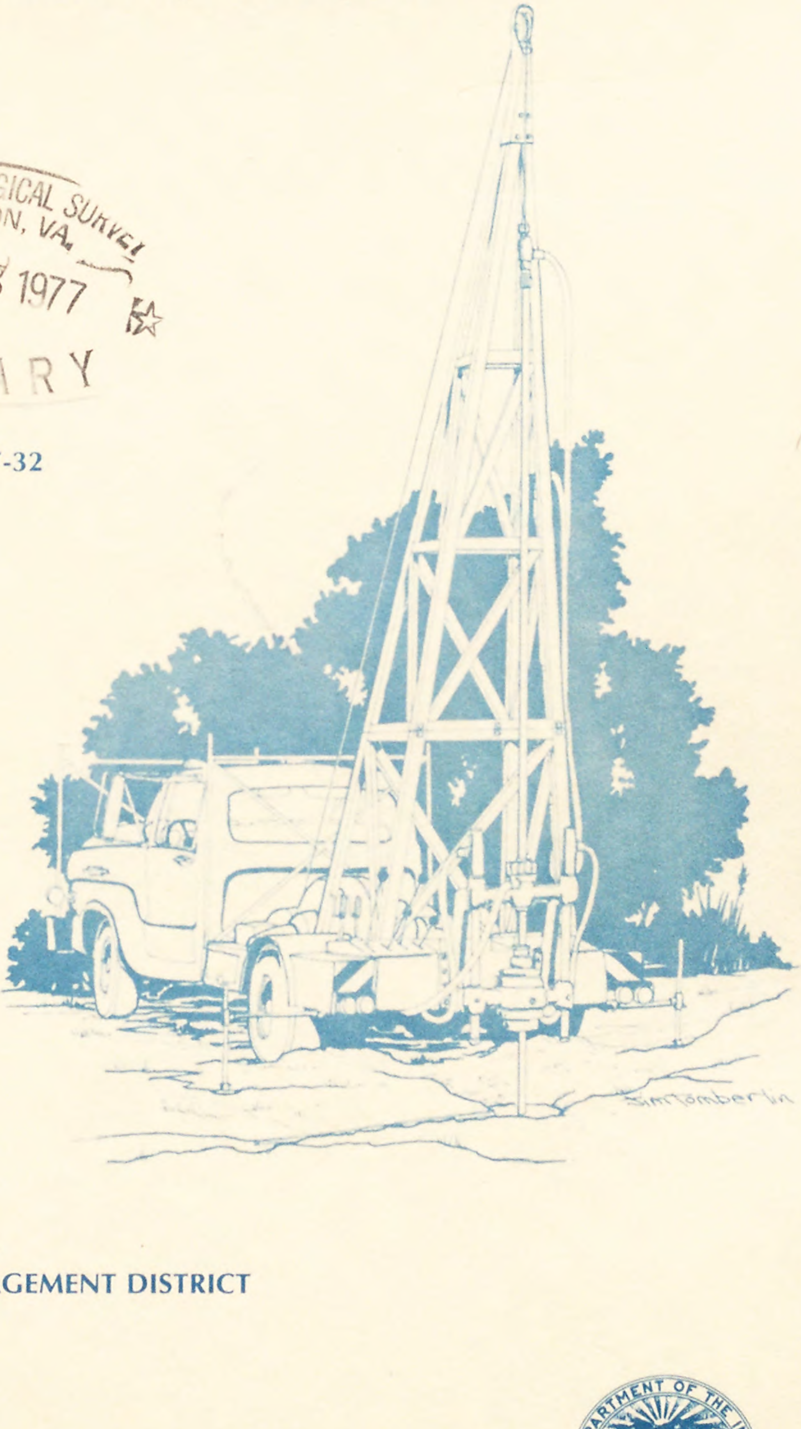
SALINE-WATER INTRUSION IN THE FLORIDAN AQUIFER IN THE FERNANDINA BEACH AREA, NASSAU COUNTY, FLORIDA

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 77-32



Prepared in cooperation with the
ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

WRI 77-32 SALINE-WATER INTRUSION IN THE FLORIDAN AQUIFER IN THE FERNANDINA BEACH AREA, NASSAU COUNTY, FLORIDA WRI 77-32

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16. Abstracts The Floridan aquifer is the major source of water for municipal and industrial use in northeastern Nassau County, Florida. Pumpage from the aquifer at Fernandina Beach has created a cone of depression in the potentiometric surface which is at or below sea level in a 35-square mile area. Since 1880 water levels have declined more than 120 feet near the center of pumping, and chloride concentrations have increased from about 20 to a maximum of 800 milligrams per liter in some deep wells. The saline water probably is connate water which comes from zones below 1,250 and 2,000 feet. Several alternate methods to control the migration of saline water are discussed.

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September 1977

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SALINE-WATER INTRUSION IN THE FLORIDAN AQUIFER IN THE FERNANDINA BEACH AREA, NASSAU COUNTY, FLORIDA

By

Roy W. Fairchild and C. B. Bentley

ABSTRACT

The Floridan aquifer, consisting of about 1,500 feet of mostly Eocene limestone, is the major source of water for industrial, commercial, and public supplies in northeastern Nassau County, Florida. It is overlain by clastic material that contains beds of clay and sandy clay which retard the upward movement of water and confine the water under artesian pressure.

Pumpage from the aquifer at Fernandina Beach was about 57 million gallons per day in 1975. Withdrawals have created a cone of depression in the potentiometric surface which is at or below sea level in an area of about 35 square miles.

Since 1880 water levels have declined more than 120 feet near the center of pumping and 35 feet in the western part of the area of investigation. Associated with this decline is an increase in the chloride concentration in the water from several wells in about a 9-square-mile area at Fernandina Beach. Chloride concentrations in water discharged by wells more than 1,250 feet deep in that area have increased from 100 to 800 milligrams per liter since 1953, while chloride concentrations in water from wells 800 to 1,250 feet deep near the center of pumping ranges from 46 to 81 milligrams per liter. Original chloride concentrations probably ranged from 20 to 30 milligrams per liter.

The saline water in the upper part of the Floridan aquifer probably is connate water which comes from zones below 1,250 feet and 2,000 feet, respectively. Relatively impermeable barriers in the aquifer at about 1,150 feet retard upward movement of saline water into the overlying freshwater zones. Where these barriers are breached by deep wells or possible fractures, the saline water from deeper zones under higher artesian pressure is allowed to move upward into the freshwater zones.

In the area of heavy pumping the simultaneous occurrence of declining artesian pressure and saline-water intrusion indicate that the two conditions are closely related. Several alternative methods to control the upward migration of saline water in aquifers are reduced pumping, well sealing, well field design and well construction, and protective pumping.

INTRODUCTION

The economy of Fernandina Beach depends largely on an adequate source of freshwater to supply two paper manufacturing plants and the residents. Practically all of this freshwater comes from wells in the Floridan aquifer. Since 1939, withdrawals of water from the Floridan aquifer have lowered the artesian pressure in the aquifer and created an extensive cone of depression in the potentiometric surface throughout eastern Nassau County. These changes have caused saline water to move into many of the deeper wells and gradually increase the chloride concentration in many of the shallower wells in the aquifer.

Purpose

In October 1974, the U. S. Geological Survey in cooperation with the St. Johns River Water Management District began an investigation to determine the source, extent, and causes of saline-water intrusion in the Floridan aquifer in the Fernandina Beach area. The investigation was completed in December 1975. The information from this investigation presented in this report is intended to help water managers and users protect ground water in the Floridan aquifer against further saline-water intrusion.

Location

The area of investigation covers about 125 mi^2 in Nassau County in the northeast corner of Florida. The area most affected by saline-water intrusion is about 9 mi^2 near Fernandina Beach.

Previous investigations

Water-level and water-quality data have been collected in the Fernandina Beach area by the U. S. Geological Survey since about 1939. A report by Cooper, Kenner, and Brown (1953) on the ground-water resources in central and northern Florida, which includes the Fernandina Beach area, discusses withdrawal of water from the Floridan aquifer and the effect of that withdrawal on artesian pressures. A report by Black, Brown, and Pearce (1953) includes a brief discussion on the possibility of saltwater intrusion in northeast Florida. Derragon (1955) collected ground-water data during a reconnaissance investigation of the area. Leve (1961) completed a reconnaissance investigation of saline-water intrusion in the area followed by a comprehensive investigation of the geology and ground-water resources of Duval and Nassau Counties from 1961 to 1965 (Leve, 1966).

Data collection

Major phases of the investigation included compilation and review of existing data from U. S. Geological Survey files. Information on ground-water use, water levels, and chemical quality of water was obtained from the municipal water supplier and local industries. An inventory was made of selected wells to determine their depths, diameters, and locations. A network of 21 wells was established to monitor changes in artesian pressures in the aquifer, and a water-level recorder was installed on a well near the center of pumping to determine changes in artesian pressures during industrial shut-down periods. Water samples from 36 wells were collected and analyzed for chemical quality and results were compared with analyses of water samples collected earlier to determine changes in water quality.

The locations of wells used in this investigation are shown in figure 1. Well numbers consist of an arbitrary sequencial number preceded by a letter designating the quadrant A, B, C, or D in which the well is located. Quadrant B includes most of the area near Fernandina Beach where saline water is intruding the Floridan aquifer. Well numbers in the text and on the illustrations are designated by the quadrant letter followed by the sequential number of the well; for example, well B-2 is well 2 in quadrant B on figure 1. The U. S. Geological Survey Site Identification Number is listed at the end of this report for each well mentioned in the report.

Acknowledgments

Particular acknowledgment is given to the Executive Director of the St. Johns River Water Management District and his staff for their encouragement and support during the investigation and preparation of the report. Special appreciation is extended to Mr. Richard Johnson of that organization and to Mr. Craig Helping of the Florida Department of Environmental Regulation who provided support in deep-well sampling and geophysical logging. The writers also wish to express their appreciation to Mr. Milton Shirley, Environmental Engineer, ITT Rayonier Inc.; Mr. William Wandmacher, Technical Superintendent, Container Corporation of America; and to Mr. J. D. Daugherty, Vice President, Florida Public Utilities Company, for data supplied during this investigation.

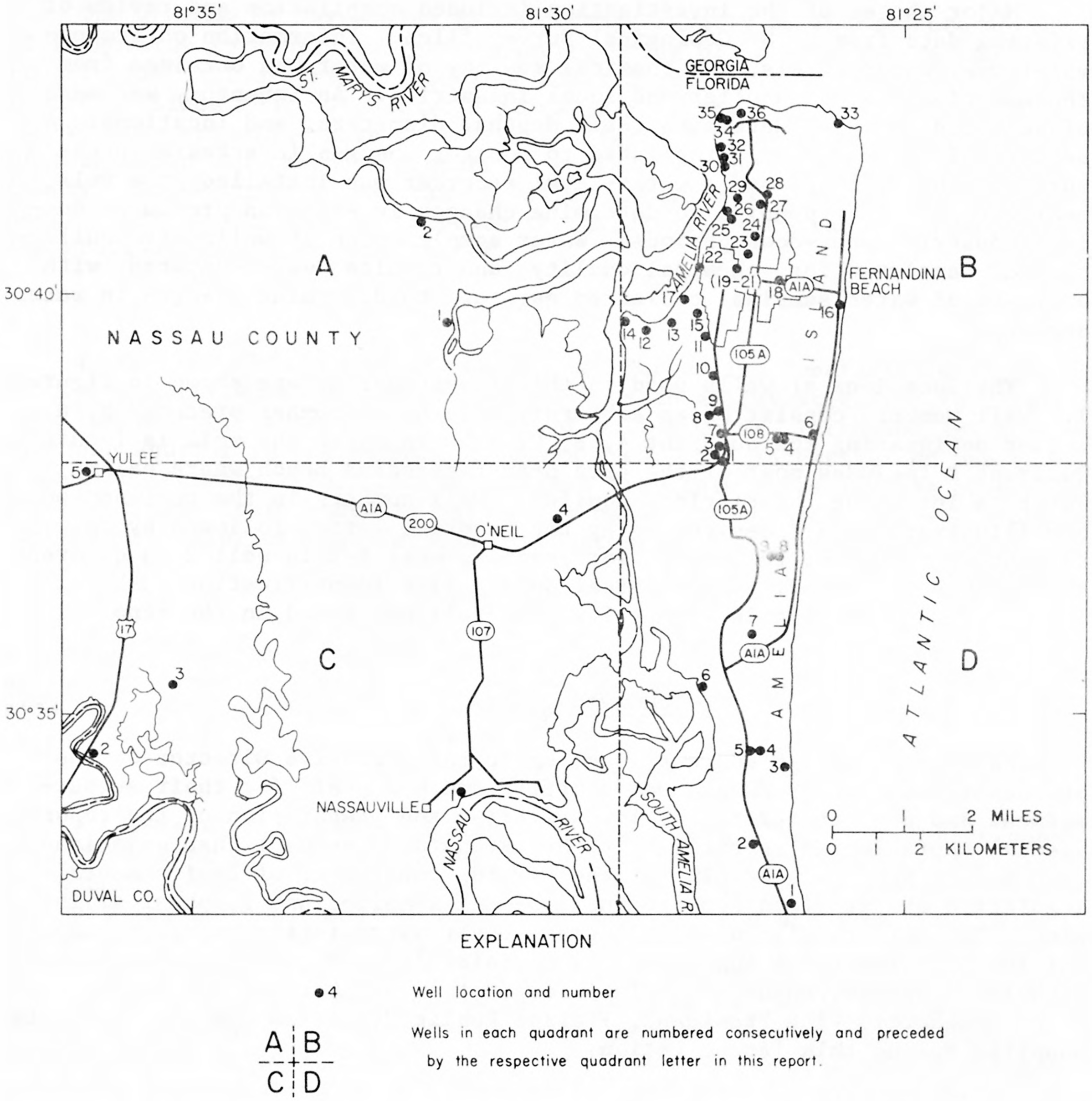


FIGURE 1.--Location of the area of investigation and selected wells.

For the use of those readers who may prefer to use metric units, the conversion factors for the English units used in this report are listed below:

Multiply English unit	By	To obtain metric unit
inches (in)	25.4	millimeters (mm)
feet (ft)	.3048	meters (m)
square feet (ft^2)	.0929	square meters (m^2)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	6.309×10^{-2}	liters per second (L/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)

GEOHYDROLOGY

The Floridan aquifer in the Fernandina Beach area is composed of about 1,500 ft of permeable limestone of Eocene age and is the principal source of water supply. The formations which make up the aquifer are, in ascending order, the Oldsmar, Lake City, and Avon Park Limestones and the Ocala Group (designated Ocala Limestone by the U. S. Geological Survey). East of the Fernandina Beach area the aquifer includes the Suwannee Limestone of Oligocene age, but this formation probably is absent in the report area.

The aquifer is overlain by the Hawthorn Formation of middle Miocene age, which consists of greenish-gray, phosphatic, calcareous clay with leneses of dolomite, limestone and sand. The clay and sandy clay beds, which are relatively impermeable, retard upward movement of water from the underlying limestone and confine it under artesian pressure in the limestone. In some areas, where the lower permeable beds in the Hawthorn Formation are not separated from the Eocene formations by relatively impermeable layers, the lower beds are considered part of the Floridan aquifer. The Hawthorn is overlain by beds of greenish-gray, sandy and shelly marl and sand. The combined thickness of the Hawthorn Formation and the post-Hawthorn deposits is more than 500 ft. For a detailed description of the formations in the Fernandina Beach area the reader is referred to Leve (1966).

GROUND WATER

Pumpage

Practically all the water for municipal, industrial, and domestic supplies in the Fernandina Beach area is obtained from wells that tap the Floridan aquifer. Wells for municipal and industrial supplies are 8 to 24 in in diameter and produce from 900 to 7,000 gal/min. Most domestic wells are 3 to 6 in in diameter and produce from 50 to 300 gal/min. In 1940 pumpage at Fernandina Beach was about 32 Mgal/d, gradually increased to about 52 Mgal/d in 1957, and has remained between 50 and 60 Mgal/d since 1961. In 1975 pumpage was about 57 Mgal/d. A graph of average daily pumpage for the years 1940-75 is shown on figure 2.

Water levels

Under natural or undisturbed conditions water in the Floridan aquifer in the Fernandina Beach area was confined under sufficient artesian pressure to cause most wells to flow. However, most of the wells no longer flow because pumping at Fernandina Beach lowers the artesian pressure to below land surface during most of the year.

The hydraulic gradient, the direction in which water in the aquifer flows, is generally from west to east, but because of the concentrated pumping the hydraulic gradient in much of the area is toward the center of an expanding depression (cone of depression) in the potentiometric surface (see figs. 4, 5, and 6). Hydrographs of selected wells show that during the last 25 years the potentiometric surface has declined as much as 35 ft near the center of pumping (fig. 3, well B-33), and as much as 25 ft in wells at a distance of 7 to 12 miles from the center of pumping (fig. 2, well C-5; fig. 3, well D-1). Approximate profiles of the potentiometric surface for each of several years since 1880 are shown on figure 4. The potentiometric surface has declined almost 35 ft in the western part of the area since 1880, an average rate of about 0.4 ft per year. Near the center of pumping, water levels have declined more than 120 ft during the same period, an average rate of about 1.3 ft per year.

That the cone of depression also is expanding horizontally is shown by potentiometric maps for 1946 and 1959 (Leve, 1961) and by data collected during this investigation (figs. 5 and 6). For example, in 1946 the sea-level contour line enclosed an area of about 2 mi^2 where the potentiometric surface had been depressed to or below sea level. The area increased to about 35 mi^2 by 1975.

The effect of pumping on water levels at Fernandina Beach is shown by short-term hydrographs (fig. 7) compiled from data collected during this investigation. The rise in water levels during times when industrial wells were not pumping is apparent on all of the hydrographs, especially December 1974 and 1975, and July 1975. Annual fluctuations of water levels range from 2 to 3 ft in areas distant from the center of pumping and from

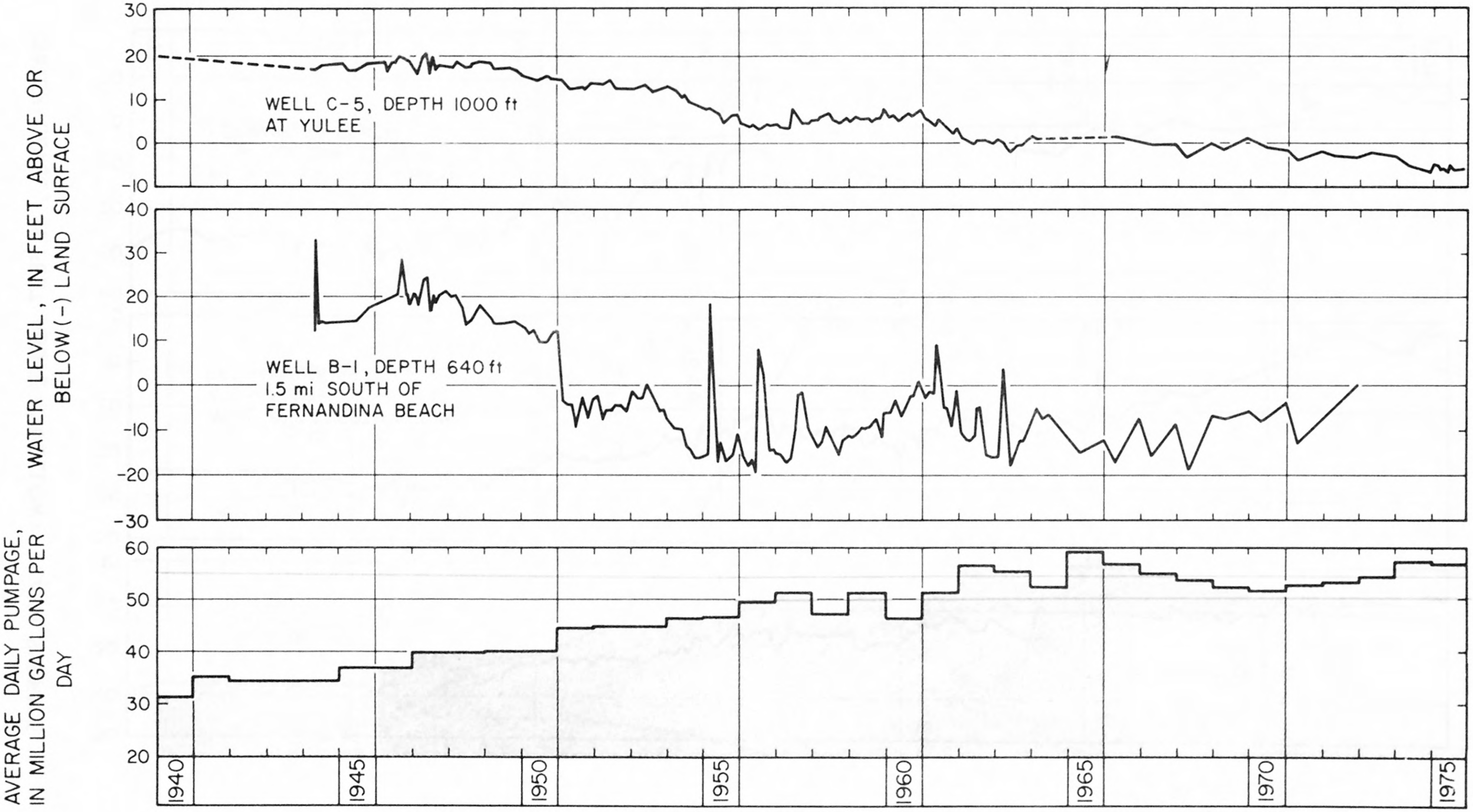


FIGURE 2.--Hydrographs of wells B-1 and C-5, and average daily pumpage at Fernandina Beach.

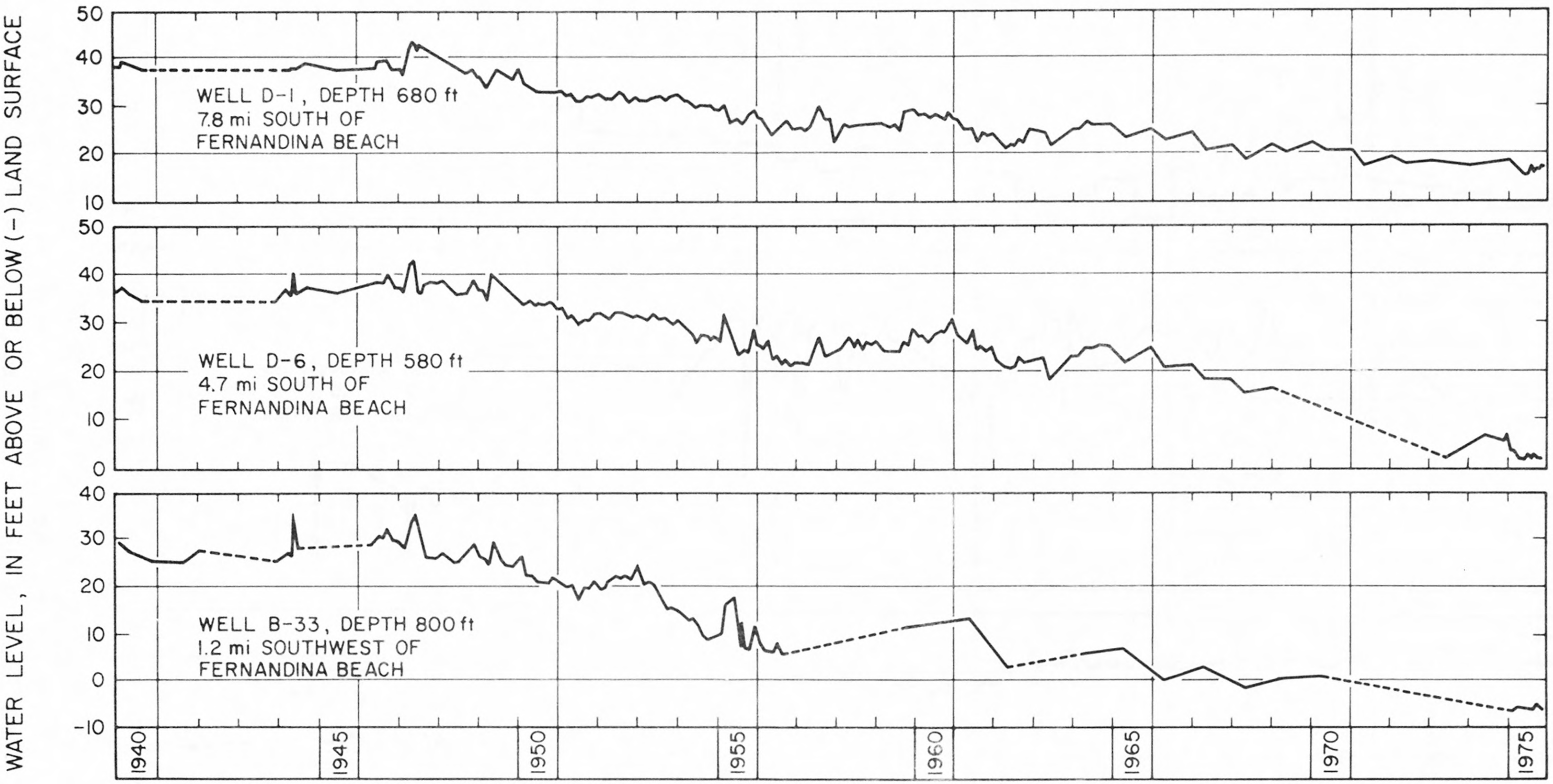


FIGURE 3.--Hydrographs of wells D-1, D-6, and B-33

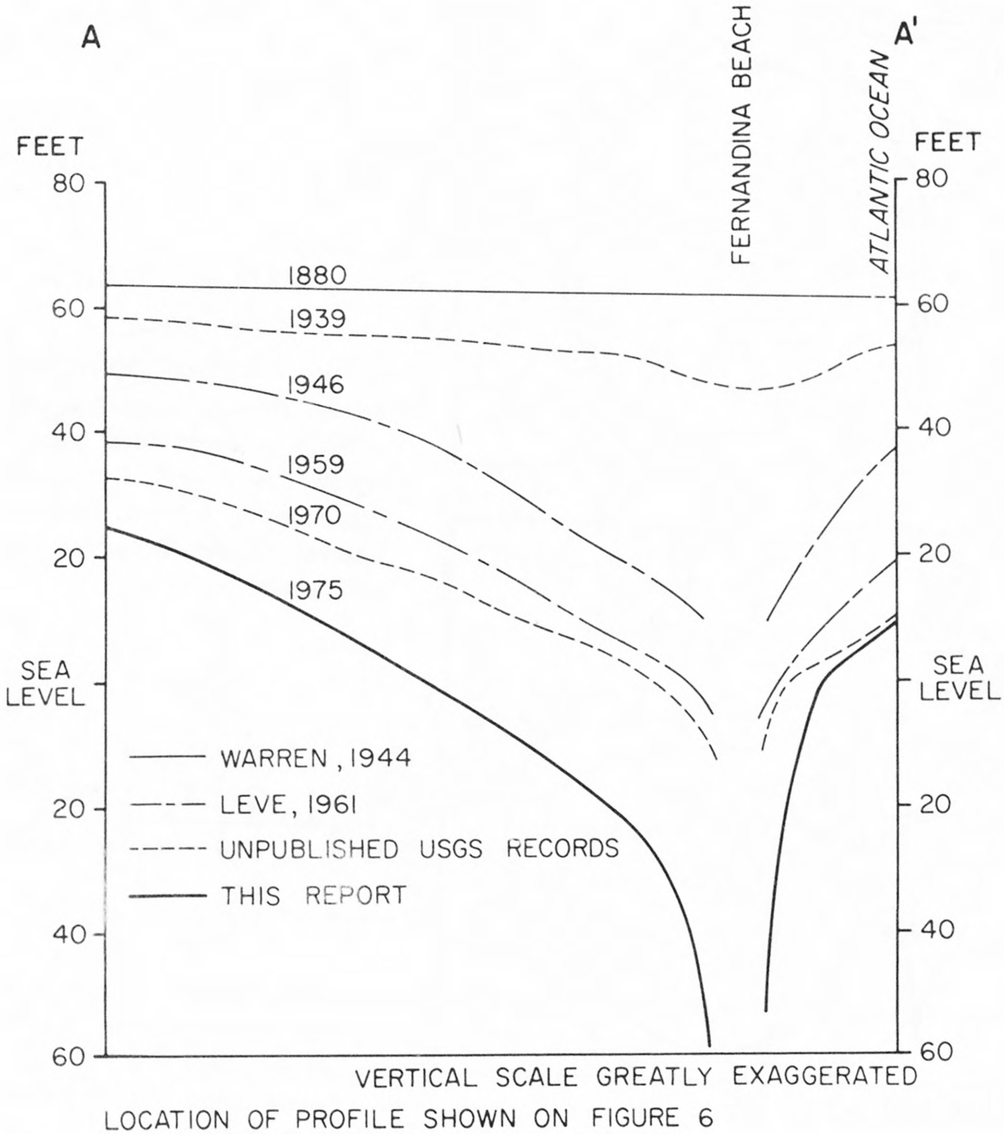
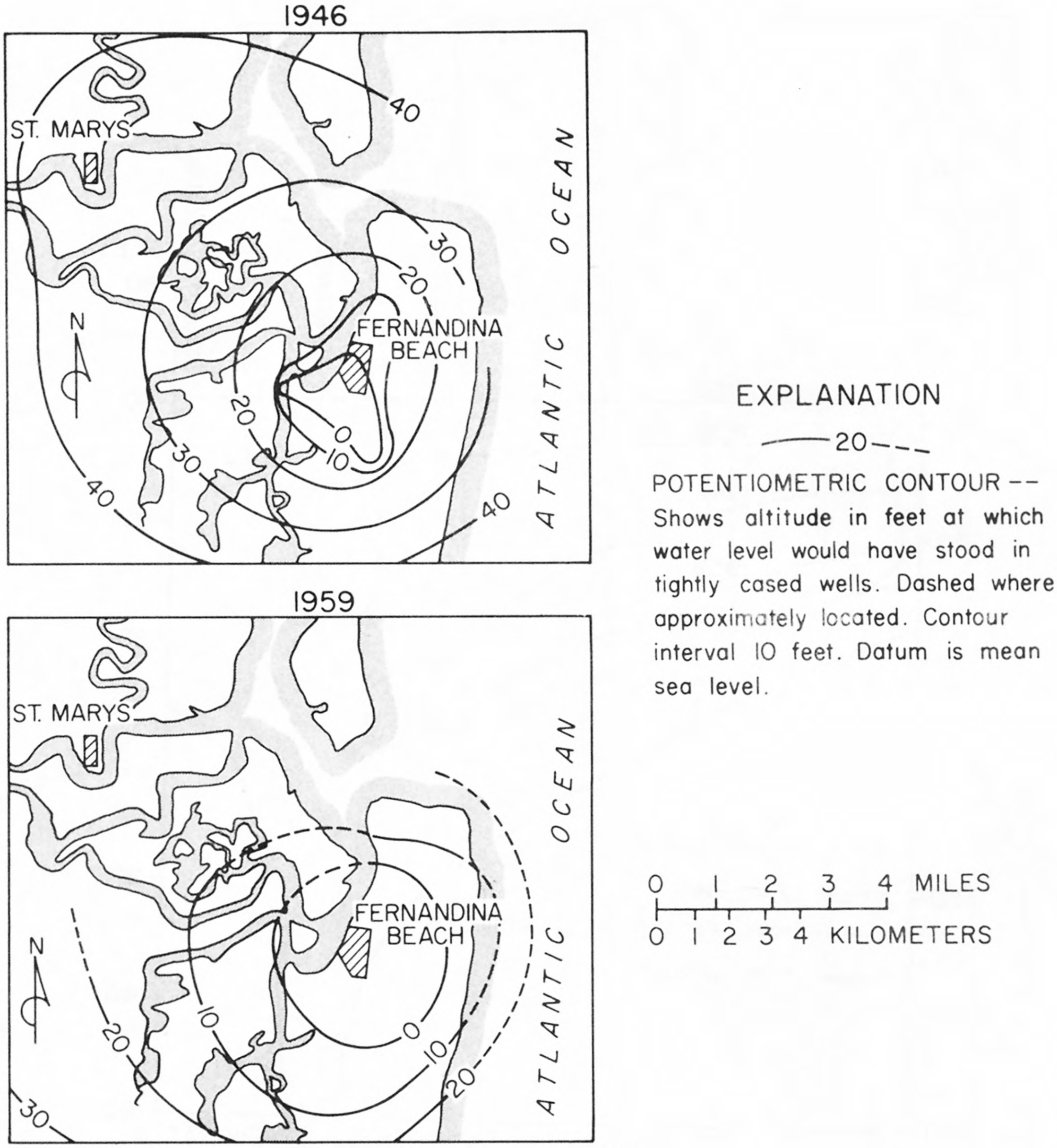
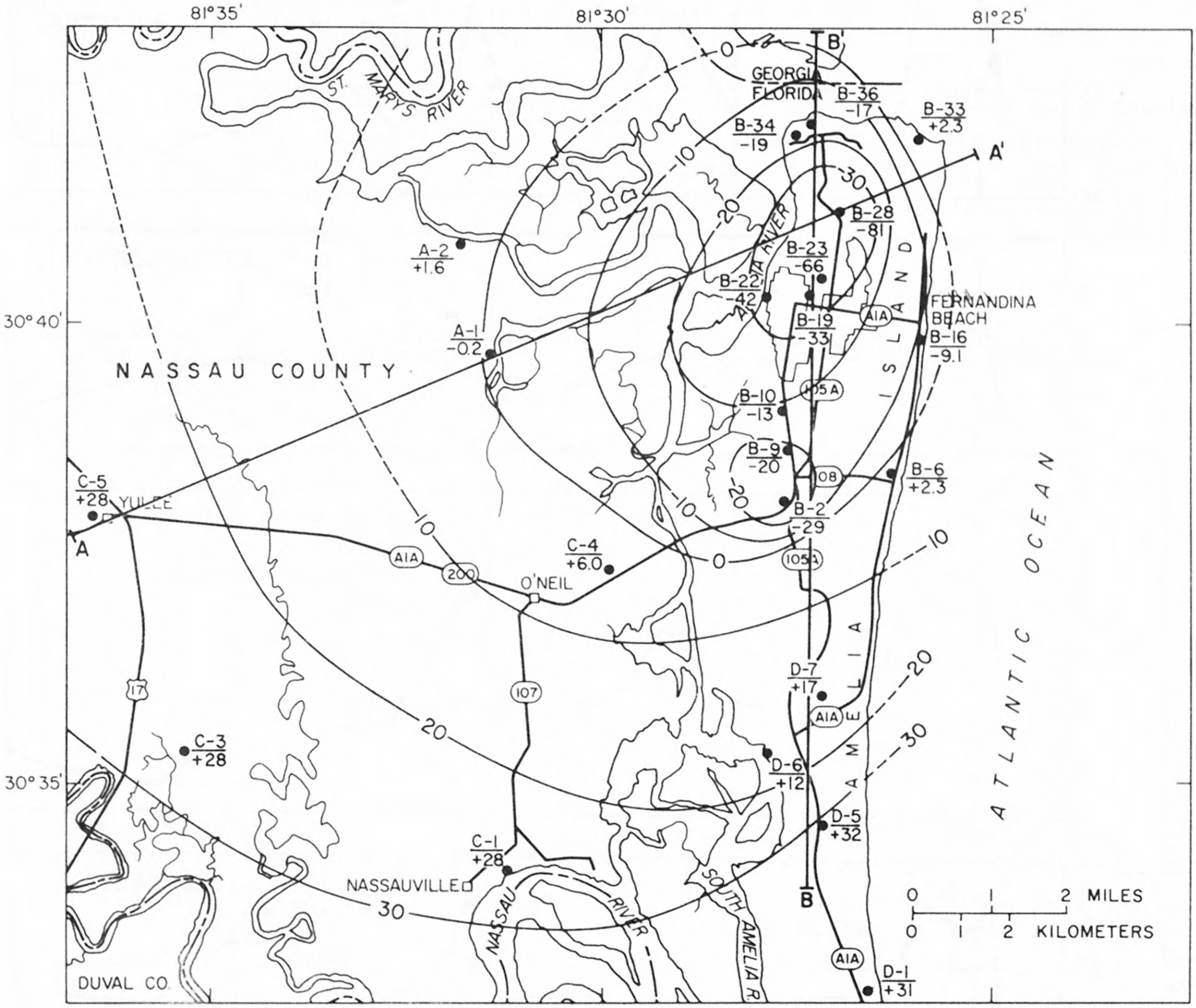


FIGURE 4.--Generalized profiles of the potentiometric surface of the Floridan aquifer in the Fernandina Beach area.



Modified from Leve, 1961

FIGURE 5.--The potentiometric surface of the Floridan aquifer in the Fernandina Beach area in 1946 and 1959 (modified from Leve, 1961).



EXPLANATION

C-4 / +6.0 ●	WELL—Shows well number (above line) and water level in feet above (+) or below (-) mean sea level (below line).
——20- - -	POTENTIOMETRIC CONTOUR — Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Contour interval is 10 feet. Datum is mean sea level.
A ⊢—⊣ A'	Location of geologic sections shown on figures 4 and 8.

FIGURE 6.--Potentiometric surface of the Floridan aquifer in eastern Nassau County, December 1975.

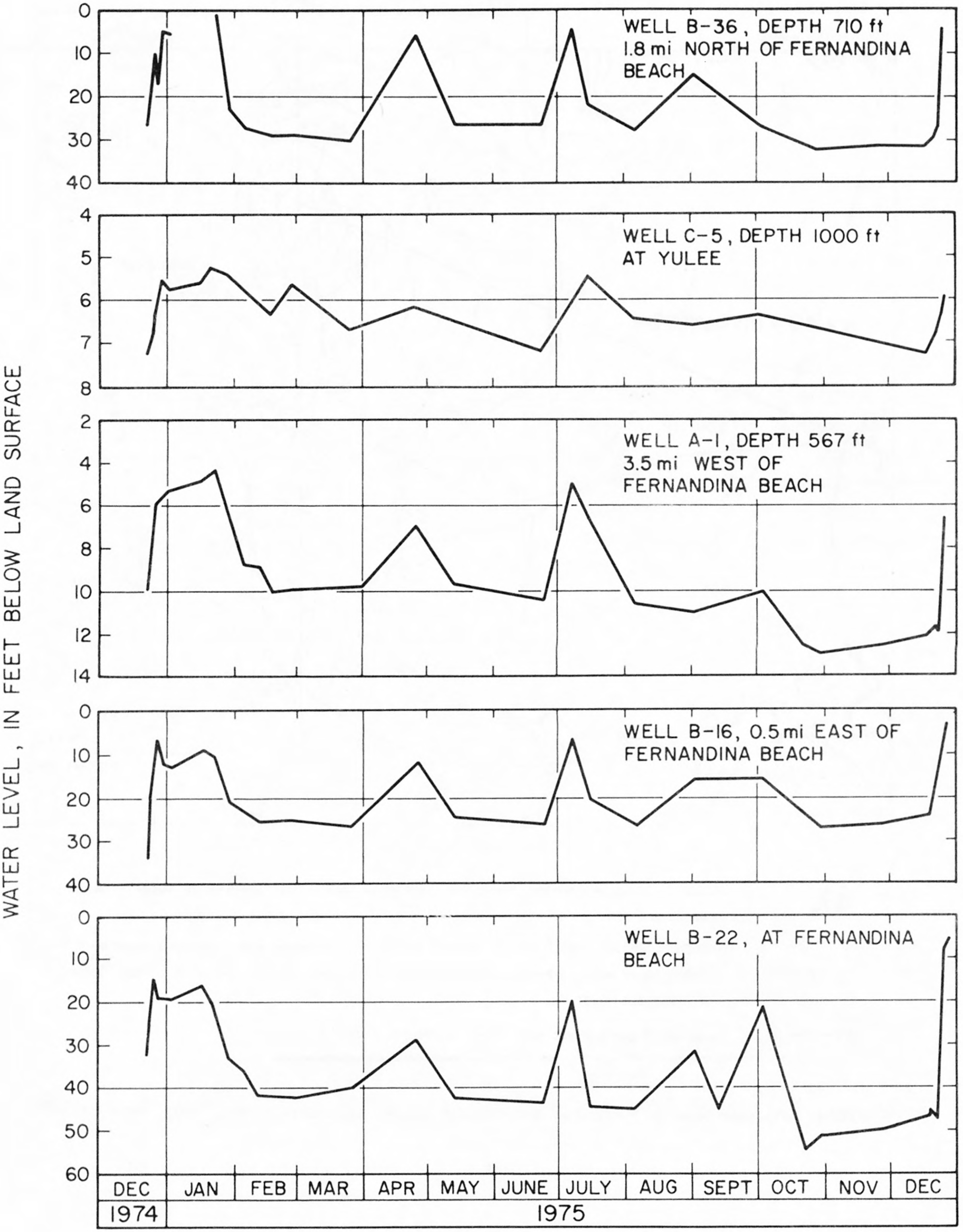


FIGURE 7.--Hydrographs of selected wells.

20 ft to more than 40 ft near the center. This wide fluctuation in water levels near the center of pumpage is a result of variations in rates of withdrawals from nearby industrial wells.

Profiles of the potentiometric surface also show the effect of periodic industrial pumping on water levels (fig. 8). During nonpumping periods water levels in many wells that tap the Floridan aquifer recover to above land surface. Water levels do not fully recover to the level of the original potentiometric surface, however, because the length of non-pumping periods is too short.

On the basis of water-level differences between well B-10, which is 1,840 ft deep, and nearby shallower wells that penetrate only the upper zones of the aquifer, artesian pressure in the deeper zones is as much as 20 ft higher than that in the upper zones. According to Leve (1966, p. 24-26) permeable limestone beds in the Ocala Group are separated from similar beds in the underlying Lake City and Oldsmar Limestones by relatively impermeable dolomite beds which restrict the vertical upward movement of water between the overlying and underlying permeable zones. Where a zone of low permeability that separates two zones is breached either by the construction of deep wells or by fractures, water from the zone of higher pressure can flow upward through well bores or the fractures into the zone of lower pressure.

SALINE-WATER INTRUSION

The chloride concentration of water in wells that tap the Floridan aquifer in the area of investigation is shown on figure 9. The chloride concentration of water in all wells except well B-23 was determined from samples collected at the well head; therefore, the water in each sample may be a mixture of water from more than one water-bearing zone in the aquifer.

As shown on figure 9, the chloride concentration in water from 36 wells in the area of investigation ranged from 23 to 925 milligrams per liter. Of the samples collected from 32 of the wells chloride concentrations ranged from 23 to 112 mg/L, and samples from 4 wells contained water with chloride concentrations that ranged from 136 to 925 mg/L. Well B-2 (fig. 1) was sampled at the well head and at depths of 600 and 925 ft. The sample collected at the well head while the well was flowing had a chloride concentration of 65 mg/L; the sample from 600 ft had a chloride concentration of 80 mg/L and the sample collected from 925 ft had a chloride concentration of 245 mg/L. Well B-23 (fig. 1) was sampled at depths of 580 and 960 ft and the water had chloride concentrations of 46 and 64 mg/L at the respective depths. The increase in chloride concentration with depths of sample collection from wells B-5 and B-23 indicates that the salinity of the water in many of the wells shown on figure 9, especially at Fernandina Beach, probably is higher in the deeper parts of the wells.

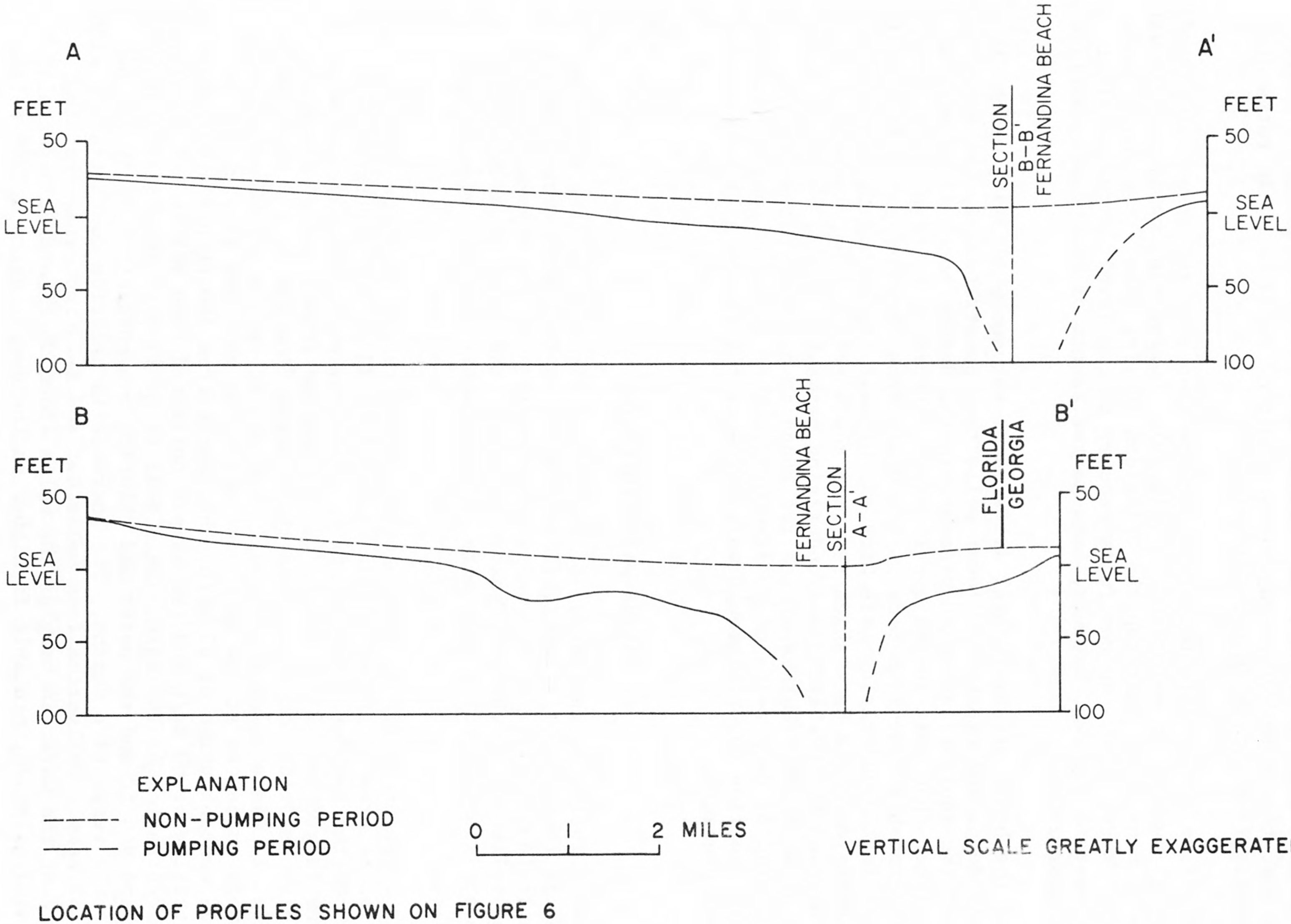


FIGURE 8.--Generalized profiles of the Floridan aquifer potentiometric surface showing effects of periodic industrial pumping December 1975.

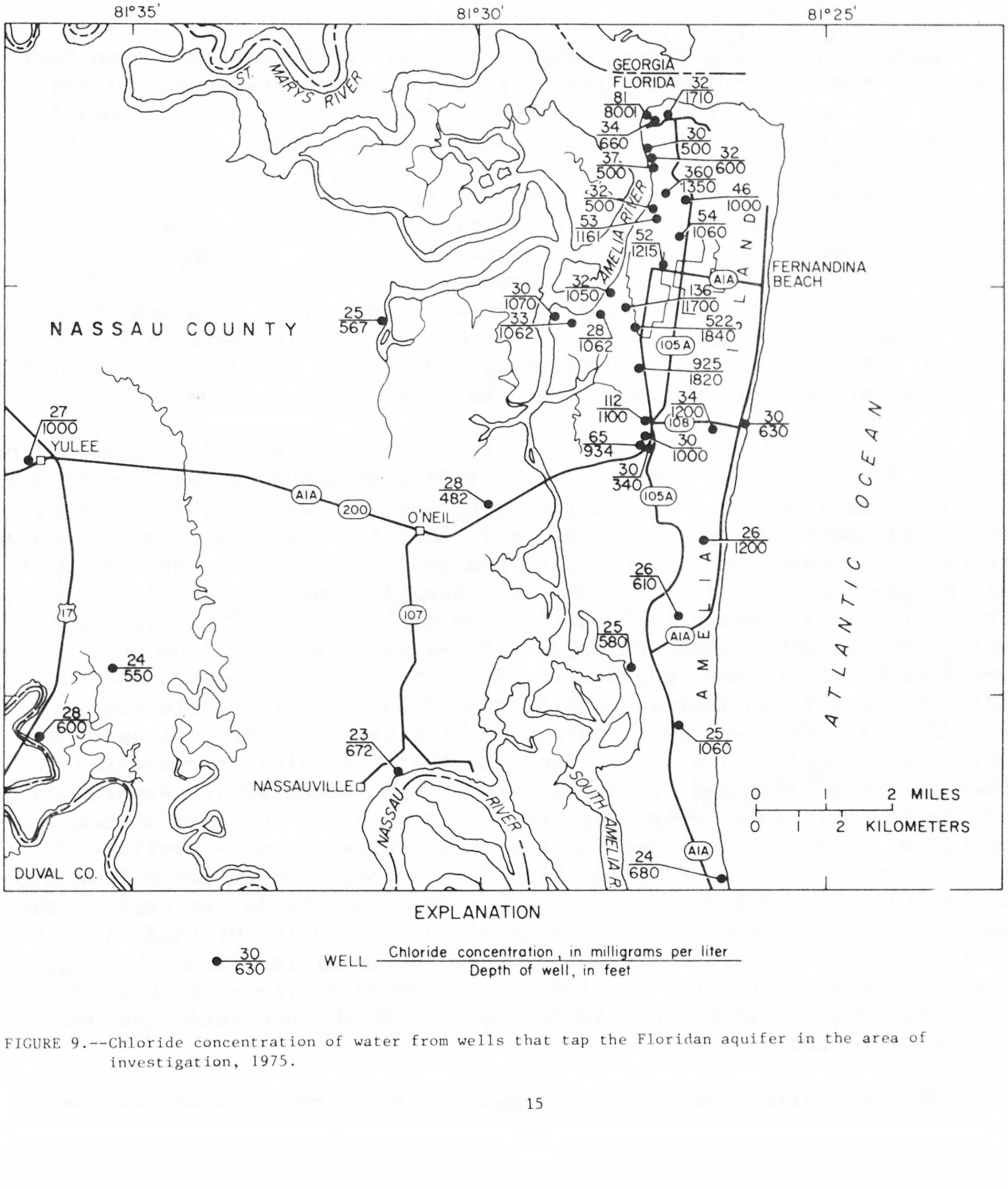


FIGURE 9.--Chloride concentration of water from wells that tap the Floridan aquifer in the area of investigation, 1975.

Increases in the chloride concentration of water in wells in shallow coastal aquifers generally is an indication of lateral seawater encroachment. In the area of investigation, however, the increase of chloride concentrations with depth and the higher concentrations of chloride in the deeper wells indicate that intrusion of saline water is by upward migration of connate water from deep zones in the aquifer. No indication of lateral movement of seawater in the Floridan aquifer in the area was found in this investigation.

Leve (1966 p. 63) reports that a zone at the base of the Avon Park Limestone and the top of the Lake City Limestone is one source of saline water. The water directly above and below the zone was considerably fresher, which indicates that the water in the zone at that time was isolated from water in the rest of the aquifer. Probably the main source of contamination is highly saline water below a depth of 2,000 ft in the aquifer. Water from this zone is restricted from moving upward into the freshwater zone by a relatively impermeable barrier at a depth of about 1,150 ft, (Leve, 1966, p. 25-29). However, saline water can move into the upper zone where the relatively impermeable barrier is breached by open well bores or fractures. It can also move through the barrier if the pressure in the upper zone is sufficiently reduced and saline water under higher pressure can seep gradually through the relatively impermeable rock.

Figure 10, 11 and 12 show that since 1952 the chloride concentration in well B-10, which is 1,820 ft deep, increased about 800 mg/L; well B-15, 1,700 ft deep, increased about 100 mg/L; and well B-11, 1,840 ft deep, increased about 500 mg/L. In well B-7, 1826 ft deep, the chloride concentration increased about 1,300 mg/L from 1952 to 1962. In 1962 the well was plugged to 1,100 ft. In 1964 the chloride concentration in water from that well had decreased to less than 100 mg/L but in 1975 increased to 112 mg/L. On the other hand, chlorides of the water samples from well B-20, which is 1,215 ft deep ranged from 25 to 35 mg/L between 1924 and 1971 (fig. 12). Since 1971 an increase has been noticed. Samples collected from the well in 1972, 1974 and 1975 contained chloride in concentrations of 46, 28 and 52 mg/L, respectively, and indicate that the chloride concentration in that well has increased between 17 and 27 mg/L since 1971. Several wells, 800 to 1,250 ft deep, which tap the shallow zone of the aquifer near the center of major pumping contain water with chloride concentrations that range from 46 to 81 mg/L. The chloride concentration in water from these wells indicates that saline water has moved from the deeper part of the aquifer to the shallower part. Some of this intrusion probably is through nearby uncased wells open to both zones. Wells distant from the center of pumping yield water with chloride concentration averages of about 30 mg/L. Water in those wells has not increased in chloride concentration over the period of record.

The hydraulic gradient on the east flank of the cone of depression along the coastline is steeper than that on the west (fig. 6). This suggests that either the transmissivity of the Floridan aquifer on the east flank of the cone is lower than that elsewhere in the area or that the aquifer is receiving recharge at the coast or offshore. The Floridan

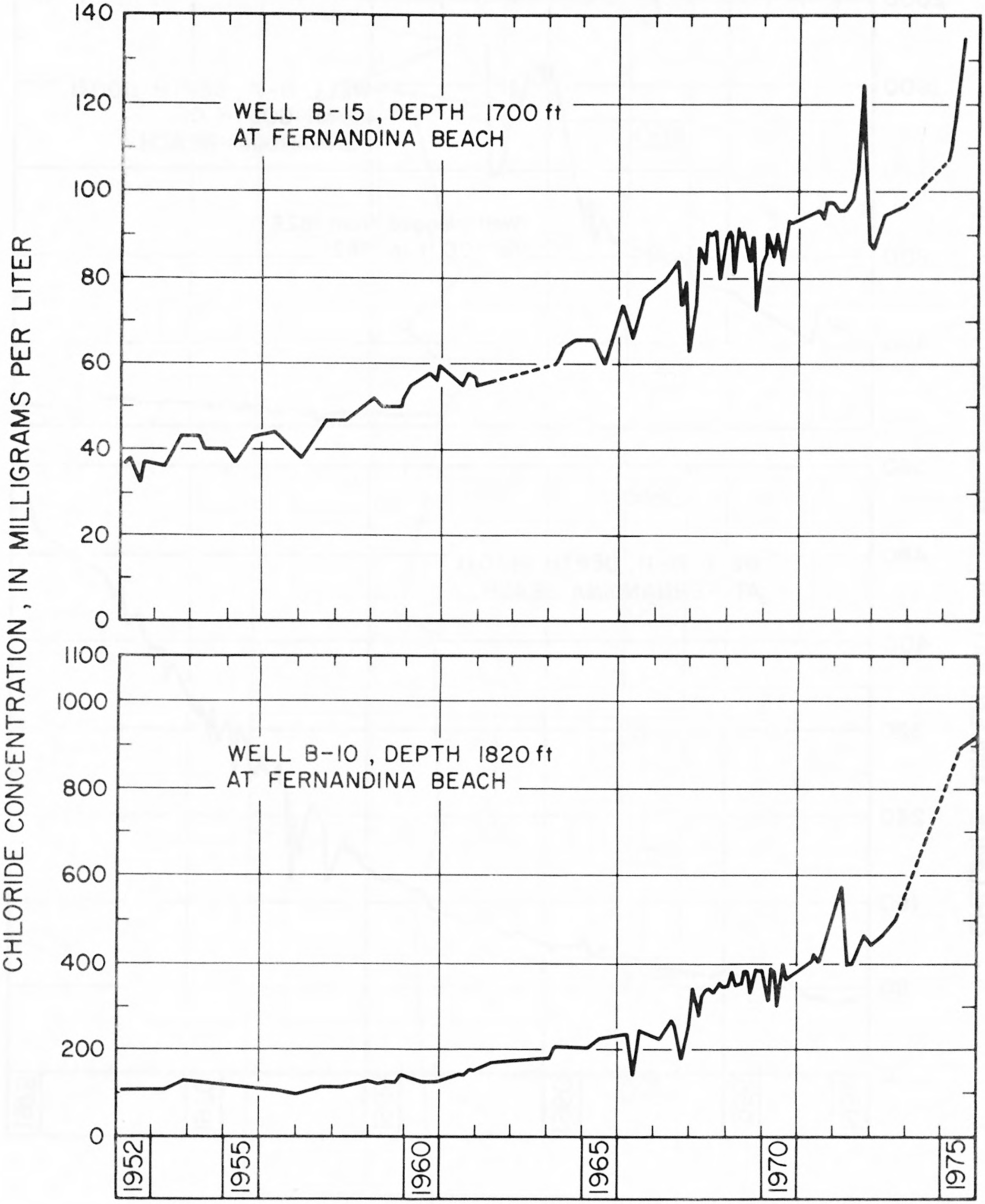


FIGURE 10.--Graphs of the chloride concentration of water from wells F-10 and B-15 at Fernandina Beach.

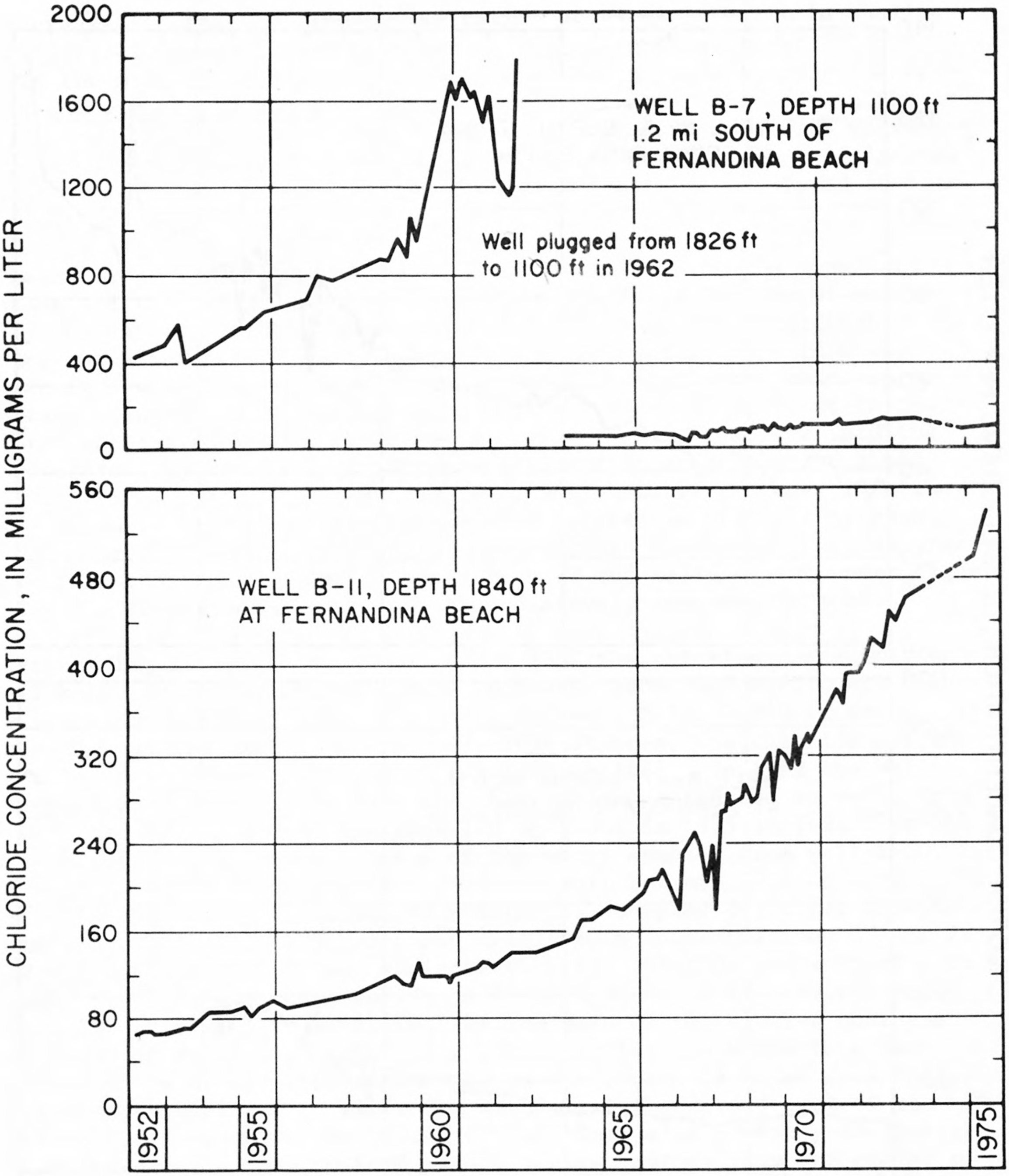


FIGURE 11.--Graphs of the chloride concentration of water from wells B-7 and B-11 at Fernandina Beach.

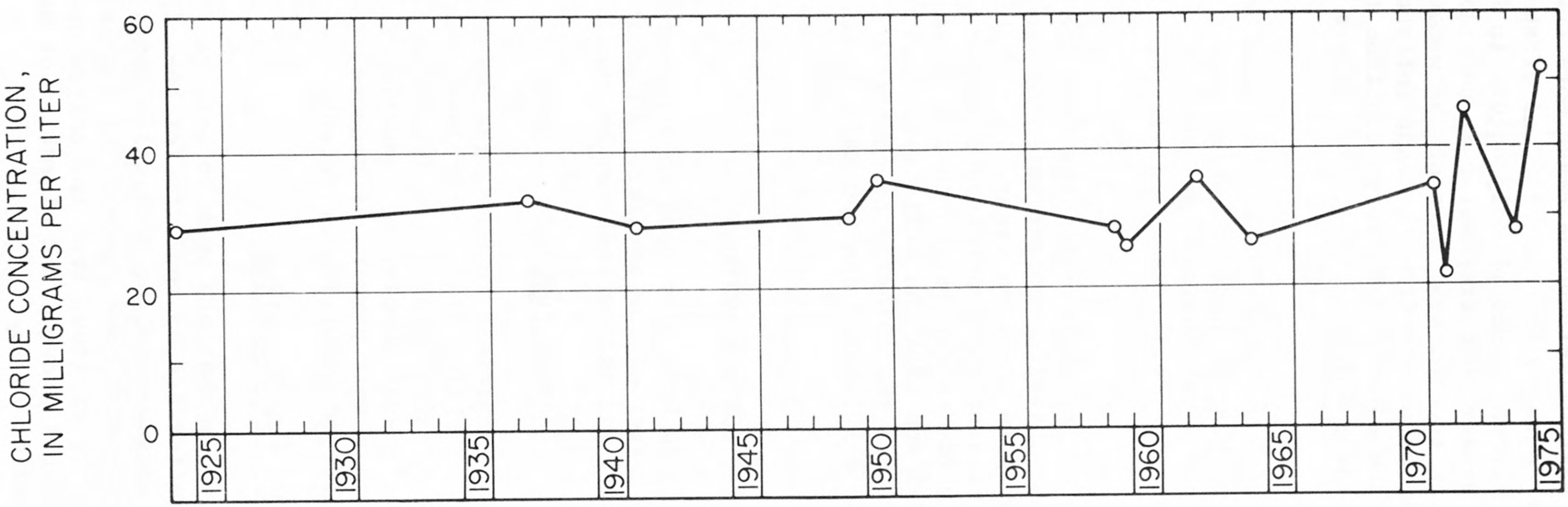


FIGURE 12.--Graph of chloride concentration of water from well B-20 at Fernandina Beach.

aquifer extends offshore east of Fernandina Beach more than 60 mi and the upper part of the aquifer contains freshwater 23 mi offshore (Manheim and Horn, 1968, p. 223-225). Seawater undoubtedly occurs in the aquifer offshore, but because it is denser than freshwater it underlies the freshwater as a wedge-shaped body with the thickest part of the wedge seaward. If recharge to the aquifer is occurring from the east (offshore), there is a possibility that, should the cone of depression continue to expand, seawater ultimately will move laterally through the aquifer toward the area of withdrawal.

Since 1962 the rate of pumping at Fernandina Beach has remained essentially constant at about 55 Mgal/d; however, water levels have continued to decline. Although the decline may indicate an overdraft, it more likely reflects a regional decline due to increases in pumping in Jacksonville and other areas.

The relation between the cumulative pumpage from the Floridan aquifer at Fernandina Beach and the chloride concentration in water in wells B-10, B-11 and B-15 during 1940-75 is shown on figure 13. Initially these wells were from 1,072 to 1,100 ft deep and penetrated only the upper part of the aquifer. In 1940 the chloride concentration in all these wells was less than 30 mg/L. Between 1945 and 1951 the wells were deepened to depths of 1,700 to 1,840 ft, and by 1975 the chloride concentration had increased to more than 900 mg/L in well B-10, more than 500 mg/L in well B-11, and about 140 mg/L in well B-15.

CONTROL METHODS

Several alternate methods have been used in other areas to control the upward migration of saline water in the aquifer. In addition to those outlined below, other tried and untried methods may be available.

Reduced pumping

A reduction in pumping sufficient to cause the potentiometric surface of the aquifer to rise and stabilize at a higher level would substantially reduce or prevent continued saline water intrusion. Such reduction could be achieved through termination of pumping or reduction in the pumping rate of individual wells. The more that pumping is reduced, the greater will be the tendency of the saltwater to stabilize or recede.

Well Sealing

Abandoned and active wells that are open to both saline water and freshwater zones in the aquifer act as conduits for the migration of saline water into the freshwater zones. Sealing such wells entails backfilling the wells through the saline-water zone, usually by pumping an impermeable material such as cement slurry or grout from the bottom upward through the saline-water zones. This would prevent the migration of saline water through open well bores into freshwater zones.

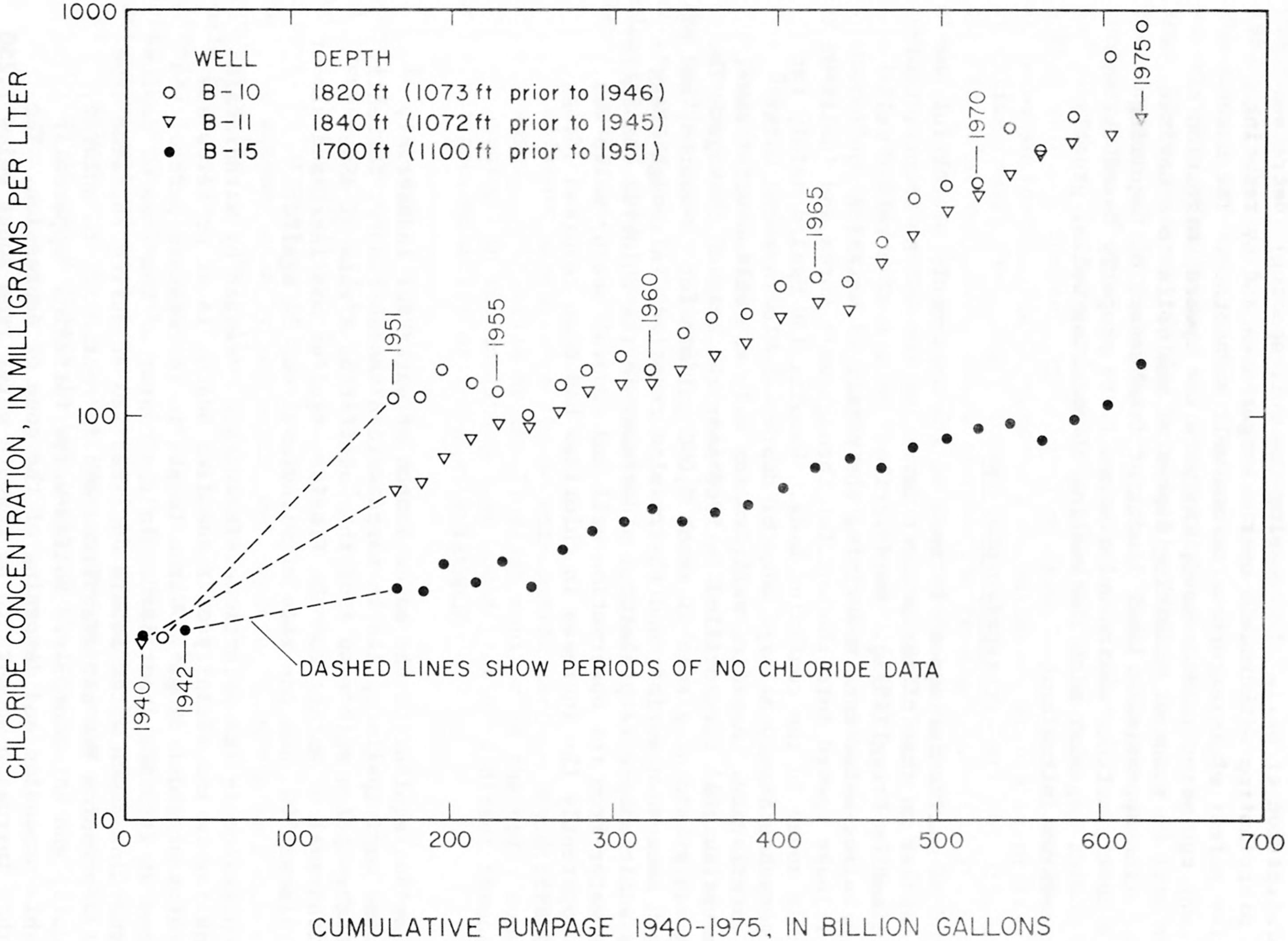


FIGURE 13.--Relation between available cumulative annual pumpage at Fernandina Beach 1940-75 and the chloride concentration in wells B-10, B-11, B-15.

Well-field design and well construction

Decentralization of wells (increasing the well spacing) decreases drawdown by distributing withdrawals over a larger area and by reducing the cumulative effect of interference of one well on another. The more drawdown at any one point is decreased, the more the upward migration of saline water will be reduced. Limiting depths of new wells to a maximum of 1,150 feet (the approximate lower limits of freshwater) or requiring deeper wells that penetrate saline-water zones to be properly cased through those zones could, together with the sealing of existing wells, greatly reduce saline-water intrusion.

Protective pumping

A method of particular appeal because of its apparently successful use in an area similar to that of the present investigation--Glynn County, Georgia--is outlined by Gregg (1971). He described the use of a relief well which taps a saline-water zone underlying the principal artesian aquifer. Saline water leaks upward into the aquifer through well bores and faults or semi-permeable zones in the confining beds. Pumping 130 Mgal/d mainly for industrial purposes caused a large cone of depression to form and water quality to deteriorate. A relief well, to tap only the saline-water zone, and an observation well were drilled in 1968 near the area of leakage. The relief well was pumped at a rate of about 3,000 gal/min for 10 months, except for a 2-month shut-down period, and the results reported. Although Gregg's conclusions admittedly were premature, a decrease in the chloride concentration of the water from the observation well and several nearby wells was noted, and apparently the increase in chlorides had been reversed (Gregg, 1971, p. 27-29).

SUMMARY

The Floridan aquifer is the major source of water for industrial, commercial and municipal supplies in northeastern Nassau County. Currently (1975), water is being withdrawn from the aquifer at a rate of about 57 Mgal/d. Withdrawal of water from the Floridan aquifer has increased almost 60 percent since 1940 when the rate of withdrawal was 34 mgal/d.

The depression in the potentiometric surface, created by withdrawals from the aquifer in the vicinity of Fernandina Beach, is at or below sea level in a area of about 35 mi^2. Water levels in the western part of the area declined 35 ft since about 1880. In the center of the cone of depression at Fernandina Beach water levels declined 120 ft during the same time. The cone of depression has not stabilized and is continuing to enlarge, both vertically and horizontally. Saline-water intrusion apparently is a result of this expansion and deepening of the cone of depression. The source of this intrusion appears to be connate water from zones below 1,250 ft and 2,000 ft.

Chloride concentrations in water in several wells in the cone of depression at Fernandina Beach increased from about 100 to 800 mg/L since 1952 with highest chloride concentrations in wells more than 1,250 ft deep. The rate of increase in chloride concentration also is greatest in these wells, particularly those with high rates of withdrawal and prolonged pumping. There is a correlation between the decline in artesian pressure and the increase of chloride concentrations. This indicates that the chloride concentration of water in a well generally is related first to its depth, and second to the rate and duration of withdrawals from the aquifer. The higher chloride concentration in water from deeper wells and the continuing increase in the chloride concentration indicate that highly mineralized water is moving upward from deeper zones of the aquifer, where the artesian pressure is relatively high, below about 1,250 ft and 2,000 ft. The pressure gradient between the upper and the lower zones enables saline water in the lower zones to migrate upward through uncased well bores or fractures in the less permeable zones. The rate of upward migration of saline water increases when the artesian pressure of the upper freshwater zone is lowered by pumping.

Several wells 800 to 1,250 ft deep and near the center of major pumping contain water with chloride concentrations ranging from 46 to 81 mg/L. This suggests that water from below this depth range is migrating upward. The decline of water levels in wells distant from the center of pumping is not as great as in those near the center of pumping, but eventual upward migration of saline water there also is a possibility because of the water-level decline.

In offshore areas where the potentiometric surface may drop below sea level, unused, leaky wells in the Floridan aquifer in the tidal zone and natural openings in the confining beds would provide a direct channel for sea water contamination of the aquifer.

Through use of conservation measures and protection of freshwater supplies based on known and tried methods, it is likely that a large part of the resource would be available for future expansion and growth in the area. The possibility of saline-water contamination could be greatly decreased by preventing excessive lowering of the artesian pressure. This could be accomplished by increasing well spacing to minimize interference between wells, by controlling withdrawals and by limiting depths of new wells to a maximum of 1,150 ft, the base of the freshwater zone. Wells already in use that penetrate deep zones of the aquifer that contain saline water at Fernandina Beach could be plugged back to 1,150 ft. An apparently successful method used under similar circumstances in another area is protective pumping, whereby a relief well pumps water only from the saline-water zone to reduce the pressure in that part of the aquifer.

FUTURE INVESTIGATIONS

The following investigations are recommended to assist local agencies in determining the most suitable locations of large-yield wells, the best methods of well construction, and optimum pumping rates for efficient utilization of the aquifer:

Monitoring program

A monitoring program is essential to obtain records of water levels, pumping rates, cumulative pumping, and water-quality data. Water levels measured at regular intervals at selected wells provide a record of the variations that occur. The intervals may be daily, weekly, monthly, or longer, depending on the rate of water-level change and the effect of this change on chloride concentration of the water. In a well where the rate of water-level change is slow, the measuring intervals may be monthly or longer. Where the levels change rapidly, frequent measurements are necessary to provide data for pump operation and regulation to prevent excessive drawdown.

The monitoring program should include one or more deep observation wells--either suitable unused wells or new wells--to monitor the deeper zones in the aquifer. The wells should be constructed to monitor and detect changes in artesian pressure and water quality in the individual zones of the aquifer.

Pumpage data can be obtained from well owners or for individual wells by means of totalizing meters installed in pump discharge lines. It is essential that the accurate records of pumpage rates, cumulative pumpage, and periods of no pumping be kept. especially of the large capacity industrial and municipal wells.

Where water salinity is increasing, frequent determinations of chloride concentrations will define the rate of increase, the sampling frequency depending on the pattern of salinity variation and magnitude of change. When water from a well is sampled for chloride analysis, a record of the pumpage and the pumping rate will provide data for evaluating the effect of pumpage and pumping rate on salinity. It would also be useful to analyze the water at less frequent intervals for chemical constituents such as dissolved-solids concentration and hardness.

Effective management of ground-water resources requires reliable records on the effect of development and draft on the aquifer. The need is especially urgent where the aquifer may be subject to the hazards of saline-water contamination or sea-water encroachment. Keeping the data includes the careful observing and accurate recording of information in a readable form, and permanent filing so that the records are readily available for all who need them.

Saline-water investigation

This investigation points out that the upward migration of connate water is the apparent primary source of saline-water contamination in the Floridan aquifer at Fernandina Beach. Although this investigation did not substantiate the lateral migration of seawater into freshwater zones of the aquifer, the possibility of its occurrence is a potential hazard if the potentiometric surface of the aquifer continues to decline. In addition to determining sources of salinity, the location of the interface between the freshwater and saline-water zones and its rate of migration should be defined.

The monitoring program outlined would be an essential part of future investigations. These investigations also should include downhole sampling, geophysical logging of wells, and aquifer testing. The drilling of test wells into the aquifer or into the overlying confining beds may be necessary in areas where hydrologic data are insufficient.

Digital model

The ability to predict how the aquifer will respond to various pumping rates over prolonged periods of time is necessary for the wise use and management of the ground-water resource. Accurate prediction requires a thorough knowledge of the aquifer system, which can be obtained through hydrologic investigations and monitoring, and through modeling of the aquifer. Digital computer models have proven to be very useful in predicting responses from various stresses. Changes in artesian pressure and, hopefully, water quality can be predicted by simulating different configurations of well locations and various pumping and recharge rates.

Additional supply

A shallow-aquifer system supplies water to a few domestic wells in the Fernandina Beach area. A quantitative and qualitative investigation of the system to evaluate its potential as a supplemental source of freshwater supply would be useful. The investigation should attempt to determine the extent and source of reported saline-water intrusion in the shallow aquifers, and if there is hydraulic continuity between the shallow system and the Floridan aquifer.

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Well Site Identification Numbers

Field No.	I. D. No.	Field No.	I. D. No.
A-1	303939081312601	B-25	304053081272501
A-2	304054081314901	B-26	304058081273001
B-1	303801081273701	B-27	304103081270002
B-2	303805081273901	B-28	304109081265501
B-3	303812081273701	B-29	304110081272001
B-4	303818081264601	B-30	304128081273301
B-5	303818081265001	B-31	304136081273301
B-6	303820081261501	B-32	304140081273201
B-7	303823081273303	B-33	304200081255501
B-8	303836081274201	B-34	304204081272701
B-9	303840081273501	B-35	304206081273201
B-10	303902081273902	B-36	304208081271801
B-11	303933081274602	C-1	303403081311301
B-12	303935081283701	C-2	303430081362601
B-13	303940081281801	C-3	303522081351401
B-14	303940081285701	C-4	303722081295401
B-15	303947081275402	C-5	303754081362701
B-16	303957081255501	D-1	303244081263701
B-17	303958081280401	D-2	303344081265901
B-18	304010081264501	D-3	303425081264001
B-19	304020081272003	D-4	303435081270301
B-20	304020081272001	D-5	303435081271401
B-21	304020081272005	D-6	303519081275301
B-22	304022081275001	D-7	303557081271001
B-23	304028081271001	D-8	303655081265201
B-24	304041081270501	D-9	303655081265401

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