficial and Floridan aquifers, thereby increasing recharge to and decreasing natural discharge from the Floridan aquifer; and (3) an increase in ground-water inflow to the area and a reversal or modification of the natural hydraulic gradient of the potentiometric surface toward the east. There is also an increase in the initial head differences among the water-bearing zones of the aquifer, thereby increasing leakage from deeper zones of higher artesian heads to the upper zone.

The water quality in the upper water-bearing zone is fairly uniform: concentrations of dissolved solids generally range from 400 to 600 milligrams per liter, chloride 20 to 40 milligrams per liter, and sulfate 100 to 190 milligrams per liter. In Fernandina Beach, water from four wells tapping this zone has relatively high chloride concentrations, as great as 190 milligrams per liter. Based on existing water-quality data, there is no evidence of saline water intrusion in the upper water-bearing zone of the Floridan aquifer in the study area. In Fernandina Beach, water in the middle zone is more mineralized than water in the upper zone. Chloride concentrations of water from several wells more than 1,250 feet deep increased from less than 100 to more than 1,000 milligrams per liter since 1952.

Future development of the Floridan aquifer within the study area, in particular the coastal part, may be limited to the upper water-bearing zone. The presence of relatively high chloride concentrations of water from wells tapping the middle and lower zones in the coastal area limits the development of these zones as a freshwater supply. Existing development of the aquifer along the coast and the resulting declines in the potentiometric surface may restrict the amount of future development from the upper zone. In the western part of the study area, little is known about the hydrogeology of the middle and lower zones and these zones may be a potential source of freshwater.

The effects of future development on the water levels of the upper water-bearing zone were estimated based on a mathematical model. Steady-state drawdowns would be about 1.24 feet at 10,000 feet and 0.3 feet at 50,000 feet from a pumping well per 1 million gallons per day increase in pumpage. Assuming a 50 percent increase in pumpage at each of the major pumping centers from 82 to 123 million gallons per day within the study area, the net decline in water levels in observation wells about 5 to 10 miles from the pumping centers were 9.9 to 17.4 feet. About 30 miles offshore, west of the inferred position of the freshwater-saltwater interface, the net decline was only 2 feet.

The surficial aquifer, consisting of thin permeable zones of sand, shell, and limestone, provides water to wells at rates of 10-50 gallons per minute, but is not considered a source for large ground-water supplies. The estimated transmissivity ranges from less than 100 feet squared per day for the fine-grained, well-sorted sand to 10,000 feet squared per day for the sand and shell beds. Water is generally of acceptable quality for most uses except near the coast and tide-affected streams that contain saltwater.

## INTRODUCTION

The primary source of water supply in Nassau County, Fla., and Camden County, Ga., is the Floridan (principal artesian) aquifer, an excellent aquifer with several water-bearing zones. Significant withdrawals began in 1939, principally for industrial supply with minor amounts for other uses. Industrial use in 1940 was 30 Mgal/d and increased to about 80 Mgal/d by 1962. Since about 1962, withdrawals of water from this aquifer have remained constant at about 55 Mgal/d at Fernandina Beach, Nassau County and increased from about 20 to 40 Mgal/d at St. Marys, Camden County. As a result, artesian pressure in the aquifer has declined in an area of more than 200 $mi^2$. The decline near the center of pumpage is more than 120 feet below the estimated artesian pressure in 1880 prior to development of the aquifer (Stringfield and others, 1941).

Increased salinity has been observed in water from a few wells in the area. The increase has been most pronounced in the deeper wells below 1,200 feet in depth near the center of pumpage (Fairchild and Bentley, 1977).

## Purpose and Scope

To determine the overall effects of continued withdrawals of ground water in eastern Nassau County, Fla. and southeastern Camden County, Ga., the U.S. Geological Survey in cooperation with the Ocean, Highway and Port Authority of Nassau County, Fla., conducted an investigation of the ground-water resources. The purpose of the investigation was to provide water users with data necessary for the prudent use and protection of the resource, and to appraise sources of ground-water supplies that may be utilized in the future. Major emphasis of the investigation was placed in areas of largest ground-water withdrawal, Fernandina Beach, Fla. and St. Marys, Ga.

Specific objectives were to determine: (1) the amount, extent, rate, and source of water-quality changes in the Floridan aquifer, especially in the upper zone (Ocala Limestone); (2) the effects of future ground-water development on the water quality and water levels of the Floridan aquifer; (3) the maximum possible pumpage rate that will not cause significant water-quality deterioration in the upper zone of the Floridan aquifer; and (4) the availability of other sources of ground-water supplies.

The investigation, completed in 1980, is summarized in this report. The report presents information on the geology and hydrology of the study area. Major consideration was given to the principal aquifer in the area, the Floridan aquifer. The report presents and interprets information on the physical characteristics of the Floridan aquifer, the chemical quality of water in the aquifer, and the quality and quantity of saline water in the deeper water-bearing zones of the aquifer. The hydrogeology and water quality of the overlying surficial aquifer was also investigated. This aquifer can be an important source of water for recharge to the Floridan aquifer. Also, locally, the surficial aquifer can be an alternative source of water for rural domestic and small public supply.

Information presented in this report was obtained from data collected during this investigation, unpublished data on file with the U.S. Geological Survey, and published reports. Table 1 lists wells and gives pertinent data on wells in which current and historical data were collected. The location of the wells is shown on figure 1.

## Previous Investigations

Water-level and water-quality records have been collected in southeast Georgia and northeast Florida since 1936. The geology and the occurrence of ground water have been described by Sellards and Gunter (1910); Matson and Sanford (1913), Stringfield (1936); Stringfield and others (1941); Cole (1944); Cooper (1944); Cooke (1945); Vernon (1951); Cooper and others (1953); Stewart and Counts (1958); Stewart and Croft (1960); and Leve (1961a; 1961b). Detailed investigations of the geology and occurrence of ground water of Nassau County were made by Leve (1966) and Fairchild and Bentley (1977).

Table 1.--Record of wells

| Local well no. | Latitude-Longitude | Depth (ft) | Cased (ft) | Use | Owner | Date drilled | Remarks |
|---|---|---|---|---|---|---|---|
| | | | | Surficial aquifer | | | |
| NS-2 | 3040550812720.01 | 93 | 85 | Unused | Container Corporation of America | -- | -- |
| NS-7 | 3037020814302.01 | 65 | -- | Domestic | W. F. Nessler | 1964 | |
| NS-8 | 3038000812801.01 | 100 | -- | do. | B. Thornton | 1950 | -- |
| NS-9 | 3038040813615.01 | 146 | -- | do. | J. L. Koen | 1956 | -- |
| NS-14 | 3035070813032.01 | 65 | 65 | do. | C. L. Lasserre | -- | -- |
| NS-15 | 3044240814115.01 | 100 | -- | do. | K. H. Olfort | 1952 | -- |
| NCS-0 | 3040420812725.01 | 100 | -- | Industrial | Container Corporation of America | -- | -- |
| NCS-10 | 3040410812710.01 | 100 | -- | do. | do. | -- | -- |
| SJ-6 | | 75 | -- | Domestic | Cook, Nassau County | -- | (From Frazee and McClaugherty, 1980) No. 20 |
| SJ-20 | 3040000813800.01 | 54 | 46 | Observation | St. Johns River Water Management District | -- | |
| CS-1 | 3058090814343.01 | 26 | 18 | Domestic | F. Hamilton | -- | -- |
| CS-2 | 3047390814137.01 | 75 | 75 | Industrial | Standard Oil, Kingsland | -- | -- |
| DS-34 | 3031250813715.01 | 100 | -- | Public supply irrigation | Church | 1965 | -- |
| DS-82 | 3035560813645.01 | 95 | -- | Domestic | J. Sullivan | 1954 | -- |
| DS-44 | 3030220813937.01 | 89 | -- | Unused | City of Jacksonville | -- | -- |
| WT-24 | 3030430813722.01 | 10 | 8 | Observation | U.S. Geological Survey | 1972 | -- |
| | | | | Floridan aquifer | | | |
| | | | | Duval County | | | |
| D-77 | 3030150813433.01 | 706 | 466 | Public supply | V. W. L. Crop | 1969 | -- |
| D-401 | 3032160814333.01 | -- | -- | do. | Duval County | -- | -- |
| D-411 | 3034580813640.01 | 1,000 | -- | Domestic | R. L. Wise | 1955 | -- |
| D-578 | 3032440814343.01 | 450 | -- | Stock watering | City of Jacksonville | 1960 | -- |
| D-753 | 3031040812844.01 | 600 | 500 | Domestic | I. M. Thompson | 1974 | -- |

Table 1.--Record of wells--Continued

| Local well no. | Latitude-Longitude | Depth (ft) | Cased (ft) | Use | Owner | Date drilled | Remarks |
|---|---|---|---|---|---|---|---|
| | | | | **Floridan aquifer** | | | |
| | | | | Nassau County | | | |
| N-2 | 3035190812753.01 | 580 | 350 | Domestic | Gerbin | 1932 | -- |
| N-7 | 3040200812720.01 | 1,215 | 545 | Public supply | Florida Public Utilities | 1971 | Well No. 8 |
| N-8 | 3032440812637.01 | 680 | -- | Unused | Amelia Island | 1937 | -- |
| N-9 | 3034570812715.01 | 586 | -- | Domestic | Morse | 1930 | -- |
| N-12 | 3038010812737.01 | 640 | -- | do. | Sheffield | 1938 | -- |
| N-16 | 3038200812615.01 | 630 | -- | Unused | Davis | 1934 | -- |
| N-19 | 3042130812708.01 | 710 | -- | Observation | State of Florida | -- | -- |
| N-20 | 3039390813126.01 | 567 | -- | Unused | Metz | -- | -- |
| N-22 | 3039400812818.01 | 1,100 | 553 | Industrial | ITT Rayonier | 1962 | -- |
| N-24A | 3040200812720.01 | 1,100 | -- | Public Supply | Florida Public Utilities | -- | Depth may be 1,215 ft. |
| N-28 | 3037430812900.01 | 578 | -- | Domestic | State of Florida Road Department | 1927 | -- |
| N-30 | 3039210812746.01 | 750 | -- | Public Supply | Florida Public Utilities | 1937 | -- |
| N-31 | 3038120812737.01 | 1,000 | 560 | Industrial | ITT Rayonier | 1964 | ITT No. 12 |
| N-32 | 3038360812742.01 | 1,070 | 557 | do. | do. | 1948 | ITT No. 9 |
| N-33 | 3040220812750.01 | -- | -- | Unused | Chadwick | 1925 | -- |
| N-35 | 3039350812837.01 | 1,062 | 560 | Industrial | ITT Rayonier | 1965 | ITT No. 13 |
| N-37 | 3040510812736.01 | 1,250 | 550 | Destroyed | Container Corporation of America | 1950 | Container No. 3 |
| N-38 | 3041400812732.01 | 500 | -- | Industrial | Smith Fishmeal | 1930 | -- |
| N-38A | 3041360812733.01 | 600 | -- | do. | do. | -- | -- |
| N-39 | 3039470812754.01 | 1,100 | 535 | do. | ITT Rayonier | 1937 | ITT No. 1 |
| N-39D | 3039470812754.02 | 1,700 | 535 | do. | do. | 1951 | ITT No. 1 deepened to 1,700 ft. |

Table 1.--Record of wells--Continued

| Local well no. | Latitude-Longitude | Depth (ft) | Cased (ft) | Use | Owner | Date drilled | Remarks |
|---|---|---|---|---|---|---|---|
| N-40 | 3039420812814.01 | 1,054 | 549 | Industrial | ITT Rayonier | 1938 | ITT No. 2, plugged in 1962 |
| N-41 | 3039330812746.01 | 1,072 | 546 | do. | do. | 1938 | ITT No. 3 |
| N-41D | 3039330812746.02 | 1,840 | 546 | do. | do. | 1946 | ITT No. 3 deepened to 1,840 ft. |
| N-42 | 3039370812824.01 | 1,055 | 550 | do. | do. | 1938 | ITT No. 4, abandoned & plugged in 1965 |
| N-43 | 3039020812739.01 | 1,055 | 546 | do. | do. | 1938 | ITT No. 5 |
| N-43D | 3039020812739.02 | 1,820 | 546 | do. | do. | 1946 | ITT No. 5, deepened to 1,820 ft. |
| N-44 | 3037540813627.01 | 1,000 | 450 | Domestic | Seaboard System Railroad | -- | -- |
| N-45 | 3039450813125.01 | 500 | -- | do. | Sether | 1938 | -- |
| N-46 | 3034350812714.01 | 1,016 | 492 | Public Supply | Amelia Island | 1971 | -- |
| N-47 | 3040410812705.01 | 1,260 | 555 | Industrial | Container Corporation of America | 1951 | Container No. 4 |
| N-50 | 3036580814226.01 | 569 | -- | Irrigation | Fingar | 1938 | -- |
| N-53 | 3040180813828.01 | 500 | -- | Domestic | ITT Rayonier | 1936 | -- |
| N-54 | 3037220812954.01 | 482 | -- | Unused | -- | -- | -- |
| N-56 | 3040280812721.01 | 976 | 580 | Observation | -- | 1974 | Container No. 11 |
| N-57 | 3035220813514.01 | 550 | -- | Domestic | Buckner | 1975 | -- |
| N-58 | 3038400812735.01 | 1,000 | 546 | Industrial | ITT Rayonier | 1940 | ITT No. 6 |

Table 1.--Record of wells--Continued

| Local well no. | Latitude-Longitude | Depth (ft) | Cased (ft) | Use | Owner | Date drilled | Remarks |
|---|---|---|---|---|---|---|---|
| N-60 | 3039400812857.01 | 1,065 | 550 | Industrial | ITT Rayonier | 1942 | ITT No. 7 |
| N-62 | 3038230812733.01 | 2,130 | 600 | do. | do. | 1945 | Exploratory well ITT No. 8 |
| N-62D | 3038230812733.02 | 1,826 | 600 | do. | do. | -- | ITT No. 8 plugged back to 1,826 ft. in 1946 |
| N-62DD | 3038230812733.03 | 1,100 | 600 | do. | do. | -- | ITT No. 8 plugged back to 1,100 ft. in 1962 |
| N-65 | 3040410812705.02 | 1,060 | 550 | do. | Container Corporation of America | 1967 | Container No. 9 |
| N-66 | 3041030812700.02 | 1,000 | 570 | do. | do. | 1955 | Container No. 10 |
| N-67 | 3043170813723.01 | -- | -- | Recreation | ITT Rayonier | -- | -- |
| N-68 | 3039580812804.01 | 1,050 | 560 | Industrial | do. | 1970 | ITT No. 14 |
| N-69 | 3040530812725.01 | 1,161 | 550 | do. | Container Corporation of America | 1962 | Container No. 7 |
| N-70 | 3042040812727.01 | 660 | -- | Unused | State of Florida | -- | Ft. Clinch |
| N-72 | 3035570812710.01 | 610 | -- | Irrigation | Fernandina Beach | -- | -- |
| N-73 | 3038180812646.01 | 1,200 | -- | Public Supply | Florida Public Utilities | -- | No. 6 |
| N-74 | 3038180812650.01 | 1,200 | -- | do. | do. | -- | No. 7 |
| N-76 | 3031190812649.01 | -- | -- | do. | State of Florida | -- | -- |
| N-82 | 3041090812655.01 | 1,404 | 550 | Industrial | Container Corporation of America | 1955 | Container No. 5 |
| N-82D | 3041090812655.02 | 1,032 | 550 | Observation | do. | -- | No. 5 plugged back to 1,032 ft. in 1975 |
| N-83 | 3040200812720.03 | 1,205 | 550 | Public Supply | Florida Public Utilities | -- | No. 5 |

Table 1.--Record of wells--Continued

| Local well no. | Latitude-Longitude | Depth (ft) | Cased (ft) | Use | Owner | Date drilled | Remarks |
|---|---|---|---|---|---|---|---|
| N-87 | 3040200812720.01 | 731 | -- | Public Supply | Florida Public Utilities | -- | No. 3, N-24C |
| N-88 | 3041030812700.01 | 1,140 | 580 | Industrial | Container Corporation of America | 1950 | Container No. 2 |
| N-88D | 3041030812700.02 | 2,105 | 1,450 | Destroyed | do. | 1959 | No. 2 deepened to 2,105 ft. in 1959 |
| N-90 | 3040550812720.01 | 895 | 610 | Abandoned | do. | 1937 | Container No. 1 |
| N-92 | 3041280812733.01 | 500 | -- | Unused | Menhaden Company | -- | -- |
| N-96 | 3043150813712.01 | -- | -- | Domestic | ITT Rayonier | -- | -- |
| N-97 | 3034300813626.01 | 600 | -- | do. | Higgenbogen | -- | -- |
| N-100 | 3034030813113.01 | 672 | -- | Unused | Wilder | 1920 | -- |
| N-102 | 3036550812654.01 | 800 | -- | Irrigation | Fernandina Beach | 1963 | -- |
| N-106 | 3038050812739.01 | 1,101 | 568 | Unused | ITT Rayonier | 1951 | ITT No. 10 |
| N-110 | 3041100812720.01 | 1,408 | 550 | Industrial | Container Corporation of America | 1955 | Container No. 6 |
| N-110D | 3041100812720.02 | 1,250 | 550 | do. | do. | -- | No. 6 plugged back to 1,250 ft. in 1965 |
| N-110DD | 3041100812720.03 | 1,076 | 550 | do. | do. | -- | No. 6 plugged back to 1,076 ft. in 1976 |
| N-111 | 3040580812730.01 | 1,237 | 568 | Destroyed | do. | 1964 | Container No. 8 (old) |
| N-111D | 3040580812730.02 | 1,019 | 550 | Industrial | do. | 1974 | Container No. 8 (new) |
| N-112 | 3039570812555.01 | -- | -- | Unused | Fletcher | -- | -- |
| N-113 | 3033280812703.01 | 1,016 | 509 | Irrigation | Amelia Island | 1971 | -- |
| N-117 | 3040010812803.01 | 2,102 | 2,000 | Observation | U.S. Geological Survey | 1979 | Test-monitor well |
| N-120 | 3040570812710.01 | 952 | 550 | Industrial | Container Corporation | 1978 | Container No. 12 |

Table 1.--Record of wells--Continued

| Local well no. | Latitude-Longitude | Depth (ft) | Cased (ft) | Use | Owner | Date drilled | Remarks |
|---|---|---|---|---|---|---|---|
| | | | | Camden County | | | |
| C-1 | 3047580813105.01 | 525 | 320 | Observation | U.S. Navy | 1968 | -- |
| C-2 | 3046270813712.01 | 474 | 80 | Unused | ITT Rayonier | 1930 | -- |
| C-3 | 3043480813239.01 | 600 | 400 | Unused | J. Kennedy | -- | -- |
| C-4 | 3047390813431.01 | 894 | 590 | Fire Protection | U.S. Navy | 1955 | -- |
| C-5 | 3047530814125.01 | 548 | 446 | Public Supply | Kingland | 1938 | -- |
| C-6 | 3055420814224.01 | 566 | 472 | Domestic | L. E. Johnson | -- | -- |
| C-7 | 3058040814413.01 | 877 | 399 | do. | H. Williams | -- | -- |
| C-8 | 3047560813111.01 | 990 | 555 | Observation | U.S. Geological Survey | 1979 | Test well |
| C-9 | 3049100813238.01 | -- | -- | -- | E. Park | -- | -- |
| C-10 | 3050310813427.01 | 650 | 450 | Domestic | M. F. Tapley | 1961 | -- |
| C-11 | 3045100813438.01 | 770 | -- | do. | G. H. Davis | 1964 | -- |
| C-12 | 3045140813902.01 | -- | -- | Public Supply | State of Georgia | -- | -- |
| C-13 | 3058150814330.01 | -- | -- | -- | W. Briese | -- | -- |
| C-14 | 3048040814054.01 | 516 | 466 | Domestic | E. Gross | 1968 | -- |
| C-15 | 3049210814356.01 | -- | -- | -- | B & S Chicken | -- | -- |
| C-16 | 3045220812817.01 | 645 | 552 | Observation | National Park Service | -- | GGS3426 |
| C-17 | 3046170812806.01 | -- | -- | Domestic | Rockefeller | -- | -- |
| C-18 | 3046460812807.01 | 730 | 538 | do. | Greyfield | 1931 | -- |
| C-19 | 3050170812801.01 | -- | -- | do. | -- | -- | -- |
| C-20 | 3051220812756.01 | -- | -- | Unused | National Park Service | -- | -- |
| C-21 | 3051220812756.02 | -- | -- | do. | do. | -- | -- |
| C-22 | 3051440812553.01 | -- | -- | Domestic | do. | -- | -- |
| SM-1 | 3044110813232.01 | 1,063 | 516 | Unused | Gillman Paper Company | 1941 | GP Co. No. 1 |
| SM-4 | 3044000813232.01 | 1,220 | 519 | Industrial | do. | 1953 | GP Co. No. 4 |
| SM-5 | 3044110813319.01 | 1,215 | 529 | do. | do. | 1953 | GP Co. No. 5 |
| SM-6 | 3044140813325.01 | 1,259 | 520 | do. | do. | 1956 | GP Co. No. 6 |
| SM-7 | 3044080813233.01 | 1,041 | 530 | Unused | do. | 1960 | GP Co. No. 7 |
| SM-8 | 3044160813236.01 | 1,199 | 556 | Industrial | do. | 1963 | GP Co. No. 8 |
| SM-9 | 3044080813234.01 | 1,041 | 530 | do. | do. | 1970 | GP Co. No. 9 |

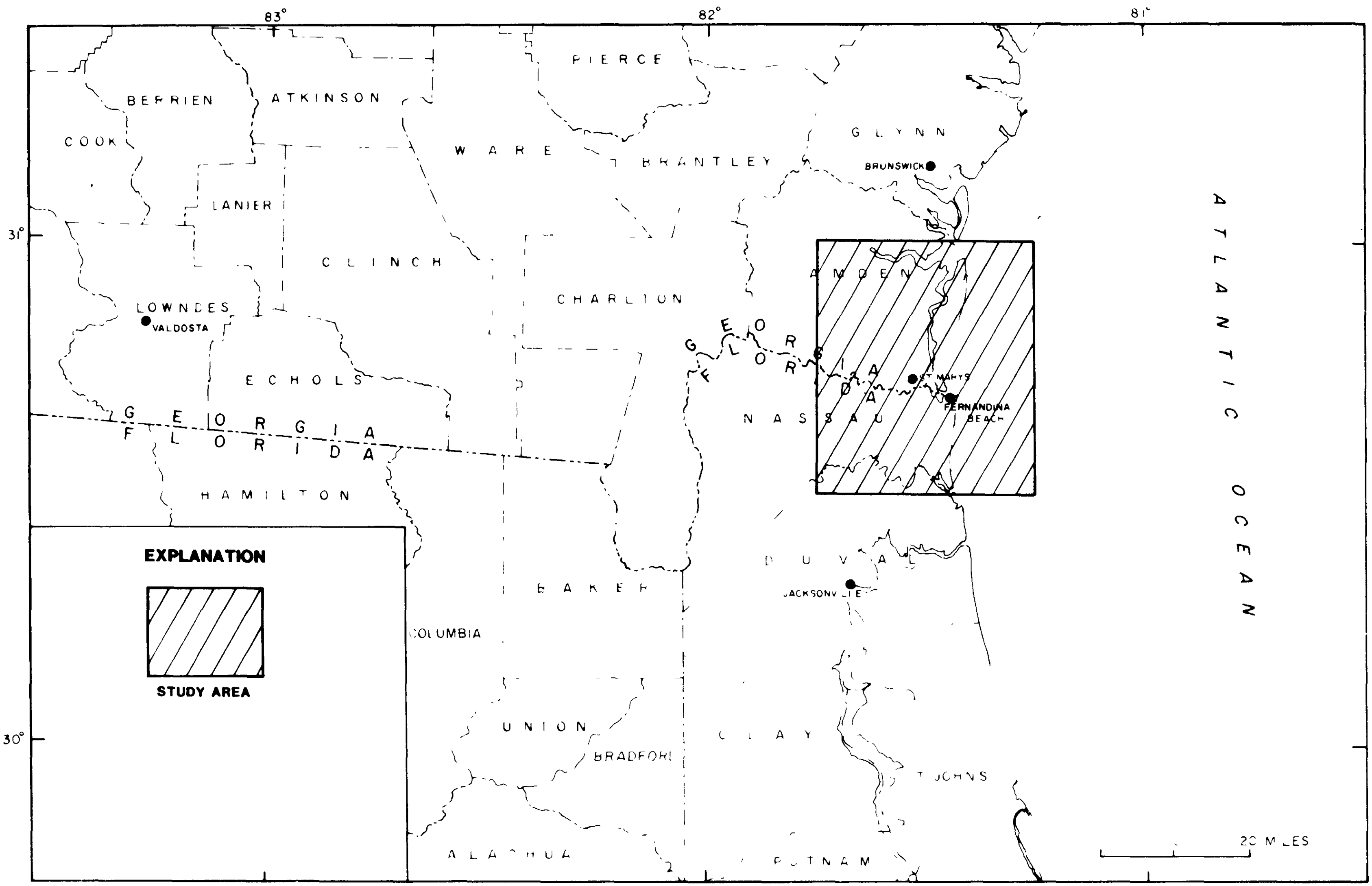



Figure 1.--Location, topography, and drainage of the study area and location of wells.

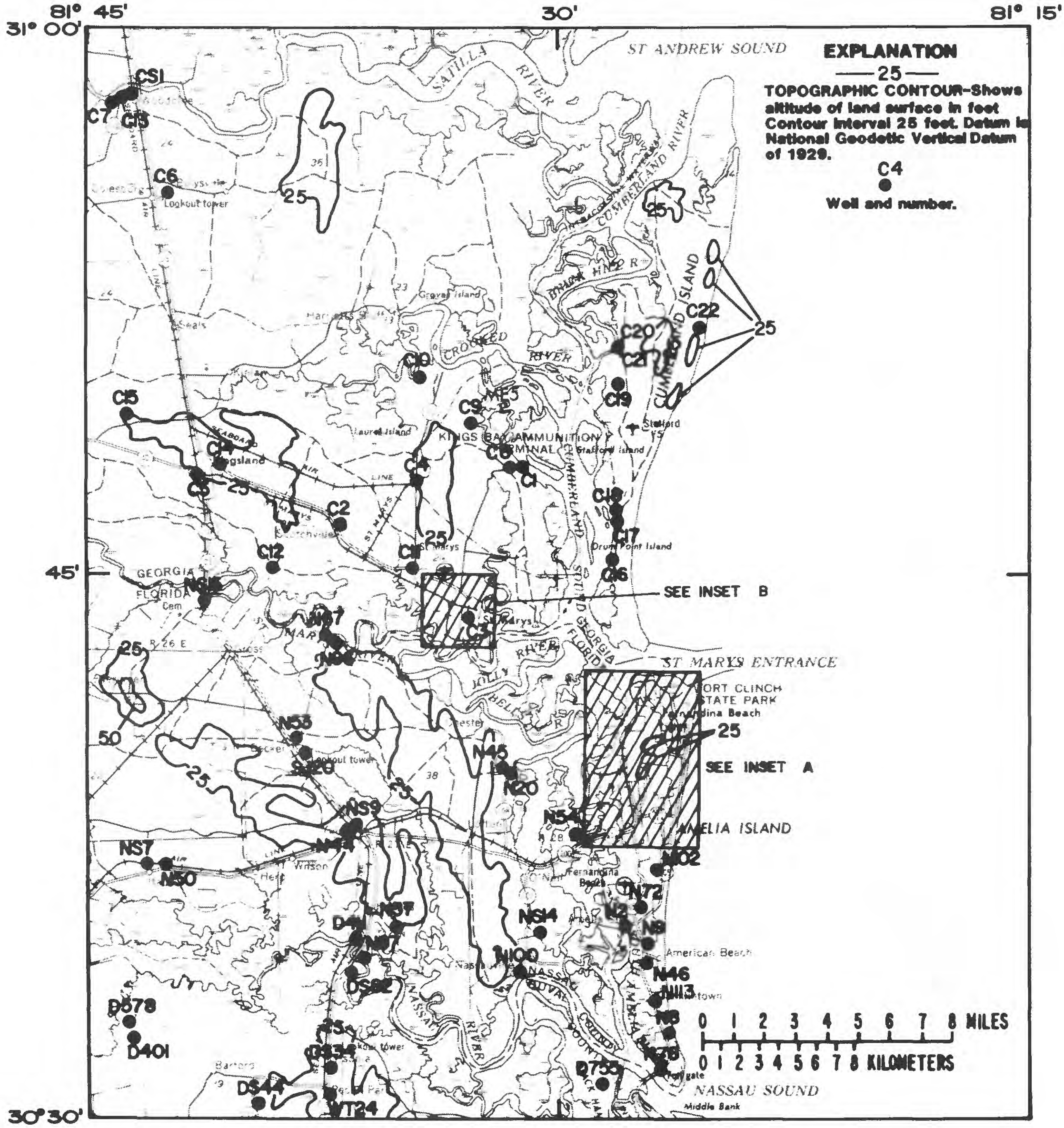



Figure 1.--Location, topography, and drainage of the study area and location of wells.--Continued

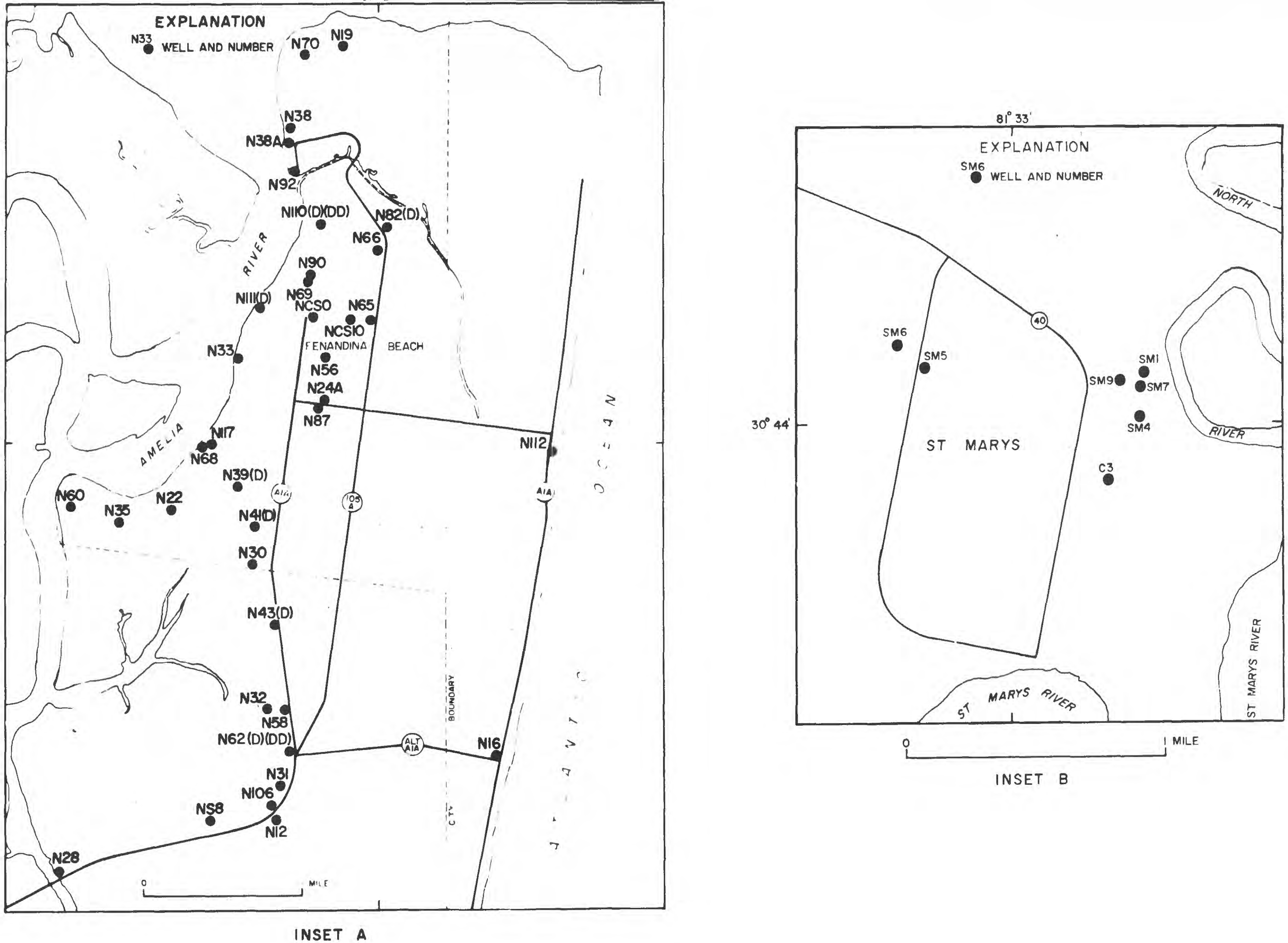



Figure 1.--Location, topography, and drainage of the study area and location of wells.--Continued

Extensive historical records on well construction, well reworking, plugging, pumping rates, water levels, and water quality were tabulated for two industrial well fields at Fernandina Beach by Duncan (written commun., 1978) and R. W. Harden and Associates (written commun., 1978). A detailed investigation of water quality variations in an industrial well field in north Fernandina Beach was made by R. W. Harden and Associates (1979).

## Acknowledgments

The author wishes to express his appreciation to E. E. Lasserre, Chairman, and members of the Ocean, Highway and Port Authority, Nassau County for their support during this investigation. The author gratefully acknowledges the valuable assistance provided by Richard Hopper, Jerry Ford, Marian Marshman, and Harry Mills of ITT Rayonier, Inc.; A. D. Harris, M. Kendrick, and Jan Bray of Container Corporation of America; staff members of Florida Public Utilities; and staff members of Gillman Paper Company; all of whom provided valuable data and either permitted or assisted in conducting tests, sampling, and measuring wells.

Particular acknowledgment is given to R. W. Harden, R. W. Harden and Associates, and to James Frazee, Jr., St. Johns River Water Management District, for data provided.

Appreciation is expressed to the many residents in the area who permitted access to their properties and allowed the sampling of water and measuring of water levels in their wells.

# DESCRIPTION OF STUDY AREA

The study area, about 1,100 $mi^2$, is in northeastern Florida and southeastern Georgia (fig. 1). The study area extends from latitude 30°30'N northward into southeastern Georgia and from longitude 81°45'E eastward into the Atlantic Ocean. It includes eastern Nassau County and northern Duval County, Fla., and the southeastern part of Camden County, Ga.

In 1980, the population of Nassau County and Camden County was 32,894 and 16,779, respectively. Nearly 40 percent of the population is located in incorporated areas, generally along the coast. Fernandina Beach in Nassau County and St. Marys in Camden County are the principal cities in the area. The population of the counties is expected to double by the year 2000.

## Physiography

The study area is in the Coastal Lowlands physiographic division (Puri and Vernon, 1964). The topography of the area is largely controlled by a series of ancient marine terraces (Cooke, 1945; Leve, 1966; and Healy, 1975a) which were formed during Pleistocene time when the sea stood above its present level. Erosional processes have modified and obscured the remnants of these terraces. Altitude of land surface range from sea level along the coast to about 50 feet near the western edge of the study area. The land surface generally is less than 25 feet above sea level level (fig. 1).

Surface drainage is principally through the Nassau, St. Marys, and Satilla Rivers and their tributaries. Much of the coastal area is drained by numerous small brackish-water streams that flow into the Intracoastal Waterway or into the ocean. Large parts of the area, generally associated with the relatively flat terraces, are poorly drained and contain numerous small shallow lakes and swamps.

The average annual runoff of streams in the area ranges from about 10 to 20 inches. The average annual runoff for the St. Marys River Basin is about 10 to 15 inches and for the coastal area between the St. Marys and St. Johns River, which includes the Nassau River, about 15 to 20 inches (Hughes, 1978).

## Climate

The climate of the area is humid subtropical and is characterized by long, warm, relatively wet summers and mild, relatively dry winters. The mean annual rainfall for the area ranges from less than 52 inches to about 54 inches. At Fernandina Beach, the mean annual rainfall for the period 1947 to 1976 was about 53 inches and ranged from about 40 to 76 inches (St. Johns River Water Management District, 1977).

About 60 percent of the annual rainfall occurs from June through September, usually as showers of short duration and thunderstorms. Normal rainfall during this period ranges from about 6 to 8 inches per month. The relatively dry season occurs from October to May, when normal rainfall ranges from about 2 to 4 inches per month, and is usually associated with frontal activity.

The evapotranspiration within the area is estimated at 30 to 40 inches per year, with almost 60 percent occurring from April through September (Fairchild, 1972; St. Johns River Water Management District, 1977; Miller and others, 1978).

# HYDROGEOLOGIC FRAMEWORK

The geology of northeast Florida and southeastern Georgia is discussed in detail by Cooke (1945), Herrick and Vorhis (1963), Puri and Vernon (1964), Leve (1966), Stringfield (1966), and Cramer and Arden (1980). The geology of the area is summarized in table 2 and in the geologic section in figure 2.

The aquifer system considered here ranges in age from Paleocene to Holocene. Older rocks are not discussed. Miocene and younger sediments consist mostly of sand and clay (fig. 3), which contain water in pore spaces. Paleocene, Eocene, Oligocene where present, and some Miocene sediments are limestone and dolomite where water occurs and moves principally in bedding and cross joints, and interconnected pore spaces commonly enlarged by ground-water solution. Some of the limestone units, especially in the Ocala Limestone of late Eocene age, are granular and bioclastic, and owe their high permeability mainly to high primary porosity.

Table 2.--Generalized hydrogeology of the study area

| Geologic age | Stratigraphy | Approximate thickness (ft) | Lithology | Hydrogeologic unit | Hydrologic properties |
|---|---|---|---|---|---|
| Holocene to Pliocene | Undifferentiated surficial deposits | 100 | Discontinuous sand, clay, and shell beds | Surficial aquifer | Sand and shell deposits provide local limited water supplies |
| Miocene | Hawthorn Formation | 400 | Interbedded phosphatic sand, clay, marl, and limestone | Upper Confining Unit | Sand, shell, and limestone deposits provide local limited water supplies, both artesian and non-artesian. Low permeability clays serve as the principal confining beds for the Floridan aquifer below. |
| Eocene — Upper | Ocala Limestone[a] | 350 | Massive fossiliferous chalky to granular marine limestone sequence | Floridan aquifer (principal artesian): Upper Water-bearing zone | Principal source of ground water. High permeability overall. |
| Eocene — Middle | Claibornian: Avon Park Limestone | 100 | Alternating beds of massive granular and chalky limestones, and dense dolomites | Floridan aquifer (principal artesian): Upper Semiconfining zone | Low permeability limestone and dolomite. |
| Eocene — Middle | Claibornian: Lake City Limestone | 500 | | Floridan aquifer (principal artesian): Middle Water-bearing zone | Principal source of ground water. |
| Eocene — Lower | Oldsmar Limestone | 700 | | Floridan aquifer (principal artesian): Lower Semiconfining zone | Low permeability limestone and dolomite. |
| | | | | Floridan aquifer (principal artesian): Lower Water-bearing zone | Highly permeable, increases in salinity noted. |
| Paleocene | Cedar Keys Limestone | ? | Uppermost appearance of evaporites; dense limestones | Lower Confining unit | Highly mineralized water, very low permeability. |

[a]May include some Suwannee Limestone of Oligocene age.

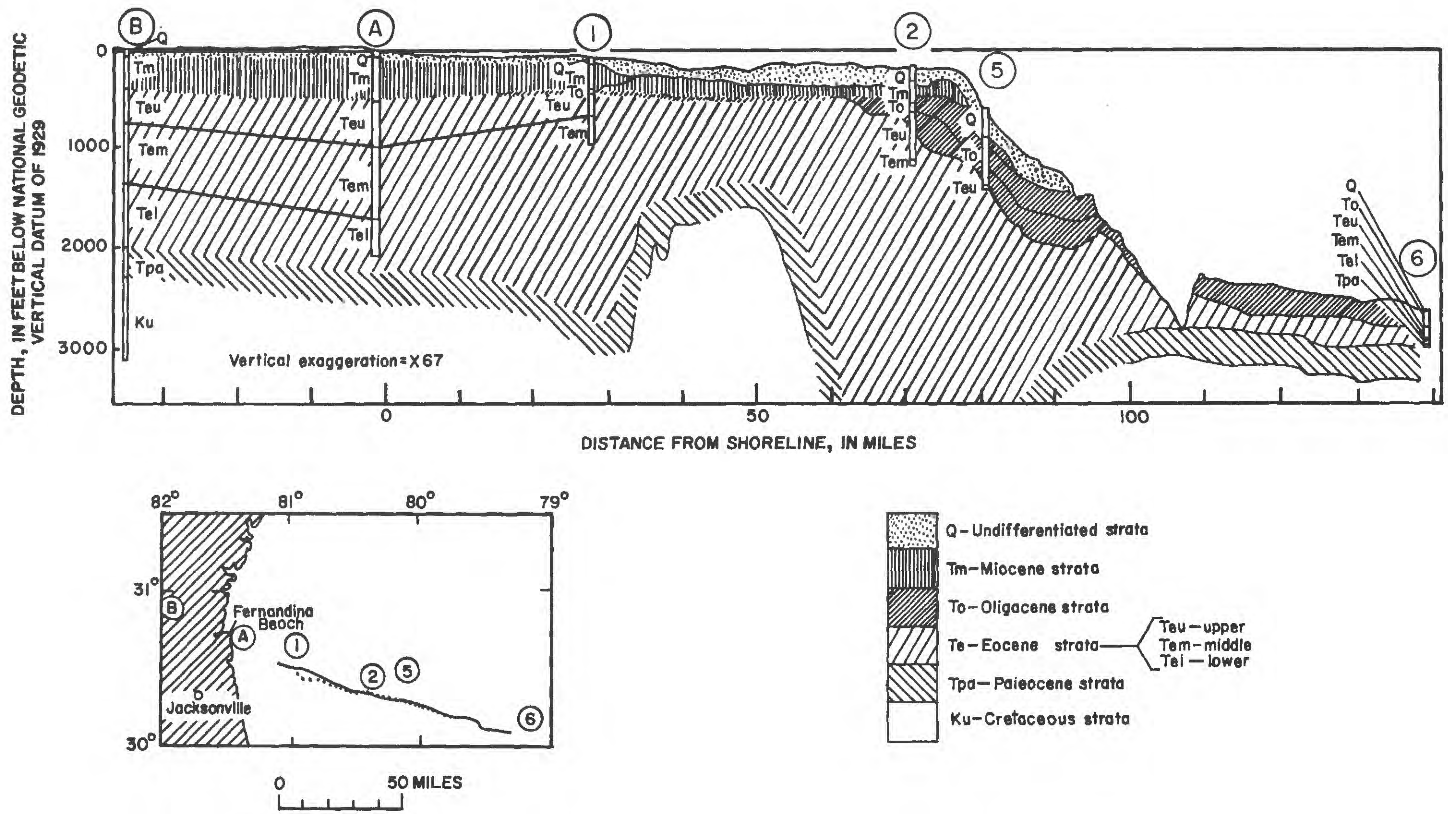



Figure 2.--Geologic section (from Emery and Zarudzki, 1967).

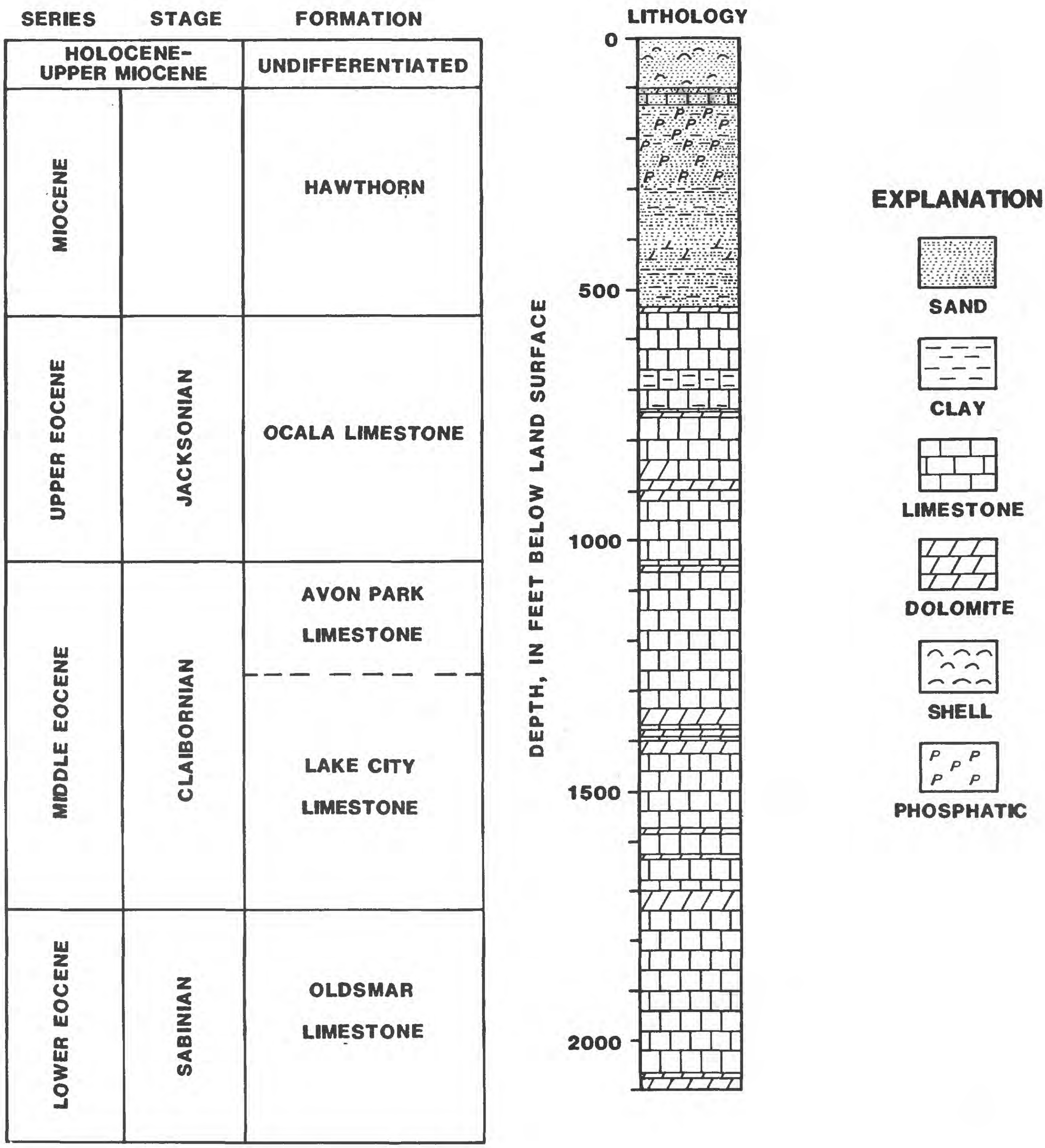



Figure 3.--Generalized geologic column showing formations penetrated by wells in the study area and lithology.

The stratigraphic section slopes and thickens gently to the east and northeast from the crest of an anticlinal structural high named the Peninsular Arch (Applin, 1951, p. 3). This northwest-trending structure in central Florida and southern Georgia affected the thickness and type of sediments in northern Florida from early Mesozoic until middle Late Cretaceous time. The Ocala Uplift which occurred later is parallel to and southwest of the Peninsular Arch. It affected the thickness and deposition of middle Eocene and younger sediments. In northeastern Florida and southeastern Georgia, a thick sequence of Mesozoic and Cenozoic deposits occur in a northeast plunging syncline called the Southeast Georgia Basin, which was the site of more or less continuous deposition since Jurassic time (Murray, 1961, p. 96-97; Miller and others, 1978, p. 14).

From aerial photographs, Vernon (1951, p. 48 and fig. 11) mapped a pattern of fractures and possible faults in northeastern Florida. The fractures consist of a primary set, trending northwest and a secondary set, trending northeast.

Leve (1978) showed two generally northward-trending inferred faults in central Duval County, Fla., that formed a graben with a maximum vertical displacement of more than 150 feet. The northern extent of the faults is not known. Gregg and Zimmerman (1974) showed two inferred faults in Brunswick, Ga., and three hypothetical faults nearby, and indicated that the displacement along these inferred faults could be as much as 50 feet. Several of the faults trend northward and form horsts and grabens.

## GROUND WATER

Most stratigraphic units in the area yield some water to wells, but their water-bearing characteristics differ considerably. Units have been classified hydrologically as aquifers or confining beds. An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. In the area, two aquifers have been recognized: (1) the surficial aquifer, and (2) the Floridan (principal artesian) aquifer.

An extensive confining unit separates the surficial and Floridan aquifers. This confining bed yields little water to wells and retards inter-aquifer ground-water flow. However, this confining bed does transmit, or leak, some water from one aquifer to another. Confining beds also occur within the Floridan aquifer and locally divide the aquifer into discrete water-bearing zones.

Table 2 presents the major hydrologic units underlying the study area and their stratigraphic equivalent.

Certain water-bearing properties, such as the transmissivity and the storage coefficient, can be estimated by comparing the type of material comprising the aquifer with laboratory measurements of hydraulic conductivity, and specific-yeild, and aquifer tests run on similar materials in nearby areas. Hydraulic conductivity is the volume of water that will move, in unit time, under a unit hydraulic gradient through a unit area of aquifer measured at right angles to the direction of flow. Transmissivity is the rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient and is equivalent to the hydraulic conductivity multiplied by the thickness of the aquifer. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in static head. Specific yield is the ratio of volume of water that will drain by gravity from a saturated rock or soil to the volume of rock or soil.

## Ground-Water Withdrawal

The principal source of ground water is the Floridan aquifer. The aquifer supplies all the ground water used for industrial and public supply and an undetermined amount of the rural supply. Small amounts of ground water are withdrawn from the surficial aquifer, primarily from a shallow rock zone, for rural domestic supply.

More than 90 percent of the ground water is used for industrial purposes: the remainder is for public and rural domestic supply. Little water is used for agricultural irrigation or livestock supply.

Prior to 1938, ground-water withdrawal in Fernandina Beach and St. Marys was less than 0.5 Mgal/d. Pumpage increased to about 3.5 Mgal/d between January 1, 1939 and December 1, 1939. After December 1, 1939, pumpage increased to more than 30 Mgal/d (Cooper and Warren, 1945). In 1970, ground-water use was about 54 Mgal/d in Nassau County, Fla. and by 1977, ground-water use increased some 20 percent to about 65 Mgal/d (table 3). In Camden County, Ga., ground-water use was 32 Mgal/d in 1970 and increased to 40 Mgal/d in 1977. In 1980, it decreased to about 54 Mgal/d in Nassau County and 37 Mgal/d in Camden County.

Ground-water withdrawal in Nassau County is concentrated in Fernandina Beach, which accounted for 89 percent of the total water used in 1980; in Camden County, withdrawal is concentrated in St. Marys which used about 98 percent of the water in 1980. Other important centers of pumpage adjacent to the study area include Jacksonville, Fla. and Brunswick, Ga. with average withdrawal rates of 200 and 105 Mgal/d, respectively (Johnston, 1978).

Table 3.--Ground-water use in Nassau County, Florida and Camden County, Georgia

[In million gallons per day]

| Year | Public supply: Population served (thousands) | Public supply: Use | Industrial self-supplied[1] | Irrigation: Acres | Irrigation: Use | County self-supplies: Population served (thousands) | County self-supplies: Domestic | County self-supplies: Livestock | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Nassau County | | | | | |
| [a]1970 | 8.9 | 2.0 | 50.0 | 0 | 0 | 11.7 | 1.4 | .22 | -- |
| [b]1975 | 5.8 | 2.4 | 57.93 | 175 | .52 | 23.3 | 1.83 | 0.41 | 63.09 |
| [c]1977 | 8.3 | 2.54 | 58.11 | 25 | .17 | 17.6 | 2.36 | 1.44 | 64.62 |
| [d]1980 | -- | 2.58 | 44.97 | -- | .76 | -- | 4.55 | .83 | 53.69 |
| | | | | Camden County | | | | | |
| [e]1970 | 3.0 | .35 | 30.75 | -- | .09 | 6.4 | .32 | .01 | 31.52 |
| [f]1975 | -- | .54 | 38 | -- | -- | -- | -- | -- | -- |
| [f]1977 | 3.6 | .70 | 38.37 | -- | .11 | 7.7 | .40 | .02 | 39.6 |
| [g]1980 | -- | 1.69 | 35.07 | -- | .07 | -- | .63 | .02 | 37.48 |

[1] Includes water used for thermoelectric power generation.
[a] Pride (1973).
[b] Leach (1978).
[c] Leach and Healy (1980).
[d] Marella (1982).
[e] Carter and Johnson (1974) and H. R. Stiles, WRD, Doraville, Georgia (written commun., Nov. 29, 1979).
[f] Robert Pierce, Dept. of Natural Resources, Atlanta, Georgia (written commun., June 16, 1980).
[g] Pierce, Barber, and Stiles (1982).

## Surficial Aquifer

The surficial aquifer, about 100 to 200 feet thick, consists of a series of relatively thin permeable zones separated locally by a number of relatively thin confining beds. Three water-bearing zones were recognized by Leve (1966, p. 20): (1) sand and shell zone in the Holocene and Pleistocene deposits, (2) the shell, limestone, and sand zone in the Pliocene or upper Miocene deposits, and (3) limestone and sand zone in the clayey sand and sandy clay confining beds in the upper part of the Hawthorn Formation. The lithology of these deposits changes laterally as well as vertically and the permeable and nonpermeable zones are discontinuous.

The sand and shell zone extends from land surface to depths of about 25 to 50 feet. This zone is underlain by 0-50 feet of semiconfining beds. These beds are in turn underlain by the principal water-bearing zone of the surficial aquifer, the shell, limestone, and sand zone. This zone, the most laterally extensive in the area, and known locally as the shallow rock aquifer where it is limestone, is about 10 to 40 feet thick and is 50 to 100 feet below land surface.

The limestone and sand zone in the upper part of the Hawthorn Formation is generally thin and is discontinuous layers or lenses within the clayey sand and sandy clay beds of the upper confining unit. The zone occurs at depths between 150 and 200 feet below land surface and ranges in thickness from a few feet to about 40 feet. Ground water in this zone is confined.

### Water-Bearing Properties

Little information is available on the water-bearing properties of the surficial aquifer in the area. Table 4 presents the range of hydraulic conductivity and specific yield of materials ranging from clay to gravel. The transmissivity of the sand and shell zone probably ranges from less than 100 $ft^2/d$ for the fine grained, well sorted sand to about 1,000 $ft^2/d$ for the sand and shell beds (table 5). Assuming a hydraulic conductivity of 3 to 30 ft/d (from table 4) and a saturated thickness of 20 feet, the estimated transmissivity for a fine grained sand would be 60 to 600 $ft^2/d$.

In Duval County, south of Nassau County, Causey and Phelps (1978, p. 20) reported that calculated transmissivity values for the shallow rock zone ranged from 250 $ft^2/d$ to a maximum of about 1,300 $ft^2/d$, assuming full artesian conditions. In east-central St. Johns County, Hayes (1981) reported a transmissivity of about 7,000 $ft^2/d$ for a sand and shell bed, which may be equivalent to the shallow rock zone, about 50 to 100 feet below land surface.

A transmissivity of about 700 $ft^2/d$ was determined from an aquifer test in the surficial aquifer near Kingsland, Ga. (Law Engineering, written commun., undated). The zone tested, 60 to 90 feet in depth, is probably equivalent to the shallow rock zone.

Table 4.--Average values of hydraulic conductivity and specific yield of various materials

[Modified from Walton, 1970]

| Material | Hydraulic conductivity (ft/d) | Specific yield (percent) |
|---|---|---|
| Clay, silt | 0.00013-0.27 | 1-10 |
| Sand | 13-400 | 10-30 |
| Gravel | 130-2000 | 15-30 |
| Sand and gravel | 27-670 | 15-25 |
| Sandstone | 0.013-6.7 | 5-15 |
| Shale | 0.0000013-0.013 | 0.5- 5 |
| Limestone | -- | 0.5- 5 |

Table 5.--Estimated hydraulic parameters of the hydrologic units

| Units | Average thickness (ft) | Specific storage (per ft) | Vertical hydraulic conductivity (ft/d) | Transmissivity ($ft^2/d$) | Storage coefficient[1] |
|---|---|---|---|---|---|
| Surficial aquifer | 100 | $10.x10^{-6}$ - 0.2 | -- | 100-10,000 | $1x10^{-4}$ - 0.2 |
| Upper confining unit | 400 | $1.0x10^{-5}$ | 0.001 | -- | -- |
| Floridan aquifer | | | | | |
| upper water-bearing zone | 500 | $1.0x10^{-6}$ | -- | 20,000-50,000 | $5x10^{-4}$ |
| semiconfining zone | 200 | $1.0x10^{-6}$ | .001 | -- | -- |
| middle water-bearing zone | 500 | $1.0x10^{-6}$ | -- | 40,000-60,000 | $5x10^{-4}$ |
| semiconfining zone | 300 | $1.0x10^{-6}$ | .001 | -- | -- |
| lower water-bearing zone | 100 | $1.0x10^{-6}$ | -- | 75,000 | $1x10^{-4}$ |
| Lower confining unit | -- | $1.0x10^{-6}$ | .001 | -- | -- |

[1]Estimated based on compressibility of water and aquifer thickness (Lohman, 1972, p. 53).

The specific yield of an unconfined aquifer generally ranges between 0.1 and 0.3 (table 4). The average specific yield of an unconfined aquifer for long periods of draining is about 0.2 (Lohman, 1972, p. 8). The storage coefficient is estimated to be 0.2 for the water-table zone and the unconfined part of the shallow rock zone. The storage coefficient of the confined part of the shallow rock zone and the water-bearing zones of the Hawthorn Formation is estimated to be about $1x10^{-5}$ to $1x10^{-3}$.

## Ground-Water Flow, Recharge, and Discharge

Ground water in the surficial aquifer occurs under unconfined and confined conditions depending on the water-bearing zone penetrated or the depth of the penetration.

Ground water in the sand and shell zone generally is unconfined. Water levels range from near land surface in the coastal and low-lying areas to more than 10 feet below land surface in the topographically higher areas such as in the beach ridge areas on Amelia and Cumberland Islands and in the western part of the study area. The average depth to the water table is about 5 feet below land surface. The water table is a slightly subdued replica of the topography. The water table is near sea level along the coast and streams, which are tidally affected, increasing to altitudes of about 20 feet in the flat, poorly drained meander plain in the central and western parts of the study area. The direction of ground-water flow is generally eastward towards the Atlantic Ocean. The altitude of the water table on Amelia and Cumberland Islands ranges from sea level at the coast to about 20 feet altitude along the beach ridges and interior parts of the islands.

Seasonal fluctuations of the water table are generally less than 5 feet (fig. 4). Water levels generally are highest in September, at or near the end of the rainy season, and gradually decrease during the relatively dry season to their lowest levels in April or May.

Ground water in the shallow rock zone is generally unconfined. Water levels in wells that tap this zone are equal to or slightly less than the water table. They range from near land surface in the flat low-lying areas to more than 10 feet below land surface in topographically higher areas such as the beach ridges.

Ground water in the limestone and sand zone in the upper part of the Hawthorn Formation is confined. In eastern Nassau County, water levels in wells that tap this zone range in depth from about 8 to 14 feet below land surface.

The surficial aquifer is recharged primarily by local rainfall. Of the 52 to 54 inches per year average rainfall, an estimated 30 to 40 inches are lost to evapotranspiration. An additional 5 to 10 inches is storm runoff. The remainder infiltrates the soil and recharges the surficial aquifer which in turn returns nearly the entire amount to streams as base flow. Every inch of rainwater that reaches the aquifer represents 17.4 $Mgal/mi^2$ of recharge.

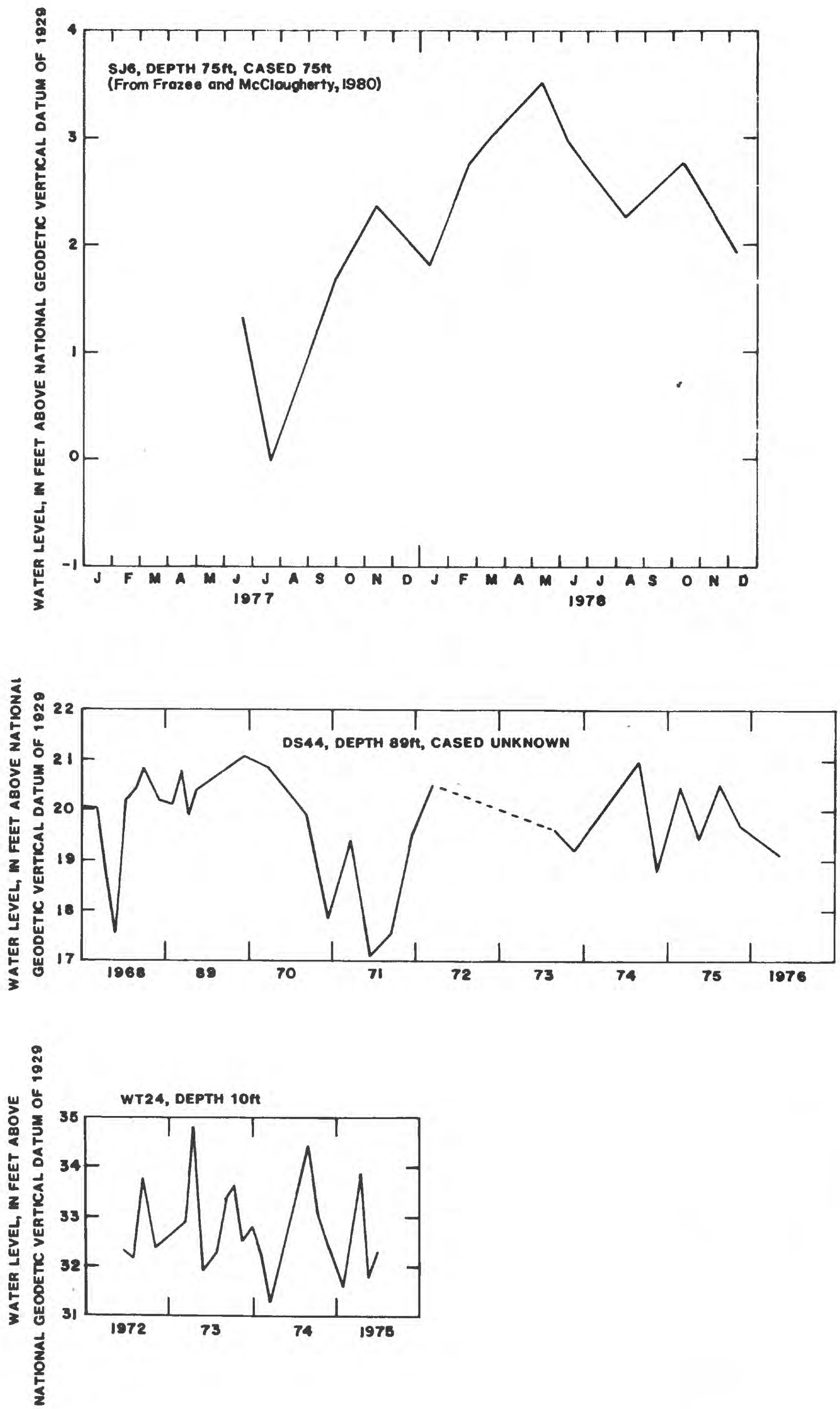



Figure 4.--Hydrographs of selected wells tapping the surficial aquifer.

Recharge to the surficial aquifer also results from upward leakage of water from the Floridan aquifer where the potentiometric surface of that aquifer is above the water table as well as by lateral ground-water flow from adjacent areas. Some recharge occurs as influent seepage from streams at high stage. An undetermined amount of recharge occurs as infiltration of irrigation water, discharge from septic tanks, and infiltration of water from flowing or improperly constructed wells.

Ground-water discharge from the surficial aquifer is largely by evapotranspiration and seepage into surface-water bodies. Additional discharge is by downward leakage to the Floridan aquifer where the water table is above the potentiometric surface, lateral ground-water flow to adjacent areas, and pumpage.

## Upper Confining Unit

The upper confining unit lies between the surficial and the Floridan aquifers and consists of sand, shell, and limestone deposits of low to moderate permeability, separated by thin, clay beds of very low permeability. In the study area, this unit is about 400 feet thick and includes all or part of the Hawthorn Formation (table 2 and fig. 3).

Franks and Phelps (1979, p. 5) estimated the vertical hydraulic conductivity of the upper confining unit to be $1x10^{-3}$ ft/d based on laboratory analyses of cores from test wells in Duval County. A similar value was reported by Miller and others (1978, p. 95) for the Osceola National Forest area about 50 miles west of the study area.

The leakance coefficient is the ratio of vertical hydraulic conductivity, K', and thickness, b', of a confining bed. The leakance coefficient is estimated to be about $2.5x10^{-6}$ (ft/d)/ft, based on a confining bed thickness of 400 feet and a vertical hydraulic conductivity of $1x10^{-3}$ ft/d.

The specific storage is the volume of water released from or taken into storage per unit volume of the porous medium per unit change in head or simply, the storage coefficient per vertical unit of thickness. In Duval County, Franks and Phelps (1979, p. 4) estimated a specific storage value of $1x10^{-5}$/ft based on laboratory analyses of core samples and field extensometer tests of the Hawthorn Formation reported by Miller and others (1978, p. 95).

## Floridan Aquifer

The Floridan aquifer, the principal source of potable water in the area, is a thick, stratified sequence of limestone and dolomite. The aquifer is about 1,600 feet thick and includes the following stratigraphic units in descending order; the Suwannee Limestone of Oligocene age (the Suwannee is thin to nonexistent in the study area and for this report is included in the Ocala Limestone); the Ocala Limestone of late Eocene age; the Avon Park and Lake City Limestones (undifferentiated Claibornian stage) of middle Eocene age; the Oldsmar Limestone of early Eocene age; and the upper part of the Cedar Keys Limestone of Paleocene age (table 2).

The top of the Floridan aquifer ranges from about 400 feet below sea level in the western part of the study area to about 600 feet below sea level in the northeast and generally corresponds to the top of the Ocala Limestone (fig. 5). The uppermost stratigraphic occurrence of persistent evaporite deposits in the Cedar Keys Limestone is generally recognized as the base of the Floridan aquifer.

The water-bearing zones within the Floridan aquifer consist of soft, porous limestone and porous highly fractured dolomite beds. The hard, massive dolomite and limestone are relatively impermeable and act as semiconfining beds that restrict the vertical movement of water within the aquifer. In the study area, the semiconfining beds appear continuous, thus isolating the water-bearing zones.

Three major water-bearing zones have been recognized in the study area (Bentley, 1979, p. 526). The upper and middle water-bearing zones, about 530 to 1,000 feet and 1,200 to 1,700 feet below land surface, respectively, contain freshwater and are separated by relatively impermeable limestone and dolomite. A third, the lower water-bearing zone, about 2,000 to 2,100 feet below land surface contains very saline water with chloride concentrations in excess of 8,000 mg/L. All the zones are not precisely defined depth-wise and may vary a few feet within the study area.

## Water-Bearing Properties

The transmissivity, determined from aquifer tests of the upper water-bearing zone of the aquifer, ranges from about 20,000 to 50,000 $ft^2/d$ (table 5). At Fernandina Beach, Cooper and Warren (1945, p. 279) reported a transmissivity of 20,000 to 21,000 $ft^2/d$ based on an aquifer test of short duration on wells penetrating about 500 feet of the aquifer. They also computed the transmissivity based on the shape of the large cone of depression around Fernandina Beach to be 25,000 $ft^2/d$, slightly more than the aquifer test values. Bentley (1979, p. 531) reported a transmissivity of 30,000 $ft^2/d$ for the upper water-bearing zone based on a nine-well aquifer test at Fernandina Beach; however, the results had to be modified to compensate for the effect of two of the wells which also penetrated the middle water-bearing zone of the aquifer.

Transmissivity of the upper part of the aquifer at Fernandina Beach was estimated by the closed contour method (Lohman, 1972), using potentiometric maps constructed for 1946 and 1959 (Leve, 1966) and 1975 (Fairchild and Bentley, 1977). The transmissivities estimated from the 1946 and 1959 maps were 37,000 and 60,000 $ft^2/d$, respectively. During these periods, about 50 percent of the total pumpage was from wells that penetrated both the upper and middle water-bearing zones, while the other 50 percent was from wells that penetrated only the upper zone. The transmissivity estimated from the 1975 map was 25,000 $ft^2/d$. During this period less than one third of the total pumpage was from wells that penetrated both zones (R. W. Harden and Associates, 1979). In St. Marys, Ga., Warren (1944, p. 104) reported an average transmissivity of 19,000 $ft^2/d$ for the upper water-bearing zone and about 10 miles north of St. Marys, R. E. Krause (U.S. Geological Survey, written commun., 1980) reported a transmissivity of 43,000 $ft^2/d$ for a well penetrating 435 feet of the aquifer. Based on this information, the transmissivity of the upper water-bearing zone varies within the study area and ranges from about 20,000 to 50,000 $ft^2/d$ (table 5).

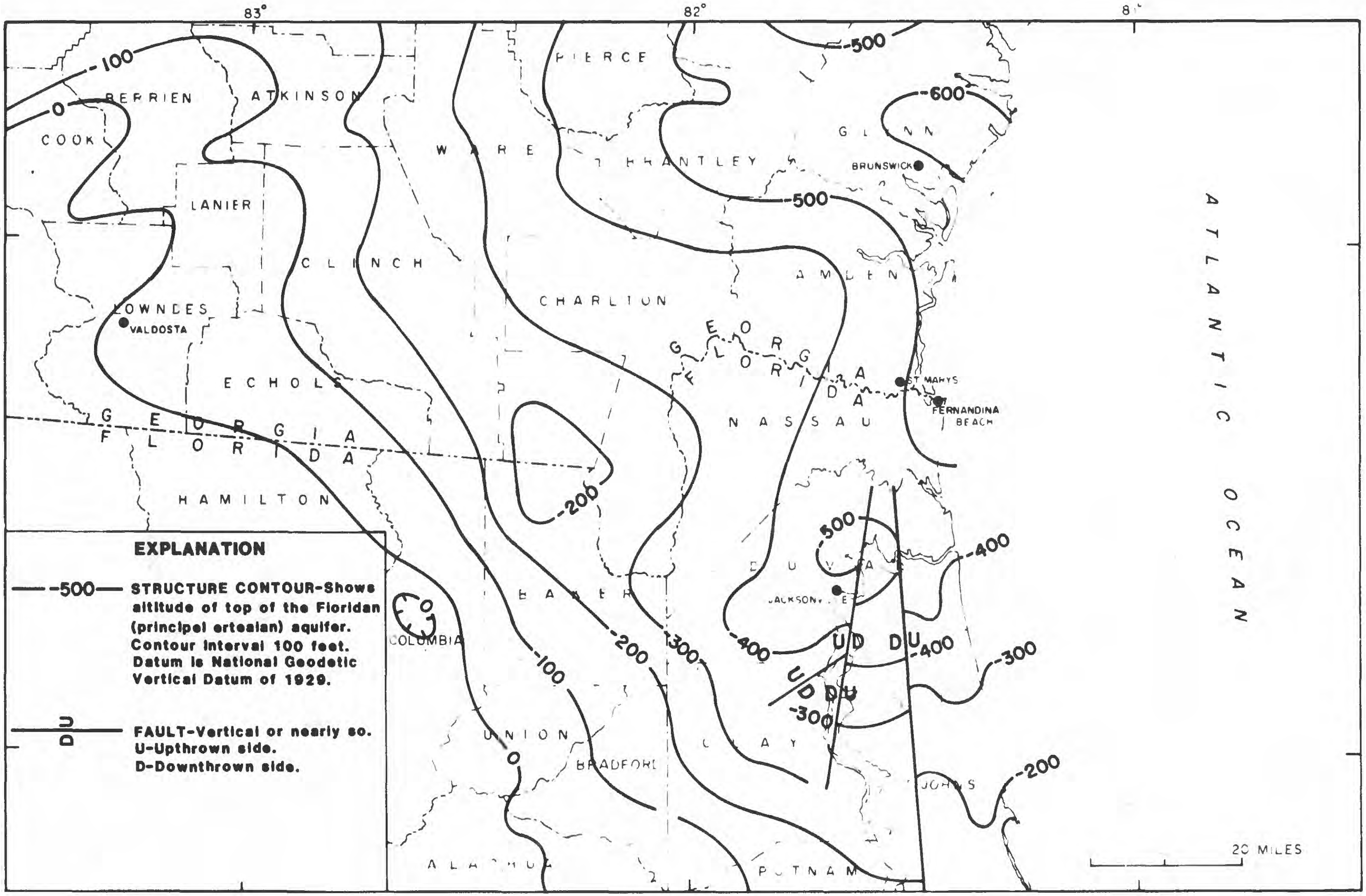



Figure 5.--Top of the Floridan (principal artesian) aquifer (from Miller, 1982).

The transmissivities of the middle and lower water-bearing zones have not been determined by aquifer tests. However, values of transmissivity were determined for the combined upper and middle zones in the southern part of Duval County, about 15 and 20 miles south of the study area. Franks and Phelps (1979, p. 7) reported transmissivities of 100,000 and 30,000 $ft^2/d$ for 2 wells that penetrated about 700 feet of the aquifer (upper and middle water-bearing zones). However, based on considerations of anisotropy of the aquifer, well penetration, and details of the individual pumping tests, Franks and Phelps (1979, p. 6) reported an average transmissivity for the combined upper and middle zones (the main producing zones of the aquifer in Duval County) to be an estimated 80,000 $ft^2/d$. Transmissivity of the middle zone alone is estimated to be in the range of 40,000 to 60,000 $ft^2/d$.

Little information is available on the transmissivity of the lower water-bearing zone of the Floridan aquifer. The estimated transmissivity, based on 1981 U.S. Geological Survey numerical modeling studies for the lower water-bearing zone in the study area is about 75,000 $ft^2/d$ (R. E. Krause, U.S. Geological Survey, written commun., 1981).

The storage coefficient of most confined aquifers ranges from about $1x10^{-5}$ to $1x10^{-3}$ (Lohman, 1972). In northeastern Florida and southeastern Georgia, the storage coefficient of the upper 200 to 700 feet of the Floridan aquifer, determined from aquifer tests, ranged from $1.5x10^{-4}$ to $2.1x10^{-2}$ (Cooper and Warren, 1945; Stringfield, 1966; Leve, 1968a; Franks and Phelps, 1979; and Bentley, 1979). In the Fernandina Beach-St. Marys area, the storage coefficient of the upper water-bearing zone ranged from $2x10^{-4}$ to $4x10^{-4}$ (Cooper and Warren, 1945; Bentley, 1979). The specific storage, based on aquifer test data, ranged from $4x10^{-7}$ to $7x10^{-7}$ per foot, somewhat less than the value of $1x10^{-6}$ per foot reported by Lohman (1972, p. 8) for confined aquifers. Franks and Phelps (1979, p. 6) determined a representative value of specific storage, $1x10^{-6}$ per foot, based on aquifer test data in Duval County. The specific storage of the aquifer is estimated to be about $1.0x10^{-6}$ per foot of thickness. The storage coefficients of the upper, middle, and lower water-bearing zones, based on specific storage of $1x10^{-6}$/ft and thickness of 500, 500, and 100 feet, are estimated to be $5x10^{-4}$, $5x10^{-4}$, and $1x10^{-4}$, respectively (table 5).

## Semiconfining Zones

Within the Floridan aquifer, beds of dense, relatively impermeable limestone and dolomite confine ground water in three discrete water-bearing zones. These beds or semiconfining zones have relatively low hydraulic conductivities compared to the major water-bearing zones, yield very little water, and retard interzone ground-water flow in the aquifer. The 2 zones, about 200 and 300 feet thick, occur at depths of about 1,000 and 1,700 feet below land surface.

The semiconfining zones, like aquifers, store water and transmit water but at a much slower rate. Water from zones of higher artesian head can leak through semiconfining zones to water-bearing zones of lower pressure. The rate of flow or leakage depends on the thickness, vertical hydraulic conductivity, and the hydraulic gradient across the semiconfining zone.

Pride and others (1966, p. 68) reported vertical hydraulic conductivities of $1.3 \times 10^{-5}$ to $2.7 \times 10^{-3}$ ft/d for cored samples of very hard, very dolomitic limestone from the Avon Park, Lake City, and Oldsmar Limestones in the Green Swamp area of central peninsular Florida. A vertical hydraulic conductivity value of $1.0 \times 10^{-3}$ is used in this study and is based on values determined during ongoing investigations (R. E. Krause, U.S. Geological Survey, oral commun., January 1982; E. C. Hayes, U.S. Geological Survey, oral commun., January 1982). This value is also within the range reported by Pride and others (1966). Based on a vertical hydraulic conductivity of $1 \times 10^{-3}$ ft/d and thicknesses of 200 and 300 feet, the leakance coefficient is estimated to be $5.0 \times 10^{-6}$ (ft/d)/ft for the upper semiconfining zone and $3.3 \times 10^{-6}$ (ft/d)/ft for the lower semiconfining zone. However, the actual value of the vertical hydraulic conductivity is unknown, but could range from $10^{-2}$ to $10^{-5}$.

The specific storage of the semiconfining zones is assumed to be equal to the specific storage of the water-bearing zones, about $1.0 \times 10^{-6}$ per foot of thickness because the zones have similar lithology as water-bearing zones.

## Potentiometric Surface

The potentiometric surface, which represents the head, is an imaginary surface defined by the levels to which water will rise in tightly cased wells that tap an aquifer (Lohman, 1972). The regional configuration of the potentiometric surface of the upper part of the Floridan aquifer is shown in figure 6. The potentiometric highs on the surface represent areas of recharge. Potentiometric highs occur in areas in central Georgia, extending northeast into South Carolina and near Putnam County, Fla., as well as Valdosta, Ga. In these areas, the aquifer is at or near land surface, covered by permeable sediments, or the confining beds overlying the aquifer are breached by sinkholes.

Depressions in the potentiometric surface indicate areas of discharge along streams or near springs or ground-water withdrawals. The major depressions in the potentiometric surface (fig. 6) occurring in Jacksonville, Fernandina Beach-St. Marys, and Brunswick areas, are from ground-water withdrawals. The depressions near Green Cove Springs in Clay County, Fla. are from spring discharge.

The regional flow of ground water is generally from west to east and is perpendicular to and towards potentiometric contours of lower altitude. In the study area, the potentiometric surface ranged from about 40 feet above sea level in the western part to below sea level at Fernandina Beach and St. Marys. Positive heads of about 30 feet extend more than 50 miles offshore (Johnston and others, 1980).

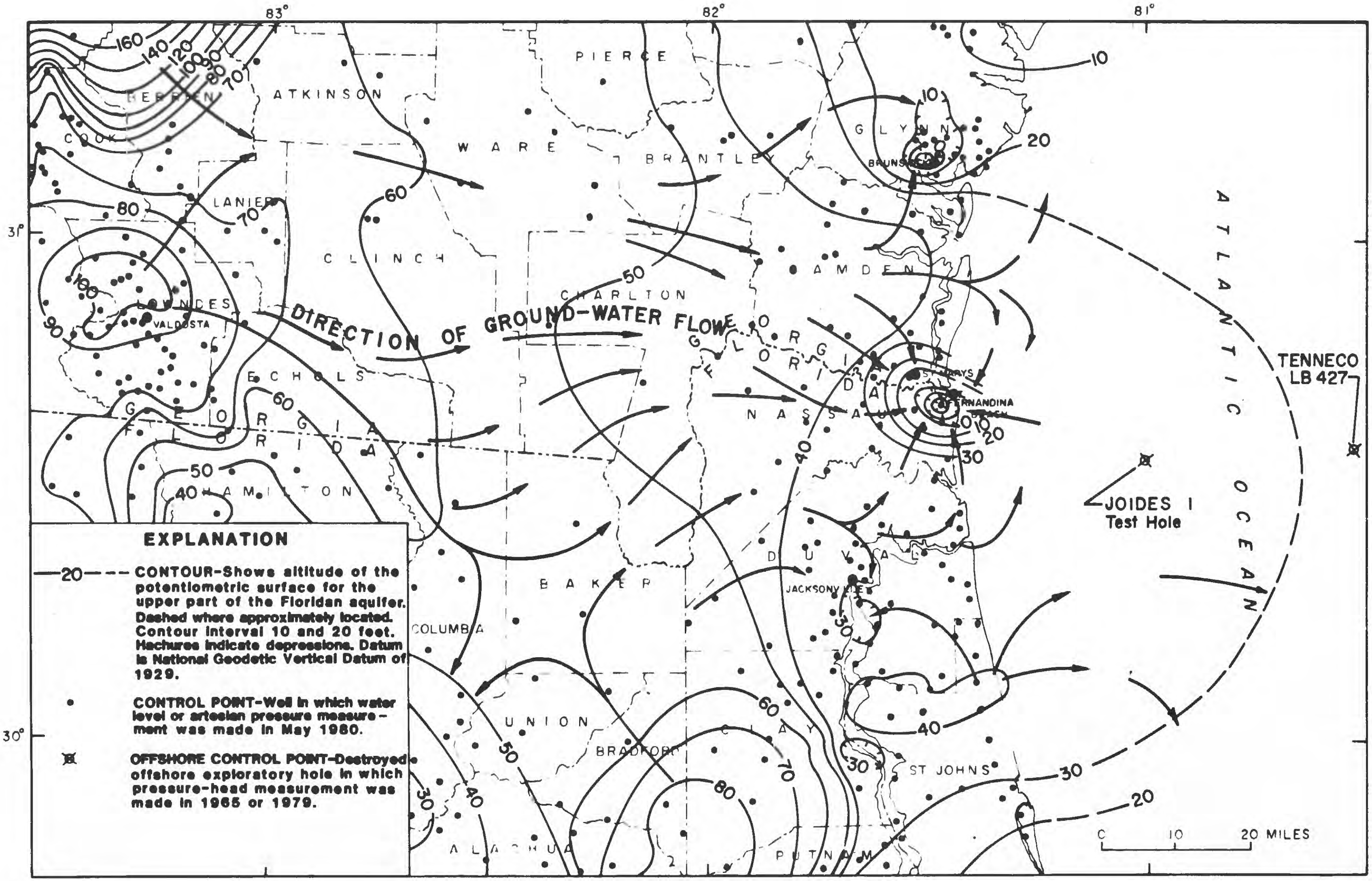



Figure 6.--Potentiometric surface of the upper part of the Floridan aquifer in northeastern Florida and southeastern Georgia, May 1980 (modified from Johnson and others, 1981).

The potentiometric surface of the upper part of the Floridan aquifer in May 1980, is shown in figures 7 and 8. Most wells in the area penetrate the upper 200 to 500 feet of the aquifer and tap the upper water-bearing zone. Some large industrial supply wells in Fernandina Beach and St. Marys penetrate 700 to 1,200 feet of the aquifer and tap the upper and middle water-bearing zones. The potentiometric surface in this area may represent an integrated pressure surface of both zones. The surface ranges from more than 40 feet above sea level in the western part to more than 100 feet below sea level in the center of the cone of depression in Fernandina Beach. Pumping levels in some wells are more than 150 feet below sea level. Ground-water flow is toward the center of the cone of depression in the potentiometric surface.

## Seasonal Fluctuations and Areas of Artesian Flow

Seasonal fluctuations of the potentiometric surface are in response to changes in recharge and discharge. Seasonal and year to year fluctuations during 1939-80 are shown in the hydrographs of selected wells in the study area (fig. 9). Fluctuations in the potentiometric surface are primarily caused by pumpage. Annual fluctuations of water levels range from less than 2 feet in areas distant from the center of pumpage to more than 50 feet near the center of pumpage. The wide fluctuations in the potentiometric surface near the center of pumpage are a result of variations in the rate of withdrawal from nearby industrial supply wells. Figure 10 shows the daily variation of water levels in well N-32 from January to September 1980. During this period, water levels ranged from about 37 feet below sea level to slightly above sea level. During a 24-hour period, fluctuations may range from less than 1 foot to more than 15 feet.

In the study area, wells will generally flow except in a relatively high topographic area near Yulee and within and near the cone of depression in the potentiometric surface at Fernandina Beach-St. Marys area.

## Long-Term Trends

In the study area, the estimated potentiometric surface of the upper part of the Floridan aquifer prior to development ranged from about 60 to 65 feet above sea level (fig. 11). Sellards and Gunter (1910) reported artesian pressures in wells that penetrated the upper part of the Floridan aquifer at Fernandina (now Fernandina Beach) and Callahan, just west of the study area, at 61 and 67 feet above sea level, respectively. Those observations agree with the estimated predevelopment potentiometric surface in the area.

Figure 12 shows the decline in the potentiometric surface of the upper water-bearing zone of the Floridan aquifer in the study area based on the difference between the estimated potentiometric surface prior to development (fig. 11) and May 1980 (fig. 7 and 8). In the northern, western, and southern third of the study area, declines were about 25 to 30 feet increasing to more than 100 feet towards the center of pumpage.

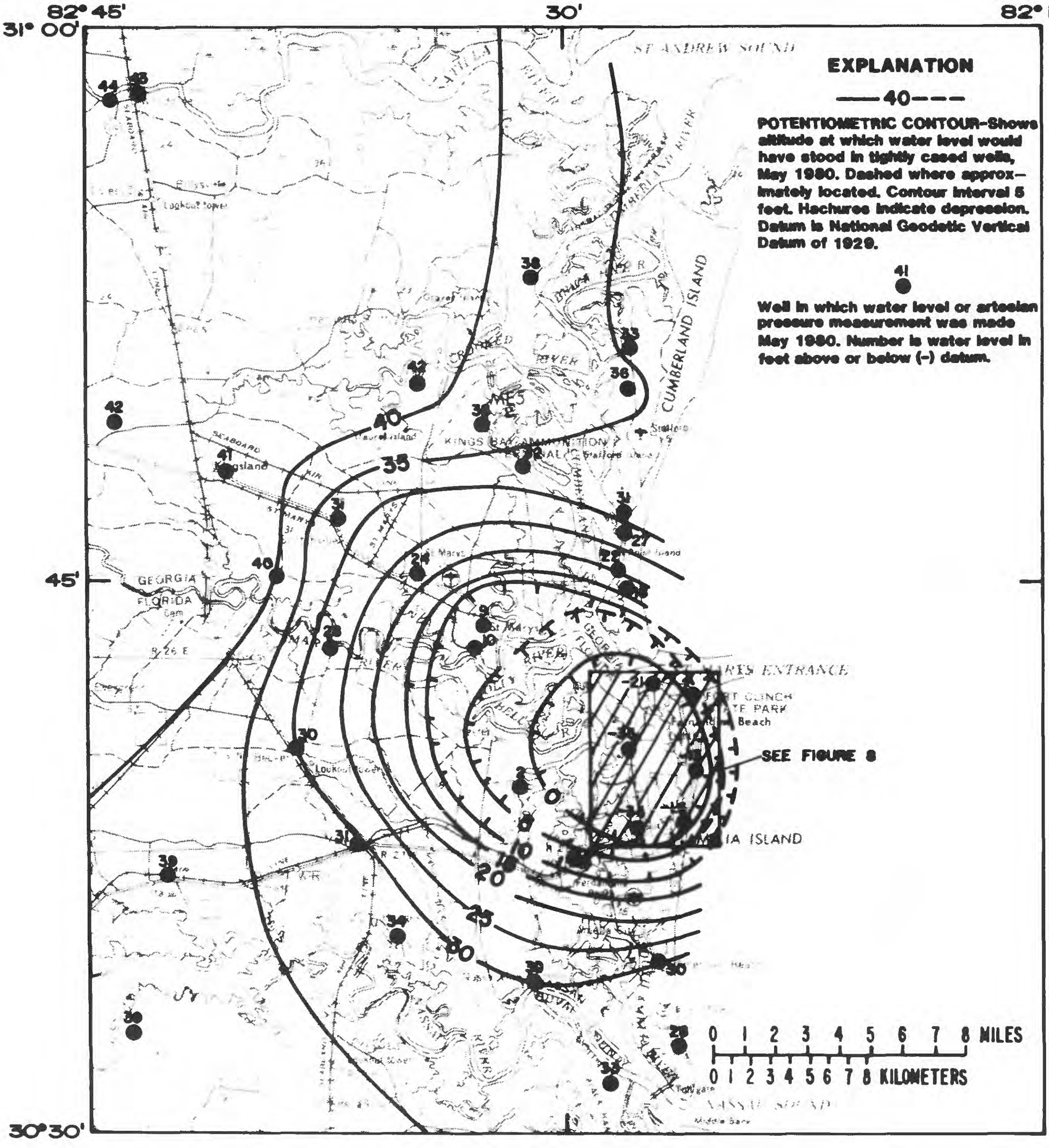
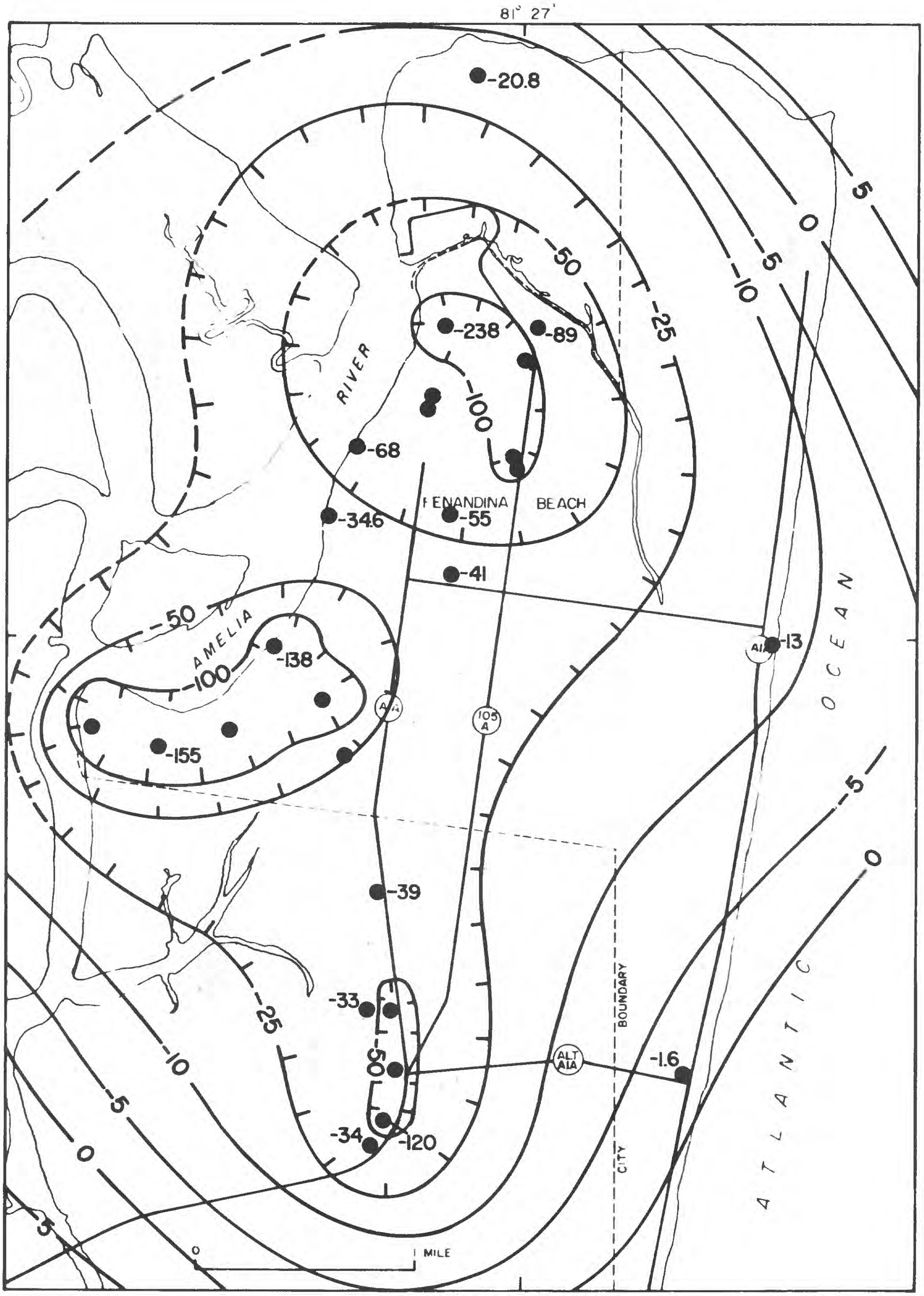



Figure 7.--Potentiometric surface of the upper part of the Floridan aquifer, May 1980.




**EXPLANATION**

—0— — POTENTIOMETRIC CONTOUR- Shows altitude at which water level would have stood in tightly cased wells, May 1980. Dashed where approximately located. Hachures indicate depressions. Contour interval variable. Datum is National Geodetic Vertical Datum of 1929.

● -13 Well in which water level or artesian pressure measurement was made May 1980. Number is water level in feet above or below (-) datum.

Figure 8.--Potentiometric surface of the upper part of the Floridan aquifer in the Fernandina Beach area, May 1980.

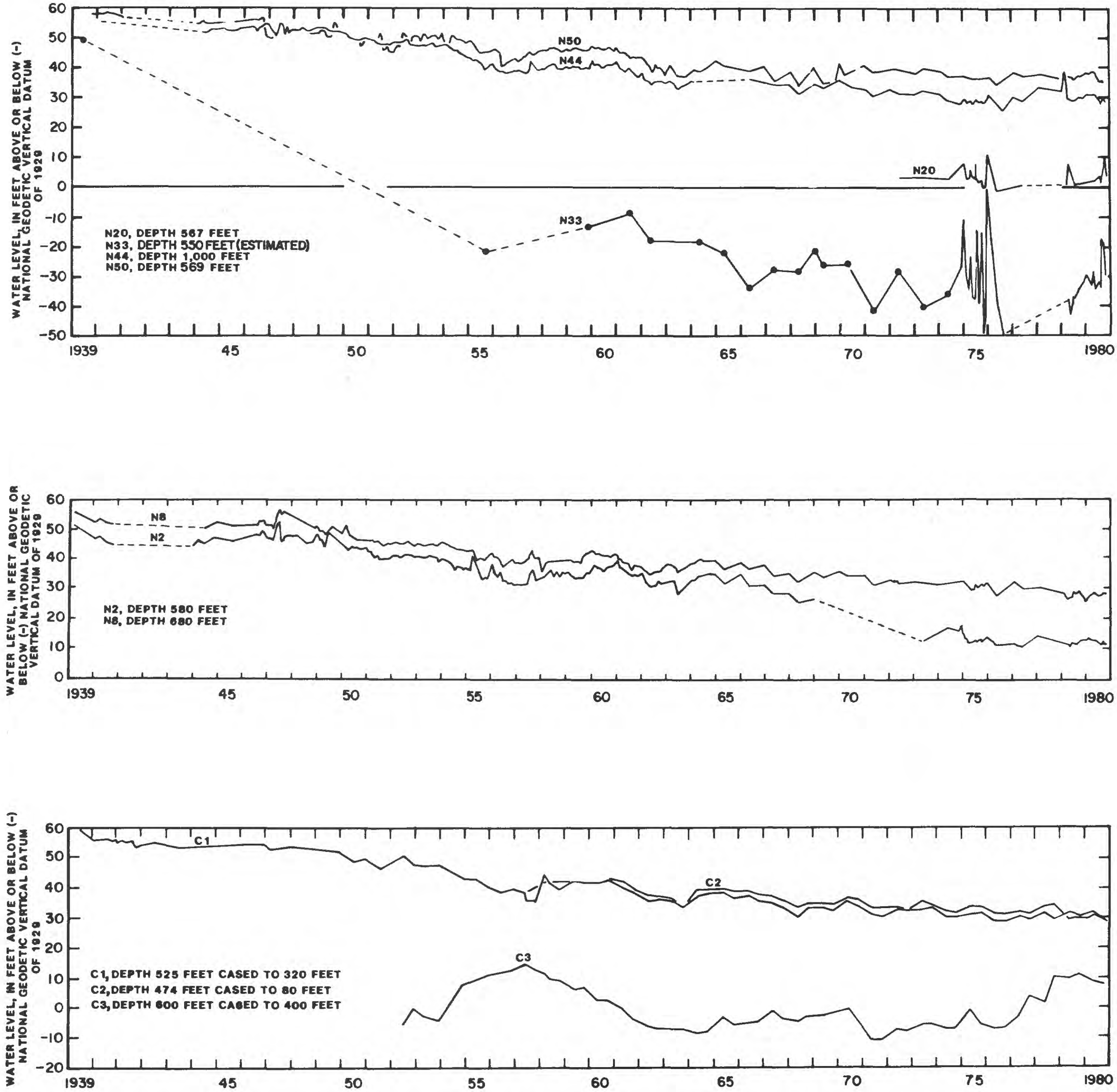



Figure 9.--Hydrographs from selected wells that tap the upper part of the Floridan aquifer.

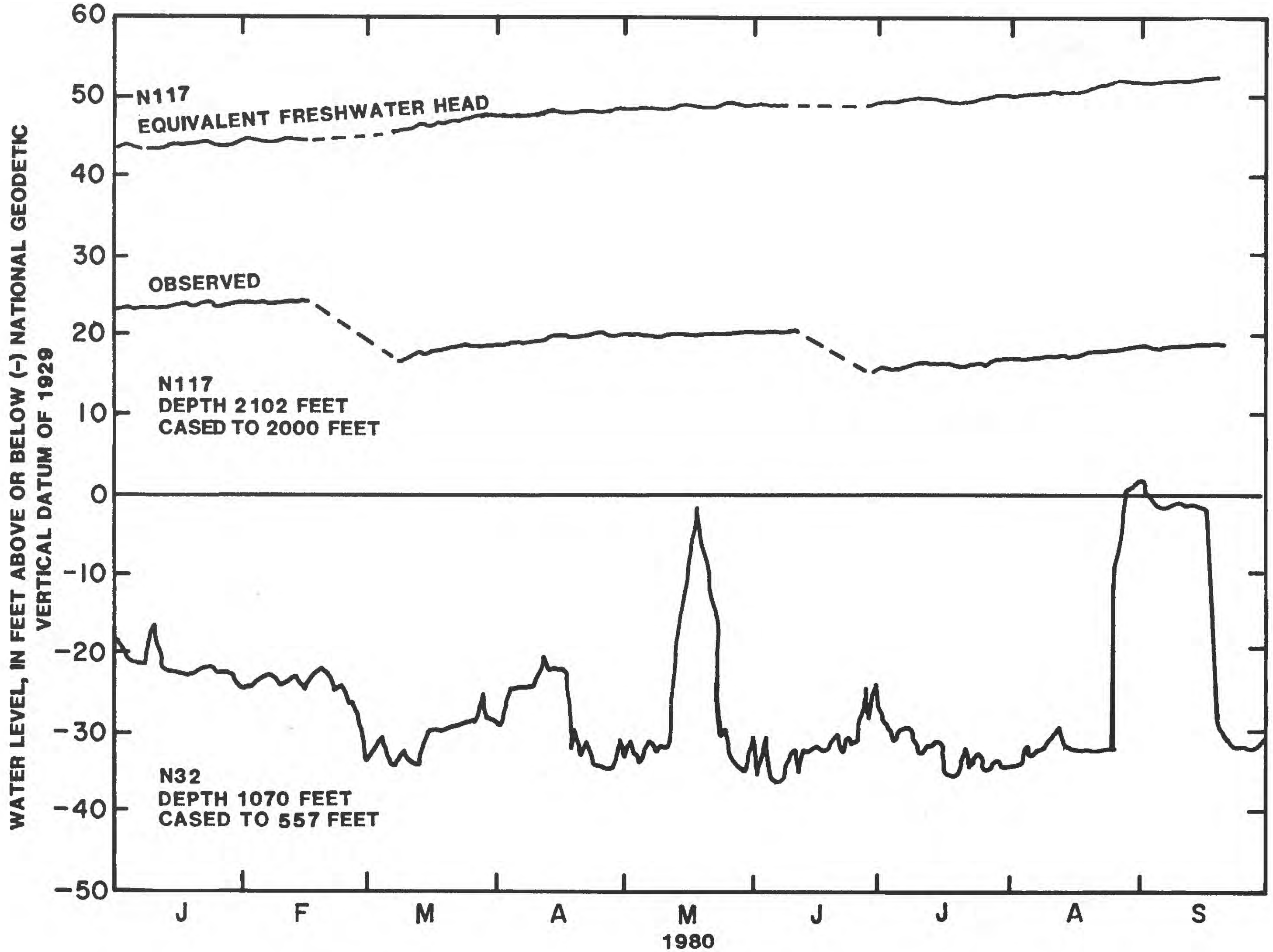



Figure 10.--Hydrographs of well N-32 and well N-117, January to September 1980.

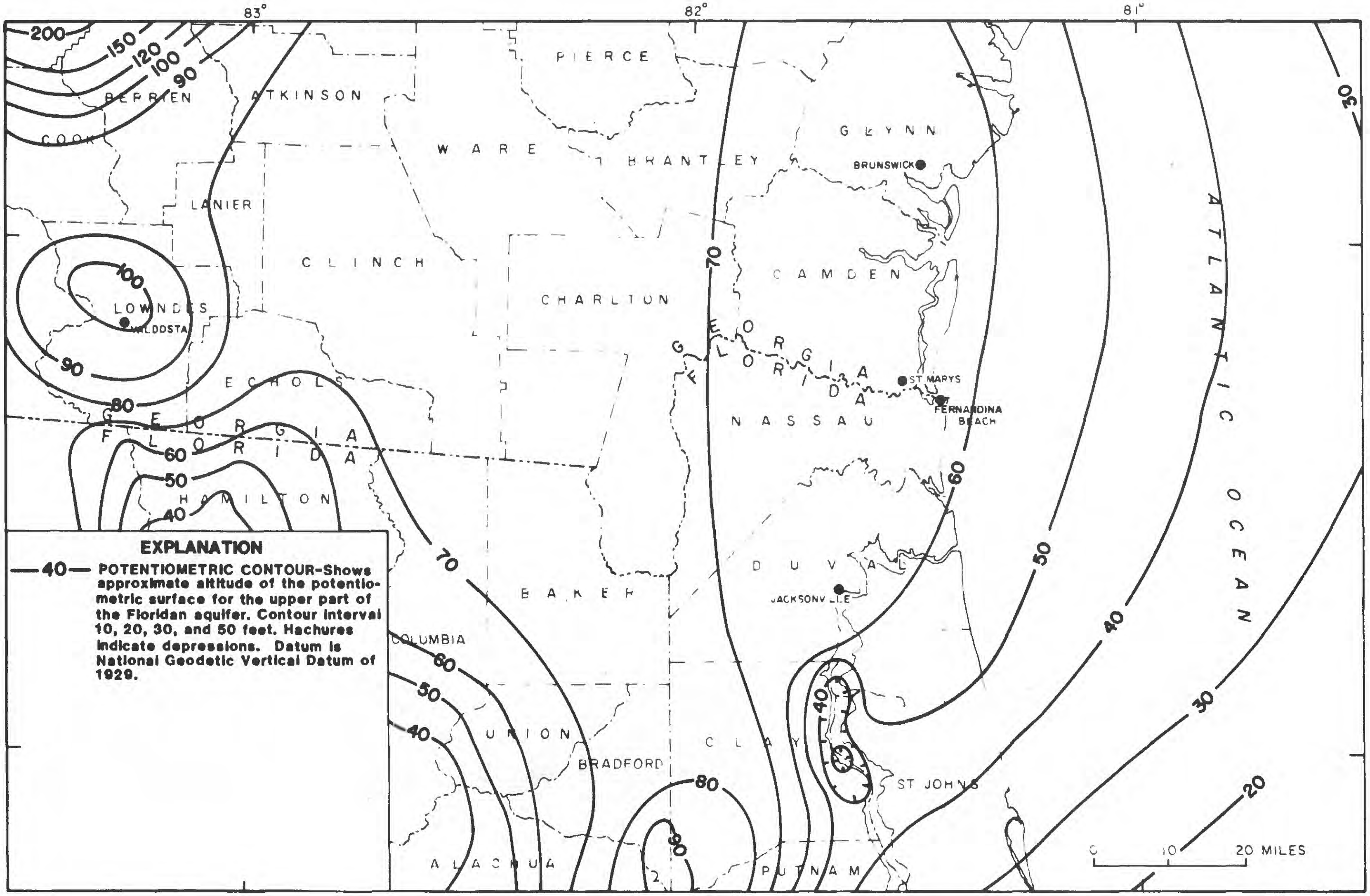



Figure 11.--Estimated potentiometric surface of the upper part of the Floridan aquifer, prior to development (from Johnson and others, 1980).

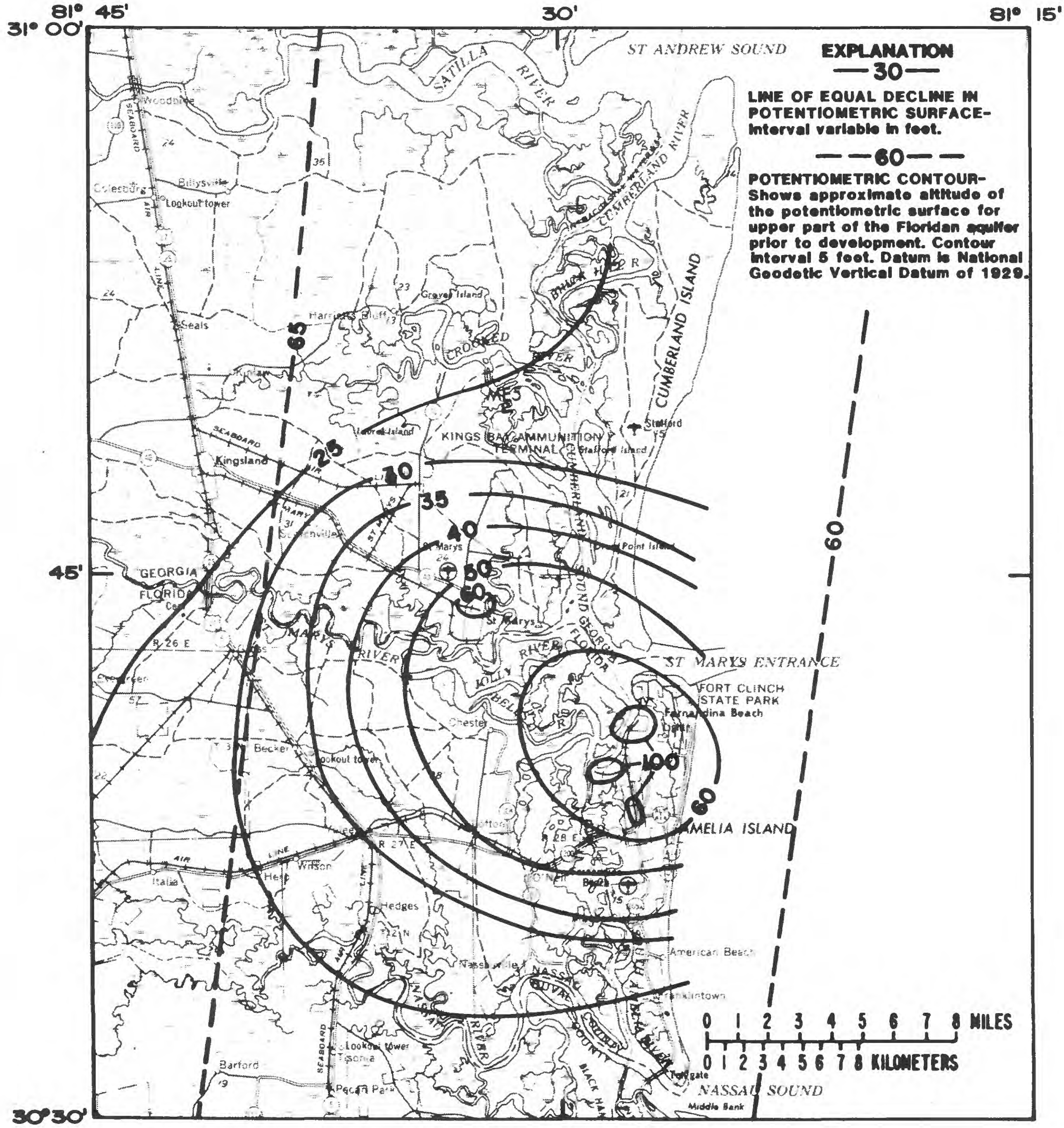



Figure 12.--Estimated potentiometric surface of the upper part of the Floridan aquifer prior to development, and the decline in potentiometric surface, prior to development to May 1980.

From 1939-40 to 1980, water levels in wells N-2, N-8, N-44, N-50, C-1, and C-2, located about 6 to 15 miles from centers of pumpage, declined 20 to 40 feet (fig. 9). During the same period, water levels in well N-33, near the center of pumpage declined about 95 feet. Most of this decline in well N-33 (about 60 feet) occurred before 1960.

In 1975-76 and 1979-80, water levels in well N-33, based on monthly and bimonthly measurements, varied from about 50 feet below sea level to near sea level (fig. 9). Actual trends could not be determined accurately; however, there does not appear to be any decline in the water level in well N-33 from 1975 to 1980.

Offshore about 30 miles east of Fernandina Beach, Johnston and others (1982) reported a slight head decline, probably less than 10 feet, at the JOIDES 1 hole. This assumption was based on the estimated predevelopment head and the reported head of 30 to 38 feet above sea level by Wait and Leve (1967, p. A127). Johnston and others (1982) also concluded that equivalent freshwater head calculations of 24 to 29 feet from drill-stem test data suggest that the decline in head is insignificant at the Tenneco site, about 50 miles east of Fernandina Beach.

## Head Relationships and Vertical Flow

The first deep exploratory well (N-62) to penetrate the full thickness of the Floridan aquifer in the study area was drilled in 1945 just south of Fernandina Beach. It was drilled to a depth of 2,130 feet and was cased to 567 feet below land surface. As the well was deepened from 567 to 2,130 feet, the hydraulic heads (artesian pressure) at different depth intervals were measured by packer tests (Scofield, 1945; Cooper and Peek, 1954). Table 6 presents the depth interval tested and corresponding artesian pressure. The static head at depths above 1,050 feet, was about 20 feet above sea level. Below a depth of 1,050 feet, the static head ranged from 39 feet above sea level at the 1,100 to 1,130 foot interval to 52 feet above sea level at the 1,772 to 1,802 foot interval.

Most production wells in the area prior to 1945 withdrew water from the upper water-bearing zone, above a depth of 1,050 feet. The head in the producing zone above 1,050 feet below land surface had been lowered about 40 feet from an estimated predevelopment head of about 60 feet above sea level. The artesian head in the middle and lower water-bearing zones not penetrated by production wells, had not been lowered appreciably by the pumping.

Flow traverses made in well N-62 after completion, indicated that with the well flowing 1,900 gal/min, the upper water-bearing zone yielded no water to the well, but instead, about 350 gal/min flowed through the well bore into this zone from the deeper zones of higher artesian head. When the well was shut in at the surface, an estimated 700 gal/min entered the upper water-bearing zone from the deeper zones (Leve, 1966).

Table 6.--Artesian pressure at selected depth intervals determined by Packer tests during drilling of well N-62 at Fernandina Beach

[From Scofield, 1945]

| Depth interval in feet below reference point[a] | | Artesian pressure in feet of water above sea level |
|---|---|---|
| Depth of packer | Depth of well | |
| 636 | 666 | 20.5 |
| 1,100 | 1,130 | 39.3 |
| 1,200 | 1,230 | 44.0 |
| 1,262 | 1,322 | 50.2 |
| 1,380 | 1,410 | [b]41.5 |
| 1,500 | 1,530 | [b]42.0 |
| 1,772 | 1,802 | 52.0 |

[a]Reference point is 17 feet above sea level.
[b]Packer did not seal depth interval tested.

Leve (1966, p. 30) noted similar head differences and flow characteristics in wells in central and coastal Duval County, indicating that the confining beds are extensive and the zones are separated and somewhat isolated from each other.

The maximum artesian pressure measured in the middle zone during drilling of well N-62 was about 50 feet above sea level (Scofield, 1945). This was slightly less than the artesian head in the lower zone which was estimated to be 52 feet above sea level.

Before the deepening of well N-88 in an industrial well field at the north end of Fernandina Beach in 1959, the artesian pressure in the upper water-bearing zone was below land surface. After the well was deepened to 1,232 feet (top of the middle water-bearing zone) it began to flow, indicating a higher artesian pressure in the middle water-bearing zone (R. W. Harden and Associates, 1979).

During this investigation, test well N-117 was completed to a depth of 2,102 feet. Periodic water-level measurements were made at selected depth intervals during construction of the well (table 7). Water levels in the 568 to 632 foot and 568 to 695 foot intervals (upper water-bearing zone) were 68 and 70 feet below land surface, respectively. Water levels ranged from 36 feet below land surface at the 568 to 1,746 foot interval to about 20 feet below land surface at the 568 to 1,856 foot interval (upper and middle water-bearing zone). The combined water level of the middle and upper zones was apparently greater than the artesian head of the upper zone exclusively. The water level in the middle water-bearing zone is at least 30 feet higher than the water level in the upper zone.

Table 7.--Water level in well N-117 during drilling

| Date | Depth interval (ft) | Water level[a] (ft below land surface) |
|---|---|---|
| 12/15/78 | 568-632 | 68 |
| 12/18/78 | 568-695 | 70 |
| 1/22/79 | 568-1,746 | 36 |
| 1/24/79 | 568-1,856 | 20 |
| 2/02/79 | 568-1,914 | 23 |
| 2/05/79 | 568-1,945 | 22 |
| 2/13/79 | 568-2,080 | 34 |

[a]Water levels affected by nearby pumping wells.

During construction, a flow-meter traverse of the well was made at a depth interval of 567 to about 2,000 feet prior to the well being drilled into the lower water-bearing zone. No flow was detected below a depth of about 1,710 feet. Flow increased from about 55 gal/min at a depth of 1,710 feet to a maximum of about 160 gal/min at a depth of 1,240 feet. Flow decreased from a depth of about 1,240 feet to zero flow at a depth of about 780 feet. Water from the middle water-bearing zone had a higher water level and flowed up the well bore into the upper water-bearing zone of lower water level.

Based on this information, the water level in the middle water-bearing zone is probably near or above sea level in the Fernandina Beach area and is estimated to be about 40 to 50 feet above sea level elsewhere in the study area.

A static water-level measurement in the lower water-bearing zone, below 2,000 feet, was not determined during drilling of well N-62 in 1945. However, static water-level measurement of 52 feet above sea level was measured for the 1,772 to 1,802 foot interval during drilling of the test well. Thus in 1945, the water level in the lower zone was at least equal to and was probably greater than 52 feet above sea level.

From July 18, 1979 to September 30, 1980, daily high water levels in test well N-117 (completion interval 2,000-2,102 feet) ranged from about 15 feet to about 25 feet above sea level. Based on density differences between freshwater and the mineralized water found in the monitored zone, the equivalent freshwater head of the monitored zone ranged from about 30 to 50 feet above sea level.

From January to September 1980, equivalent freshwater heads increased from 44 to 52 feet above sea level (fig. 10). The apparent decrease of observed water levels of well N-117 during February and June were the result of increased salinities of the water in the cased section of the well after sampling. From January to September 1980, daily high water levels in well N-32 which penetrates only the upper water-bearing zone and is about 2 miles south of the well N-117, were about 16 to 36 feet below sea level except during periods of reduced pumpage when water levels recovered to near or slightly above sea level. There was no apparent fluctuation in the equivalent freshwater water levels of the well N-117 during May 11-17 and August 23 to September 15 compared to fluctuations of about 30 feet in well N-32. Thus, in this area, the lower zone is effectively isolated from the upper water-bearing zone and probably the middle zone also.

## Lower Confining Unit

The lower confining unit consists of gray, hard, dense to porous dolomite grading downward to a soft, granular, oolitic limestone which is impregnated with evaporites (Cole, 1944; Chen, 1965; Leve and Goolsby, 1966). As stated previously, the uppermost stratigraphic occurrence of persistent evaporite deposits in the Cedar Keys Limestone is generally recognized as the base of the Floridan aquifer (table 2).

About 8 miles south of the study area, a test well penetrated about 500 feet (from about 1,990 to 2,486 feet below land surface) of the lower confining unit (Leve and Goolsby, 1966). The unit was described as decreasing in permeability with depth and yielding very little water. A fluid velocity log of the well made after completion showed no measurable flow entering or leaving the borehole below 2,050 feet. Freshwater extended down to about 2,100 feet. Below 2,100 feet, the water contained up to 7,700 mg/L chloride and 4,000 mg/L total hardness.

In northeastern Nassau County, about 10 miles west of the study area, a deep oil-test well penetrated rocks of Paleocene age and older. Saltwater was encountered between 2,095 and 2,120 feet below sea level, about 100 feet below the Oldsmar Limestone-Cedar Keys Limestone contact and is thought to be within the lower confining unit. A sample of this water contained about 1.5 times the chloride concentration of seawater (Cole, 1944).

## WATER QUALITY

Ground water contains dissolved minerals in varying amounts that affect its quality and use. The mineral constituents and the degree of mineralization depend upon the quality of water recharged to the aquifer, the composition and solubility of the soil and rock through which the water passes, and the duration of contact. In coastal areas, the quality is affected by the mixing of freshwater with seawater. In the study area, the quality may be degraded where freshwater is mixed with saline water from deeper water-bearing zones of higher artesian head or with residual seawater that is within a water-bearing zone.

In coastal areas, where aquifers are hydraulically connected to the sea, a zone of contact or a freshwater-saltwater interface is formed between the lighter freshwater flowing to the sea and the heavier underlying seawater. Because of natural forces such as tidal action, and wet or dry periods, as well as manmade forces such as pumpage, static conditions do not exist in aquifers. Instead, a zone of diffusion or dynamic equilibrium exists where fresh and saltwater are mixed. A sharp interface does not exist (Cooper and others, 1964, p. C1). The depth to the interface is related to the height that freshwater stands above sea level. Pumping lowers the water level in the aquifer resulting in a decrease of freshwater flow seaward. With decreased freshwater flow, the freshwater-saltwater interface moves landward to a point of new dynamic equilibrium. This phenomenon is called saltwater intrusion.

Wells in the area are commonly constructed with tens to hundreds of feet of open-hole section and water pumped from these wells may come from one or more water-bearing zones. Thus, the quality of water pumped from a well depends upon which zones are tapped and the proportion of water derived from each zone (Wilson, 1977).

The source and significance of various constituents and properties of ground water are discussed in detail by Hem (1970): those constituents and properties that have a practical bearing on water use are summarized in "Water Resources Data for Florida--Water Year 1979" (U.S. Geological Survey, 1980).

The recommended limits for selected chemical constituents and physical properties of water for public water supplies and for some industrial and agricultural uses are listed in tables 8 and 9, respectively.

The amount of the dissolved minerals in the water is indicated by the dissolved solids concentration. In the study area the dissolved solids comprise primarily calcium, magnesium, sodium, bicarbonate, sulfate, and chloride. The total concentration of dissolved solids in water is ordinarily determined from the weight of the dry residue remaining after evaporation at 180°C or it may be calculated if the concentrations of each of the major ions is known. In the study area, dissolved-solids concentration is approximately equivalent to 0.7 times the specific conductance. Specific conductance is the capacity of the water to conduct an electric current and is a measure of total mineral concentration.

Table 8.--Recommended quality standards for public water supplies

| Chemical substance | Limit not to be exceeded EPA[a] | DPC[b] |
|---|---|---|
| | **Physical** | |
| Color | 75 Pt-Co units | |
| pH | 5.0-9.0 units | 6.0-8.5 units |
| Turbidity | | 50 units |
| | **Chemical (in mg/L)** | |
| Chloride | 250 | 250 |
| Fluoride[c] | 1.4-2.4 | 1.4-1.6 |
| Iron | 0.3 | 0.3 |
| Nitrite nitrogen | 1.0 | |
| Nitrate nitrogen | 10 | |
| Sulfate | 250 | |
| Dissolved solids (residue) | | 500 |

[a]U.S. Environmental Protection Agency (1976, 1977).
[b]Florida Department of Pollution Control (1973).
[c]The concentration of fluoride should be between the limits expressed, depending on the annual average of maximum daily air temperatures at a location being considered.

Table 9.--Recommended limits of dissolved solids, total hardness, and chloride in water for selected industrial and agricultural uses

[From McKee and Wolf, 1963]

| Use | Dissolved solids (mg/L) | Total hardness (mg/L as $CaCO_3$) | Chloride (mg/L) |
|---|---|---|---|
| Brewing, general | 500-1,500 | 200-300 | 60-100 |
| Carbonated beverages | 850 | 200-250 | 250 |
| Dairy industry | -- | 180 | 30 |
| Food equipment washing | 850 | 10 | 250 |
| Pulp and paper processing water | | | |
| Groundwood pulp | 500 | 200 | 75 |
| Soda and sulfate pulps | 250 | 100 | 75 |
| Kraft paper, bleached | 300 | 100 | 200 |
| Kraft paper, unbleached | 500 | 200 | 200 |
| Fine papers | 200 | 100 | -- |
| Textile manufacture | -- | 0- 50 | 100 |
| Irrigation | 700 | -- | 100 |
| Stock watering | 2,500 | -- | 1,500 |

The U.S. Geological Survey has assigned terms for waters of high dissolved solids as follows (Hem, 1970, p. 219):

| | Dissolved solids [milligram per liter (mg/L)] |
|---|---|
| Slightly saline | 1,000 - 3,000 |
| Moderately saline | 3,000 - 10,000 |
| Very saline | 10,000 - 35,000 |
| Briny | More than 35,000 |

Water hardness is caused by polyvalent cations, primarily calcium and magnesium. Total hardness is defined as the sum of all polyvalent cations present in solution, expressed as the equivalent quantity of calcium carbonate.

The classification of hardness used by the U.S. Environmental Protection Agency (1976) is as follows:

| Description | Total hardness, mg/L as $CaCO_3$ |
|---|---|
| Soft | 0-75 |
| Moderately hard | 75-150 |
| Hard | 150-300 |
| Very hard | 300 |

The detrimental effects of hard water include use of extra soap and detergent to create suds, formation of scale deposits, yellowing of fabrics, and toughening of vegetables when cooked. No limit was recommended in the National Primary or Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1977). Recommended limits of total hardness for some industrial uses are listed in table 9.

Chloride in ground water may be derived from several sources including recharging rainwater, intrusion of saltwater into the aquifer, solution of minerals containing chloride, and from activities of man such as disposal of sewage or industrial waste. Aquifers also may contain salty water that in part is connate water (water of deposition) or that was introduced during high stands of the sea subsequent to deposition. In either case, such aquifers have not been completely flushed by freshwater circulation. Chloride in concentrations of 300 mg/L or more in combination with sodium gives a salty taste to water, and increases the corrosiveness of water.

Sulfate in ground water is derived from solution of rocks and soils containing gypsum, iron sulfides and other sulfur compounds. High sulfate concentrations are difficult to treat and may cause severe scaling problems in pipes and boilers, and in drinking water may produce undesirable laxative effects.

## Surficial Aquifer

Water in the surficial aquifer is generally of acceptable quality for most uses. It is low in dissolved mineral content, contains few impurities and generally does not require treatment. Near the coast and tidally affected streams, and in areas where saltwater intrusion has occurred, the water increases in mineral content and approaches that of saltwater.

In the upland areas and the western part of the study area, the water from the sand and shell zone contains less dissolved solids and is generally not as hard as water from other zones of the surficial aquifer. The sulfate concentration is low and the magnesium concentration is considerably less than the calcium concentration; however, the water is moderately to slightly acidic. In some places, iron concentrations exceed 0.3 mg/L, the recommended limit.

Causey and Phelps (1978, p. 28) presented field analyses of water from test wells tapping the sand and shell zone in Duval County. The range of selected constituents and properties of the water is listed below:

| Constituent or property | Range |
|---|---|
| Specific conductance | 42-340 micromhos per centimeter at 25°C |
| Iron | 0.02-12 mg/L |
| pH | 4.8-6.2 (units) |

Water in the sand and shell zone is of marginal quality for drinking throughout the coastal area where saline water is predominant. Local fresh, shallow, ground-water lenses containing potable water do occur in the area (Frazee and McClaugherty, 1980).

The chemical quality and physical properties of water from selected wells that tap the shallow rock zone are presented in table 10. Areal distribution of selected constituents are shown in figure 13. The quality of water in the shallow rock zone varies significantly between the upland areas near Yulee and the lowlands of the estuarine marsh and islands near the Intracoastal Waterway. The quality is similar to that of the freshwater of the sand and shell zone, but it is generally more mineralized. With the exception of locally high iron concentrations, water from wells tapping the shallow rock zone is generally potable except in areas where the aquifer has been intruded by seawater.

Little information is available on the water quality of the permeable limestone and sand beds in the upper part of the Hawthorn Formation. Water from these beds presently is used for some domestic and small irrigation supply; thus, the water is probably suitable for most purposes.

Table 10.--Chemical analyses of water from selected wells tapping the surficial aquifer

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DS-34, 3031250813715.01, Depth 100 feet | | | | | | | | | | | | | | | | |
| 1-19-68 | -- | 480 | 8.0 | 55 | 28 | 8.5 | 1.4 | -- | 246 | 300 | 12 | 0.4 | 0.4 | 252 | [a]257 | 0.9 |
| DS-82, 3035560813645.01, Depth 95 feet | | | | | | | | | | | | | | | | |
| 9-22-66 | 22.7 | 535 | 7.3 | 59 | 19 | 19 | 1.8 | -- | -- | 188 | 23 | 80 | .5 | 226 | [a]348 | -- |
| NS-14, 3035070813032.01, Depth 65 feet | | | | | | | | | | | | | | | | |
| 6-01-66 | -- | 600 | 8.1 | 65 | 23 | 18 | 3.0 | -- | -- | 194 | 24 | 92 | .5 | 257 | [a]402 | -- |
| NS-7, 3037020814302.01, Depth 65 feet | | | | | | | | | | | | | | | | |
| 6-08-66 | 22.7 | 560 | 8.2 | 64 | 24 | 23 | 5.1 | -- | -- | 272 | 19 | 54 | .6 | 259 | [b]362 | -- |
| NS-8, 3038000812801.01, Depth 100 feet | | | | | | | | | | | | | | | | |
| 6-08-66 | 23.3 | 800 | 8.0 | 119 | 5.6 | 48 | 1.4 | -- | -- | 346 | 97 | 0 | .3 | 321 | [b]488 | -- |
| NS-9, 3038040813615.01, Depth 146 feet | | | | | | | | | | | | | | | | |
| 6-08-66 | 22.2 | 510 | 7.5 | 92 | 4.1 | 13 | 1.5 | -- | -- | 312 | 17 | .4 | .2 | 247 | [b]314 | 1.4 |
| SJ-20, 3040000813800.01, Depth 54 feet | | | | | | | | | | | | | | | | |
| 1-03-79 | 17.5 | 352 | 7.7 | 60 | 11 | 11 | 1.1 | 0.5 | -- | 269 | 10 | 4.1 | .2 | -- | [b]234 | 1.2 |
| NCS-10, 3040410812710.01, Depth 100 feet | | | | | | | | | | | | | | | | |
| 5-25-65 | -- | 642 | 7.9 | 71 | 10 | 46 | 1.8 | -- | -- | 204 | 96 | 21 | .1 | 220 | [a]398 | .14 |
| NCS-0, 3040420812725.01, Depth 100 feet | | | | | | | | | | | | | | | | |
| 5-25-65 | -- | 6,620 | 7.8 | 266 | 77 | 1,060 | 14 | -- | -- | 430 | 1,750 | 488 | .1 | 980 | [a]4,070 | 1.1 |
| NS-2, 3040550812720.01, Depth 93 feet | | | | | | | | | | | | | | | | |
| 5-25-65 | -- | 768 | 8.0 | 80 | 36 | 30 | 2.1 | -- | -- | 192 | 49 | 176 | .6 | 348 | [a]608 | 0 |

Table 10.--Chemical analyses of water from selected wells tapping the surficial aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NS-15, 3044240814115.01, Depth 100 feet | | | | | | | | | | | | | | | | |
| 8-06-65 | -- | 390 | 7.9 | 52 | 15 | 9.8 | 1.3 | -- | -- | 226 | 8.0 | 6.4 | 0.4 | 190 | [a]214 | 0.01 |
| CS-1, 305809081434.01, Depth 26 feet | | | | | | | | | | | | | | | | |
| 4-16-65 | -- | 570 | 7.5 | 96 | 6.4 | 19 | .6 | -- | -- | 276 | 39 | 31 | .2 | 266 | [b]346 | -- |
| CS-2, 3047390814137.01, Depth 75 feet | | | | | | | | | | | | | | | | |
| 4-16-65 | -- | 308 | 7.6 | 50 | 4.1 | 9.1 | 1.1 | -- | -- | 165 | 15 | 8.0 | .3 | 142 | [b]179 | -- |

[a]Residue upon evaporation.
[b]Sum of constituents.

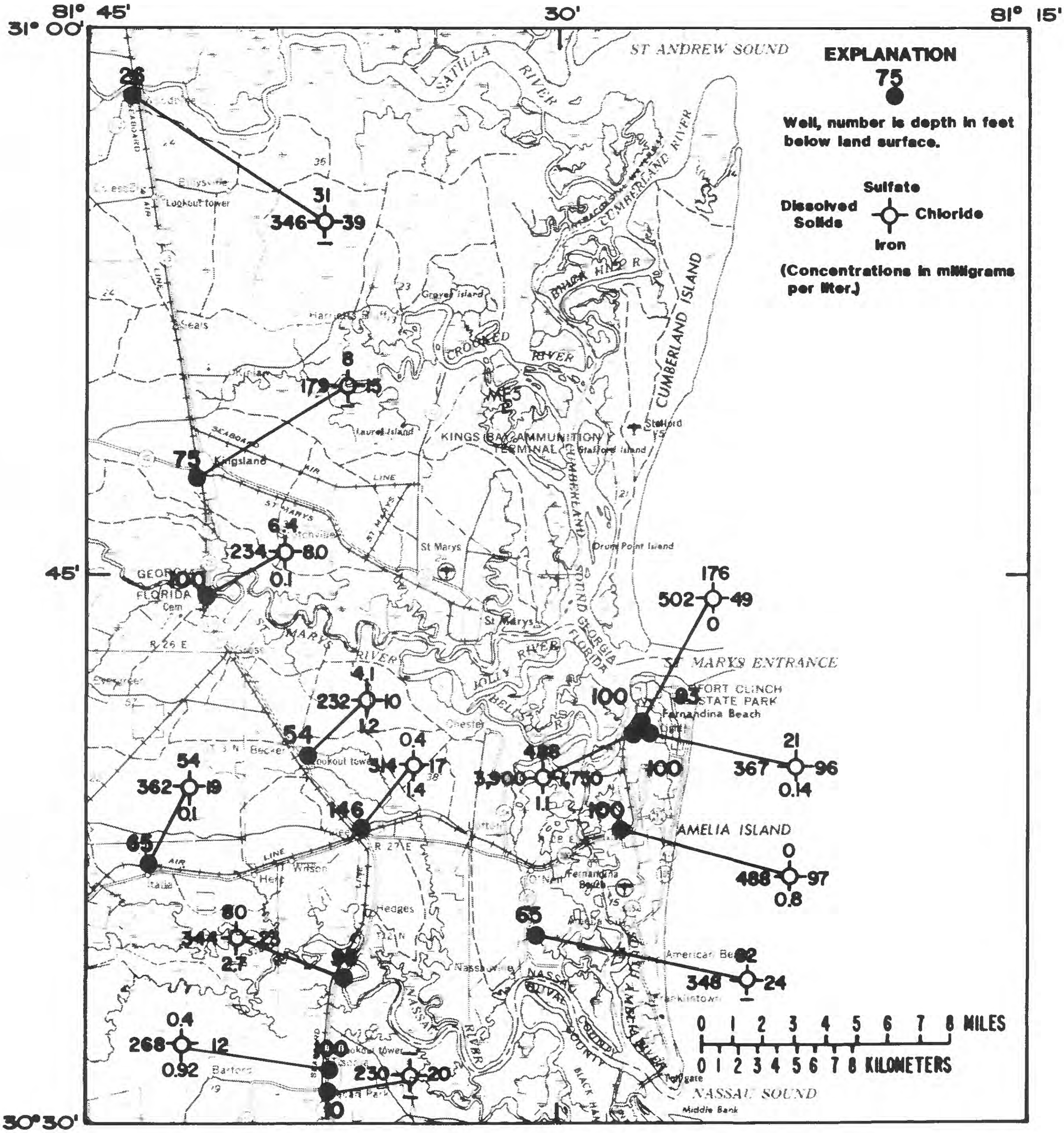



Figure 13.--Chemical analyses of water from selected wells tapping the surficial aquifer.

## Floridan Aquifer

Water in the Floridan aquifer is generally more mineralized and harder than water from the surficial aquifer. The concentrations of most chemical constituents vary within the aquifer both areally and vertically. Natural variations also exist within the individual water-bearing zones and are primarily related to the detailed lithologic and hydraulic characteristics of the individual water-bearing units within the larger water-bearing zones. Regionally, the water quality of water from wells tapping similar units or zones show some consistency. However, significant variations in concentrations of various chemical constituents may occur with depth within the larger water-bearing zones. Other factors such as length of pumping prior to sampling, pumping rate, period of time a well was inactive prior to sampling, adequacy of prior plugging, well construction, and interference effects from other wells may effect the water quality of samples from wells.

In the study area, most information on the quality of water in the Floridan aquifer is limited to the upper water-bearing zone. Few wells in the area penetrate more than 600 feet of the aquifer except in the Fernandina Beach-St. Marys area. In this area, probably less than 10 public and industrial supply wells penetrate from 700 to 1,300 feet of the aquifer tapping both upper and middle water-bearing zones. Only two exploratory-production wells (since destroyed), and one test-monitor well have penetrated the upper, middle, and lower water-bearing zones (about 1,600 feet of the aquifer).

### Upper Water-Bearing Zone

Representative chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer are presented in table 11. Additional historical data are available for some of the wells in table 11 and other wells in the area. The areal distribution of selected constituents is shown in figure 14. The wells sampled were less than 1,180 feet deep and generally cased to about 350 to 550 feet below land surface. Most water samples were collected at the well head.

The quality of water is fairly uniform in the study area. It is primarily a calcium-magnesium bicarbonate-sulfate type water with total hardness concentrations ranging from 240 to 340 mg/L. In general, the total hardness and mineral content of the water increase toward the north and coastal area. Dissolved solids concentrations range from less than 400 mg/L in the southwestern part to about 600 mg/L near the coast. Chloride concentrations generally range from about 20 to 25 mg/L in the southern and southwestern part of the study area to about 40 mg/L in the northern and coastal areas. Sulfate concentrations range from 100 to 190 mg/L, generally increasing to the north and east.

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D-77, 3030150813433.01, Depth 706 feet | | | | | | | | | | | | | | | | |
| 5-00-79 | 22.0 | 555 | 7.6 | 56 | 29 | 15 | 1.4 | .3 | -- | 188 | 25 | 100 | -- | 260 | [b]410 | -- |
| 5-03-77 | 23.5 | 415 | -- | 41 | 29 | 18 | 2.0 | 0.53 | -- | -- | -- | 92 | -- | 220 | -- | -- |
| D-401, 3032160814333.01, Depth - | | | | | | | | | | | | | | | | |
| 4-30-79 | 24.0 | 570 | -- | -- | -- | -- | -- | -- | -- | -- | 25 | -- | -- | 260 | -- | -- |
| 5-04-77 | 24.0 | 585 | -- | 61 | 30 | 16 | 1.9 | .57 | -- | 207 | 28 | 100 | -- | 280 | [b]440 | -- |
| D-411, 3034580813640.01, Depth 1,000 | | | | | | | | | | | | | | | | |
| 5-02-79 | 22.0 | 535 | -- | -- | -- | -- | -- | -- | -- | -- | 24 | -- | -- | 240 | -- | -- |
| 4-10-78 | 21.7 | 582 | 7.2 | 58 | 29 | 17 | 2.0 | .53 | 156 | 190 | 24 | 120 | 0.5 | 270 | [a]368 | 0.02 |
| 11-21-66 | 22.2 | 565 | 7.5 | 58 | 28 | 16 | 1.9 | -- | -- | 172 | 24 | 118 | .7 | 260 | -- | .11 |
| D-578, 3032440814343.01, Depth 450 feet | | | | | | | | | | | | | | | | |
| 9-05-79 | 24.0 | 590 | 7.5 | 62 | 27 | 16 | 1.6 | .42 | 140 | 171 | 23 | 110 | .6 | 270 | [a]384 | -- |
| D-753, 3031040812844.01, Depth 600 feet | | | | | | | | | | | | | | | | |
| 4-30-79 | 22.5 | 535 | -- | -- | -- | -- | -- | -- | -- | -- | 23 | -- | -- | 240 | [c]370 | -- |
| N-2, 3035190812753.01, Depth 580 feet | | | | | | | | | | | | | | | | |
| 4-04-78 | 22.8 | 608 | 7.2 | 57 | 30 | 19 | 2.3 | .61 | 156 | 190 | 25 | 130 | .6 | 270 | [b]450 | -- |
| 10-08-70 | -- | -- | -- | 62 | 28 | -- | -- | -- | 144 | 175 | 27 | 182 | -- | 274 | [a]430 | -- |
| 3-25-65 | 22.8 | 562 | 7.8 | 61 | 30 | 18 | 2.1 | -- | 162 | 198 | 25 | 116 | .5 | 276 | [b]379 | -- |

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | N-8, 3032440812637.01, Depth 680 feet | | | | | | | | | | |
| 5-02-79 | 23.0 | 570 | -- | -- | -- | -- | -- | -- | -- | -- | 24 | -- | -- | 270 | -- | -- |
| 4-04-78 | 22.8 | 587 | 7.3 | 56 | 30 | 17 | 2.2 | 0.61 | 156 | 190 | 24 | 120 | 0.5 | 260 | [b]440 | -- |
| 10-08-70 | -- | -- | 7.5 | 68 | 22 | -- | -- | -- | 144 | 175 | 27 | 163 | .8 | 264 | [a]415 | -- |
| | | | | | | N-9, 3034570812715.01, Depth 586 feet | | | | | | | | | | |
| 5-05-77 | -- | 615 | -- | -- | -- | -- | -- | -- | -- | -- | 29 | -- | -- | 280 | [c]430 | -- |
| | | | | | | N-12, 3038010812737.01, Depth 640 feet | | | | | | | | | | |
| 12-05-75 | 20.5 | 580 | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 262 | [c]410 | -- |
| | | | | | | N-16, 3038200812615.01, Depth 630 feet | | | | | | | | | | |
| 12-26-75 | 22.5 | 680 | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 322 | [c]480 | -- |
| | | | | | | N-19, 3042130812708.01, Depth 710 feet | | | | | | | | | | |
| 10-04-77 | -- | -- | -- | 74 | 37 | 22 | 2.2 | .65 | -- | -- | 31 | 160 | .5 | 340 | -- | 0.03 |
| 12-28-75 | 24.0 | 700 | -- | -- | -- | -- | -- | -- | -- | -- | 32 | -- | -- | 336 | [c]490 | -- |
| | | | | | | N-20, 3039390813126.01, Depth 567 feet | | | | | | | | | | |
| 5-04-77 | -- | 610 | -- | -- | -- | -- | -- | -- | -- | -- | 23 | -- | -- | 290 | [c]430 | -- |
| 12-19-75 | 22.0 | 610 | -- | -- | -- | -- | -- | -- | -- | -- | 25 | -- | -- | 292 | -- | -- |
| 5-01-62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 34 | -- | -- | -- | -- | -- |
| | | | | | | N-22, 3039400812818.01, Depth 1,100 feet | | | | | | | | | | |
| 5-13-75 | -- | 670 | -- | -- | -- | -- | -- | -- | -- | -- | 28 | -- | -- | 314 | [c]470 | -- |

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-24A, 3040200812720.01, Depth 1,100 (1,215?) feet | | | | | | | | | | | | | | | | |
| 4-05-78 | 22.6 | 705 | 7.3 | 53 | 32 | 37 | 7.7 | 1.0 | -- | 200 | 25 | 140 | 0.6 | 284 | [b]500 | 0.02 |
| 6-17-71 | -- | 710 | 7.3 | 66 | 36 | 28 | 3.2 | -- | 180 | 220 | 35 | 170 | .7 | 314 | [a]491 | -- |
| 4-03-64 | 23.0 | -- | 7.4 | 57 | 34 | -- | -- | -- | 178 | 217 | 27 | 216 | .6 | 248 | [a]492 | -- |
| N-28, 3037430812900.01, Depth 578 feet | | | | | | | | | | | | | | | | |
| 4-11-78 | 22.5 | 611 | 7.3 | 62 | 33 | 21 | 2.6 | .70 | 164 | 200 | 30 | 140 | -- | 290 | [b]490 | -- |
| N-30, 3039210812746.01, Depth 750 feet | | | | | | | | | | | | | | | | |
| 4-05-78 | 23.2 | 965 | 7.2 | 77 | 40 | 51 | 3.0 | .78 | 170 | 210 | 109 | 160 | .5 | 380 | [b]650 | 0 |
| 6-13-62 | -- | 676 | 7.5 | 72 | 33 | 22 | 2.0 | -- | 172 | 210 | 30 | 144 | .7 | 360 | [a]507 | -- |
| N-31, 3038120812737.01, Depth 1,000 feet | | | | | | | | | | | | | | | | |
| 5-13-75 | -- | 661 | -- | -- | -- | -- | -- | -- | -- | -- | 32 | -- | -- | 308 | [c]460 | -- |
| N-32, 3038360812742.01, Depth 1,070 feet | | | | | | | | | | | | | | | | |
| 7-08-75 | -- | 660 | -- | -- | -- | -- | -- | -- | -- | -- | 28 | -- | -- | 312 | [c]460 | -- |
| N-35, 3039350812837.01, Depth 1,062 feet | | | | | | | | | | | | | | | | |
| 4-06-78 | 24.0 | 736 | 7.2 | 64 | 35 | 27 | 2.6 | .7 | 172 | 210 | 44 | 160 | .5 | 332 | [b]540 | 0 |
| 5-13-75 | -- | 709 | -- | -- | -- | -- | -- | -- | -- | -- | 36 | -- | -- | 336 | -- | -- |
| N-38A, 3041360812733.01, Depth 600 feet | | | | | | | | | | | | | | | | |
| 5-04-77 | -- | 710 | -- | -- | -- | -- | -- | -- | -- | -- | 34 | -- | -- | 340 | [c]500 | -- |

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-44, 3037540813627.01, Depth 1,000 feet | | | | | | | | | | | | | | | | |
| 9-07-77 | 24.1 | 654 | 7.2 | 62 | 37 | 18 | 2.1 | 0.65 | 170 | 200 | 26 | 140 | -- | 300 | [b]490 | 0.08 |
| 5-12-75 | -- | 615 | -- | -- | -- | -- | -- | -- | -- | -- | 28 | -- | -- | 312 | [c]430 | -- |
| 3-25-75 | 24.4 | 612 | 7.2 | 64 | 35 | 18 | 2.2 | -- | -- | 196 | 28 | 144 | 0.5 | 304 | [b]490 | .03 |
| N-45, 3039450813125.01, Depth 500 feet | | | | | | | | | | | | | | | | |
| 4-10-78 | 22.3 | 702 | 7.3 | 65 | 35 | 21 | 2.5 | .63 | 172 | 210 | 28 | 160 | .5 | 310 | [b]520 | -- |
| 5-06-74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 32 | -- | -- | 302 | -- | -- |
| 3-29-67 | 22.8 | 640 | 7.6 | 68 | 36 | 21 | 2.1 | -- | -- | 194 | 31 | 154 | .8 | 318 | [a]466 | .07 |
| N-46, 3034350812714.01, Depth 1,016 feet | | | | | | | | | | | | | | | | |
| 2-28-80 | 20.0 | 575 | 8.0 | 58 | 32 | 18 | 2.3 | .57 | 150 | -- | 24 | 120 | .7 | 280 | [a]382 | -- |
| 4-04-78 | 23.0 | 614 | 7.4 | 53 | 31 | 18 | 1.9 | .61 | 156 | 190 | 24 | 130 | .6 | 260 | [b]450 | -- |
| N-50, 3036580814226.01, Depth 569 feet | | | | | | | | | | | | | | | | |
| 5-04-79 | 22.0 | 550 | -- | -- | -- | -- | -- | -- | -- | -- | 24 | -- | -- | 280 | [c]385 | -- |
| 5-12-75 | -- | 560 | -- | -- | -- | -- | -- | -- | -- | -- | 26 | -- | -- | 280 | [c]390 | -- |
| 5-01-70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 25 | -- | -- | 272 | -- | -- |
| 3-26-65 | 22.4 | 560 | 7.5 | 61 | 29 | 17 | 1.8 | -- | 147 | 179 | 25 | 119 | .5 | 273 | [a]369 | .04 |
| N-53, 3040020813812.01, Depth 500 feet | | | | | | | | | | | | | | | | |
| 5-01-79 | 22.5 | 640 | -- | -- | -- | -- | -- | -- | -- | -- | 28 | -- | -- | 320 | [c]450 | -- |
| 5-12-75 | -- | 642 | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 334 | [c]450 | -- |
| N-54, 3037220812954.01, Depth 482 feet | | | | | | | | | | | | | | | | |
| 5-04-77 | -- | 645 | -- | -- | -- | -- | -- | -- | -- | -- | 29 | -- | -- | 300 | [c]450 | -- |

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-57, 3035220813514.01, Depth 550 feet | | | | | | | | | | | | | | | | |
| 5-03-78 | 28.0 | 560 | -- | -- | -- | -- | -- | -- | -- | -- | 24 | -- | -- | 270 | [c]390 | -- |
| N-58, 3038400812735.01, Depth 1,000 feet | | | | | | | | | | | | | | | | |
| 5-01-79 | 23.5 | 620 | -- | -- | -- | -- | -- | -- | -- | -- | 28 | -- | -- | 310 | [c]430 | -- |
| N-60, 3039400812857.01, Depth 1,070 feet | | | | | | | | | | | | | | | | |
| 5-13-75 | -- | 678 | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 328 | [c]470 | -- |
| N-62DD, 3038230812733.03, Depth 1,100 feet | | | | | | | | | | | | | | | | |
| 4-06-78 | 24.0 | 986 | 7.2 | 67 | 41 | 68 | 1.6 | 0.8 | 164 | 200 | 130 | 170 | 0.6 | 375 | [b]680 | 0.01 |
| 7-08-75 | 24.0 | 895 | -- | -- | -- | -- | -- | -- | -- | -- | 98 | -- | -- | 356 | -- | -- |
| N-65, 3040410812705.02, Dept 1,060 feet | | | | | | | | | | | | | | | | |
| 5-14-75 | -- | 745 | -- | -- | -- | -- | -- | -- | -- | -- | 54 | -- | -- | 360 | [c]520 | -- |
| N-66, 3041030812700.02, Depth 1,032 feet (plugged back from 1,404 feet in 1975) | | | | | | | | | | | | | | | | |
| 5-02-79 | 24.5 | 720 | -- | -- | -- | -- | -- | -- | -- | -- | 34 | -- | -- | 340 | [c]500 | -- |
| 4-07-78 | 25.0 | 733 | 7.2 | 70 | 37 | 23 | 2.7 | .76 | 170 | 200 | 33 | 180 | .5 | 330 | [b]550 | .01 |
| 5-09-78 | 25.5 | 695 | -- | -- | -- | -- | -- | -- | -- | -- | 32 | -- | -- | 340 | [c]490 | -- |
| N-67, 3043170813723.01, Depth - | | | | | | | | | | | | | | | | |
| 5-01-79 | 21.5 | 710 | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 330 | [c]500 | -- |
| 12-19-75 | 21.0 | 700 | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 332 | [c]490 | -- |
| N-68, 3039580812804.01, Depth 1,050 feet | | | | | | | | | | | | | | | | |
| 5-05-77 | -- | 740 | -- | -- | -- | -- | -- | -- | -- | -- | 40 | -- | -- | 350 | [c]520 | -- |

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-69, 3040530812725.01, Depth 1,161 feet | | | | | | | | | | | | | | | | |
| 12-19-75 | -- | 795 | -- | -- | -- | -- | -- | -- | -- | -- | 53 | -- | -- | 350 | [c]560 | -- |
| N-70, 3042040812727.01, Depth 660 feet | | | | | | | | | | | | | | | | |
| 12-28-75 | -- | 710 | -- | -- | -- | -- | -- | -- | -- | -- | 34 | -- | -- | 336 | [c]500 | -- |
| N-72, 3035570812710.01, Depth 610 feet | | | | | | | | | | | | | | | | |
| 5-05-77 | -- | 645 | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 310 | [c]450 | -- |
| N-76, 3031190812649.01, Depth - | | | | | | | | | | | | | | | | |
| 5-07-76 | -- | 490 | -- | -- | -- | -- | -- | -- | -- | -- | 21 | -- | -- | 240 | [c]340 | -- |
| N-92, 3041280812733.01, Depth 500 feet | | | | | | | | | | | | | | | | |
| 12-19-75 | -- | 700 | -- | -- | -- | -- | -- | -- | -- | -- | 32 | -- | -- | 320 | [c]490 | -- |
| N-96, 3043150813712.01, Depth - | | | | | | | | | | | | | | | | |
| 5-04-77 | -- | 720 | -- | -- | -- | -- | -- | -- | -- | -- | 33 | -- | -- | 340 | [c]500 | -- |
| 5-12-75 | -- | 665 | -- | -- | -- | -- | -- | -- | -- | -- | 32 | -- | -- | 348 | -- | -- |
| 5-01-70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 30 | -- | -- | 320 | -- | -- |
| N-97, 3034300813626.01, Depth 600 feet | | | | | | | | | | | | | | | | |
| 5-04-77 | -- | 608 | -- | -- | -- | -- | -- | -- | -- | -- | 29 | -- | -- | 270 | [c]430 | -- |
| N-100, 3034030813113.0I, Depth 672 feet | | | | | | | | | | | | | | | | |
| 9-07-77 | 22.7 | 578 | 7.1 | 58 | 30 | 16 | 2.0 | 0.50 | 160 | 190 | 22 | 120 | -- | 270 | [b]440 | 0.06 |
| 5-09-66 | -- | 570 | 7.9 | 58 | 29 | 16 | 1.5 | -- | -- | 181 | 26 | 108 | 0.8 | 268 | [a]400 | .01 |

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-102, 3036550812654.01, Depth 800 (1,200?) feet | | | | | | | | | | | | | | | | |
| 4-05-78 | 23.0 | 663 | -- | -- | -- | -- | -- | -- | -- | -- | 33 | -- | -- | 290 | [c]460 | -- |
| N-106, 3038050812739.01, Depth 1,101 feet | | | | | | | | | | | | | | | | |
| 4-12-78 | 25.0 | 1,160 | 7.7 | 65 | 47 | 97 | 3.9 | 0.92 | 139 | 170 | 194 | 160 | 0.6 | 220 | [b]740 | -- |
| 9-11-75 (Downhole sampler) | | | | | | | | | | | | | | | | |
| (600 feet) | -- | 690 | -- | -- | -- | -- | -- | -- | -- | -- | 80 | -- | -- | 268 | -- | -- |
| (925 feet) | -- | 1,240 | -- | -- | -- | -- | -- | -- | -- | -- | 245 | -- | -- | 410 | -- | -- |
| N-110DD, 3041100812720.03, Depth 1,076 feet (plugged back from 1,250 feet in 1976) | | | | | | | | | | | | | | | | |
| 4-07-78 | 25.5 | 844 | 7.1 | 71 | 38 | 36 | 3.0 | .82 | 164 | 200 | 60 | 190 | .5 | 340 | [b]600 | 0.01 |
| N-111D, 3040580812730.01, Depth 1,019 feet | | | | | | | | | | | | | | | | |
| 4-07-78 | 25.0 | 743 | 7.3 | 69 | 37 | 25 | 2.7 | .76 | 164 | 200 | 35 | 180 | .5 | 336 | [b]550 | .01 |
| 5-14-75 | -- | 700 | -- | -- | -- | -- | -- | -- | -- | -- | 38 | -- | -- | 340 | -- | -- |
| N-113, 3033440812659.01, Depth 1,016 feet | | | | | | | | | | | | | | | | |
| 7-08-75 | 24.0 | 570 | -- | -- | -- | -- | -- | -- | -- | -- | 22 | -- | -- | -- | -- | -- |
| C-4, 3047390813431.01, Depth 894 feet | | | | | | | | | | | | | | | | |
| 9-26-69 | -- | 714 | 7.8 | 73 | 38 | 25 | 2.2 | -- | 169 | 206 | 38 | 150 | .6 | 339 | [a]481 | -- |
| C-5, 3047530814125.01, Depth 548 feet | | | | | | | | | | | | | | | | |
| 11-26-59 | -- | 735 | 7.7 | 79 | 36 | 22 | 2.6 | -- | 162 | 198 | 32 | 185 | .1 | 345 | [a]568 | -- |
| C-6, 3055420814224.01, Depth 566 feet | | | | | | | | | | | | | | | | |
| 8-05-69 | -- | 610 | 7.9 | 56 | 29 | 29 | 3.2 | -- | 148 | 180 | 38 | 106 | .6 | 260 | [a]403 | -- |

Table 11.--Chemical analyses of water from wells tapping the upper water-bearing zone of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C-7, 3058040814413.01, Depth 877 feet | | | | | | | | | | | | | | | | |
| 8-05-69 | -- | 700 | 8.1 | 63 | 32 | 33 | 2.6 | -- | 157 | 192 | 52 | 116 | 0.5 | 289 | [a]449 | -- |
| C-16, 3045220812817.01, Depth 645 feet | | | | | | | | | | | | | | | | |
| 8-14-79 | -- | -- | 7.4 | 67 | 40 | 26 | 3.0 | -- | 161 | 196 | 38 | 169 | .7 | 332 | 472 | -- |
| 9-16-80 | 23.0 | 740 | -- | -- | -- | -- | -- | -- | -- | -- | 34 | 190 | -- | -- | [c]520 | -- |
| C-17, 3046170812806.01, Depth - | | | | | | | | | | | | | | | | |
| 9-16-80 | 22.0 | 750 | -- | -- | -- | -- | -- | -- | -- | -- | 31 | 180 | -- | -- | [c]525 | -- |
| C-18, 3046460812807.01, Depth 730 | | | | | | | | | | | | | | | | |
| 9-16-80 | 24.5 | 730 | -- | -- | -- | -- | -- | -- | -- | -- | 37 | 170 | -- | -- | [c]510 | -- |
| C-19, 3050170812801.01, Depth - | | | | | | | | | | | | | | | | |
| 9-16-80 | 23.0 | 710 | -- | -- | -- | -- | -- | -- | -- | -- | 37 | 160 | -- | -- | [c]500 | -- |
| C-20, 3051220812756.01, Depth - | | | | | | | | | | | | | | | | |
| 9-16-80 | 24.0 | 720 | -- | -- | -- | -- | -- | -- | -- | -- | 38 | 170 | -- | -- | [c]500 | -- |
| C-21, 3051220812756.02, Depth - | | | | | | | | | | | | | | | | |
| 9-16-80 | 24.5 | 730 | -- | -- | -- | -- | -- | -- | -- | -- | 38 | 170 | -- | -- | [c]510 | -- |
| C-22, 3051440812553.01, Depth - | | | | | | | | | | | | | | | | |
| 9-16-80 | 23.5 | 710 | -- | -- | -- | -- | -- | -- | -- | -- | 37 | 170 | -- | -- | [c]500 | -- |
| SM-9, 3044080813234.01, Depth 1,041 | | | | | | | | | | | | | | | | |
| 4-11-78 | 25.2 | 746 | 7.2 | 72 | 37 | 25 | 2.7 | 0.74 | 170 | 210 | 36 | 170 | .5 | 330 | [b]550 | 0.01 |

[a]Residue upon evaporation.
[b]Sum of constituents.
[c]Estimate based on specific conductance.

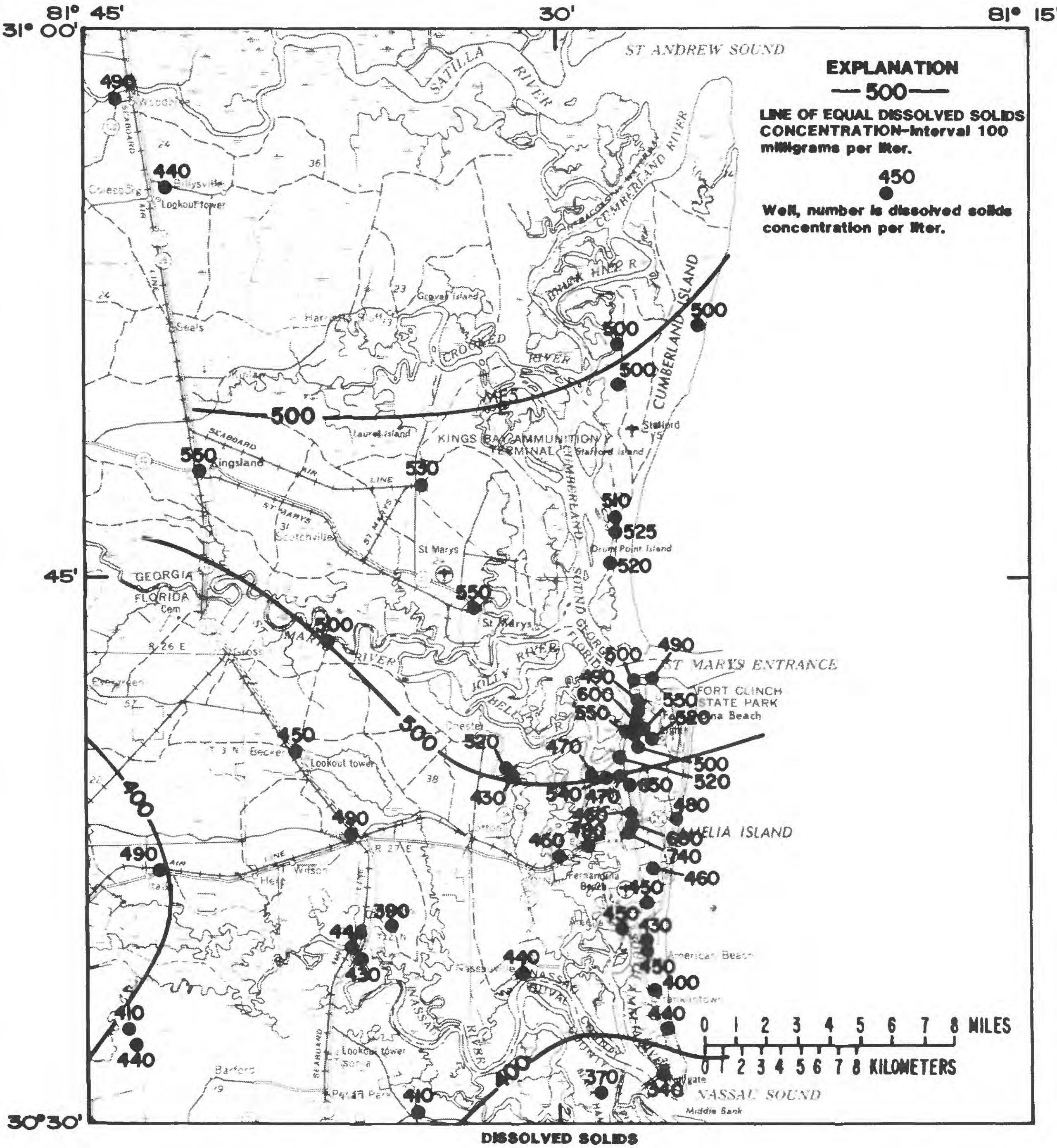



Figure 14.--Areal distribution of selected chemical constituents of water from wells tapping the upper water-bearing zone of the Floridan aquifer, 1975-80.

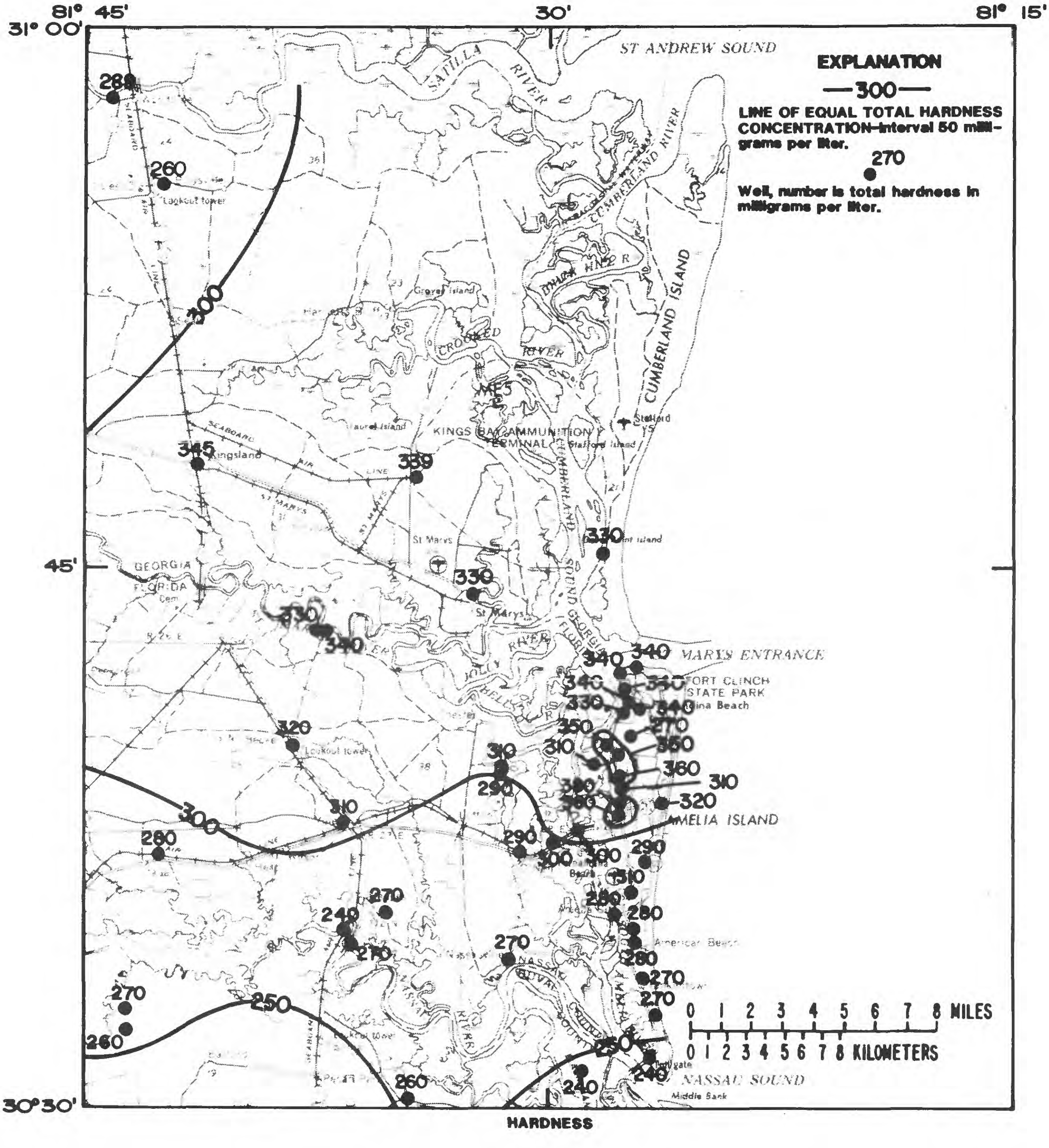



Figure 14.--Areal distribution of selected chemical constituents of water from wells tapping the upper water-bearing zone of the Floridan aquifer, 1975-80.--Continued

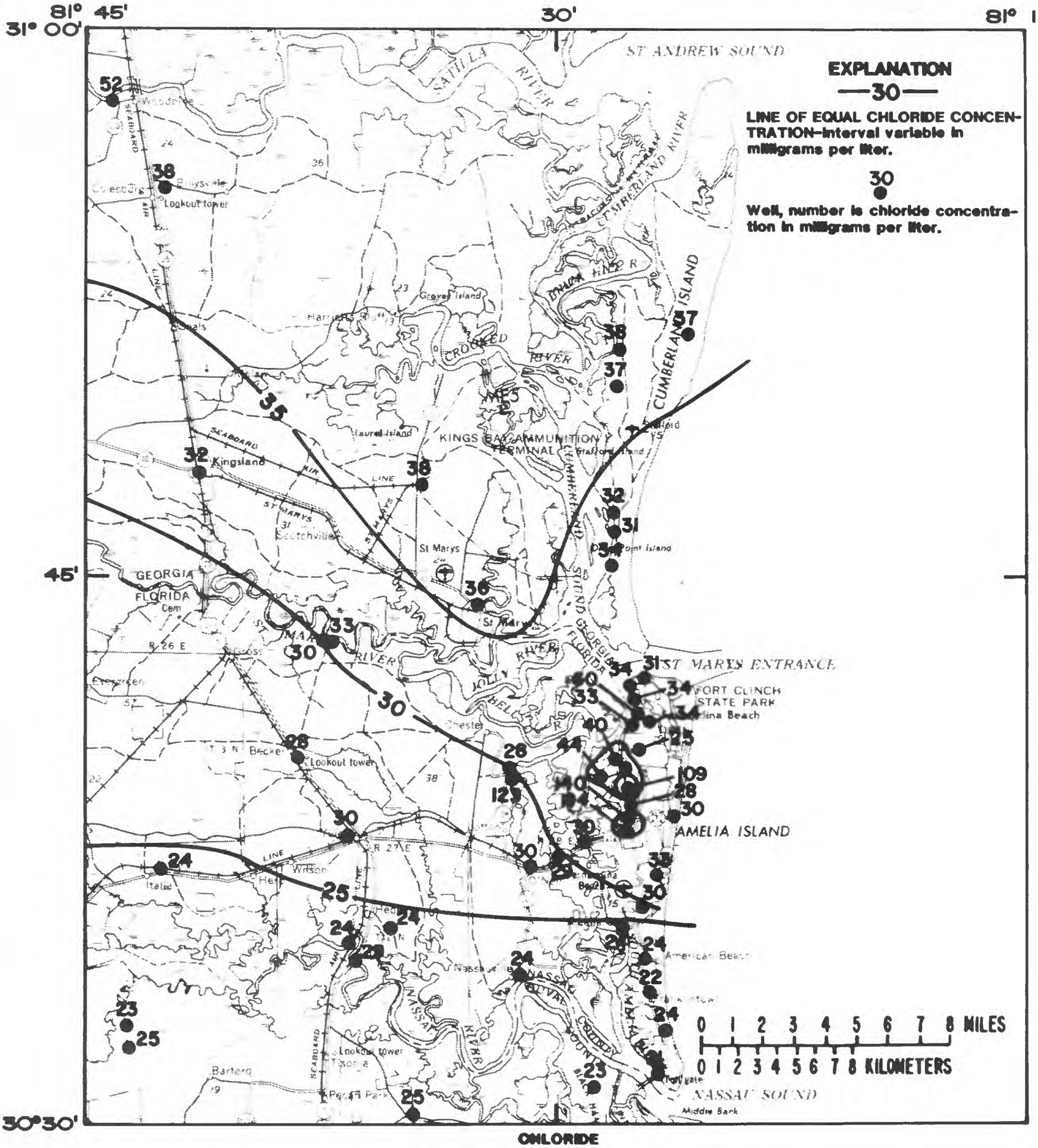



Figure 14.--Areal distribution of selected chemical constituents of water from wells tapping the upper water-bearing zone of the Floridan aquifer, 1975-80.--Continued

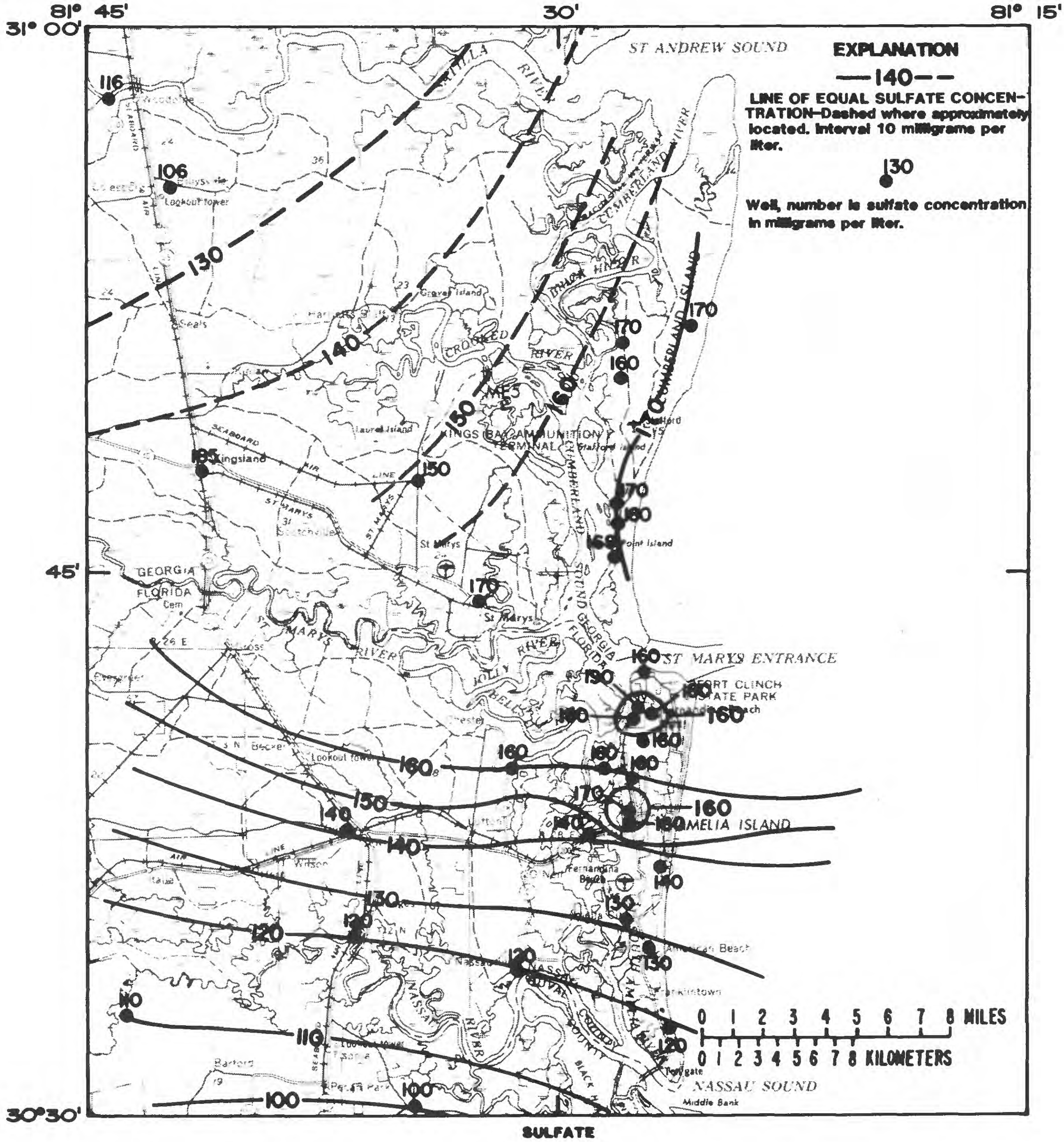



Figure 14.--Areal distribution of selected chemical constituents of water from wells tapping the upper water-bearing zone of the Floridan aquifer, 1975-80.--Continued

In the Fernandina Beach area, about four wells that draw from the upper water-bearing zone but may not exclusively, have water generally more mineralized and slightly harder than water from nearby wells. Dissolved solids concentrations range from about 600 to 740 mg/L; total hardness as $CaCO_3$ ranges from about 340 to 380 mg/L; chloride concentrations range from 60 to about 190 mg/L; and sulfate concentrations range from 160 to 190 mg/L. The increase in dissolved mineral content probably results from interzone flow through the well bore of wells tapping deeper and more mineralized water or wells having uneffective plugs or seals that previously penetrated deeper zones.

## Middle Water-Bearing Zone

Within the study area, no wells exclusively tap the middle water-bearing zone. From 1945 to 1978, as many as 14 wells in the Fernandina Beach-St. Marys area penetrated both the upper and middle water-bearing zones. In 1979, only 6 wells penetrated both zones. The remaining wells were either plugged to land surface or plugged to depths less than 1,200 feet below land surface. The water from wells that penetrate both zones of the aquifer is generally more mineralized and harder than water from wells that penetrate only the upper zone (table 12). These multizone wells range in depth from about 1,200 to 1,800 feet below land surface and are cased to depths of 550 to 600 feet. Analyses were performed on water samples collected at the well head and thus represent composites of water derived from both zones. The exact quantity of water derived from each zone is not known.

During construction of test wells in 1945, 1959, and 1979, water samples were collected at selected depth intervals or through the drill stem as the wells were deepened. Table 13 presents the chemical analyses of water sampled at selected depth intervals by packer tests during drilling of well N-62 in 1945 (Scofield, 1945). The water quality in the middle water-bearing zone (about 1,200 to 1,700 feet deep) varied with depth, but it was more mineralized and harder than water from the upper water-bearing zone. Chloride concentrations ranged from 36 mg/L at a depth of 1,500 to 1,530 feet to 153 mg/L at a depth of 1,260 to 1,320 feet. Sulfate, total hardness, and total solids concentrations showed similar variations.

Table 14 shows the concentrations of chloride and total hardness of water sampled from the drill stem as the well was deepened from 1,564 to 2,130 feet. Relatively high concentrations of chloride and total hardness were detected at 1,592 and 1,623 feet within the middle water-bearing zone. Chloride concentrations were 140 and 125 mg/L and total hardness concentrations were 632 and 587 mg/L, respectively. These results are not always indicative of the true quality of water in the formation. This is because some water could move down the borehole to the drill bit from zones already penetrated during drilling. This is especially true when drilling through less permeable to impermeable formations or zones.

Table 12.--Chemical analyses of water from wells tapping the upper and middle water-bearing zones of the Floridan aquifer

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-7, 3040200812720.05, Depth 1,215 feet | | | | | | | | | | | | | | | | |
| 2-28-80 | 25.5 | 775 | 7.4 | 74 | 40 | 31 | 2.4 | 0.77 | 160 | -- | 49 | 180 | 0.6 | 350 | [a]512 | -- |
| 6-09-75 | -- | 760 | 7.9 | 76 | 39 | 26 | 2.3 | .93 | 151 | 184 | 56 | 170 | .7 | 350 | [a]578 | .02 |
| N-39D, 3039470812754.02, Depth 1,700 feet | | | | | | | | | | | | | | | | |
| 4-06-78 | 27.5 | 1,170 | 7.4 | 93 | 52 | 1.4 | 3.4 | .94 | 164 | 200 | 146 | 240 | .5 | 450 | [c]819 | 0.000 |
| 7-08-75 | 28.5 | 1,100 | -- | -- | -- | -- | -- | -- | -- | -- | 136 | -- | -- | 448 | -- | -- |
| 7-22-70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 94 | -- | -- | 435 | -- | -- |
| N-41D, 3039330812746.02, Depth 1,840 feet (ITT Rayonier) | | | | | | | | | | | | | | | | |
| 7-15-75 | 28.2 | 2,340 | -- | -- | -- | -- | -- | -- | -- | -- | 500 | -- | -- | 596 | -- | -- |
| 7-22-70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 340 | -- | -- | 532 | -- | -- |
| N-43D, 3039020812739.02, Depth 1,820 feet | | | | | | | | | | | | | | | | |
| 7-08-75 | 27.5 | 3,500 | -- | -- | -- | -- | -- | -- | -- | -- | 892 | -- | -- | 792 | -- | -- |
| 1973 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 475 | 266 | -- | 585 | 1,581 | -- |
| 7-22-70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 407 | -- | -- | 407 | -- | -- |
| N-47, 3040410812705.01, Depth 1,260 feet (Container) | | | | | | | | | | | | | | | | |
| 7-10-78 | -- | 1,320 | 7.7 | 92 | 52 | 90 | -- | -- | -- | -- | 179 | 216 | -- | 440 | 950 | -- |
| N-62D, 3038230812733.01, Depth 1,826 feet | | | | | | | | | | | | | | | | |
| 6-13-62 | 27.8 | 4,490 | 7.6 | 212 | 100 | 688 | 10 | -- | 148 | 180 | 1,150 | 400 | .7 | 940 | [b]3,020 | -- |
| N-82, 3041090812655.01, Depth 1,404 feet | | | | | | | | | | | | | | | | |
| 3-25-65 | 28.9 | 2,000 | 7.1 | 140 | 77 | 175 | 5.8 | -- | -- | 176 | 359 | 372 | .9 | 668 | [b]1,250 | .29 |
| N-110D, 3041100812720.02, Depth 1,408 feet, plugged back to 1,250 feet in 1965 | | | | | | | | | | | | | | | | |
| 5-25-65 | -- | 1,590 | 8.1 | 118 | 67 | 122 | 4.6 | -- | -- | 182 | 260 | 306 | .7 | 570 | [a]1,122 | .01 |

Table 12.--Chemical analyses of water from wells tapping the upper and middle water-bearing zones of the Floridan aquifer--Continued

[All values are in milligrams per liter unless otherwise indicated]

| Date sampled | Temperature (°C) | Specific conductance (umhos/cm) | pH (units) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Strontium (Sr) | Alkalinity (as $CaCO_3$) | Bicarbonate ($HCO_3$) | Chloride (Cl) | Sulfate ($SO_4$) | Fluoride (F) | Hardness, total (as $CaCO_3$) | Dissolved solids | Iron, dissolved (Fe) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-110D, 3041100822720.02, Depth 1,250 feet | | | | | | | | | | | | | | | | |
| 7-15-75 | 29.4 | 2,620 | -- | -- | -- | -- | -- | -- | -- | -- | 518 | -- | -- | 776 | -- | -- |
| SM-6, 3044140813325.01, Depth 1,259 feet | | | | | | | | | | | | | | | | |
| 4-11-78 | 28.0 | 738 | 7.2 | 69 | 36 | 24 | 2.5 | 0.74 | 170 | 210 | 32 | 180 | 0.5 | 320 | -- | 0.01 |

[a] Residue upon evaporation.
[b] Sum of constituents.
[c] Estimate based on specific conductance.

Table 13.--Chemical analyses of water from selected depth intervals during drilling of well N-62 at Fernandina Beach

| Depth interval | Total solids (mg/L) | Total hardness as $CaCO_3$ (mg/L) | Chloride Cl (mg/L) | Sulfate $SO_4$ (mg/L) | Alkalinity as $CaCO_3$ (mg/L) | pH (units) |
|---|---|---|---|---|---|---|
| | | | Packer tests | | | |
| 1100-1130 | 423 | 270 | 26 | 136 | -- | 7.8 |
| 1200-1230 | 529 | 323 | 43 | 162 | 162 | 7.7 |
| 1260-1320 | 1,022 | 586 | 153 | 360 | 152 | 7.5 |
| 1380-1410 | 676 | 402 | 62 | 230 | 159 | 7.4 |
| 1500-1530 | 518 | 342 | 36 | 175 | 161 | 7.3 |
| 1770-1802 | 547 | 328 | 39 | 170 | 165 | 7.4 |
| | | | Composite samples | | | |
| 567-1050 | 495 | 329 | 29 | 168 | 165 | 7.9 |
| 567-1410 | 750 | 449 | 91 | 264 | -- | 7.4 |
| 567-1802 | 860 | 515 | 96 | 317 | -- | 7.3 |
| 567-2130 | 909 | 519 | 102 | 325 | -- | 7.2 |

Table 14.--Concentrations of chloride and total hardness of water obtained through the drill stem as well N-62 was deepened from 1,564 to 2,130 feet

| Depth of well (ft) | Chloride (mg/L) | Total hardness as $CaCO_3$ (mg/L) | Depth of well (ft) | Chloride (mg/L) | Total hardness as $CaCO_3$ (mg/L) |
|---|---|---|---|---|---|
| 1,564 | 70 | 414 | 1,860 | 57 | 384 |
| 1,592 | 140 | 632 | 1,890 | 58 | 385 |
| 1,623 | 125 | 587 | 1,921 | 57 | -- |
| 1,653 | 80 | 457 | 1,950 | 53 | 363 |
| 1,684 | 55 | 376 | 1,978 | 53 | -- |
| 1,713 | 60 | 388 | 2,008 | -- | 346 |
| 1,742 | 60 | 393 | 2,039 | 55 | 367 |
| 1,770 | 60 | 399 | 2,101 | 126 | 543 |
| 1,830 | 58 | 384 | 2,130 | 120 | -- |

Composite water samples were also collected at land surface as the well was deepened. Partial chemical analyses were made of samples at depth intervals of 567-1,050 feet, 567-1,410 feet, and 567-1,802 feet (table 13). The mineral content and hardness increased substantially as the well was deepened from 1,050 to 1,410 feet. Chloride concentrations increased from 29 to 91 mg/L and total hardness, from 329 to 449 mg/L. From 1,410 to 1,802 feet, the mineral content and hardness increased only slightly, probably because this interval produced little additional water to the well bore.

Well N-88, originally drilled to a depth of 1,140 feet and cased to 580 feet was deepened to 2,105 feet and cased to 1,432 feet in 1959 (R. W. Harden and Associates, 1979). The well was deepened using the air lift reverse-circulation method and water samples were collected during drilling. Concentrations of chloride and total hardness as $CaCO_3$ ranged from 31 to 348 mg/L and from 250 to 670 mg/L, respectively. Relatively high chloride concentrations (109 to 348 mg/L) were detected at a depth interval of 1,240 to 1,460 feet. Below 1,460 feet to a depth of about 1,800 feet, chloride concentration varied and ranged from 36 to 72 mg/L. Total hardness showed similar variations with depth ranging from 282 to 492 mg/L. The depth intervals in which higher concentrations of chloride and total hardness occurred were similar to those detected in well N-62 in 1945.

In 1979, test well N-117 was completed to a depth of 2,102 feet below land surface. Water samples were obtained through the drill stem during drilling by reverse air rotary method from 632 to 2,094 feet. Table 15 lists the chloride concentrations of water during drilling from 632 to 2,094 feet and table 16 lists specific conductance of water during drilling from 1,476 to 2,080 feet.

Chloride concentrations ranged from 25 to 35 mg/L to a depth of 1,071 feet. In the interval between 1,102 and 1,195 feet, the chloride concentration increased from 47 to 620 mg/L. From 1,195 to 1,509 feet, chloride concentrations varied from 470 to 710 mg/L. Below 1,509 feet, chloride concentrations decreased to 61 mg/L at 1,600 feet and again increased to 440 mg/L at 1,663 feet. Chloride varied slightly, ranging from 320 to 440 mg/L to a depth of 1,819 feet, decreasing to 50 mg/L at 2,008 feet. Specific conductance showed similar fluctuations ranging from 1,000 to 3,600 umhos/cm at 25°C to a depth of 1,991 feet. The depth intervals, in which higher concentrations of chloride and specific conductance occurred were similar to those detected in the two wells drilled earlier.

The presence of lower chloride water in the lower part of the middle water-bearing zone below about 1,540 feet suggests that various parts of the zone are less permeable than others. If the high chloride water occurs in the more permeable parts of the zone, its presence may be due to relatively recent lateral movement of saline water. However, if the high chloride water occurs in the less permeable parts, it may represent residual seawater or connate water that has not been completely flushed by the fresh ground-water flow system.

Table 15.--Chloride concentrations of water samples obtained through the drill stem as well N-117 was deepened from 632 to 2,094 feet

| Depth (ft) | Chloride (mg/L) | Depth (ft) | Chloride (mg/L) |
|---|---|---|---|
| 632 | 31 | 1,460 | 710 |
| 664 | 31 | 1,446 | 640 |
| 695 | 35 | 1,477 | 470 |
| 727 | 30 | 1,509 | 470 |
| 758 | 30 | 1,538 | 160 |
| 789 | 31 | 1,569 | 150 |
| 820 | 28 | 1,600 | 61 |
| 851 | 25 | 1,631 | 110 |
| 883 | 30 | 1,663 | 440 |
| 914 | 30 | 1,694 | 390 |
| 945 | 32 | 1,726 | 420 |
| 977 | 29 | 1,756 | 320 |
| 1,006 | 30 | 1,788 | 350 |
| 1,039 | 30 | 1,819 | 360 |
| 1,071 | 34 | 1,851 | 210 |
| 1,102 | 47 | 1,882 | 260 |
| 1,133 | 120 | 1,914 | 270 |
| 1,164 | 190 | 1,945 | 270 |
| 1,195 | 620 | 1,976 | 240 |
| 1,226 | 710 | 2,008 | 50 |
| 1,258 | 700 | 2,039 | 100 |
| 1,290 | 700 | 2,071 | 912 |
| 1,322 | 650 | 2,084 | 4,800 |
| 1,353 | 690 | 2,094 | 7,800 |
| 1,384 | 560 | -- | -- |

Table 16.--Specific conductance of water samples obtained through the drill stem as well N-117 was deepened from 1,476 to 2,080 feet

| Date | Depth (ft) | Specific conductance (umhos at 25°C) | Date | Depth (ft) | Specific conductance (umhos at 25°C) |
|---|---|---|---|---|---|
| 1/16/79 | 1,476 | 1,600 | 1/23/79 | 1,820 | 1,690 |
| | 1,517 | 2,100 | | 1,830 | 1,540 |
| | 1,536 | 1,900 | | 1,840 | 1,560 |
| 1/17/79 | 1,545 | 1,500 | | 1,861 | 1,280 |
| | 1,577 | 1,000 | 2/01/79 | 1,866 | 1,500 |
| | 1,600 | 1,000 | | 1,882 | 1,500 |
| 1/18/79 | 1,632 | 1,220 | | 1,887 | 1,600 |
| | 1,642 | 1,420 | | 1,891 | 1,500 |
| | 1,652 | 1,380 | 2/02/79 | 1,914 | 1,440 |
| | 1,663 | 2,090 | | 1,935 | 1,500 |
| | 1,673 | 1,850 | | 1,944 | 1,650 |
| | 1,683 | 1,850 | | 1,945 | 1,500 |
| | 1,694 | 1,880 | 2/05/79 | 1,960 | 1,580 |
| 1/19/79 | 1,712 | 2,200 | | 1,976 | 1,420 |
| | 1,726 | 1,750 | | 1,991 | 1,490 |
| | 1,733 | 1,850 | 2/12/79 | 2,013 | 1,430 |
| 1/22/79 | 1,744 | 1,700 | | 2,018 | 1,230 |
| | 1,757 | 1,580 | | 2,025 | 1,160 |
| | 1,767 | 3,600 | | 2,040 | 1,380 |
| | 1,777 | 1,680 | | 2,054 | 1,140 |
| | 1,788 | 1,800 | | 2,060 | 1,060 |
| | 1,798 | 1,760 | | 2,064 | 1,080 |
| | 1,808 | 1,700 | | 2,074 | 5,200 |
| | | | | 2,080 | 15,000 |
| | | | 2/13/79 | 2,080 | 22,000 |

## Lower Water-Bearing Zone

The first well to penetrate the lower water-bearing zone was well N-62 in 1945. During drilling of this well, chloride concentrations of water sampled through the drill stem increased from 55 mg/L at a depth of 2,039 feet to 126 mg/L at 2,101 feet (table 14). Hardness also increased from 367 to 543 mg/L at the same depths (Scofield, 1945). In October 1945, several months after the well (depth interval 600-2,130 feet) had been in use as a supply well, water samples were collected at selected depth intervals by lowering a 3/4-inch diameter pipe into the well (Cooper and Peek, 1954). The samples represent composites of water below the sampled depth. Chloride concentrations increased markedly from 164 mg/L at a depth interval of 1,302 to 2,130 feet to 322 mg/L at 1,785 to 2,130 feet. A maximum chloride concentration of 426 mg/L was measured at 2,100 to 2,130 feet. The increase in chloride concentration may indicate lateral movement of saltwater in the well through the permeable zone just above 2,100 feet (Cooper and Peek, 1954, p. 25), since flow meter traverses showed that little or no water entered the well below 2,100 feet.

Increases in mineral content in 1946 necessitated grouting (plugging) back the well from a depth of 2,130 to 1,826 feet, and the chloride concentration of the water decreased to an estimated 90 mg/L (P. L. Duncan, ITT Rayonier, Inc., written commun., 1978).

In 1959, well N-88 penetrated the lower water-bearing zone to a depth of 2,105 feet below land surface. From 2,000 to 2,090 feet, chloride concentrations of water samples obtained through the drill stem generally increased from 43 to 108 mg/L (R. W. Harden and Associates, 1979). The completion interval of the well was 1,432 to 2,105 feet. From 1959 to 1964, chloride concentrations fluctuated from about 60 to 130 mg/L. The well was grouted (plugged) to land surface in 1973.

Only one well, test well N-117, presently penetrates the lower water-bearing zone (2,000 to 2,102 feet) of the aquifer. Table 17 lists the chemical analyses of water taken from the well between March 1979 and June 1980. The water is very saline (about 20,000 mg/L dissolved solids) and is classified as a sodium-chloride type. Chloride concentrations ranged from 8,100 mg/L in March 1979 to 9,600 mg/L in March 1980, about half the chloride concentration of seawater. Sulfate concentrations ranged from 1,600 to 1,700 mg/L.

During drilling of test well N-117, water samples were obtained through the drill stem as the well was deepened. Chloride increased markedly below 2,039 feet to a maximum of 7,800 mg/L at 2,094 feet (table 15). Specific conductance showed a similar increase from about 1,100 umhos/cm at 25°C at 2,054 feet to a maximum of 27,000 umhos/cm at 25°C at a depth of 2,080 feet.

Table 17.--Chemical analyses of water from well N-117

| Date | Temperature, water (°C) | Agency analyzing sample (code number) | Specific conductance (micromhos) | pH field (units) | Carbon dioxide dissolved (mg/L as $CO_2$) | Alkalinity (mg/L as $CaCO_3$) | Alkalinity, carbonate (mg/L as $CaCO_3$) | Bicarbonate (mg/L as $HCO_3$) | Carbonate (mg/L as $CO_3$) | Hardness (mg/L as $CaCO_3$) | Hardness noncarbonate (mg/L $CaCO_3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar, 1979 | | | | | | | | | | | |
| 26... | -- | -- | 25000 | 6.9 | 33 | 135 | 134 | 164 | 0 | 4100 | 4000 |
| Mar, 1980 | | | | | | | | | | | |
| 04... | 31.0 | 80010 | 28200 | 7.1 | -- | 140 | -- | -- | -- | 3700 | 3600 |
| Jun | | | | | | | | | | | |
| 26... | 30.5 | 80010 | 28300 | 7.2 | -- | 140 | -- | -- | -- | 3500 | 3400 |
| Sep | | | | | | | | | | | |
| 09... | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Jan, 1981 | | | | | | | | | | | |
| 21... | 30.0 | 80010 | 27800 | 6.9 | -- | -- | -- | -- | -- | 4100 | 3900 |
| May | | | | | | | | | | | |
| 12... | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Jun | | | | | | | | | | | |
| 16... | 30.5 | 80010 | 26000 | 7.0 | -- | -- | -- | -- | -- | 4300 | -- |

| Date | Calcium dissolved (mg/L as Ca) | Magnesium-dissolved (mg/L as Mg) | Sodium, dissolved (mg/L as Na) | Potassium, dissolved (mg/L as K) | Chloride, dissolved (mg/L as Cl) | Sulfate dissolved (mg/L as $SO_4$) | Fluoride, dissolved (mg/L as F) | Silica, dissolved (mg/L as $SiO_2$) | Iron, dissolved (ug/L as Fe) | Strontium, dissolved (ug/L as Sr) | Solids residue at 180° C dissolved (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar, 1979 | | | | | | | | | | | |
| 26... | 760 | 520 | 4200 | 94 | 8100 | 1600 | 1.0 | -- | 90 | 18 | -- |
| Mar, 1980 | | | | | | | | | | | |
| 04... | 500 | 590 | 5200 | 130 | 9600 | 1700 | .7 | -- | -- | 16000 | -- |
| Jun | | | | | | | | | | | |
| 26... | 520 | 530 | 4800 | 130 | 8900 | 1600 | .8 | 24 | -- | 17000 | 20800 |
| Sep | | | | | | | | | | | |
| 09... | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Jan, 1981 | | | | | | | | | | | |
| 21... | 750 | 530 | 4700 | 98 | 8600 | 1700 | .8 | 27 | -- | 18000 | 17900 |
| May | | | | | | | | | | | |
| 12... | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Jun | | | | | | | | | | | |
| 16... | 760 | 570 | 5100 | 100 | 9600 | 1900 | .7 | 22 | -- | 18000 | 18600 |

Table 17.--Chemical analyses of water from well N-117--Continued

| Date | Solids, sum of constituents, dissolved (mg/L) | Iodide, dissolved (mg/L as I) | Bromide, dissolved (mg/L as Br) | Potassium 40 dissolved (pCi/L as $K_4O$) | Specific conductance (micromhos) | Alkalinity (mg/L as $CaCO_3$) | Hardness, noncarbonate (mg/L $CaCO_3$) |
|---|---|---|---|---|---|---|---|
| Mar, 1979 | | | | | | | |
| 26... | -- | -- | -- | -- | -- | -- | -- |
| Mar, 1980 | | | | | | | |
| 04... | -- | 1.9 | 40 | -- | -- | -- | -- |
| Jun | | | | | | | |
| 26... | 16600 | .05 | .1 | -- | -- | -- | -- |
| Sep | | | | | | | |
| 09... | -- | -- | -- | -- | -- | -- | -- |
| Jan, 1981 | | | | | | | |
| 21... | 16500 | .18 | 27 | 73 | 26400 | 130 | -- |
| May | | | | | | | |
| 12... | -- | -- | -- | -- | -- | -- | -- |
| Jun | | | | | | | |
| 16... | 18200 | .17 | 40 | 75 | 25300 | 130 | 4100 |

## GROUND-WATER DEVELOPMENT

### Surficial Aquifer

An estimated 1 to 2 Mgal/d of water are derived from the surficial aquifer in the study area. The water is primarily used for rural domestic and livestock supply, lawn irrigation, and in heat exchange units for heating and air conditioning.

Water in the surficial aquifer is generally obtained from the shell, limestone, and sand zone. Most wells drilled into the aquifer are 2 inches in diameter and range in depth from 50 to 150 feet. The casing is either driven or jetted to the top of the zone and an open hole is then drilled into the zone below the casing. Typical 2-inch diameter wells yield 20 to 50 gal/min. A few 5-inch diameter wells in Fernandina Beach yield 50 to 80 gal/min (Leve, 1966, p. 23).

Some water is obtained from the sand and shell zone in the Pleistocene and Holocene deposits by sandpoint wells from 0.5 to 2 inches in diameter. The casing is either driven or jetted to a depth of 10 to 30 feet. Wells 1.25 inches in diameter normally yield between 10 and 15 gal/min. However, some wells in relatively thick and permeable beach sands along the coast yield as much as 25 gal/min.

Where the sand, shell, and limestone zones in the upper Miocene and younger deposits yield insufficient quantities of water or poor quality water, supplies often are obtained from the limestone and sand zone in the upper part of the Hawthorn Formation. Wells generally are drilled to depths of 200 to 250 feet and cased to a depth of 120 to 150 feet. Wells 2 inches in diameter yield from 30 to 50 gal/min.

The surficial aquifer has the potential for being a dependable source of water for small public and domestic supplies because it is readily recharged by precipitation. Near the coast and on barrier islands, water quality may limit development of the aquifer, primarily because of lateral or upward migration of saltwater underlying the freshwater parts of the aquifer.

Aquifer properties can be used to estimate drawdown in the unconfined aquifer at varying distances from a pumped well and at any time in a well after pumping begins. Using the Theis equation for nonsteady flow without vertical leakage (Lohman, 1972, p. 15), distance-drawdown curves and time-drawdown curves were developed for an unconfined aquifer having a transmissivity of 1,000 $ft^2/d$ and a storage coefficient (specific yield) of 0.2 (fig. 15). Simulated drawdowns based on the Theis equation are very nearly correct as long as the drawdown is small in comparison to the saturated thickness of the unconfined aquifer.

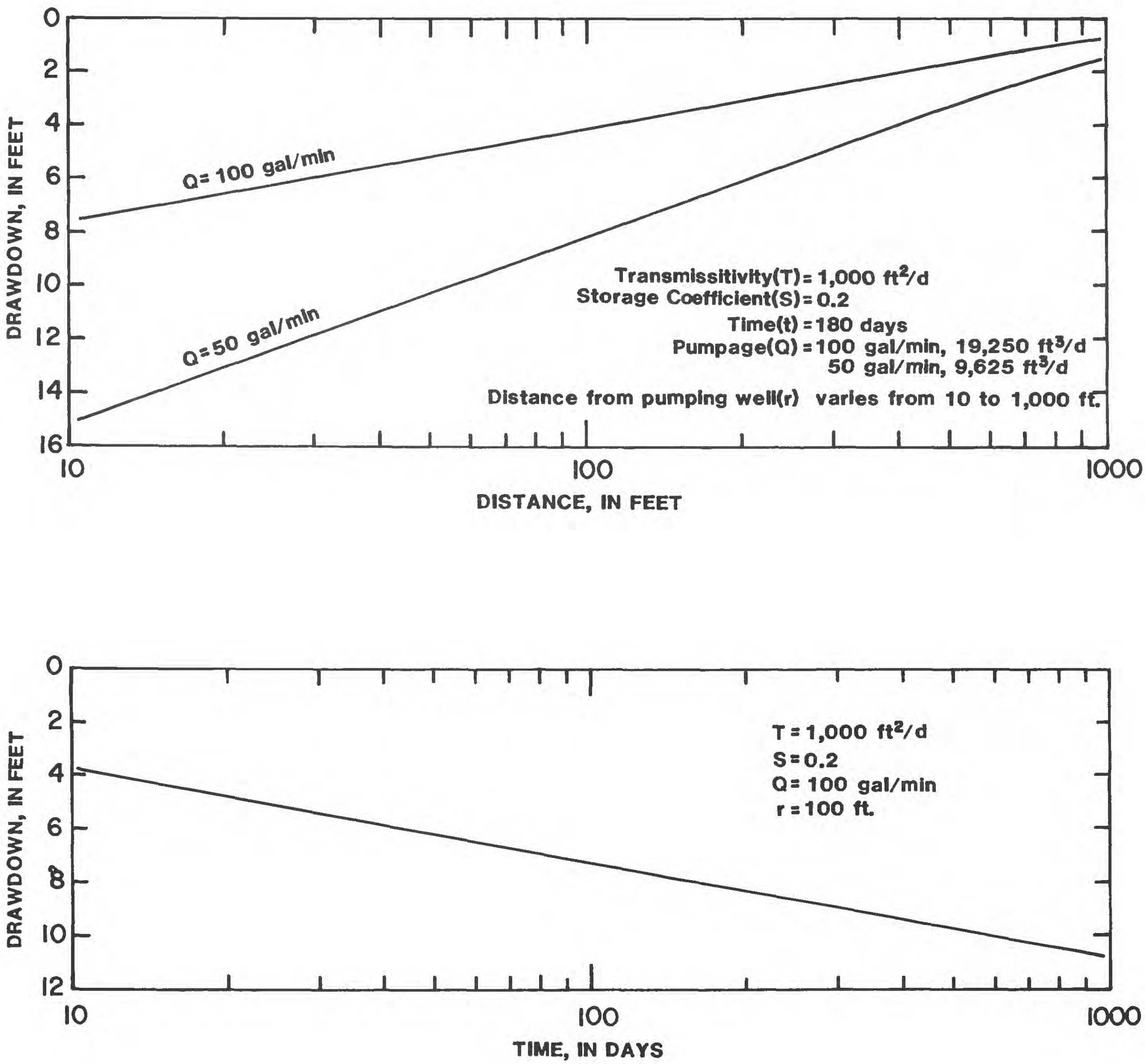



Figure 15.--Distance-drawdown and time-drawdown curves for the surficial aquifer using selected aquifer characteristics.

As shown in figure 15, distance-drawdown curves were developed for a single well pumping at rates of 50 and 100 gal/min for a pumping period of 180 days. At distances of 100 and 1,000 feet from the pumped well, projected drawdowns were about 4.0 and 0.7 feet, respectively, at a rate of 50 gal/min, and about 8.1 and 1.5 feet, respectively, at a rate of 100 gal/min.

A time-drawdown curve was developed for a single well pumping at a rate of 100 gal/min (fig. 15). At a distance of 100 feet from the pumping well, simulated drawdowns were 3.8, 7.2, and 10.8 feet at 10, 100, and 1,000 days since pumping began.

Estimated drawdowns generally represent optimum values obtained under ideal conditions, since many of the assumptions for the Theis equation (Lohman, 1972, p. 15) are not adequately satisfied in the study area. These assumptions include (1) a homogeneous and isotropic aquifer, (2) the aquifer is of infinite areal extent, (3) the discharging well penetrates the entire thickness of the aquifer, and (4) the water removed from storage is discharged instantaneously with decline in head (constant storage coefficient).

The surficial aquifer supplies water to numerous domestic and small irrigation wells in the study area; however, it has only limited use as an alternative source of water for public and industrial supply. The aquifer is thin and heterogeneous, has low values of transmissivity, and has low yields to pumping wells. Near the coast, the aquifer is subject to saltwater intrusion and inundation by seawater during tidal flooding.

## Floridan Aquifer

The Floridan aquifer is the principal source of potable water in northeast Florida and southeastern Georgia. In the Fernandina Beach-St. Marys area, water from the aquifer primarily is used for industrial-self supply. Minor amounts of water are used for public and rural supply.

Yields of wells that tap the Floridan aquifer range from less than 500 gal/min for wells 6 inches or less in diameter that are completed in only the upper water-bearing zone, to more than 5,000 gal/min for wells 12 inches or more in diameter that are completed in the upper or both the upper and middle water-bearing zones of the aquifer.

In the study area, the wells are cased to the top of the aquifer, 350 to 600 feet below land surface and completed as open holes to depths of about 500 to 1,800 feet, depending on the quantity and quality of water needed. Small diameter domestic wells are generally 2 to 4 inches in diameter, 500 to 700 feet in depth, and cased to 450 to 500 feet. Large diameter industrial wells are generally 18 inches or more in diameter, 1,000 to 1,500 feet in depth, and cased to about 550 to 600 feet.

In 1979, about 92 Mgal/d was pumped from 2 industrial supply well fields in Fernandina Beach and one at St. Marys (fig. 16). In 1980, pumpage decreased to 80 Mgal/d (Richard Marella, St. Johns River Water Management District, written commun., Nov. 15, 1982). One well field is in the northern part of Fernandina Beach and includes 7 active wells that produced an estimated 28.7 Mgal/d in 1979 and 24.46 Mgal/d in 1980, 3 inactive wells used for monitoring purposes, and 3 wells which have been plugged and abandoned (R. W. Harden and Associates, 1979, p. 3). A second well field is in the southern part of Fernandina Beach and includes 8 active wells that produced an estimated 25.4 Mgal/d in 1979 and 20.07 Mgal/d in 1980, 1 monitor well, 3 wells which are either inactive or abandoned, and 2 wells that have been plugged and abandoned. The well field in St. Marys has 6 active wells that produced an estimated 38 Mgal/d in 1979 and 35 Mgal/d in 1980.

Development of the Floridan aquifer is limited to the upper and middle water-bearing zones in the Fernandina Beach-St. Marys area. In 1980, only 3 active wells in Fernandina Beach, with combined pumpage of 10 Mgal/d, tapped both zones. Four wells in St. Marys, with an estimated yield of 24 Mgal/d, are thought to tap both the upper water-bearing zone and the upper most part of the middle water-bearing zone. No production wells draw from the lower water-bearing zone of the aquifer.

## HYDROLOGIC EFFECTS OF DEVELOPMENT OF THE FLORIDAN AQUIFER

### Ground-Water Flow

A simplified conceptual model of the Floridan aquifer consists of three highly permeable water-bearing zones separated by semiconfining beds of relatively low permeability, all of which are confined above and below by confining beds (fig. 17). Estimated hydraulic parameters of the various units of the model are presented in figure 17.

An analytical method for evaluating layered aquifers or zones has been described and modified by Hantush (1956; 1960). The Hantush modified method takes into account the effects of storage in, and leakage through confining beds overlying and underlying an aquifer or zone (Hantush, 1960, p. 3714-3717, case 1).

Using the Hantush modified method, time-drawdown and distance-drawdown curves were computed for the upper water-bearing zone (fig. 18). The curves were developed for a single well pumping at 5 Mgal/d and an average transmissivity of 30,000 $ft^2/d$. A Theis curve for nonleaky conditions is shown on the distance-drawdown graph for comparison.

The equations of Hantush (1960) for computing drawdowns are applicable only within certain time ranges that depend on the hydraulic parameters of the confining and semiconfining beds. Drawdown solutions for the upper water-bearing zone were obtainable for times less than 4 days and more than 8,000 days, about 22 years. Drawdowns for intermediate times were obtained by interpolating between the two segments.

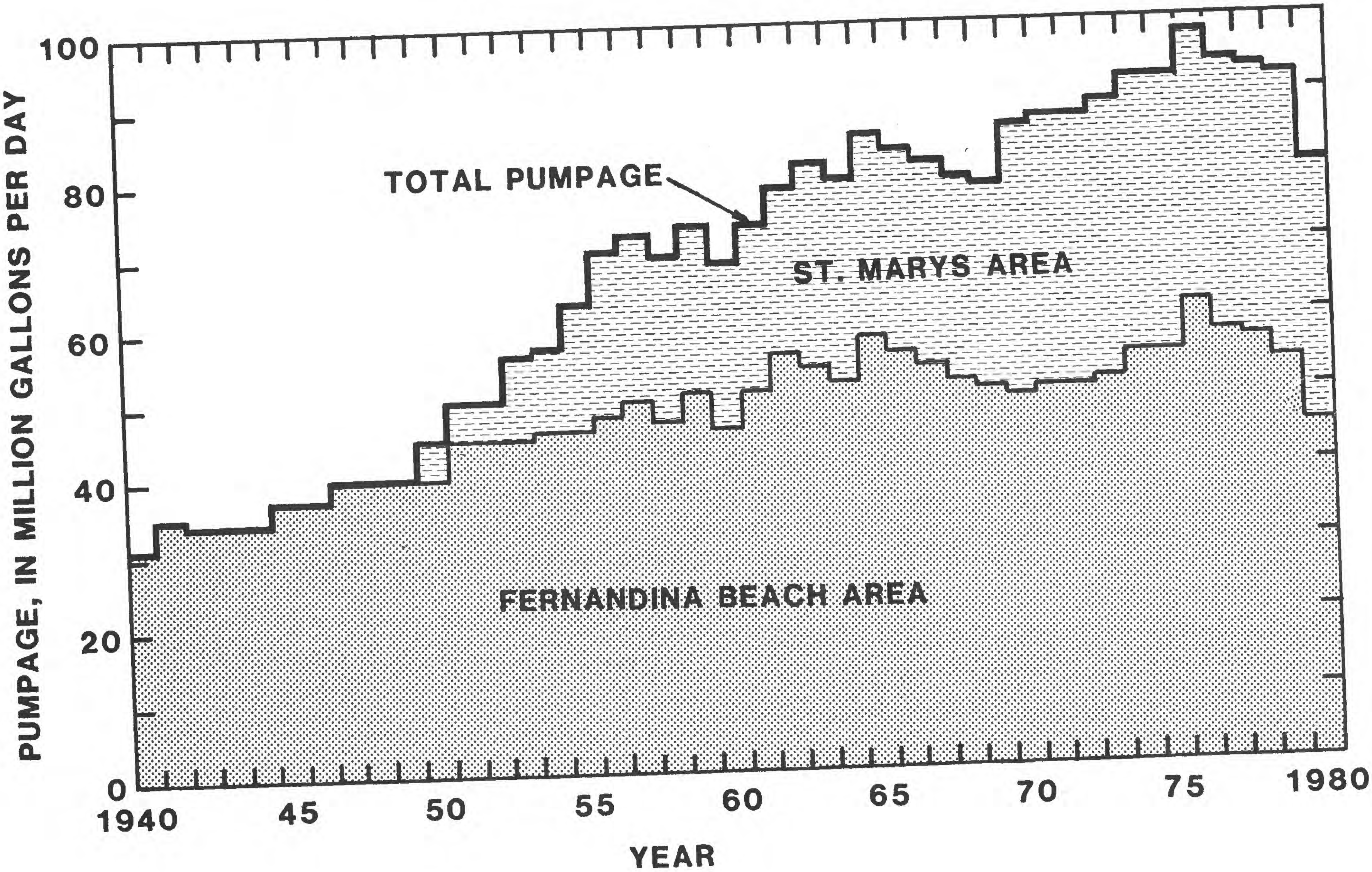



Figure 16.--Estimated ground-water withdrawal for industrial self-supplied water use, 1940-80.

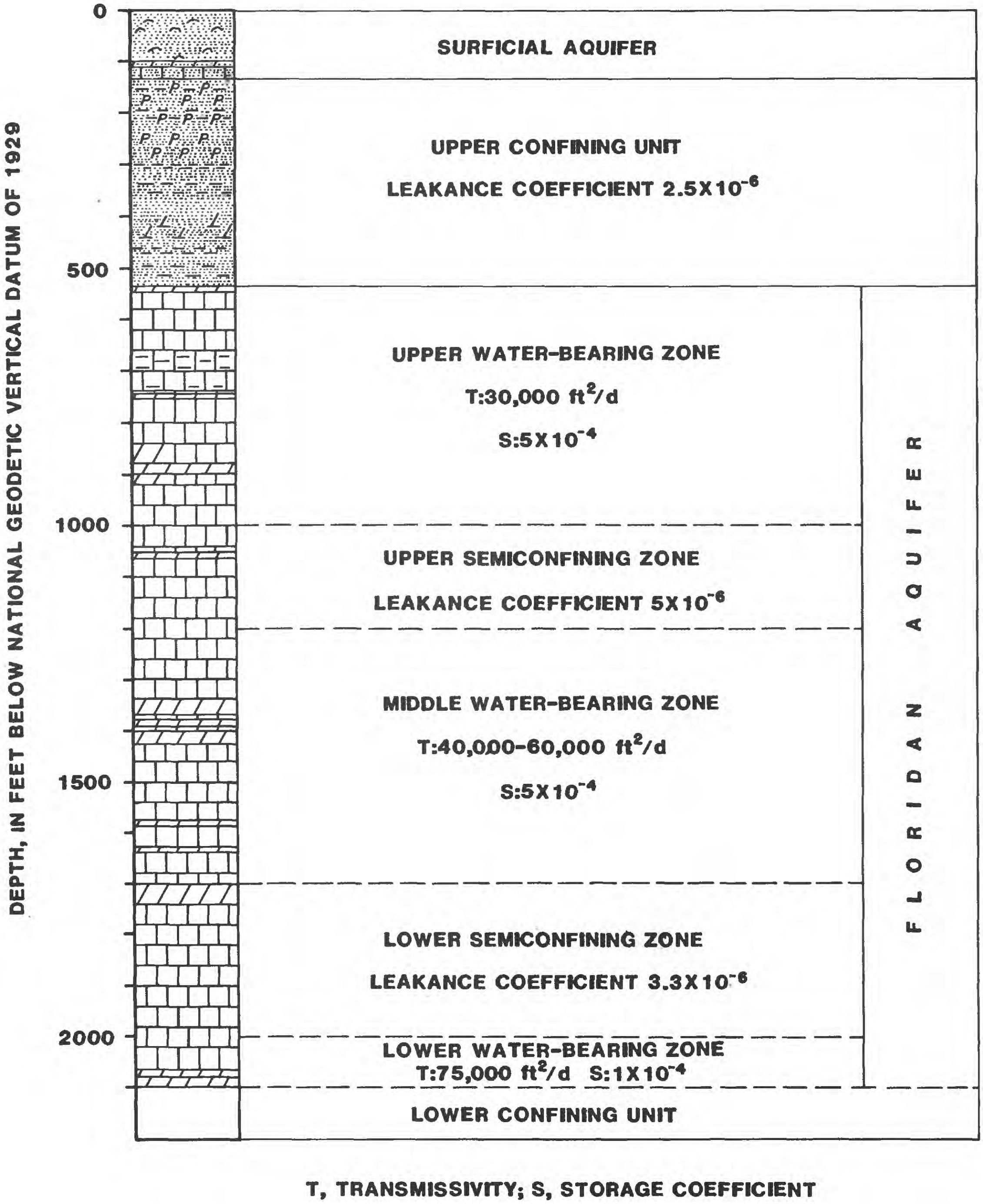



Figure 17.--Simplified model of the Floridan aquifer within the study area and selected hydraulic parameters.

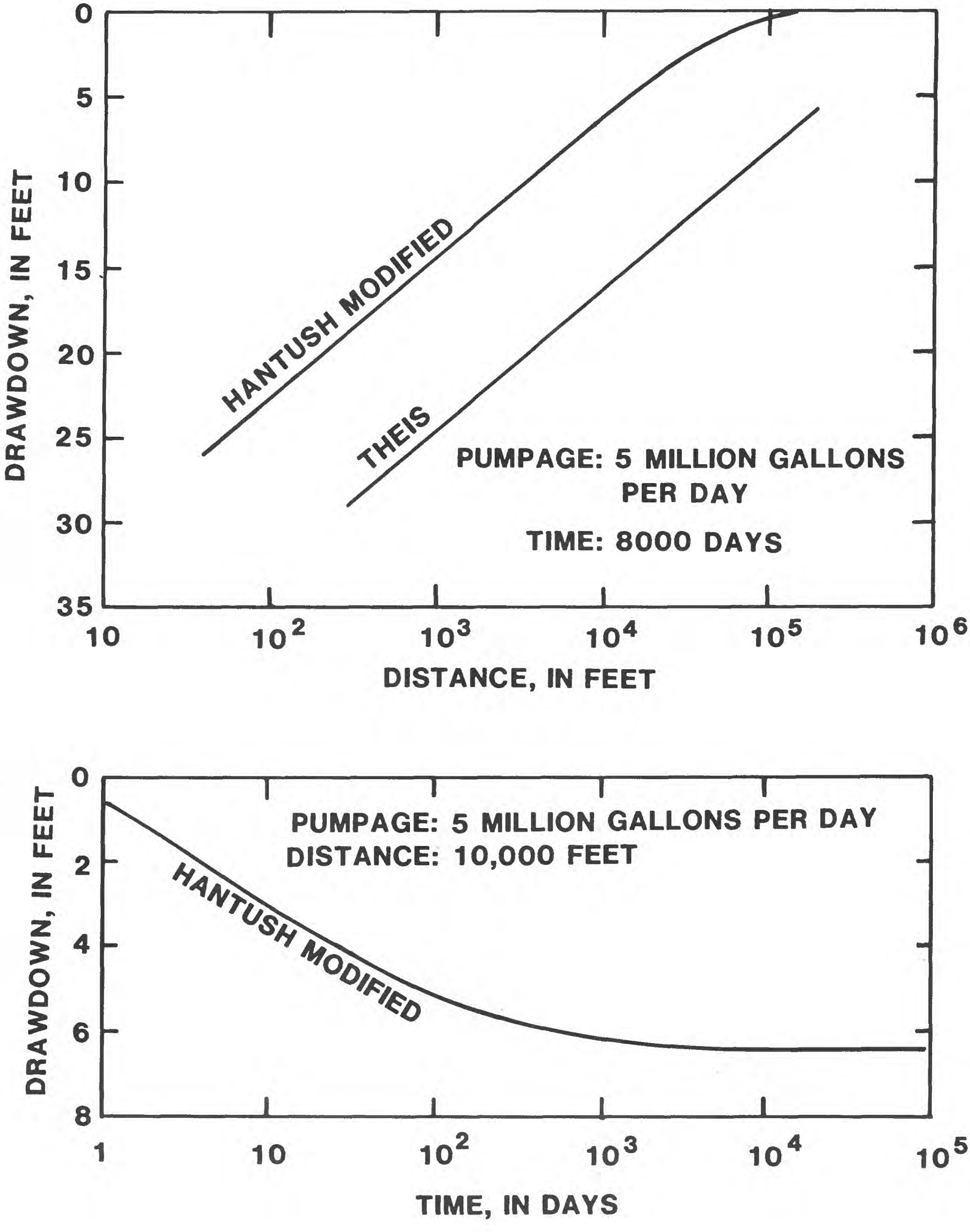



Figure 18.--Time-drawdown and steady-state distance-drawdown curves for the upper water-bearing zone of the Floridan aquifer.

At a distance of 10,000 feet from the pumping well, drawdowns would be about 3.0 feet after 10 days and about 5.9 feet after 365 days of pumping. After pumping 8,000 days, equilibrium would be established with a maximum drawdown of 6.4 feet reached.

Based on the distance-drawdown curve developed for a pumping period of 8,000 days, maximum drawdowns were about 14.5, 6.4, and 1.5 feet about 1,000, 10,000, and 50,000 feet, respectively, from the pumping well.

Calculated drawdowns, based on the mathematical model and estimated hydraulic parameters of the upper water-bearing zone and the overlying and underlying confining beds, were compared with historical water-level declines in selected wells. Four wells penetrating the upper water-bearing zone were selected (fig. 19) and the decline was calculated for the period from the estimated predevelopment head about 1880 to 1980 and for the period 1938-39 to 1980. A decline was also determined for the JOIDES 1 test hole (fig. 6).

The maximum drawdown for each pumping well is effectively reached and maintained after about 5 years independent of the pumping rate (Franks and Phelps, 1979). During 1976-79, total pumpage of the major pumping centers in the study area averaged 95 Mgal/d and ranged from 94 to 100 Mgal/d.

Major pumping centers in the study area and in nearby Jacksonville, Fla. and Brunswick, Ga. were identified and the distance between the pumping centers and each observation well was measured. The daily pumping rates for each pumping center were then calculated based on 1975-79 water-use data and adjusted to include only pumpage from the upper water-bearing zone. An estimated 82 Mgal/d was calculated for Fernandina Beach-St. Marys area and 100 Mgal/d each for Jacksonville (E. C. Hayes, U.S. Geological Survey, oral commun., 1980) and Brunswick. To simplify calculations, pumpage at each center was assumed to be from one well and drawdown at each observation well is the sum of the drawdowns caused by each pumping center. Drawdowns were calculated both by the Hantush (1960) modified leakance formula and the Theis nonleaky equation for confined aquifers (Lohman, 1972) which provided an upper limit for drawdown (table 18).

The Hantush modified method is a more realistic approximation of the aquifer system than the Theis equation because it includes the effects of leakage from confining beds. Calculated drawdowns using the Hantush modified method were similar to measured drawdowns based on the difference between the estimated predevelopment heads and the 1980 measurements. The calculated drawdowns are considered reasonable estimates of observed water-level changes in the northern and western parts of the study area. However, the calculated drawdowns are less than the observed water-level changes in the southern part of the study area (well N-8). It appears that one or more of the estimated hydrologic parameters of the aquifer such as transmissivity or leakance, are lower in the southern part of the study area than in the northern part.

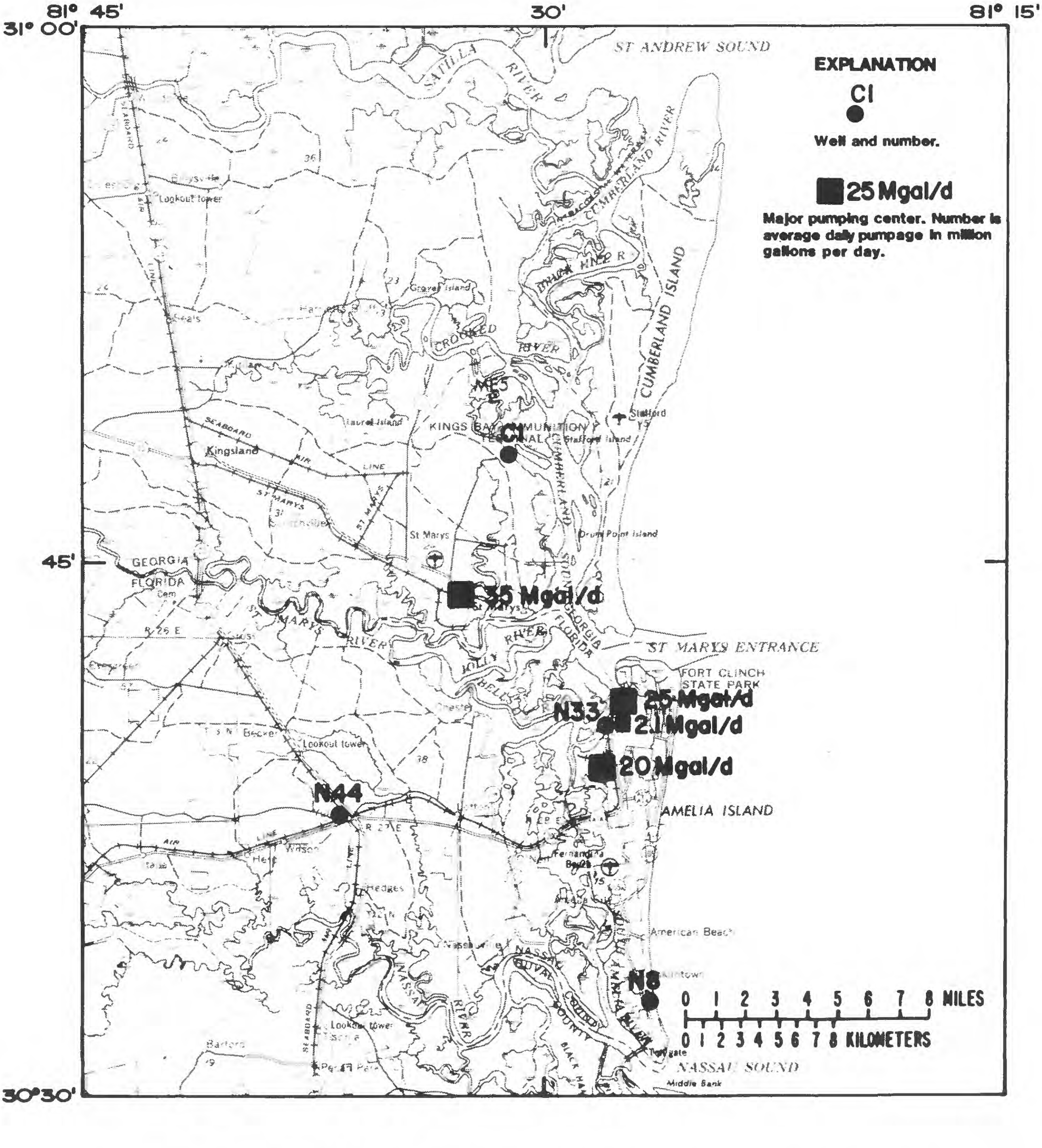



Figure 19.--Location of the major pumping centers and selected observation wells in the study area.

Table 18.--Observed and calculated water levels in selected observation wells

[Water level in feet above or below (-) sea level]

| Well number | Water level | | | Water-level change | | | |
|---|---|---|---|---|---|---|---|
| | | | | Measured | | Calculated (Hantush) | Calculated (Theis) |
| | Predevelopment (estimated) | 1938-39 | 1980 | Predevelopment to 1980 | 1938-39 to 1980 | 8,000 days (in feet) | 8,000 days (in feet) |
| N-44 | 64.0 | 57.3 | 30.9 | 33.1 | 26.4 | 30.6 | 448 |
| N-33 | 61.5 | 48.9 | -34.6 | 96.1 | 83.5 | 97.9 | 519 |
| N-8 | 61.0 | 56.0 | 28.0 | 33.0 | 28.0 | 25.4 | 429 |
| C-1 | 63.0 | 60.0 | 28.5 | 34.5 | 31.5 | 39.9 | 456 |
| JOIDES-1 | 45.0 | -- | [a]30-38 | 7-15 | -- | 5.7 | Not determined |

[a]Based on measurement reported by Waite and Leve (1967).

Other discrepancies in the calculated versus measured drawdowns in the observation wells may be due in part to: (1) variable discharge rates of the major pumping centers which have extended periods of reduced pumpage; (2) the assumption that the pumpage from each center is from one well, drawdowns near a pumping center would be less for a group of pumping wells than for a single well pumping that amount of water; and (3) interzone ground-water flow through uncased bore holes or possible geologic structures such as faults and fractures through the confining beds would modify leakance values.

The estimated hydrologic parameters of the upper water-bearing zone and adjacent confining and semiconfining beds are considered representative and can be used to evaluate the response of the zone to future rates.

The decline of the potentiometric surface of the upper water-bearing zone indicates that part of the water was derived from aquifer storage until a new dynamic equilibrium was established. Based on an estimated storage coefficient of $5.0 \times 10^{-4}$ of the upper water-bearing zone, about 100,000 gallons would be removed from the aquifer for each foot of head decline over a square mile. Assuming an approximate average long-term artesian pressure decline in the upper zone of about 30 feet over the 1,100 $mi^2$ study area, about 3,300 Mgal of water from storage was discharged from the upper zone during the period from about 1880 to 1980. The declines in artesian pressures in the middle and lower water-bearing zones are not known. The volume of water removed from storage in the upper zone is about 0.3 percent of the estimated total pumpage of $1.1 \times 10^6$ Mgal.

Initially, water is derived principally from storage; however, as the cone of depression around a well pumping from an artesian aquifer spreads out, the water ultimately is obtained from increased recharge and decreased natural discharge.

The lowering of the water level in the upper water-bearing zone may reduce leakage from the Floridan aquifer to the surficial aquifer where the head in the Floridan aquifer is above the head in the surficial aquifer. In these areas, pumpage from the Floridan aquifer reduces the water-level difference and also the amount of upward leakage. If the potentiometric surface is lowered sufficiently, such as within the cone of depression around Fernandina Beach, the flow direction can reverse and water can leak downward from the surficial aquifer to the upper water-bearing zone. The amount of leakage between aquifers or zones is a function of the leakance coefficient and the head differences between the adjacent aquifers or zones.

Based on a leakage coefficient of $2.5 \times 10^{-6}$ (ft/d)/ft for the upper confining unit, the amount of water recharged to or discharged from the Floridan aquifer from or to the surficial aquifer, respectively, is estimated at 70 $ft^3$/d or 520 gal/d per foot of head difference per square mile, a relatively small amount of water. However, assuming that the artesian head of the upper zone of the Floridan aquifer has declined an estimated 30 feet over the 1,100 mile study area, this would result in a reduction of natural discharge or an increase in effective recharge of about 17.2 Mgal/d. This volume of water is about 21 percent of the estimated daily pumpage of 82 Mgal/d from the upper zone.

Development of the upper water-bearing zone lowered the water level in this zone and has increased the initial head differences between it and the other water-bearing zones in the Floridan aquifer. This has increased the amount of leakage from the underlying middle and lower zones to the upper zone.

Based on a leakance coefficient of $5 \times 10^{-6}$ (ft/d)/ft for the upper semiconfining zone (between the upper and middle zones), the rate of upward leakage of water from the middle water-bearing zone to the upper zone is estimated at 140 $ft^3$/d per foot of head difference per square mile. The head difference between the two zones probably ranges from less than 10 feet in the western part of the study area to more than 30 feet in the Fernandina Beach area. In the 1,100 $mi^2$ study area, an estimated 1.15 Mgal/d would be recharged to the upper zone by upward leakage per foot of head difference.

The amount of water derived from aquifer storage or leakage is based mostly on estimated and assumed values of the hydraulic parameters of the aquifers or zones and the confining beds. Thus, the amount of water from storage or leakage is a very rough estimate itself.

## Saline Water Contamination

A potential effect of ground-water development in coastal areas is lateral or upward migration of salty water into the fresh, water-bearing zones. Moderately saline to briny ground water, containing more than 3,000 mg/L chloride, underlies the study area at about 2,000 feet below sea level along the coast. The depth to salty water generally increases inland.

Under natural and undisturbed conditions, ground water discharges to the Atlantic Ocean. Where aquifers are hydraulically connected to the sea, the depth to saltwater is related to the height that freshwater stands above sea level. When freshwater and saltwater are in equilibrium, the Ghyben-Herzberg relation can be used to calculate the approximate depth of the freshwater-saltwater interface. The Ghyben-Herzberg relation as given by Walton (1970) is:

$$h_s = \frac{p_f}{p_s - p_f} h_f$$

where $h_s$ is the difference between the elevation of the surface of the ocean and the elevation of the interface, $p_f$ is the freshwater density, $p_s$ is the saltwater density, and $h_f$ is the difference between the elevation of the surface of the ocean and the elevation of the water table or potentiometric surface. If $p_s = 1.025$ g/cm$^3$ and $p_f = 1.000$ g/cm$^3$, then $h_s = 40\ h_f$.

Equilibrium conditions do not exist in the aquifer and a zone of diffusion exists between saltwater and freshwater. When a zone of diffusion exists a cyclic flow is generated in the saltwater, from the floor of the sea into the zone of diffusion and back into the sea, which tends to lessen the landward extent to which saltwater moves in the aquifer (Cooper and others, 1964, C1).

Hubbert's (1940) modification of the Ghyben-Herzberg principle takes into account the dynamic nature of the ground-water flow system. The interface, which is in a state of dynamic equilibrium, is considered to be stable, with freshwater flowing over it toward the ocean. The Hubbert interface relation states that the depth below sea level to the base of freshwater is about 40 times the altitude of the freshwater head on the interface. Because the lines of equal head are curved, the head on the interface differs from that vertically above it. However, assuming that the interface has a slight slope and the lines of equal head are nearly vertical, then the freshwater heads at the interface would be similar to those measured anywhere in the freshwater section.

Before development of the aquifer, water level of the Floridan aquifer along the coast was about 60 feet above sea level (fig. 11). Based on the Hubbert's interface relation, the freshwater-saltwater interface would have naturally occurred at a depth of about 2,400 feet below sea level along the coast. However, pumpage from the aquifer since the 1940's in the Fernandina Beach-St. Marys area has lowered the potentiometric surface in the upper water-bearing zone below sea level locally reversing the natural hydraulic gradient that sloped toward the sea (fig. 7). However, the regional ground-water flow is still seaward.

Johnston and others (1982) concluded that little or no decline in the potentiometric surface in the upper water-bearing zone of the Floridan aquifer has occurred from about 30 to 50 miles offshore and east of Fernandina Beach. This was based on comparing estimated predevelopment water-level measurements with measurements made by Wait and Leve (1967, p. A127) at JOIDES 1 test hole 30 miles east of Fernandina Beach (fig. 20) and with measurements at the Tenneco test hole 50 miles east of Fernandina Beach by Johnston and others (1982). Therefore, it appears that the potentiometric surface has remained sufficiently high seaward of the study area to maintain the freshwater-saltwater interface in the upper zone far offshore. From this, there appears to be little threat of lateral saltwater intrusion landward.

It is possible that significant lateral migration of salty water has occurred in the middle water-bearing zone. The estimated 1980 water level in this zone ranged from about 40 to 45 feet above sea level near Fernandina Beach. The freshwater-saltwater interface estimated by the use of the modified Ghyben-Herzberg relation would occur at a depth of about 1,600 to 1,800 feet below sea level in the lower part of the middle water-bearing zone, once a new equilibrium position was reached.

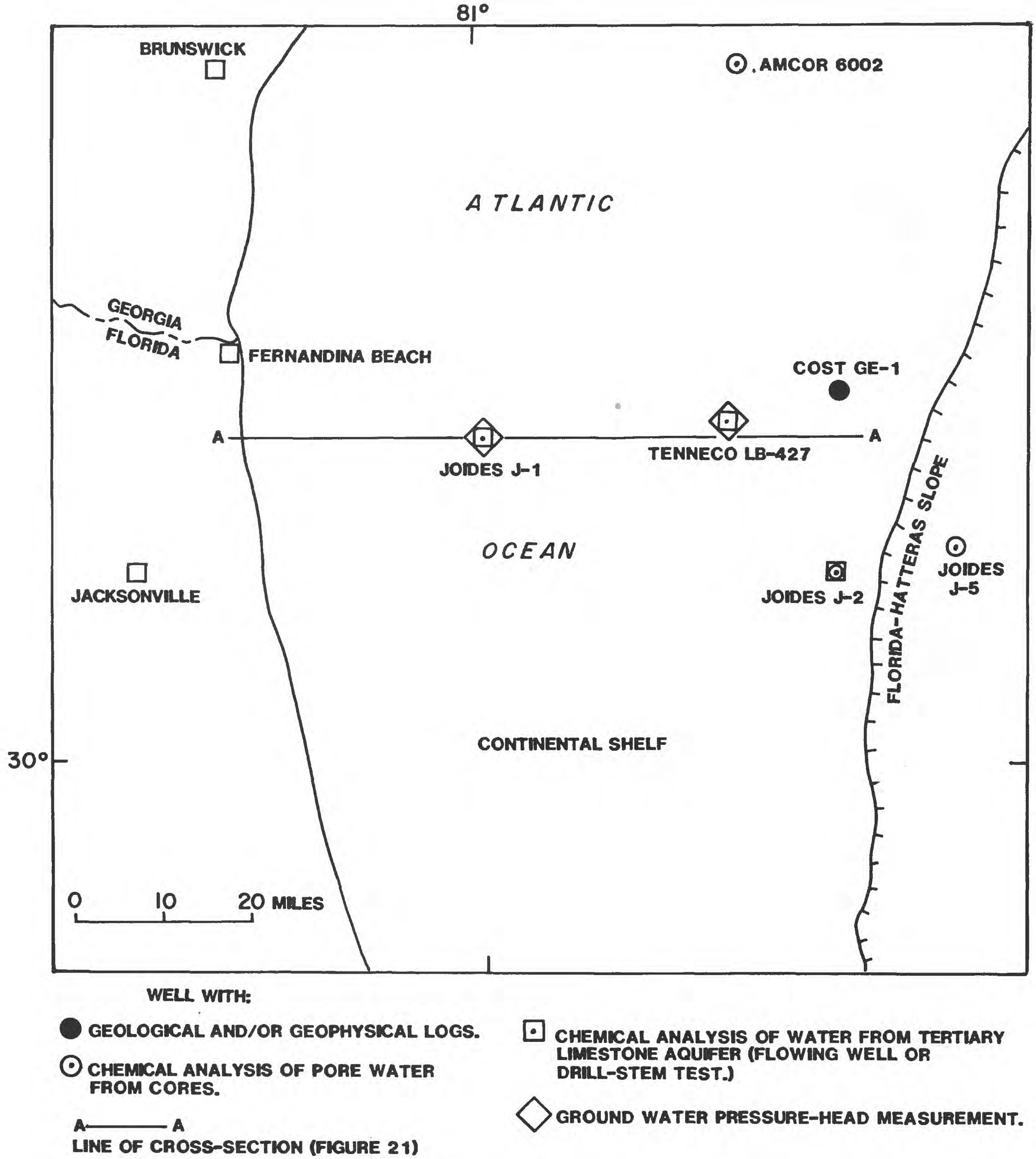



Figure 20.--Location of offshore exploratory wells near the Fernandina Beach-St. Marys area (from Johnson and others, 1982).

The equivalent freshwater water level in the lower water-bearing zone at Fernandina Beach is about 50 feet above sea level. Based on the modified Ghyben-Herzberg relation, the freshwater-saltwater interface would occur at a depth of about 2,000 feet. Chloride concentrations of water from test well N-117, which taps this zone (2,000 to 2,100 feet) are about 9,600 mg/L. This would suggest that the interface in the lower water-bearing zone in the study area is onshore.

Figure 21 shows the inferred position of the freshwater-saltwater interface based on salinity of water samples obtained from three holes JOIDES J-1 (Wait and Leve, 1967); JOIDES J-2 (G. W. Leve, U.S. Geological Survey, written commun., 1980); and Tenneco LB 427 (Johnston and others, 1982). The depth of the interface between these wells was interpolated using the Hubbert interface relation (Johnston and others, 1982). The base of the freshwater in the Floridan aquifer is at a depth of about 2,000 feet below sea level just east of Fernandina Beach decreasing in depth seaward. About 60 miles offshore, the base of the freshwater is at a depth of about 1,000 feet below sea level. If the major water-bearing zones of the Floridan aquifer are continuous and isolated to about 60 miles offshore, the freshwater-saltwater interface in the upper water-bearing zone is estimated to be about 50 to 60 miles east of Fernandina Beach. A zone of transition between the relatively freshwater, having a chloride concentration of less than 1,000 mg/L, and saltwater, having a chloride concentration of 19,000 mg/L, probably ranges from about 30 to 60 miles offshore. About 20 to 50 miles east of Fernandina Beach, the inferred position of the interface ranges from a depth of about 1,700 to about 1,200 feet below sea level (middle water-bearing zone?).

Chloride is the major anion of saltwater and moves through aquifers at nearly the same rate as intruding water (Hem, 1970). In areas where other sources of saline contamination do not exist, high chloride concentrations in ground water are an index to saline water or saltwater contamination.

Relatively high chloride concentrations have been detected in the ground water from about four wells tapping the upper water-bearing zone of the Floridan aquifer in Fernandina Beach. Chloride concentrations of water from these wells ranged from 60 to about 190 mg/L during the period 1975-80 (fig. 14). Of the four wells, which have yielded water having relatively high chloride concentrations, two of the wells (N-110 and N-62DD) once tapped both the upper and middle zones and were plugged back. Low-volume leaks in the plugging materials in the wells themselves may be the cause of the relatively high chloride concentrations. Water samples from well N-106 were collected by an electronically controlled downhole sampler and do not represent water quality from a pumped or flowing well. Chloride concentrations of water from well N-30 increased from 30 mg/L in 1962 to 109 mg/L in 1978. The well is located about 1,800 feet north of well N-43D and 1,700 feet south of well N-41D. Wells N-41D and N-43D tap both the upper and middles zones of the aquifer. Elsewhere in the study area, chloride concentrations ranged from about 20 to 40 mg/L, similar to values reported in the 1940's (fig. 14). Figure 22 shows chloride concentrations of water from selected wells tapping the upper water-bearing zone based on periodic sampling from 1940 to 1979. Chloride concentrations of water from these wells varied from less than 10 to 33 mg/L during the period of record but there was no apparent long-term trend or increase in chloride concentrations during that period.

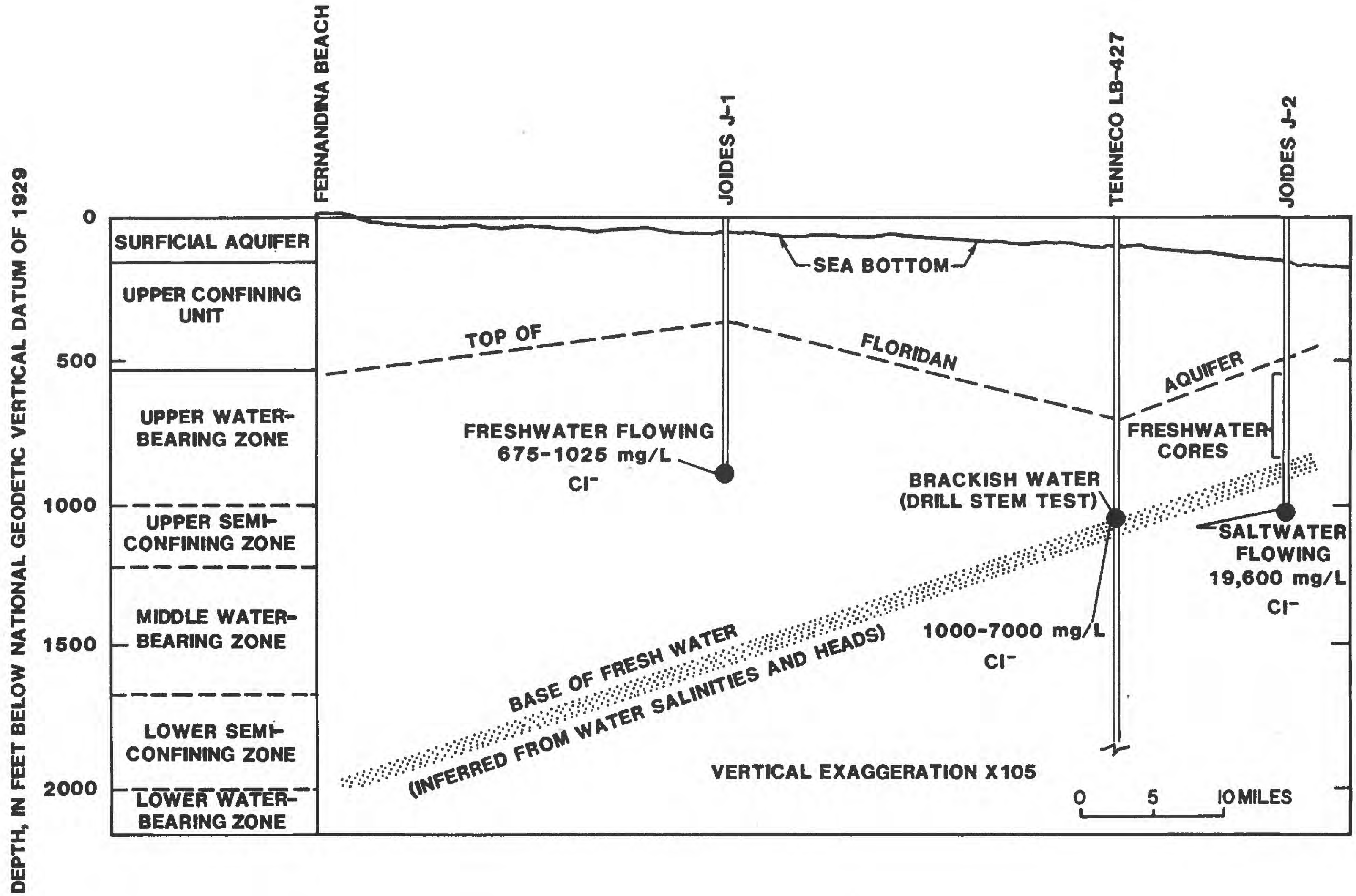



Figure 21.--Inferred position of the freshwater-saltwater interface (modified from Johnson and others, 1982).

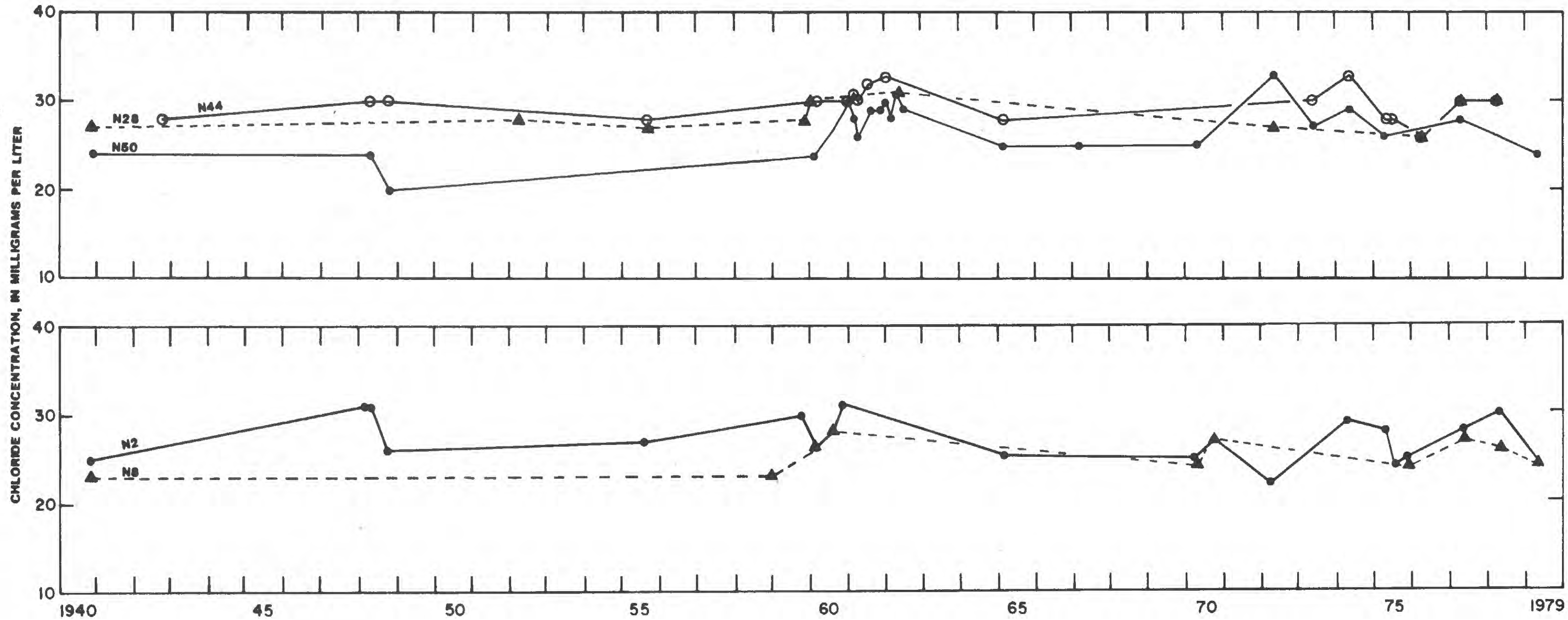



Figure 22.--Chloride concentrations of water from selected wells tapping the upper water-bearing zone of the Floridan aquifer, 1940-79.

The upper water-bearing zone appears to be effectively separated from the more mineralized water in deeper zones of the aquifer by semiconfining beds of low vertical hydraulic conductivity, although uncased or improperly plugged, deeper well bores have provided avenues of migration of more mineralized water in some wells. The water level in well N-117 which taps the lower zone showed no measurable effect from pumpage from nearby industrial wells that tap the upper zone exclusively or both the upper and middle zones. The estimated equivalent freshwater water level in test well N-117 was more than 50 feet above sea level compared to a water level of more than 30 feet below sea level for a nearby observation well and pumping levels in some industrial supply wells of as much as 200 feet below sea level less than one mile away. Also, during construction of the test well in 1979, water levels rose significantly, about 30 feet, when the well tapped both the upper and middle zones compared to when it tapped only the upper zone exclusively. R. W. Harden and Associates (1979, p. 2) reported that the chloride concentration of water in wells tapping only the upper zone at a well field in northern Fernandina Beach was the same in 1979 as in 1940. They concluded that the upper zone is isolated from the lower zones containing the more mineralized water. Based on existing data, there is no evidence of saline water intrusion in the upper water-bearing zone in the coastal or western part of the study area.

Chloride concentrations of 675 to 1,000 mg/L were reported for water samples from the upper part of the Floridan aquifer (the upper water-bearing zone) at the JOIDES 1 test hole about 30 miles offshore. The volume of water which would have to be removed to bring the water at JOIDES 1 to the Fernandina Beach-St. Marys area is about $5.9 \times 10^7$ Mgal. This represents displacing the water in a cylinder around a well 500 feet high, 30 miles in radius, and a porosity of 20 percent. Based on a withdrawal rate of 100 Mgal/d, it would take about 1,600 years to remove the necessary amount of water. This is based on the assumption that the saline water is moving laterally in the upper zone and that there is no leakage of water into the zone from above or below and no recharge.

Figure 23 shows the chloride concentrations during the period 1952 to 1979 of water from selected wells that tap (or formerly tapped) both the upper and middle water-bearing zones of the Floridan aquifer. Chloride concentrations of water in these wells are generally higher than concentrations measured in the upper zone and several wells show a gradual increase in concentration.

From 1952 to 1962, chloride concentrations of water from well N-62 (completion interval 600 to 1,826 feet) increased from about 400 to more than 1,600 mg/L (fig. 23). Chloride concentrations in water from well N-43D (completion interval 546 to 1,820 feet), about 3,600 feet north of well N-62, increased from 102 to 925 mg/L during 1952-75. Similar increases occurred in wells N-41D and N-39D, about 7,200 feet and 7,900 feet, respectively, north of well N-62. Chloride concentrations in water from well N-41D (completion interval 546 to 1,840 feet) increased from 65 to 560 mg/L during 1952-77 and in water from well N-39D (completion interval 535 to 1,700 feet), chloride increased from 37 to 260 mg/L during 1952-79. The chloride concentrations are based on analyses of water sampled at the well head and represent a composite of water from both zones or water from the highest head zones tap from the well including plugged-back portions of the lower water-bearing zone.

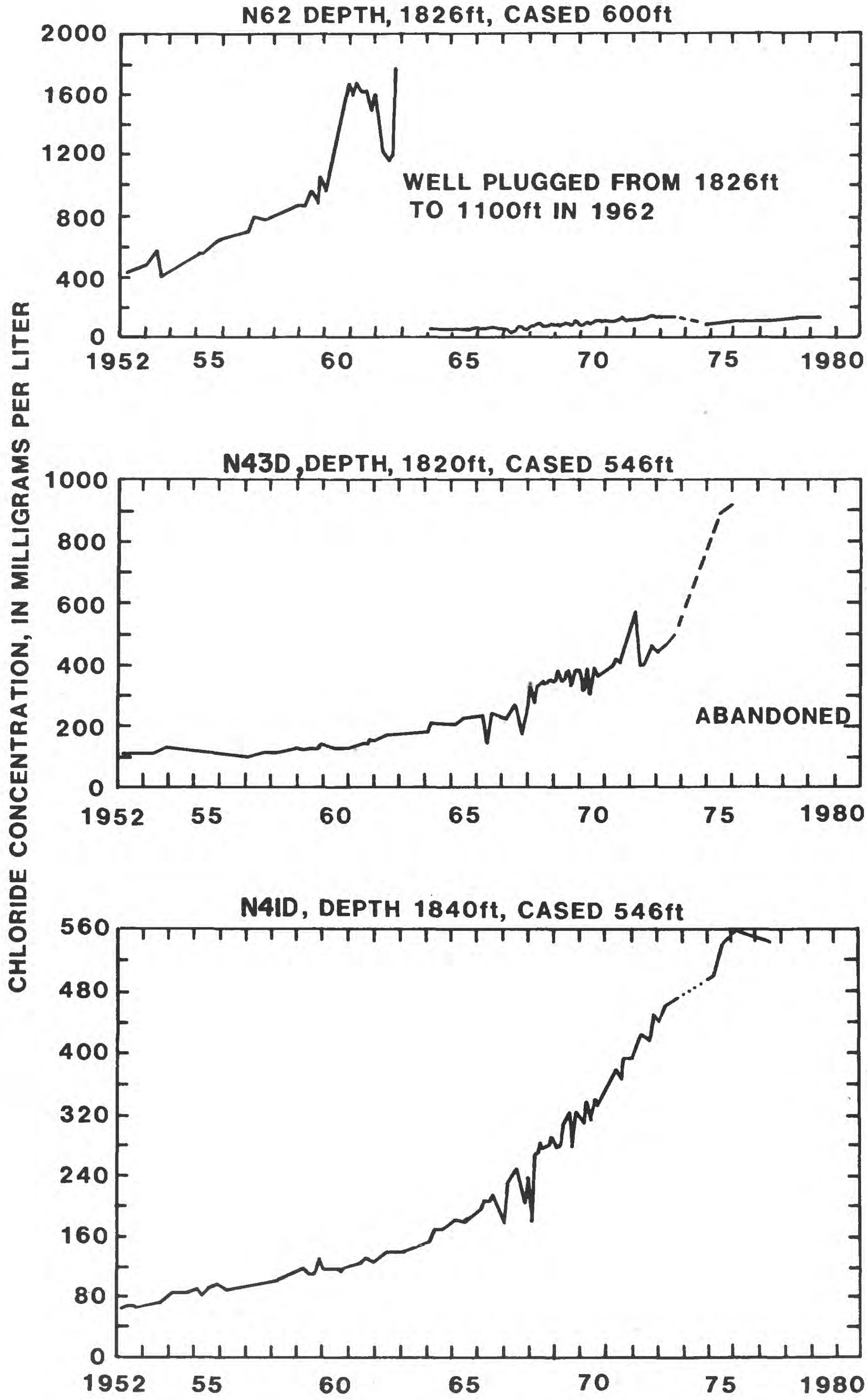



Figure 23.--Chloride concentrations of water from selected wells tapping the upper and middle water-bearing zones of the Floridan aquifer.

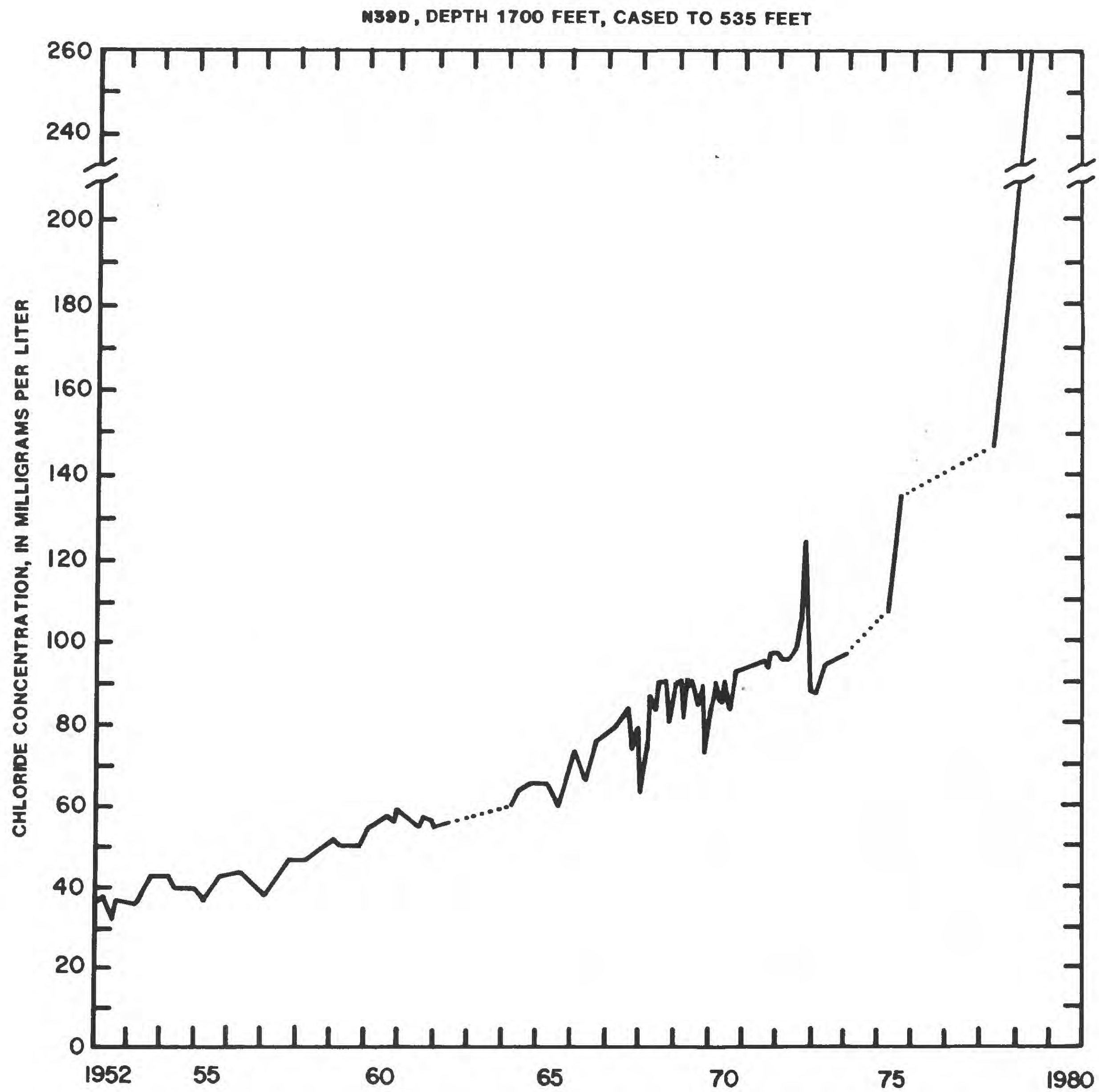



Figure 23.--Chloride concentrations of water from selected wells tapping the upper and middle water-bearing zones of the Floridan aquifer.--Continued

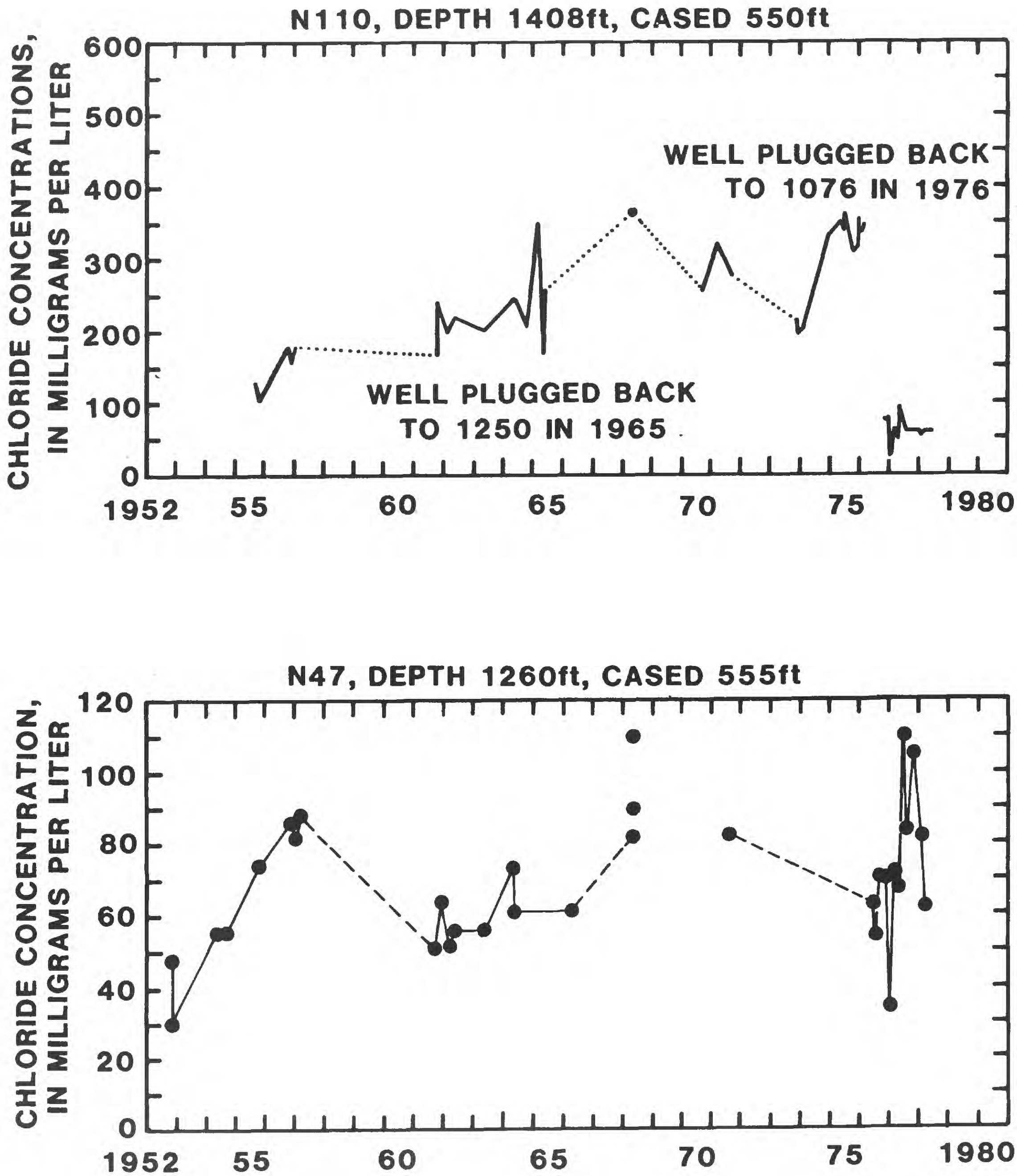



Figure 23.--Chloride concentrations of water from selected wells tapping the upper and middle water-bearing zones of the Floridan aquifer.--Continued

Chloride concentrations of water from wells N-43D, N-41D, and N-39D, that tap the upper and middle water-bearing zones, decreased northward from well N-62 (fig. 23). In 1952, the maximum chloride concentration detected in well N-62 (completion interval 600 to 1,826 feet) was about 400 mg/L and in wells N-43D, N-41D, and N-39D, the maximum concentrations were about 100, 70, and 37 mg/L, respectively. By 1960, maximum chloride concentrations increased to more than 1,600 mg/L at well N-62 (plugged back to 1,100 feet in 1962), and to 150 mg/L at N-43D, 130 mg/L at N-41D, and 60 mg/L at N-39D. In 1975, chloride concentrations in wells N-43D, N-41D, and N-39D, increased to 925, 540, and 135 mg/L, respectively.

The decrease in chloride concentrations northward from well N-62 suggests that the source of the relatively high chloride water is upward migration of saline water from the lower zone through a leaky plug in well N-62 itself, lateral migration of saline water from the south, or natural variations at various depth levels.

In 1945, after several months of pumping well N-62 (completion interval 600 to 2,130 feet) chloride concentrations increased to 426 mg/L (Cooper and Peek, 1954). In 1946, the well was plugged with alternating layers of sand, gravel, and cement back to a depth of 1,826 feet (P. L. Duncan, ITT Rayonier, Inc., written commun., 1978). In 1962, the well was again plugged back to 1,100 feet, where the chloride concentration decreased from about 1,600 to 50 mg/L.

Chloride concentrations ranging from about 100-300 mg/L have been reported in water from several wells that tap the upper and middle zones in central and coastal Duval County south of the study area (Thomas H. Thompson, written commun., January 1979; Paul Hampson, oral commun., January 1980). As indicated on the May 1980 potentiometric map, ground-water flow in this area is toward the cone of depression at Fernandina Beach (fig. 6).

Based on a study of the water quality in an industrial well field in northern Fernandina Beach, R. W. Harden and Associates (1979, p. 1) concluded that chloride increases in the water discharged by wells tapping the poor-quality water (middle water-bearing zone) below 1,200 feet, were caused by increased pumpage from wells that tap only the upper water-bearing zone, accompanied by a reduction in pressure of the upper zone. This increased head differential between the upper and middle zones caused wells that tap both zones to draw a greater proportion of water from the middle zone. Because water in the middle zone has a higher chloride concentration, the deeper wells exhibited increasing chloride levels as the shallow (upper zone) pumpage increased.

Figure 24 shows chloride concentrations of water sampled during drilling of well N-62 and N-88 in 1945 and 1959, respectively, and test well N-117 in 1979. In 1979, chloride concentrations of water at test well N-117 in the upper water-bearing zone from 632 to 1,071 feet below land surface ranged from 25 to 34 mg/L, similar to concentrations detected during drilling of test-production wells in 1945 and 1959. Chloride concentrations of as much as 153 mg/L and 126 mg/L, were detected in the

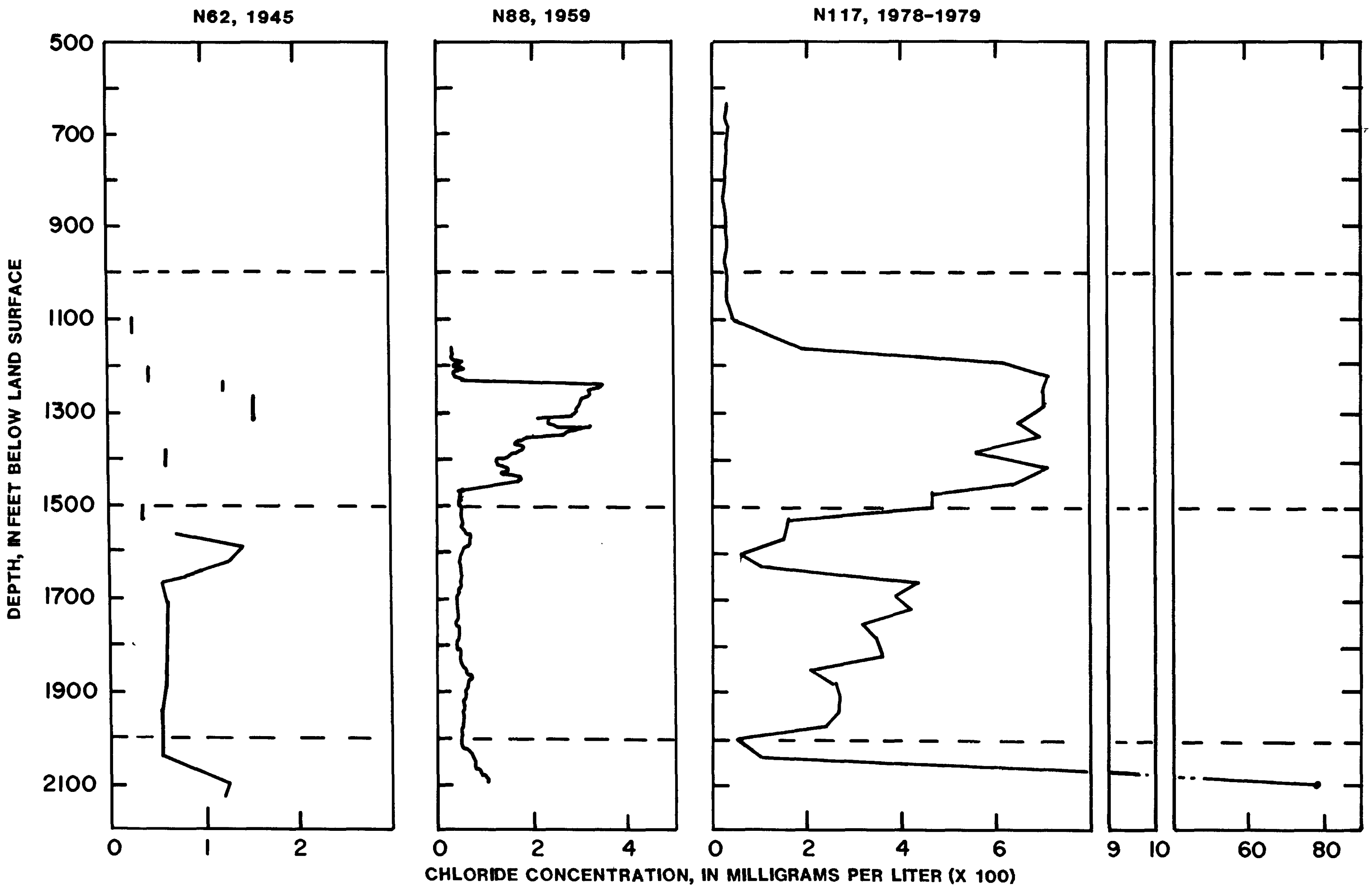



Figure 24.--Chloride concentrations of water samples obtained during drilling of well N-62 in 1945, well N-88 in 1959, and well N-117 in 1979.

middle and lower water-bearing zones, respectively, in well N-62 in 1945 when the zones were first penetrated in the Fernandina Beach area. The source of the water with relatively high chloride concentrations was probably relatively salty water within the water-bearing zones which was not completely flushed by the fresh ground-water flow system.

In well N-88 in 1959, chloride concentration of the water from the middle zone (about 3.5 miles north of well N-62) was as much as 348 mg/L. In the same well, chloride concentration of the water in the lower zone was as much as 108 mg/L at a depth of 2,090 feet.

In 1979, the chloride concentration of water sampled from the middle zone at testwell N-117 was as much as 710 mg/L. The chloride concentration of water sampled in the lower zone was as much as 7,800 mg/L. This may indicate that the chloride concentrations of water within the middle and lower water-bearing zones are increasing with time and may reflect lateral migration or upconing of the interface. It also may indicate natural variations in the zone, which was tapped at three different locations.

If the very saline water in the lower zone were hydraulically connected and in equilibrium with the freshwater in the upper zones, a lowering of the water levels in the freshwater part of the aquifer would result in an upward migration or upconing of the freshwater-saline water interface. Within the study area, semiconfining beds effectively separate the freshwater in the upper zone from the middle and lower zones containing saline to very saline water, and tend to prevent upconing.

Since the early 1940's ground-water development in the area has gradually lowered water levels in the upper zone and increased the head differences between the upper and deeper zones of the aquifer, thereby increasing leakage through the semiconfining beds. The amount of water leaking upward from the deeper zones cannot be determined accurately. However, if only a vertical flow system between all the zones is considered, a very rough estimate could be determined by assuming an average leakance coefficient for the upper and lower semiconfining zones and the middle water-bearing zone of $1 \times 10^{-5}$ (ft/d)/ft (based on an estimated average vertical hydraulic conductivity of $1 \times 10^{-2}$ ft/d and a thickness of 1,000 feet) (R. E. Krause, U.S. Geological Survey, written commun., January 1982). The rate of leakage is estimated to be about 280 $ft^3$/d per foot of head difference per square mile. Within the Fernandina Beach area the head difference between the zones ranges from about 50 to more than 200 feet and averages about 75 feet in a 24 $mi^2$ area (fig. 8). In this area, about 3.7 Mgal/d could leak upward into the upper zone. However, if the vertical hydraulic conductivity was $1 \times 10^{-3}$ ft/d, the leakance coefficient would be $1 \times 10^{-6}$ and leakage to the upper zone would be 28 $ft^3$/d per foot of head difference per square mile, about 0.37 Mgal/d in the 24 $mi^2$ Fernandina Beach area.

The estimated pumpage from the upper water-bearing zone in the Fernandina Beach area was about 45 Mgal/d in 1979. An estimated 0.8 to 8 percent of the water could be derived from leakage based upon the above calculations. These represent ratios of about 1:120 to 1:11 of water contributed from the lower zone.

It is possible that some of the increase in chloride concentrations of water from wells tapping both the upper and middle water-bearing zone, may be due to the upward leakage of water through the semiconfining beds from the lower zones. However, it is likely that most of the intrusion is through improperly constructed or plugged well bores within the area, which penetrate the lower and middle water-bearing zones containing water having a higher chloride concentration, and possible structural features such as faults and fractures. Faults and fractures or improperly constructed or plugged well bores, which penetrate the upper, middle, and lower water-bearing zones, provide conduits for the upward movement of saline water from the lower zone to the upper zone.

There is no evidence of faults or fractures in the rocks comprising the Floridan aquifer in the Fernandina Beach-St. Marys area. However, inferred or concealed faults have been reported north and south of the study area and may be present in the study area. In detailed studies of saltwater contamination in Jacksonville, Fla., Thomas H. Thompson (U.S. Geological Survey, written commun., July 1981) and G. Warren Leve (U.S. Geological Survey, written commun., January 1982) concluded that contamination of the freshwater zones of the Floridan (principal artesian) aquifer is caused by the high-chloride water rising vertically from the moderately saline to briny water-bearing zones or aquifers through faults and fractures to the upper freshwater zones and not by lateral seawater intrusion. The presence of inferred and concealed faults in nearby areas and the possibility of undetected faults and fractures create the potential for upward movement of saline water and movement laterally within the upper and middle zones towards the major pumping centers. However, such saline water movement has not been detected to date by any existing wells tapping the aquifer within the study area.

In summary, there is no discernible trend in chloride concentration of water from the upper water-bearing zone. The increase in chloride concentration of water from wells tapping both the upper and middle water-bearing zones may represent: (1) the lateral migration of saline water within the zone, (2) vertical migration of saline water from the deeper zones of the aquifer through fractures or improperly plugged well bores in the semiconfining zone, (3) naturally occurring variation within the zone, (4) natural upconing, (5) interference effects due to increased pumpage in the upper zone, or (6) a combination of two or more of the above. The increase in chloride concentration in the lower zone probably represents either lateral or vertical (upconing) saline water intrusion or a combination of both.

## Effects of Future Development

In the coastal part of the study area, future development of the Floridan aquifer may be limited to the upper water-bearing zone. The presence of relatively high chloride concentrations of water in the middle and lower water-bearing zones limits future development of freshwater supplies from these zones in this area. Extensive development of the Floridan aquifer, in particular the upper water-bearing zone in the Fernandina Beach-St. Marys area, has resulted in water-level declines of about 25 to more than 100 feet and pumping levels in some industrial supply wells of as much as 200 feet below land surface. This development may restrict the amount of future development of the upper zone in coastal areas. Existing data indicates that there has been no deterioration of the quality of water from wells that exclusively tap the upper water-bearing zone due to lateral or vertical saline water intrusion. Thus, increases in pumpage from the upper zone may be possible. In the western part of the study area, the upper water-bearing zone is not extensively developed and it is a potential source of water for future development. In this area, little is known about the hydrogeology and quality of water of the middle and lower zones of the aquifer and these zones also may be a potential source of water.

The effects of future development on the water levels of the upper water-bearing zone were determined from a mathematical model of the aquifer system. Using the Hantush modified method and assuming steady-state conditions, the calculated drawdown in an observation well that penetrates the same water-bearing zone or aquifer as the pumped well, is a function of the withdrawal rate of the pumped well. Based on a well pumping 5 Mgal/d, the calculated drawdowns or decline in water level would be 6.4 feet at a distance of 10,000 feet and 1.5 feet at a distance of 50,000 feet from the pumped well (fig. 18). This represents a decline of 1.24 feet at 10,000 feet and 0.3 feet at 50,000 feet per 1 Mgal/d of pumpage.

Table 19 shows the projected drawdown in selected wells in the study area if pumpage from the upper water-bearing zone at the four major pumping centers in the Fernandina Beach-St. Marys area increased from 82 to 123 Mgal/d, 50 percent above the estimated average daily pumpage for the period 1975 to 1979, and pumpage in Jacksonville and Brunswick remained constant. Projected water-level declines in wells N-44 and N-8 (fig. 19) located away from the center of pumpage are 43.3 and 35.3 feet, respectively, under steady-state conditions. Based on the estimated predevelopment water level in each well (table 18) and the projected declines, the water levels in wells N-44 and N-8 would be 20.7 and 25.7 feet above sea level. In well C-1, the projected decline was 57.3 feet, 5.7 feet above sea level. The projected decline in well N-33 near the center of pumpage is 138.4 feet or 77.9 feet below sea level. This represents net declines in water levels in observation wells of 9.9 to 17.4 feet about 5 to 10 miles from the major pumping centers and 40.5 feet less than 2 miles from the major pumping centers. The projected decline at the JOIDES 1 test hole, about 30 miles east of Fernandina Beach, is 7.7 feet. This represents a net decline of 2 feet.

As water levels decline in the upper water-bearing zone there would be a decrease in the natural discharge from the aquifer to the ocean and also of upward leakage to the surficial aquifer. The expanding cone of depression would also increase lateral movement from adjacent areas in the aquifer and might induce downward leakage of water from the surficial aquifer and upward leakage from the middle water-bearing zone.

Table 19.--Calculated water-level declines in selected observation wells if pumpage at major pumping centers within the study area increased 50 percent (from an estimated 82 to 123 Mgal/d)

| Well number | Predevelopment water level (in feet) | Calculated water-level decline (in feet) At existing pumpage | If pumpage increased 50 percent | Net declined |
|---|---|---|---|---|
| N-44 | 64.0 | 30.6 | 43.3 | 12.7 |
| N-33 | 61.5 | 97.9 | 138.4 | 40.5 |
| N-8 | 61.0 | 25.4 | 35.3 | 9.9 |
| C-1 | 63.0 | 39.9 | 57.3 | 17.4 |
| JOIDES-1 | 45.0 | 5.7 | 7.7 | 2.0 |

It is possible that further declines in water level of the upper water-bearing zone due to increased pumpage could result in a deterioration of water quality at some future time depending on the amount of increase and the degree of interconnection between the water-bearing zones. The decline would increase water-level differences between the upper and lower zones and also increase the rate of upward leakage or movement through faults and fractures if present. It is also possible that if water levels were reduced significantly in the middle and lower zones because of increased leakage from these zones into the upper zone, saline water could move laterally into these zones and then move upward into the upper freshwater zone.

Also, coastal wells, that are in areas of shifting shorelines, may be offshore now or in the future. In areas where the potentiometric surface is below sea level, wells that are open or have corroded casings would serve as direct conduits for seawater to flow into the aquifer.

## WATER MANAGEMENT CONSIDERATIONS

Through an understanding of the hydrology of the study area and use of various management and conservation techniques, it is possible that a large part of the ground-water resource will be available for future development. This investigation has shown that there is no immediate danger of saline water intrusion into the upper zone of the Floridan aquifer at Fernandina Beach-St. Marys area; however, it is possible that lateral and upward migration of saline water may be detected in the future by additional studies or a monitoring network. If so, it could be controlled by a number of water management techniques that have been used in other coastal areas. For example, drawdowns could be reduced by controlled pumpage or decentralization of well fields, which would reduce or slow down any saline-water intrusion into the well fields. Wells that are open to both the saline water and freshwater zones of the aquifer act as conduits for migration of saline water into the freshwater zones. The sealing or plugging back of these wells would prevent the migration of saline water through open well bores into freshwater zones (Fairchild and Bentley, 1977, p. 20). Several wells in the Fernandina Beach area have been plugged back, usually to depths of less than 1,200 feet, resulting in a substantial reduction in chloride concentrations. However, improperly plugged wells are a potential source of saline water contamination, and care must be taken to insure a proper seal.

The various water-bearing zones of the Floridan aquifer, each with distinct water quality, artesian head, and yield characteristics, could be developed for particular uses. For example, the middle and lower zones of the aquifer near and west of Fernandina containing higher chloride concentrations could be used for supply in which water quality is not critical. This would reserve the freshwater zones primarily for supply in which water quality is critical.

Hydrogeologic conditions in the western part of the study area may be suitable for enhancing aquifer recharge by means of connector wells--wells that connect the surficial aquifer with the upper water-bearing zone of the Floridan aquifer. Because of natural and pumpage-induced head differences between the aquifers, water from the surficial aquifer would move down by gravity flow, through the well, and into the upper water-bearing zone (Wilson, 1977, p. 93).

Water from the Floridan aquifer is constantly being discharged from numerous flowing wells in the study area. A program for installing or repairing controls on flowing wells that are in use and the plugging of abandoned flowing wells could prevent a substantial amount of water from discharging at the surface unused.

## ADDITIONAL STUDIES

The results of this investigation and those of Leve (1961b and 1966) and Fairchild and Bentley (1977) provide a basis for the understanding of the hydrogeology, ground-water quality, the possible source and significance of saline-water intrusion, and the use of the ground-water resources of the area and, in particular, Fernandina Beach. Increased knowledge and understanding of the hydrologic system by additional investigations and a continued and improved monitoring network, could provide a data base for more effective management of the ground-water resources.

The ability to simulate aquifer response to various pumping rates over extended periods of time and increased development is necessary for the effective management of the ground-water resources. The mathematical model used in this report provides a means of evaluating the response of the upper water-bearing zone to various stresses--assuming steady-state conditions. This represents the first phase and considers only a small part of the total ground-water flow system of the area.

## SUMMARY AND CONCLUSIONS

The Floridan aquifer is the primary source of water in eastern Nassau County, Fla. and southeastern Camden County, Ga. In 1977, ground-water use in the two counties was an estimated 105 Mgal/d, primarily for industrial use and to a much lesser extent for public supply. Small amounts of ground water are withdrawn from the surficial aquifer primarily for rural domestic supply.

The area is underlain by a thick sequence of sedimentary rocks and unconsolidated sediments of two principal types: (1) unconsolidated sand and clay (Miocene age and younger rocks); and (2) limestone and dolomite (Paleocene to Eocene age). All stratigraphic units in the area are capable of yielding some water to wells, and based on their water-bearing characteristics, have been classified as aquifers or confining beds. Two aquifers and several confining beds have been recognized in the area.

The surficial aquifer, about 100 to 200 feet thick, consists of a series of relatively thin permeable zones of sand, shell, or limestone separated locally by a number of relatively thin confining beds of clay or marl. It provides from 10 to 50 gal/min under unconfined or semiconfined conditions. The estimated transmissivity ranges from less than 100 $ft^2/d$ for the fine-grained, well sorted sand to 10,000 $ft^2/d$ for sand and shell beds.

Water in the surficial aquifer is generally of acceptable quality for most uses. It is low in mineral content, contains few impurities and generally does not require treatment. Near the coast and tide-affected streams, where saltwater intrusion to the aquifer has occurred, the water increases in mineral content and approaches that of seawater.

The upper confining unit consists of about 400 feet of dense, impermeable beds of clay, marl, limestone, and dolomite that separates the surficial and Floridan aquifers. These beds have low hydraulic conductivity and retard inter-aquifer ground-water flow; however, they do leak some water from one aquifer to another. The leakance coefficient of the upper confining unit is estimated to be about $2.5x10^{-6}$ (ft/d)/ft.

The Floridan aquifer is a stratified sequence of limestone and dolomite (Eocene age) about 1,600 feet thick in the study area. The top of the aquifer ranges from about 400 feet below sea level in the western part of the study area to about 600 feet below sea level in the northeastern part of the study area. A simplified model of the Floridan aquifer consists of upper, middle, and lower water-bearing zones of porous limestone and dolomite beds separated by semiconfining beds of hard, massive dolomite and limestone, all of which are confined above and below by confining beds.

Development of the aquifer in 1980 was primarily from the upper water-bearing zone (530 to 1,000 feet). A few wells tap both the upper water-bearing and the middle zones (1,200 to 1,700 feet below land surface). No production wells tap the lower water-bearing zone about 2,000 to 2,100 feet below land surface.

Within the study area, the transmissivity of the upper water-bearing zone is estimated to be about 20,000 to 50,000 $ft^2/d$; the middle zone, about 40,000 to 60,000 $ft^2/d$; and the lower zone, about 75,000 $ft^2/d$. Based on a specific storage of $1x10^{-6}$ per foot of aquifer thickness, the storage coefficients of the upper, middle, and lower water-bearing zones are estimated to be $5x10^{-4}$, $5x10^{-4}$, and $1x10^{-4}$, respectively.

The upper and lower semiconfining zones within the Floridan aquifer confine ground water into three discrete water-bearing zones and retard interzone ground-water flow. The 2 zones, about 200 and 300 feet thick, occur at depths of about 1,000 and 1,700 feet below land surface. The semiconfining zones leak water from water-bearing zones of higher water level to zones of lower water level. The actual value of vertical hydraulic conductivity of the semiconfining zones is unknown but could range from $10^{-2}$ to $10^{-5}$ ft/d. Based on a vertical hydraulic conductivity of $1x10^{-3}$ ft/d, the leakance coefficient is estimated to be $5.0x10^{-6}$ per day for the upper semiconfining zone and $3.3x10^{-6}$ per day for the lower semiconfining zone.

The lower confining unit, consisting of hard, dense dolomite, soft granular limestone and persistent evaporite deposits of the Cedar Keys Limestone (Paleocene age), retards the vertical movement of highly mineralized water from deeper water-bearing zones to the Floridan aquifer.

The potentiometric surface of the upper 600 feet of the Floridan aquifer ranges from more than 40 feet above sea level in the western part of the study area to more than 50 feet below sea level in the center of the cone of depression in Fernandina Beach. Pumping water levels in some wells are more than 200 feet below sea level. Water levels of about 30 feet above sea level extend more than 50 miles offshore. Ground-water flow in the study area generally is toward pumping centers or cones of depression in the potentiometric surface.

The decline in the potentiometric surface of the upper water-bearing zone, based on the difference between the estimated surface prior to development (about 1880) and May 1980 ranged from about 25 to 30 feet in the northern, western, and southern third of the study area to more than 100 feet towards the center of pumpage.

In the Fernandina Beach area, the hydraulic heads of the three major water-bearing zones of the Floridan aquifer increase with depth. Systematic and consistent water-level differences within the Floridan aquifer have been observed in other areas. These conditions set up the potential for vertical ground-water flow from zones of higher artesian head, through leaky confining beds or wells, to zones of lower head. The water level in the upper water-bearing zone is below sea level in much of the area. The water level in the middle zone is probably well above sea level in Fernandina Beach and is estimated to be about 40 to 50 feet above sea level in the western part of the study area. The equivalent freshwater water level of the saline water lower zone is estimated to be about 50 feet above sea level.

Water in the Floridan aquifer generally is more mineralized and harder than water from the surficial aquifer. The concentrations of most chemical constituents vary within the aquifer both areally and vertically with depth of penetration. The quality of water in the upper water-bearing zone is fairly uniform. The water is primarily a calcium-magnesium bicarbonate-sulfate type with total hardness concentrations ranging from 240 to 340 mg/L and dissolved solids concentrations ranging from about 400 to 600 mg/L. In general, the total hardness and mineral content of the water increases toward the north and east. Chloride concentrations generally range from about 20 to 40 mg/L and sulfate ranges from 100 to 190 mg/L. The occurrence of relatively high chloride concentrations ranging from 60 to 190 mg/L in four wells in Fernandina Beach was probably due to upward migration of more mineralized water from uncased or improperly plugged well bores. There is no evidence of saline-water intrusion in the upper water-bearing zone of the aquifer.

At Fernandina Beach, the water quality in the middle water-bearing zone varies with depth, but the water is more mineralized and harder than water from the upper water-bearing zone. Chloride concentrations of water sampled in the middle zone, sampled during drilling of test well N-117, ranged from 61 to 710 mg/L. The chloride concentration of water from several wells deeper than 1,250 feet increased from less than 100 mg/L to more than 1,000 mg/L since 1952. The high chloride concentration of water from wells tapping both the upper and middle zones and the continuing increase in concentration indicate that (1) highly mineralized water is either moving upward from the lower water-bearing zone, below 2,000 feet, where artesian pressure is relatively high, through uncased or improperly plugged well bores, or through fractures in the semiconfining zone, or moving laterally within the middle zone; (2) naturally occurring variations in chloride concentrations occur within the zone; or (3) chloride increases were caused by interference effects due to increased pumpage from wells tapping the upper water-bearing zone, which caused wells tapping the upper and middle zones to draw a greater proportion of their water from deeper zones having a higher chloride concentration.

Water in the lower water-bearing zone is very saline--of the sodium-chloride type. Dissolved solids concentrations of water from test well N-117 are about 20,000 mg/L and in 1979-80, chloride concentrations ranged from 8,100 to 9,600 mg/L, about half the concentration of seawater. Well N-62 first penetrated this zone in 1945; and chloride concentrations at that time were as much as 126 mg/L. The apparent increase in chloride concentration may be due to (1) lateral migration of highly saline water which apparently occurs near the Fernandina Beach coastline, (2) the vertical intrusion (upconing) from deeper water-bearing zones below the Floridan aquifer, or (3) the natural variation in chloride concentrations with depth.

Development of the Floridan aquifer, in particular the upper water-bearing zone, has modified the ground-water flow system resulting in an increase in ground-water recharge, a decrease in natural ground-water discharge, and a decline in the potentiometric surface. The decline in the potentiometric surface has increased the head differences between the surficial and Floridan aquifers in areas where that surface is below the water table and has also increased recharge and decreased natural discharge from the aquifer. Development of the upper water-bearing zone has increased the water-level differences among the zones in the aquifer thereby increasing the amount of leakage from the lower zones of higher water level to the upper zone.

The inferred position of the freshwater-saltwater interface in the Floridan aquifer decreases in depth seaward and ranges from a depth of about 2,000 feet below sea level (lower water-bearing zone) just east of Fernandina Beach to a depth of 1,000 feet below sea level (upper water-bearing zone?) about 50 to 60 miles east of Fernandina Beach.

Future development of the Floridan aquifer may be limited to the upper water-bearing zone. In the coastal part of the study area, the presence of relatively high chloride concentrations of water in the middle and lower water-bearing zones limits development as a freshwater supply from these zones. Also, present development of the aquifer, in particular the upper water-bearing zone, may restrict the amount of future development. In the western part of the study area, the upper water-bearing zone is a potential source for development. The middle and lower zones may be a potential source in this area, but little data is available on the hydrogeology or water quality of these zones.

The effects of future ground-water development on the water levels of the upper water-bearing zone were estimated based on a mathematical model of the Floridan aquifer. Assuming a 50 percent increase in total pumpage from the major pumping centers from 82 to 123 Mgal/d within the study area, the projected steady-state drawdowns in an observation well less than 2 miles from 2 major pumping centers, was 40.5 feet below the estimated drawdown based on existing pumpage. In observation wells about 5 to 10 miles from the major pumping centers, projected net declines were 9.9 to 17.4 feet. About 30 miles offshore, west of the inferred position of the freshwater-saltwater interface, the projected drawdown is 7.7 feet, a net decline of only 2 feet.

Further declines in the artesian head of the upper water-bearing zone of the Floridan aquifer due to increased pumpage would most likely result in: (1) a decrease in natural discharge and an increase in recharge from surficial aquifer; (2) an increase in head differences among the zones of the aquifer, thereby increasing upward leakage; and (3) a further deterioration of water quality in wells that tap both fresh and saline water zones.

The maximum possible increase in pumpage that would not cause significant water-quality deterioration and significant drawdowns in water levels in the upper zone of the Floridan aquifer cannot be determined with present data. Wells that penetrate the upper zone exclusively and that are not near deep wells, show no increase in chloride concentrations. Thus, the semiconfining beds, where not breached, appear to be effective barriers to upward migration of saline water.

If additional studies or monitoring programs indicate that saline-water intrusion is occurring in the upper zone of the aquifer in the future, a number of management and conservation techniques could be considered depending on the type and extent of intrusion. Some of these include: (1) the sealing or plugging back of wells which penetrate both saline water and freshwater zones of the Floridan aquifer; (2) reduction of pumpage and decentralization of well fields; (3) development of certain zones of the aquifer and areas for particular uses; and (4) control of flowing wells.

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