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Jacksonville Beach Subregional Flow and Transport Model

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EXECUTIVE SUMMARY

Substantial declines in ground water levels have occurred in northeast Florida due to heavy pumping in the Jacksonville area. As a result, increases in chlorides have occurred in a number of wells in the area. Ground water flow and chloride concentrations are being modeled by the St. Johns River Water Management District (SJRWMD) on a regional basis in northeast Florida, but subregional-scale flow and chloride models are required in specific areas to address problems that deal with present-day and future impacts due to pumping from individual wellfields. In addition, smaller scale, site-specific models are needed in some wellfield locations to address concerns about localized saltwater upconing due to well location, casing and open-hole depths, and pumping rates of individual wells.

In March 1995, SJRWMD authorized the University of Florida to begin work on a ground water investigation of the Jacksonville Beach area. In this investigation, which is being conducted in two phases, saltwater upconing and the location of the saltwater-freshwater interface in the Jacksonville Beach area are being analyzed at two scales of interest and detail. As part of the first phase, in which the impacts of present and future pumping regimes in the Jacksonville Beach wellfield have been evaluated at a site-specific scale, existing data were compiled and reviewed, additional data were collected, site-specific analytical and numerical modeling were conducted, and this interim technical report was prepared. In the second phase, in which the impacts of pumping in Jacksonville Beach, Atlantic Beach, and adjacent areas will be analyzed, a hydrogeologic model will be conceptualized, a subregional numerical ground water flow and chloride model will be developed, and a final technical report will be prepared.

The City of Jacksonville Beach is located in northeastern Florida in Duval County in the physiographic division of Florida known as the Coastal Lowlands. The Jacksonville Beach area is underlain by a thick sequence of marine sediments that overlie a basement complex of metamorphic strata. The sedimentary deposits are the primary water-bearing units, and they can be divided into pre-Hawthorn Tertiary carbonate formations, the Hawthorn Group, and post-Hawthorn deposits. The pre-Hawthorn formations consist of four units, i.e., from oldest to youngest, the Paleocene-age Cedar Keys Formation, the early Eocene-age Oldsmar Limestone, the middle Eocene-age Avon Park Formation, and the late Eocene-age Ocala Limestone. The Hawthorn Group is of Miocene age, and the post-Hawthorn deposits range in age from Pliocene to Holocene.

The geologic units form two aquifer systems. The post-Hawthorn deposits form the surficial aquifer system, and the pre-Hawthorn deposits comprise the Floridan aquifer system, a regionally extensive aquifer system. The two systems are separated by the upper confining unit, which includes most of the Hawthorn Group and which contains beds of low permeability that confine the water in the Floridan aquifer system. The Floridan aquifer system contains three major water-bearing zones that are separated by less-permeable confining units. The upper Floridan aquifer (upper water-bearing zone) generally corresponds to the Ocala Limestone. The middle semiconfining unit, which generally occurs in the upper part of the Avon Park Formation, separates the upper Floridan aquifer from two water-bearing zones in the lower Floridan aquifer. These units are the upper zone of the lower Floridan aquifer (middle water-bearing zone) in the lower part of the Avon Park Formation and the Fernandina permeable zone (lower water-bearing zone) in the lower Oldsmar and upper Cedar Keys Formations. These units are separated by a less permeable unit called the lower semiconfining unit.

In predevelopment time, the potentiometric surface of the upper Floridan aquifer (upper water-bearing zone) was approximately 55 feet above the National Geodetic Datum of 1929 (ft, NGVD, formerly called mean sea level) in the Jacksonville Beach area. Due to increases in ground water pumping in the area, the water levels in the Floridan aquifer system have declined throughout northeast Florida, and the potentiometric surface currently is approximately 30 to 35 ft, NGVD in the Jacksonville Beach area. Chloride concentrations in wells tapping the upper Floridan aquifer in northeast Florida range from 4.6 to 3,600 milligrams per liter (mg/L). In the study area in the vicinity of Jacksonville Beach, chloride concentrations have increased progressively over time in some wells tapping the upper Floridan aquifer. For example, in well D-164 on Fort George Island approximately eight miles north-northwest from Jacksonville Beach, the chloride concentration increased from 63 mg/L in 1930 to 340 mg/L in 1994. In well D-484 in the Jacksonville Beach wellfield, the chloride concentration increased from 84 mg/L in 1974 to 220 mg/L in 1995.

Six wells are used for water supply by the City of Jacksonville Beach. Wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) are approximately 1,200 ft deep and are open to both the upper Floridan aquifer (upper water-bearing zone) and the upper part of the lower Floridan aquifer (middle water-bearing zone). Wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23) are approximately 900 ft deep and are open only to the upper Floridan aquifer. The total water use from the Jacksonville Beach wells has averaged approximately 3 million gallons per day (mgd) (400,000 ft^3/day) since 1985. In 1995, the average water use ranged from 0.007 mgd (935 ft^3/day) at well D-2747 (no. 21) to 0.907 mgd (121,000 ft^3/day) at well D-482 (no. 11).

Chloride data for the six Jacksonville Beach wells indicate that the chlorides in the three deeper wells are significantly greater than in the three shallower wells. In 1993, for example, chloride concentrations were 97, 322.5, and 195 mg/L, respectively, in wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13), but chloride concentrations were less than 30 mg/L in wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23).

Geophysical logs have been run in three wells in the Jacksonville Beach wellfield by the U.S. Geological Survey (USGS) and SJRWMD. The USGS results for wells D-482 (no. 11) and D-484 (no. 12) and the SJRWMD results for well D-483 (well no. 13) indicate that the source of most of the flow in all three of these wells is at a depth of approximately 1,100 to 1,200 ft.

The effects of pumping from the Jacksonville Beach wells were investigated using both analytical and numerical models. The analytical solution that was used assumes the existence of a sharp interface between the fresh water and the salt water and the occurrence of a critical rise in the interface above which only an unstable cone can exist. Initial estimates for aquifer and confining bed properties were obtained from SJRWMD's northeast regional ground water flow model. For this initial set of parameters, the total critical pumping rate calculated using the analytical model for the six wells was significantly greater than the actual pumping rate that apparently is already causing critical or near critical conditions to occur. As a result of these calculations, a sensitivity analysis was performed by varying the hydraulic parameters. First, the effect of the discontinuities that apparently exist in the lower semiconfining unit in the vicinity of the Jacksonville Beach wells, which causes saltwater upconing in the middle water-bearing zone, was considered. Next, the values for transmissivity in the middle water-bearing zone and leakance for the upper confining unit were re-evaluated based on pumping test results in the Jacksonville Beach area. Based on these revisions, the calculated critical pumping rate was estimated to be approximately 900,000 ft^3/day, a value that is consistent with the actual pumping rate that apparently is beginning to cause salty water to occur in the middle water-bearing zone at Jacksonville Beach.

Input and output files for SJRWMD's northeast regional saltwater intrusion model were obtained to investigate whether the localized upconing observed at Jacksonville Beach could be quantified by developing a numerical model that is a subset of SJRWMD's regional model. In SJRWMD's regional model and two wellfield-scale models developed in this investigation, the Floridan aquifer system is represented by three layers in a numerical saltwater-intrusion model called SIMLAS. The lower water-bearing zone is represented by layer one, the middle water-bearing zone by layer two, and the upper water-bearing zone by layer three. First, a wellfield-scale model was developed by discretizing aquifer parameters from an area that is a subset of the regional saltwater intrusion model and that represents the Jacksonville Beach wellfield. In this first model, the aquifer parameters were the same as the aquifer parameters in SJRWMD's regional model for corresponding locations. The freshwater heads in layers one, two, and three and the saltwater-freshwater interface in layer one in the wellfield-scale model were in close agreement with SJRWMD's regional model, but the results from these models did not match the localized upconing in layer two that has been observed in the Jacksonville Beach wellfield. Accordingly, the wellfield-scale model was revised by adjusting the aquifer parameters to be more consistent with the analytical model results that predicted upconing could occur beneath the Jacksonville Beach wells in the middle water-bearing zone. In the second, or revised, wellfield-scale model, the freshwater heads in layers two and three are generally consistent with, but lower than, the corresponding freshwater heads in SJRWMD's regional model. In the revised model, saltwater completely occupies layer one, a saltwater-freshwater interface occurs in layer two, and fresh water occupies layer three. The interface in layer two occurs at the bottom of the production wells in layer two, which is consistent with the chloride increases that have been observed in the deep wells in the Jacksonville Beach wellfield.

The analytical and numerical models were used to investigate the hypothesis that an increased pumping rate could be achieved by pumping from only the upper water-bearing zone to avoid the upconing that apparently is occurring in the middle water-bearing zone. The aquifer parameters resulting from the sensitivity analysis were used, and the depths of penetration of the three deeper wells [D-482 (no. 11), D-484 (no. 12) and D-483 (no. 13)] were reduced to represent plugging these wells in the middle water-bearing zone. With these parameters, a critical pumping rate was calculated using the analytical model that is approximately 40 percent greater than the critical pumping rate calculated for the case that represents the existing condition of pumping from both the upper and middle water-bearing zones. The revised wellfield-scale numerical model also was utilized to investigate the effects of continuing to pump at the present rate but only from the upper water-bearing zone. The results of this simulation indicate that the saltwater-freshwater interface will remain in layer two under this scenario.

Based on the ground water-quality data from the Jacksonville Beach wellfield and the results of the analytical and numerical modeling, salty water is present in the middle water-bearing zone of the Floridan aquifer system in the vicinity of the Jacksonville Beach wellfield. The most plausible mechanism for the movement of the higher chloride water into the freshwater zone of the Floridan aquifer system in the study area appears to be the upward leakage of salt water along joints, fractures, collapse features, faults, or other structural features, which can provide a vertical hydraulic connection between freshwater zones and deeper, more saline zones. Once salt water reaches the freshwater zone, it can move laterally downgradient toward pumping centers. The results of the analytical and numerical modeling also indicate that increased pumping rates can be achieved, relative to the upconing, by pumping only from the upper water-bearing zone. This recommendation would have to be evaluated further to determine the specifics of plugging existing production wells or drilling new wells in the upper water-bearing zone.

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ABSTRACT

Substantial declines in ground water levels have occurred in northeast Florida due to heavy pumping in the Jacksonville area. As a result, increases in chlorides have occurred in a number of wells in the area, including some of the wells in the Jacksonville Beach wellfield. In March 1995, the St. Johns River Water Management District (SJRWMD) authorized the University of Florida to conduct a ground water investigation of the Jacksonville Beach area. In the first phase of the investigation, existing data were compiled and reviewed, additional data were collected, site-specific modeling was conducted, and an interim technical report was prepared. An analytical model that assumes the existence of a sharp interface between the freshwater and saltwater and the occurrence of a critical rise in the interface was used to analyze the localized saltwater upconing observed in some of the Jacksonville Beach wells. Also, the SIMLAS code, which numerically models saltwater intrusion as a sharp interface, was used to investigate whether the localized upconing could be quantified as a subset of SJRWMD's northeast regional saltwater intrusion model. The results of the investigation indicate that salty water is present in the lower part of the freshwater zone of the Floridan aquifer system in the vicinity of the Jacksonville Beach wellfield. Vertical upconing of saltwater from deeper zones through faults, fractures, or other conduits is the most likely mechanism by which saltwater is reaching the freshwater zone. The results of the analytical and numerical modeling indicate that increased pumping rates at the Jacksonville Beach wellfield can be achieved, relative to the upconing, by pumping only from the upper part of the freshwater zone. This recommendation would have to be evaluated further to determine the specifics of plugging existing production wells or drilling new wells in the upper part of the freshwater zone.

1.0 INTRODUCTION

1.1 BACKGROUND

Substantial declines in ground water levels have occurred in northeast Florida due to heavy pumping in the Jacksonville area. As a result, increases in chlorides have occurred in a number of wells in the area. Ground water flow and chloride concentrations are being modeled by the St. Johns River Water Management District (SJRWMD) on a regional basis in northeast Florida, but subregional-scale flow and chloride models are required in specific areas to address problems that deal with present-day and future impacts due to pumping from individual wellfields. In addition, smaller scale, site-specific models are needed in some wellfield locations to address localized saltwater upconing due to well location, casing and open-hole depths, and pumping rates of individual wells.

1.2 OBJECTIVES

In March 1995, SJRWMD authorized the University of Florida (UF) to begin work on a ground water investigation of the Jacksonville Beach area. In this investigation, saltwater upconing and the location of the saltwater-freshwater interface in the Jacksonville beach area are being analyzed at two scales of interest and detail. First, the impacts of present and future pumping regimes in Jacksonville Beach have been evaluated at a relatively small, site-specific scale to provide recommendations for locations and pumping rates for proposed production wells in the City of Jacksonville Beach. Second, the impacts of pumping in Jacksonville Beach, Atlantic Beach, and adjacent areas will be analyzed in terms of the hydrogeology of the Jacksonville Beach subregion. Changes in ground water levels and chloride concentrations that have occurred from predevelopment time to the present will be determined based on the availability of historic water-level and chloride data, and changes in water levels and chlorides that will occur based on changes in ground water use in the Jacksonville Beach subregion and adjacent areas will be estimated.

1.3 PHASES AND TASKS

To meet the objectives of the subregional and site-specific modeling, the investigation was divided into two phases. As part of the first phase, four tasks were performed. Existing data were compiled and reviewed (Task One), additional data were collected (Task Two), site-specific modeling was conducted (Task Three), and this interim technical report was prepared (Task Four). Next, during the second phase, a hydrogeologic model will be conceptualized (Task Five), a subregional numerical ground water flow and chloride model will be developed (Task Six), and a final technical report will be prepared (Task Seven).

In Task One, hydrologic and hydrogeologic data were compiled from existing data sources that included files and records from Jacksonville Beach, SJRWMD reports and consumptive use permit (CUP) files, consulting reports, and U.S. Geological Survey (USGS) reports. In Task Two, additional data were obtained that included pumping and chloride data and geophysical logs for the Jacksonville Beach wells and water-level and water-quality data in the Jacksonville Beach subregion. Input files were obtained for SJRWMD's northeast regional ground water flow model (Durden 1995), which utilizes the USGS MODFLOW code (McDonald and Harbaugh 1988). Also, input and output files were obtained for SJRWMD's northeast regional saltwater-intrusion model (Durden, personal communication 1995), which uses the SIMLAS code developed by HydroGeologic, Inc. (Huyakorn et al. 1993). In Task Three, an analytical model (Motz 1992) was used to evaluate the localized saltwater upconing observed in some of the Jacksonville Beach wells in terms of vertically-averaged aquifer properties, well locations, casing and open-hole depths, and pumping rates at individual wells. Also in Task Three, the SIMLAS code, which numerically models saltwater intrusion as a sharp interface, was used to investigate whether the localized upconing could be quantified using aquifer and well parameters derived as a subset of SJRWMD's regional saltwater-intrusion model. In Task Four, which includes this report, specific recommendations were developed concerning locations and pumping rates for proposed Jacksonville Beach production wells.

2.0 REGIONAL SETTING

2.1 LOCATION

The City of Jacksonville Beach is located in northeastern Florida in Duval County at approximately 30°17'30" north latitude and 81°23'30" west longitude (see Figure 1). St. Johns County is nearby to the south, and Nassau County and Camden County, Georgia, are to the northwest and north.

2.2 PREVIOUS INVESTIGATIONS

2.2.1 Regional and State-wide Investigations

A number of state-wide and regional investigations have included some aspects of the physiography, geology, hydrogeology, and hydrology of northeastern Florida, including the area in the vicinity of Jacksonville Beach. MacNeil (1950) described Pleistocene shorelines in Florida and Georgia, Puri and Vernon (1964) summarized the geology of Florida, and White (1970) described the geomorphology of the Florida peninsula. Johnston, Krause, et al. (1980) estimated the potentiometric surface of the Floridan aquifer system prior to development, including the potentiometric surface in northeastern Florida. Scott (1983 and 1988) studied and mapped the Hawthorn Group in northeastern Florida. As part of the USGS Regional Aquifer System Analysis (RASA) program, Johnston and Bush (1988) summarized aspects of the Floridan aquifer system

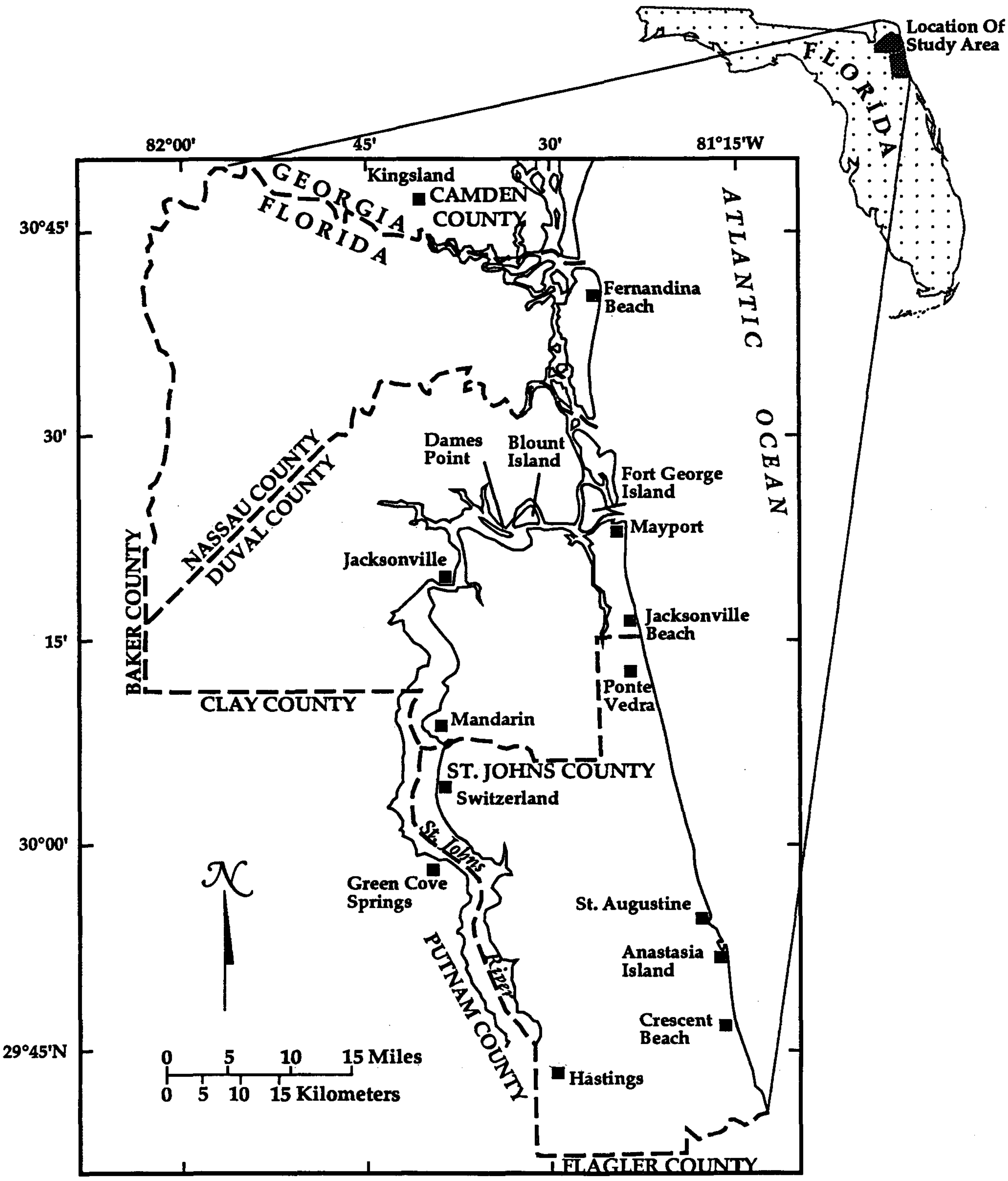


Figure 1. Jacksonville Beach and northeastern Florida

in Florida and parts of Georgia, South Carolina, and Alabama, including the hydrogeologic framework, hydraulic properties of aquifers, regional flow system, effects of ground water development, and geochemistry. Miller (1986) described in detail the hydrogeologic framework of the regional aquifers and confining units that comprise the Floridan aquifer system.

2.2.2 Investigations in Duval County and Adjacent Areas in Northeastern Florida

Leve (1966) described ground water conditions in Duval and Nassau Counties. Fairchild (1972) investigated the shallow-aquifer system in Duval County, and Fairchild and Bentley (1977) investigated saltwater intrusion in the Floridan aquifer in the Fernandina Beach area in Nassau County. Causey (1975) and Causey and Phelps (1978) investigated the depth to the water table, recharge areas, drainage basin, and topographic relief of Duval County and the availability and quality of water from the shallow aquifer system in Duval County. Franks (1980) described the surficial aquifer at the U.S. Naval Station near Mayport. Spechler and Stone (1983) appraised the interconnection between the St. Johns River and the surficial aquifer in east-central Duval County. Phelps (1984) mapped recharge and discharge areas of the Floridan aquifer in the SJRWMD and vicinity. Toth (1990) summarized the hydrogeology of the Floridan aquifer in the coastal areas of Nassau, Duval, and northern St. Johns counties. Spechler (1994) investigated saltwater intrusion and the quality of water in the Floridan aquifer system in northeastern Florida.

Brown (1980) and Brown et al. (1984, 1985, and 1986) published hydrogeologic data obtained from deep test wells at Fernandina Beach, at Kathryn Abbey Hanna Park, in east-central

Duval County, and near Ponte Vedra in northeastern St. Johns County. Johnston et al. (1982) summarized the results of hydrologic testing in an offshore exploratory well and estimated the present location of the saltwater-freshwater interface in the Floridan aquifer system offshore from Fernandina Beach.

2.2.3 Ground Water Models

As part of the RASA program, a regional ground water flow model was developed by the USGS (Bush and Johnston 1988). This model described the ground water hydraulics of the Floridan aquifer system in Florida and parts of Georgia, South Carolina, and Alabama. Also as part of the RASA program, Krause and Randolph (1989) modeled the Floridan aquifer system in southeast Georgia and adjacent parts of northeastern Florida and South Carolina. As part of SJRWMD's ground water modeling program, Durden and Motz (1991) developed a ground water flow model of the Floridan aquifer system in the Jacksonville area, and Durden (1995) developed a regional ground water flow model for northeastern Florida.

2.3 TOPOGRAPHY AND CLIMATE

Northeastern Florida and Jacksonville Beach are in the physiographic division of Florida known as the Coastal Lowlands (Puri and Vernon 1964). This land adjacent to the coastline is generally low in elevation and characterized by poorly drained marshland. Surface drainage occurs primarily by means of numerous small brackish-water streams that empty either into the channel of the Intercoastal Waterway or directly into the Atlantic Ocean (Leve 1966). The climate of northeastern Florida is classified as humid subtropical (Leve 1966), and it is characterized by warm, normally wet summers and mild, relatively dry winters. The average temperature in the Jacksonville area is about 68.5°F. The mean annual rainfall at the Jacksonville rain gage from 1867 to 1984 is 51.73 inches (Jenab et al. 1986). The driest year in the 1867-1984 period of record is 1927 with 30.44 inches, and the wettest year is 1947 with 82.27 inches of rainfall.

2.4 GEOLOGY

The Jacksonville Beach area is underlain by a thick sequence of marine sedimentary rocks that overlie a basement complex of metamorphic strata (Spechler 1994). The sedimentary deposits are the primary water-bearing units, and they can be divided into pre-Hawthorn Tertiary carbonate formations, the Hawthorn Group, and post-Hawthorn deposits (see Table 1 and Figures 2 and 3). The pre-Hawthorn formations consist of four units that range in age from Paleocene to Eocene (Miller 1986). The units from oldest to youngest are the Paleocene Cedar Keys Formation, the early Eocene Oldsmar Formation, the middle Eocene Avon Park Formation, and the late Eocene Ocala Limestone. The Miocene age Hawthorn Group is a very complex formation, consisting of clay, sand, carbonates, and phosphates in heterogeneous patterns and thicknesses throughout (Scott 1983 and 1988). The post-Hawthorn deposits range in age from Pliocene to Holocene. The formations consist of sand, carbonate, clayey sand, sandy clay, and shell (Durden 1990). The ages of these units range from 55 to 65 million years before present for the Paleocene

Table 1. Generalized geology and hydrogeology of northeastern Florida

Series	Formation		Approximate thickness (feet)	Lithology	Hydrogeologic Unit			Hydrologic Properties
Holocene to Upper Miocene	Undifferentiated surficial deposits		20-120	Discontinuous sand, clay, shell beds, and limestone	Surficial aquifer system			Sand, shell, limestone, and coquina deposits provide local water supplies.
Miocene	Hawthorn Group		100-500	Interbedded phosphatic sand, clay, limestone, and dolomite	Upper confining unit			Sand, shell, and carbonate deposits provide local limited water supplies. Low permeability clays serve as the principal confining beds for the Floridan aquifer system below.
Eocene	Upper	Ocala Limestone	100-350	Massive fossiliferous chalky to granular marine limestone	Floridan aquifer system	Upper Floridan aquifer		Principal source of ground water. High permeability overall. Water from some wells shows increasing salinity.
	Middle	Avon Park Formation	700-1,100	Alternating beds of massive granular and chalky limestones, and dense dolomites		Middle semiconfining unit		Low permeability limestone and dolomite.
						Lower Floridan aquifer	Upper zone	Principal source of ground water. Water from some wells shows increasing salinity.
	Lower	Oldsmar Formation	300-500				Lower semiconfining unit	Low permeability limestone and dolomite.
							Fernandina permeable zone	High permeability; salinity increases with depth.
Paleocene	Cedar Keys Formation		about 500	Uppermost appearance of evaporites; dense limestones	Sub-Floridan confining unit			Contains highly saline water; low permeability.

Source: Spechler 1994

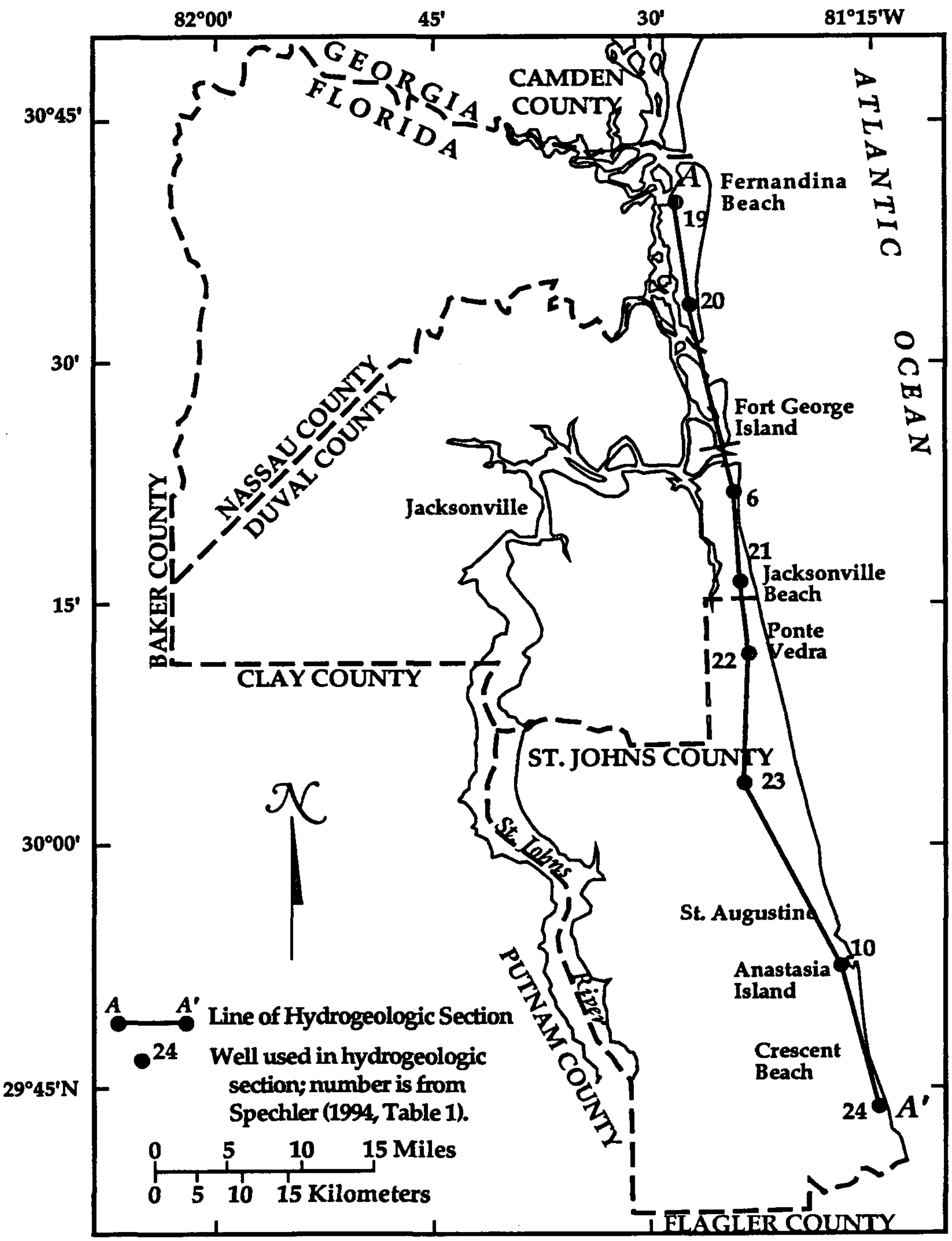
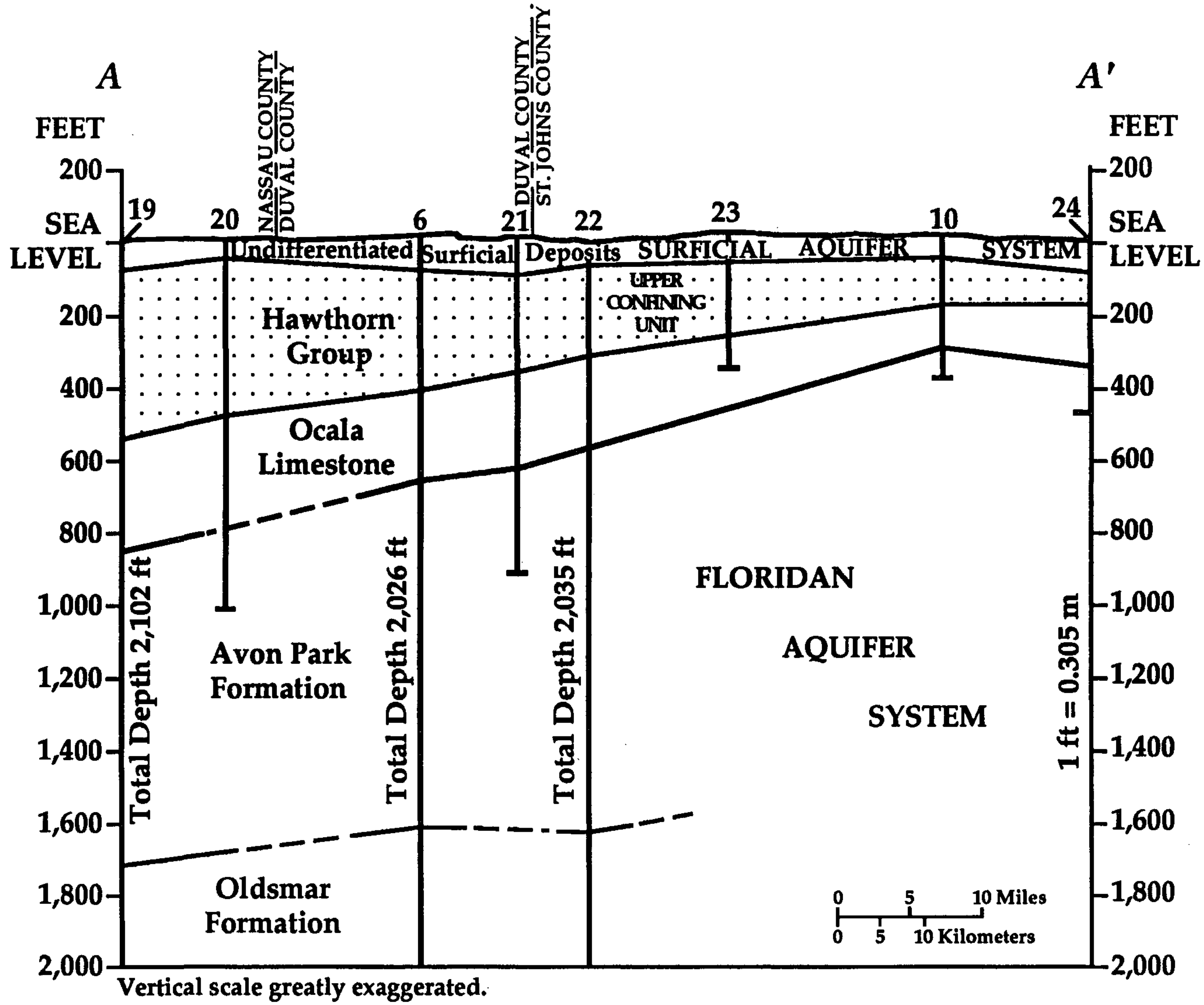


Figure 2. Location of hydrogeologic section



Source: Spechler 1994

Figure 3. Cross-section of hydrogeologic units

Cedar Keys Formation to 11,000 years before present for the Pleistocene and Holocene deposits (Batten 1987) (see Table 2).

2.5 GROUND WATER HYDROLOGY

2.5.1 Hydrogeologic Units

In the Jacksonville Beach area, the geologic units form two aquifer systems (Spechler 1994). The post-Hawthorn deposits form the surficial aquifer system, and the pre-Hawthorn deposits comprise the Floridan aquifer system, a regionally extensive aquifer system. The two systems are separated by the clays, silts, and sands of the upper confining unit, which includes most of the Hawthorn Group (see Table 1 and Figure 3). The upper confining unit contains beds of low permeability that confine the water in the Floridan aquifer system.

The Floridan aquifer system contains three major water-bearing zones that are separated by less-permeable confining units (see Table 1). The upper Floridan aquifer (upper water-bearing zone) in the study area generally corresponds to the Ocala Limestone. The middle semiconfining unit separates the upper and lower Floridan aquifers and is comprised of beds of dense, relatively less permeable limestone and dolomite of variable thickness and permeability. This unit generally occurs in the upper part of the Avon Park Formation, and it ranges in thickness from approximately 100 to 200 ft (Miller 1986). The lower Floridan aquifer lies beneath the middle semiconfining unit, and it contains two major water-bearing zones (Brown 1984). These are the upper zone of the lower Floridan aquifer (middle water-bearing zone) and the Fernandina permeable

Table 2. Time before present of various geologic ages

Geologic Epoch	Time Before Present (years × 10^6)
Pleistocene and Holocene	0.011 to 1.5
Pliocene	1.5 to 12
Miocene	12 to 20
Oligocene	20 to 35
Eocene	35 to 55
Paleocene	55 to 65

Source: Batten 1987

zone (lower water-bearing zone). These zones are separated by a less permeable semiconfining unit called the lower semiconfining unit (Durden 1995).

In the study area, the upper zone of the lower Floridan aquifer (middle water-bearing zone) consists of approximately the lower two-thirds of the Avon Park Formation, which is composed of alternating beds of limestone and dolomite. The upper zone is about 500 ft thick in the Jacksonville area, and it is about 950 to 1,400 ft below land surface (Krause and Randolph 1989). The Fernandina permeable zone (lower water-bearing zone) is a high permeability unit that lies at the base of the Floridan aquifer system in parts of southeastern Georgia and northeastern Florida (Miller 1986). In Fernandina Beach and Jacksonville, the unit is in the lower Oldsmar and upper Cedar Keys Formations (Krause and Randolph 1989). The thickness of the Fernandina permeable zone in the Jacksonville area is estimated to be approximately 100 ft (Krause and Randolph 1989).

2.5.2 Hydraulic Characteristics

Transmissivity values for the upper Floridan aquifer (upper water-bearing zone) in northeastern Florida have been obtained from aquifer tests and numerical modeling studies (Spechler 1994). Transmissivities from six wells that penetrated less than 500 ft of the aquifer were reported to range from 20,000 to 50,000 feet squared per day (ft^2/day) (Franks and Phelps 1979). Transmissivities of 31,000 and 49,000 ft^2/day were determined from aquifer tests at Fort George Island in eastern Duval County (Environmental Science and Engineering, Inc. 1985). Transmissivity results from numerical model simulation of the upper Floridan aquifer range from 35,000 to 250,000 ft^2/day (Bush and Johnston 1988; Tibbals 1990). Estimates of transmissivity in the Jacksonville, Fernandina Beach, and St. Marys areas are generally less than 50,000 ft^2/day (Durden 1995).

Transmissivity values for the upper zone of the lower Floridan aquifer (middle water-bearing zone) are not as readily available (Spechler 1994). A value of 35,600 ft^2/day was determined at Fort George Island based on a recovery test in a pumped well that was open only to the upper zone of the lower Floridan aquifer (Environmental Science and Engineering, Inc. 1985). Values of 100,000 and 300,000 ft^2/day were reported for two wells open to both the upper Floridan aquifer and the upper zone of the lower Floridan aquifer (Franks and Phelps 1979). Values of 130,000 and 200,000 ft^2/day were reported for two wells that penetrated about 700 and 750 ft of the aquifer system, respectively (Bush and Johnston 1988). Transmissivities resulting from model simulation of the upper zone of the lower Floridan aquifer range from 17,000 to 780,000 ft^2/day (Krause 1982; Durden 1995).

Aquifer test data apparently are not available for determining the transmissivity of the Fernandina permeable zone (lower water-bearing zone) (Spechler 1994). Based on the results of numerical modeling studies, the estimated transmissivity of this zone ranges from a mean value of 43,300 ft^2/day (Durden 1995) to about 75,000 ft^2/day (Krause 1982, referenced by Brown 1984).

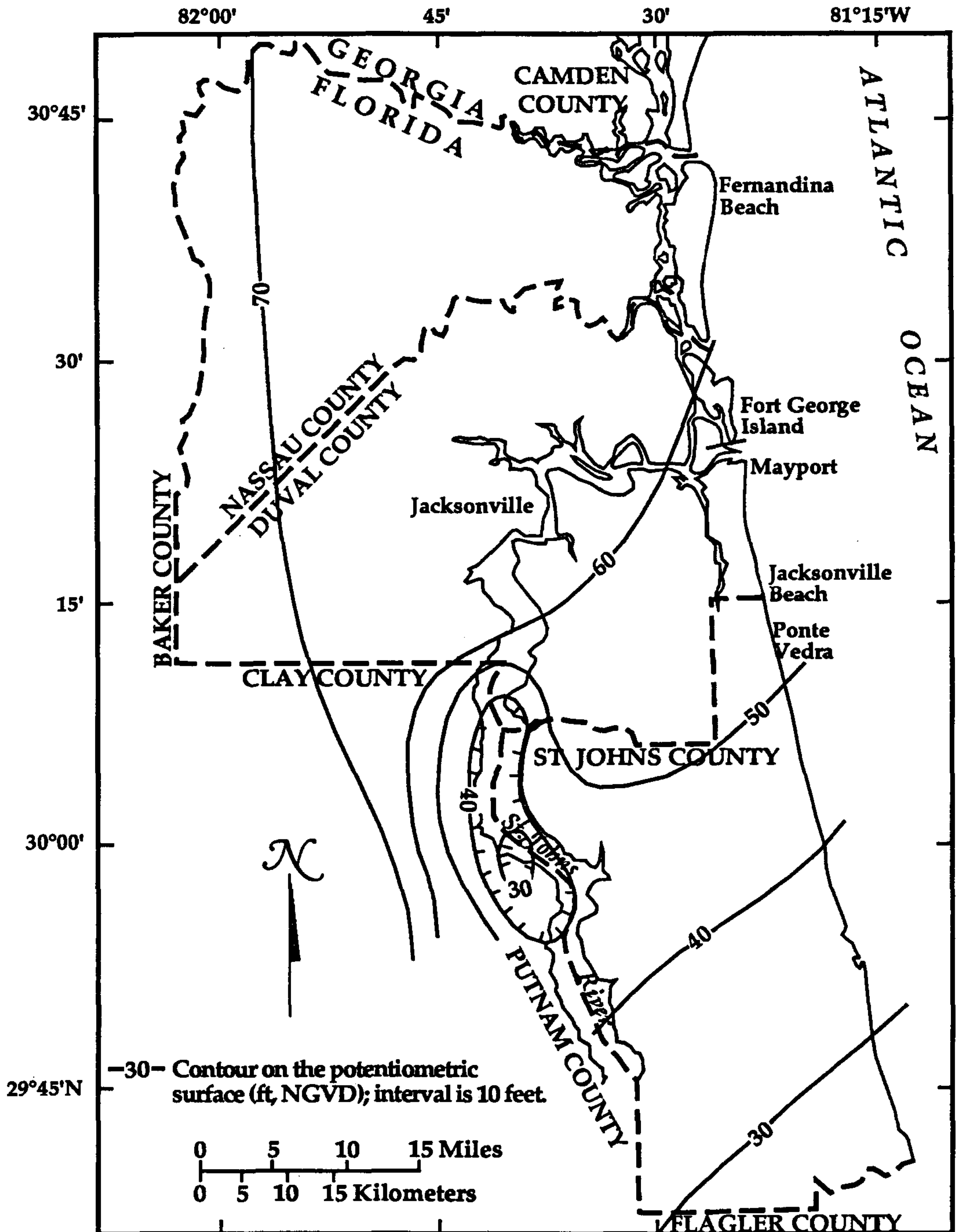
2.5.3 Water Levels

In predevelopment time, the potentiometric surface of the upper Floridan aquifer (upper water-bearing zone) was approximately 55 feet above the National Geodetic Vertical Datum of 1929 (ft, NGVD, formerly called mean sea level) in the Jacksonville Beach area (see Figure 4). In this area, the direction of ground water flow (e.g., downgradient and approximately perpendicular to the contours on the potentiometric surface) was generally from the northwest to the southeast. At the present, the shape of the potentiometric surface is considerably more complex, reflecting the impacts of large amounts of ground water pumping in the region, particularly in the City of Jacksonville and at Fernandina Beach (see Figure 5). In the Jacksonville Beach area, the potentiometric surface currently is approximately 30 to 35 ft, NGVD.

The water levels in the Floridan aquifer system have declined throughout northeastern Florida due to increases in ground water pumping in the area (Spechler 1994). Declines on the order of 20 to 40 ft have occurred in Duval County, and a decline of more than 120 ft has occurred at Fernandina Beach (see Figure 6). Hydrographs for five wells south and north of Jacksonville Beach illustrate this long-term trend (see Table 3 and Figures 7 through 12).

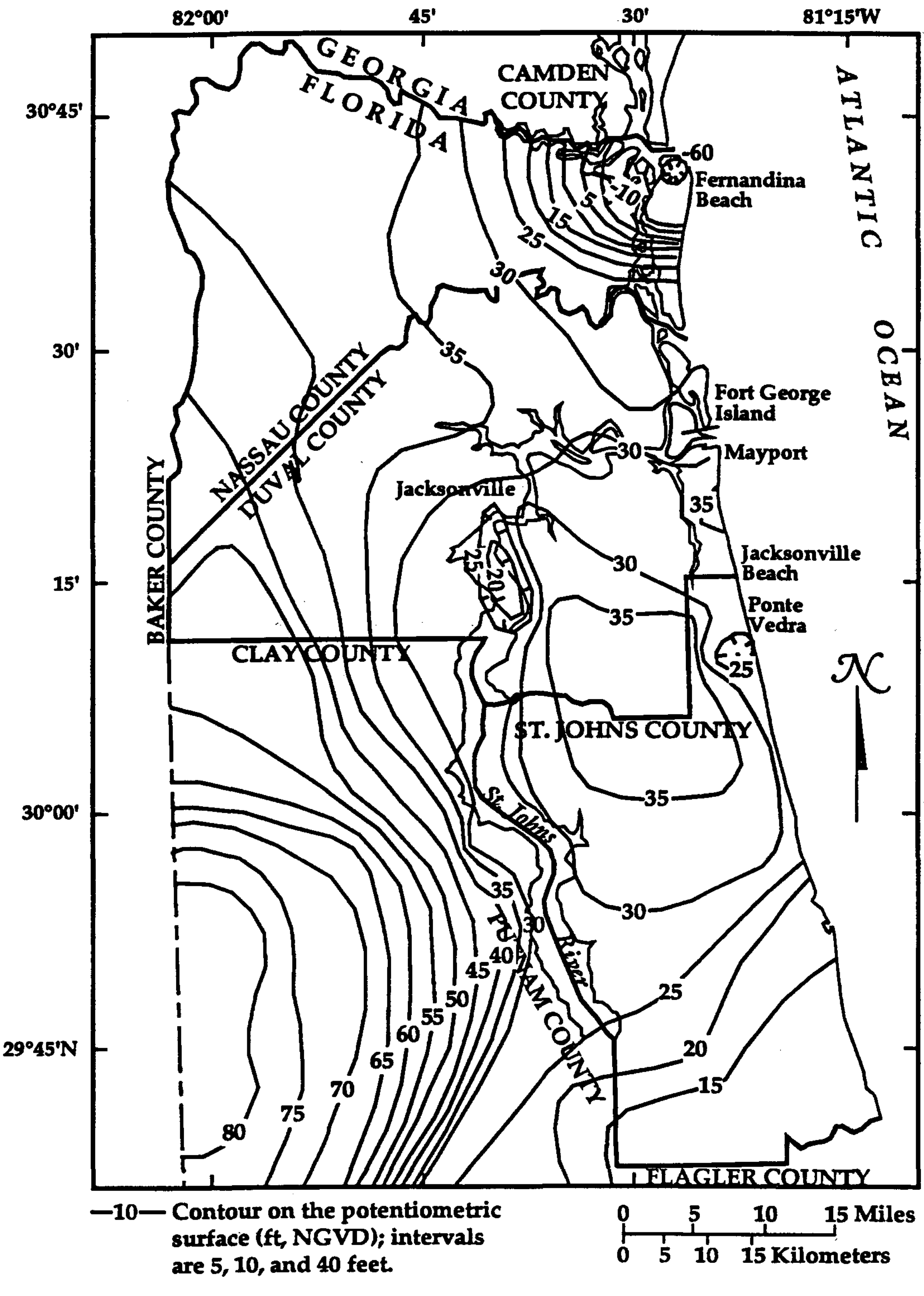
2.5.4 Chloride Concentrations

Chloride concentrations in wells tapping the upper Floridan aquifer in northeast Florida range from 4.6 to 3,600 milligrams per liter (mg/L) (Spechler 1994). The lowest concentrations occur in the extreme northeast part of Clay County, and the highest concentrations occur in the



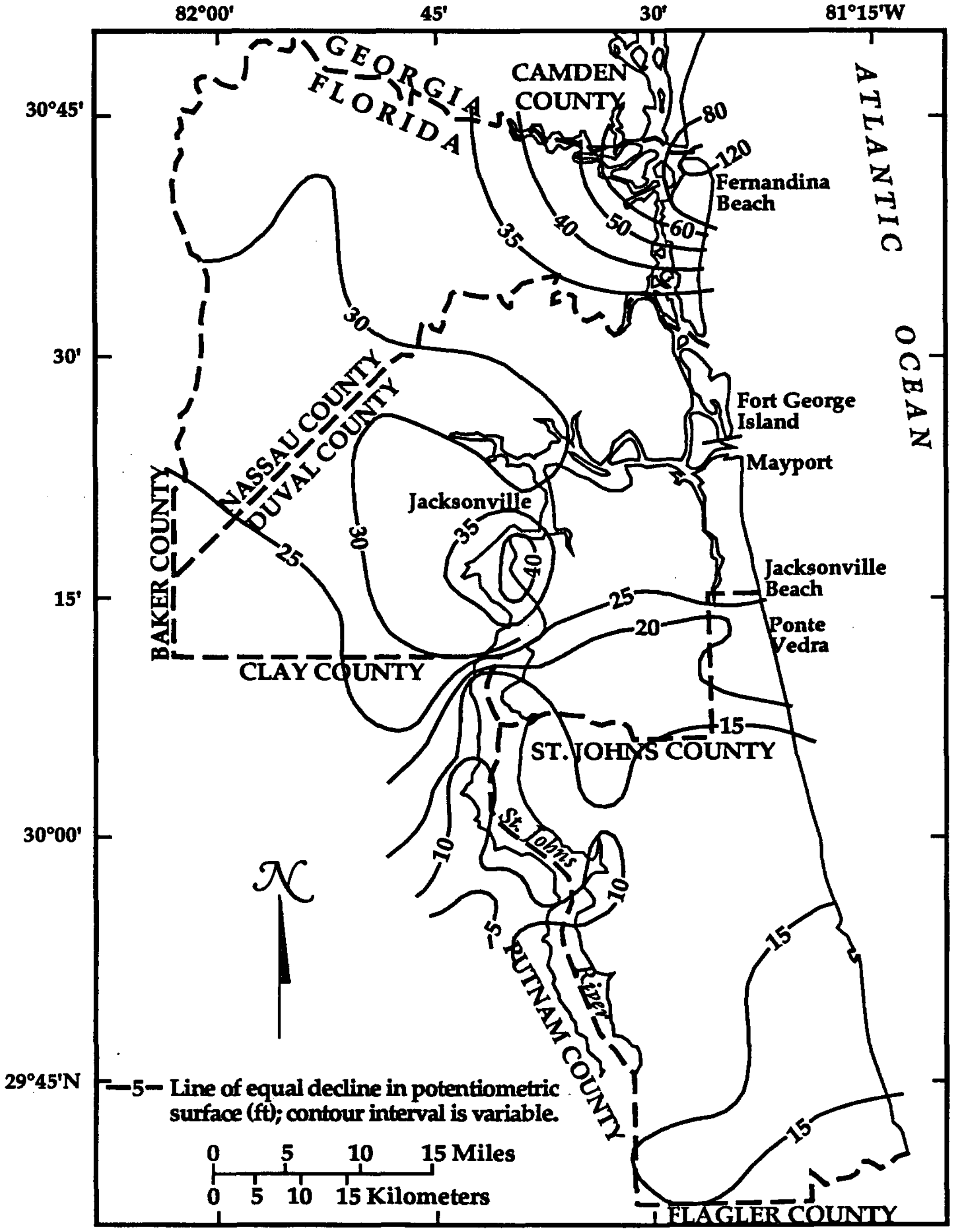
Source: Johnston et al. 1980

Figure 4. Estimated predevelopment potentiometric surface of the Upper Floridan aquifer in northeastern Florida



Source: Spechler 1994; Burtell 1990

Figure 5. Potentiometric surface of the Upper Floridan aquifer in northeastern Florida in September 1989



Source: Spechler 1994

Figure 6. Approximate decline in the potentiometric surface of the Upper Floridan aquifer from about 1880 (prior to development) to September 1989

Table 3. Details of selected water-level and chloride concentration monitoring wells

USGS Site Identification Number	Local Well Number	Other Description	Depth of Casing (feet)	Total Depth (feet)
300758081230501	SJ-5	G. Oesterreicher Well Near Palm Valley	180	350
301005081225901	SJ-55	Sawgrass near Palm Valley	--	1,009
301704081233401	D-484	City of Jacksonville Beach Well No. 12	357	1,181
301852081234201	D-160	City of Neptune Beach Well at Neptune Beach	357	585
302137081240001	D-84 (J-0148)	Seminole Drive, Atlantic Beach	--	575
302538081253101	D-164	Golf Course Well at Fort George Island	448	619

Note: Well locations are shown in Figure 7.

Sources: SJRWMD (written communication 1995) and Spechler (1994)

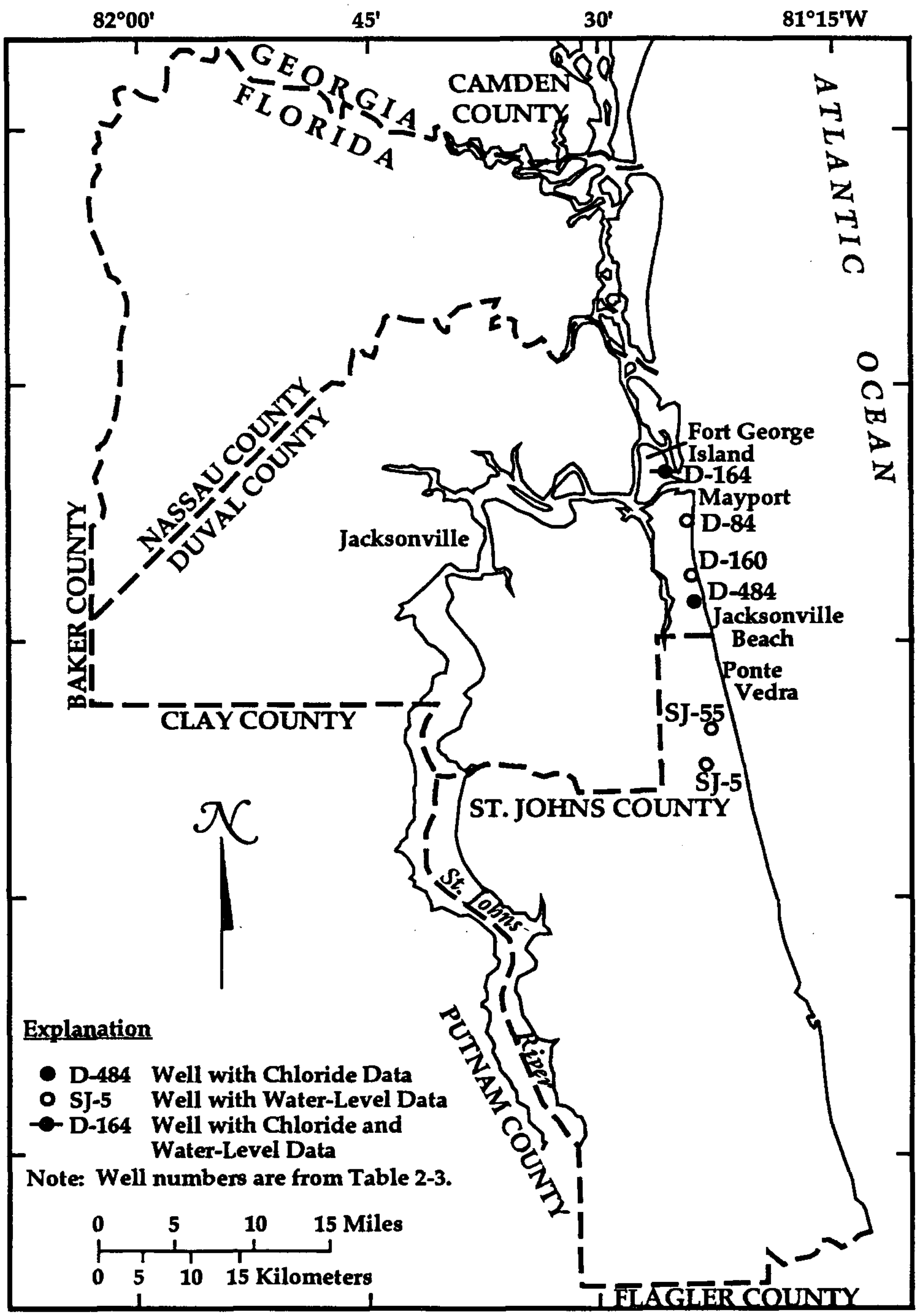


Figure 7. Locations of selected water-level and chloride concentration monitoring wells

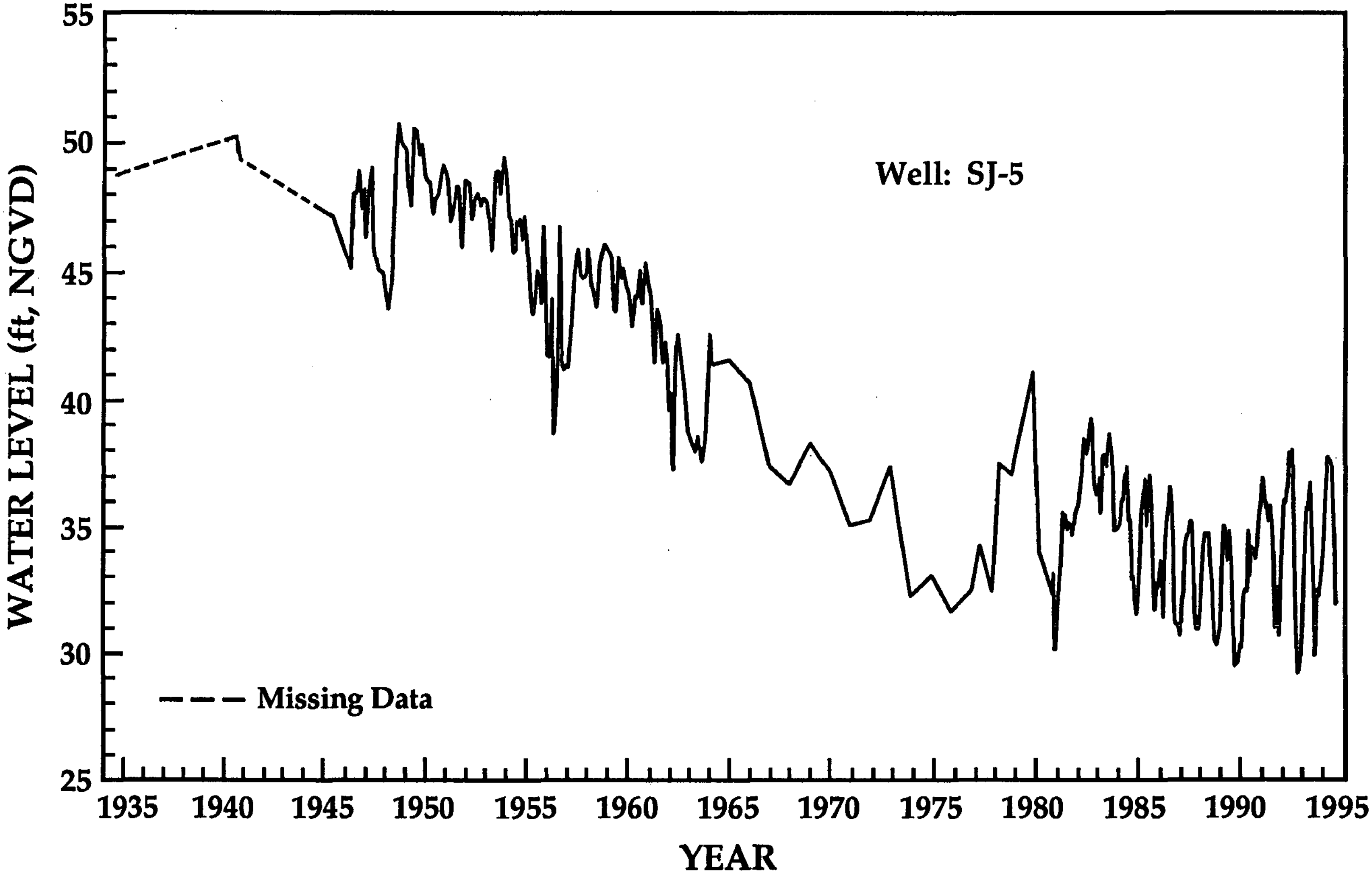


Figure 8. Hydrograph for well SJ-5

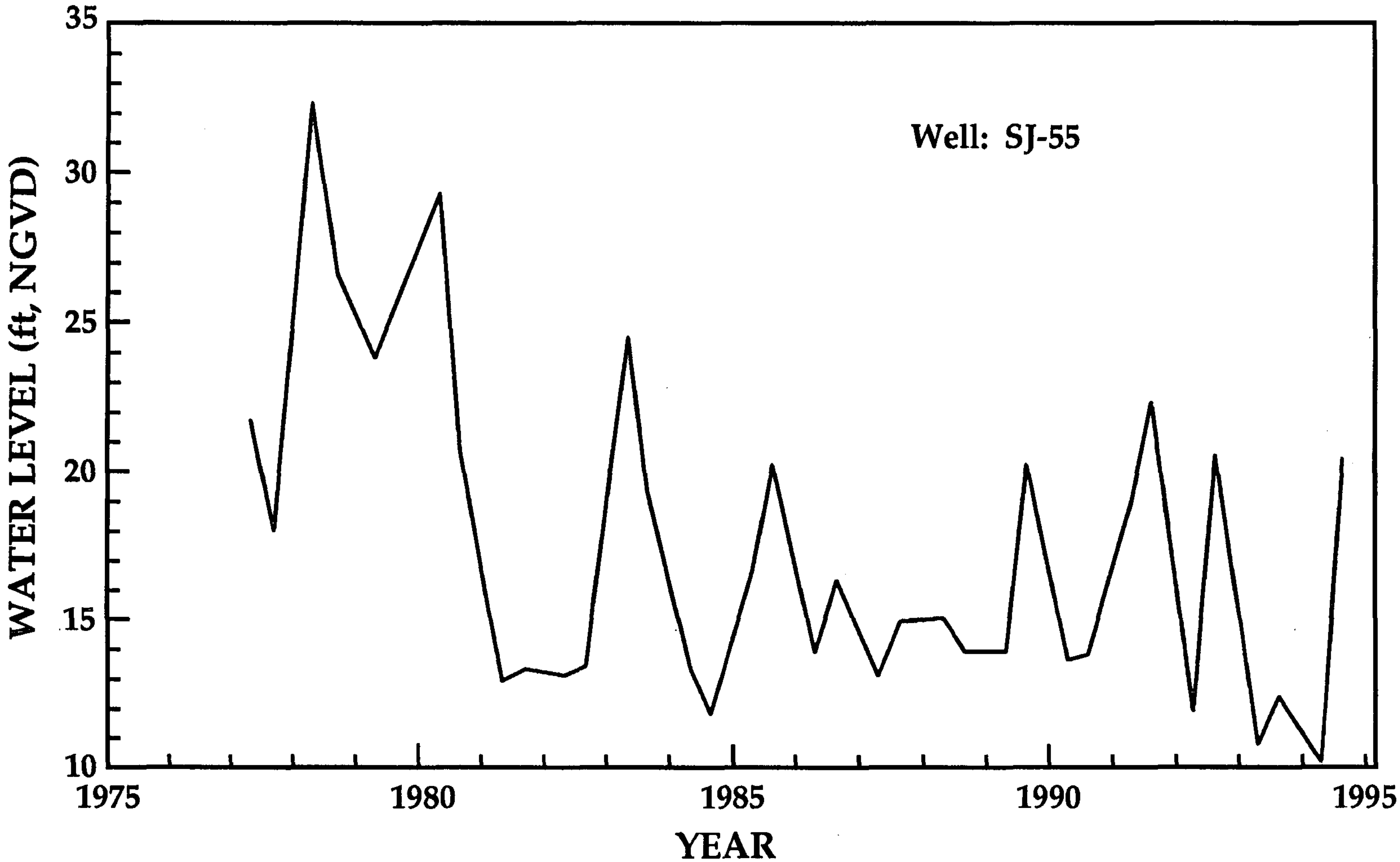


Figure 9. Hydrograph for well SJ-55

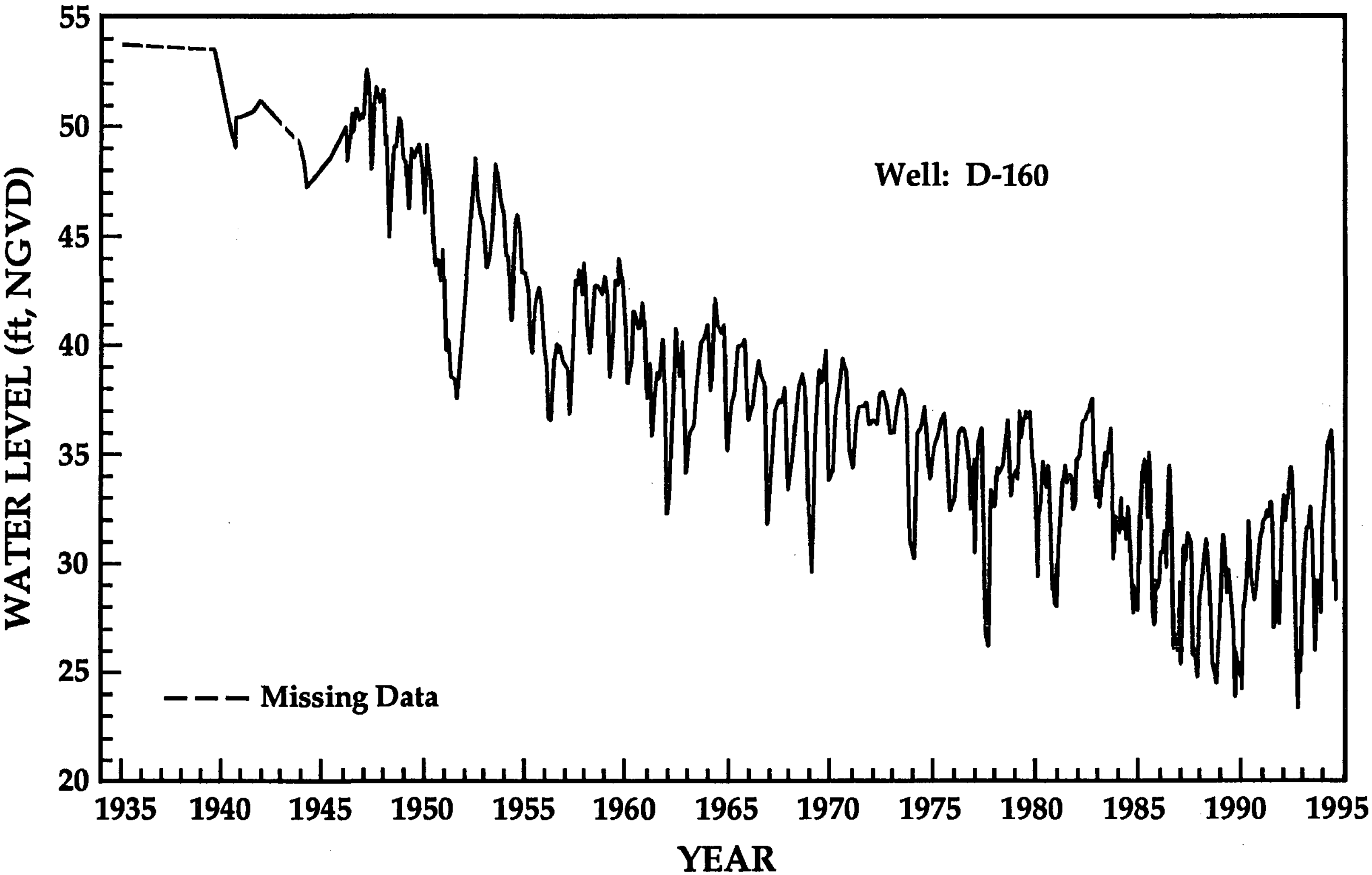


Figure 10. Hydrograph for well D-160

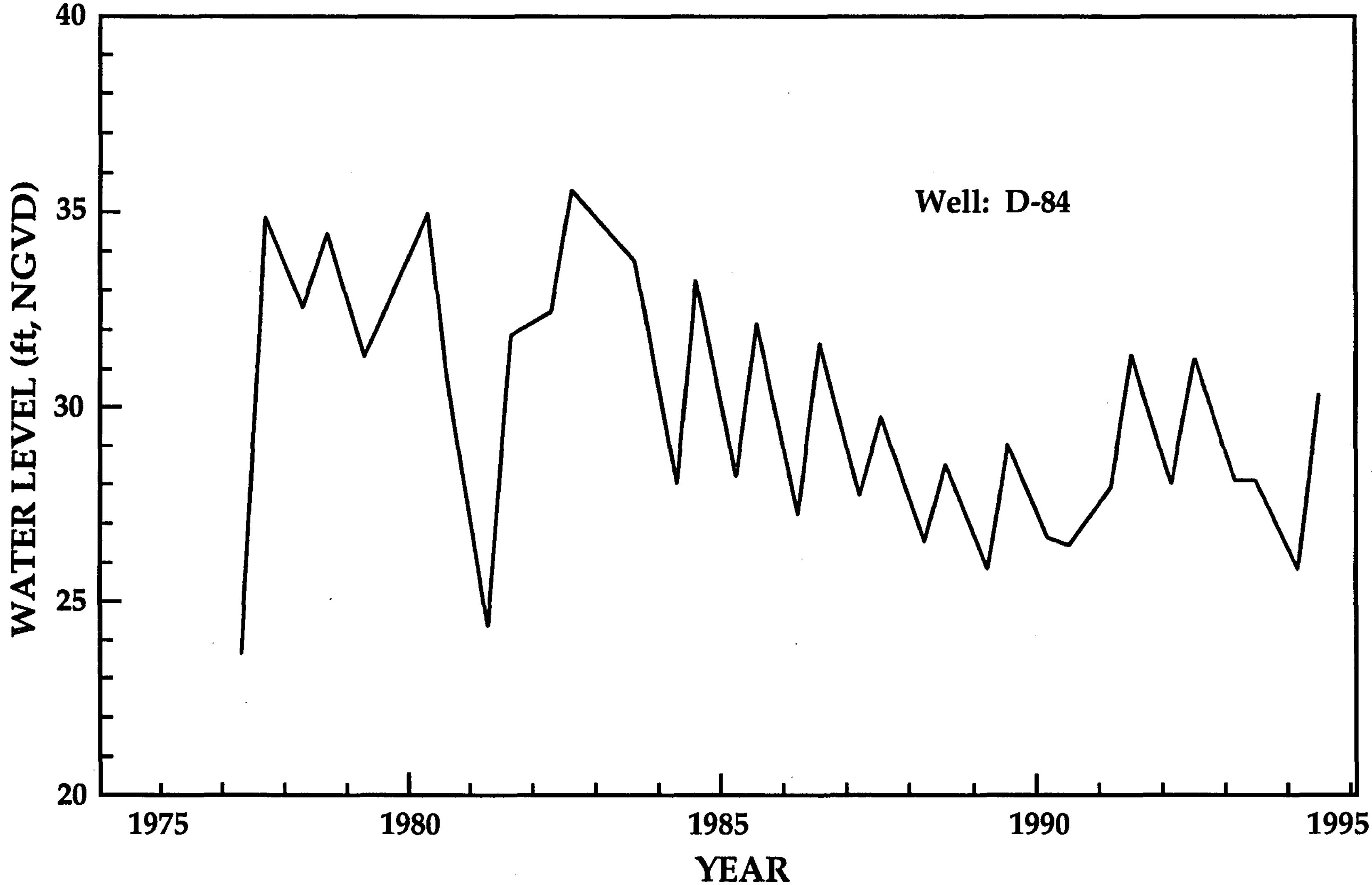


Figure 11. Hydrograph for well D-84

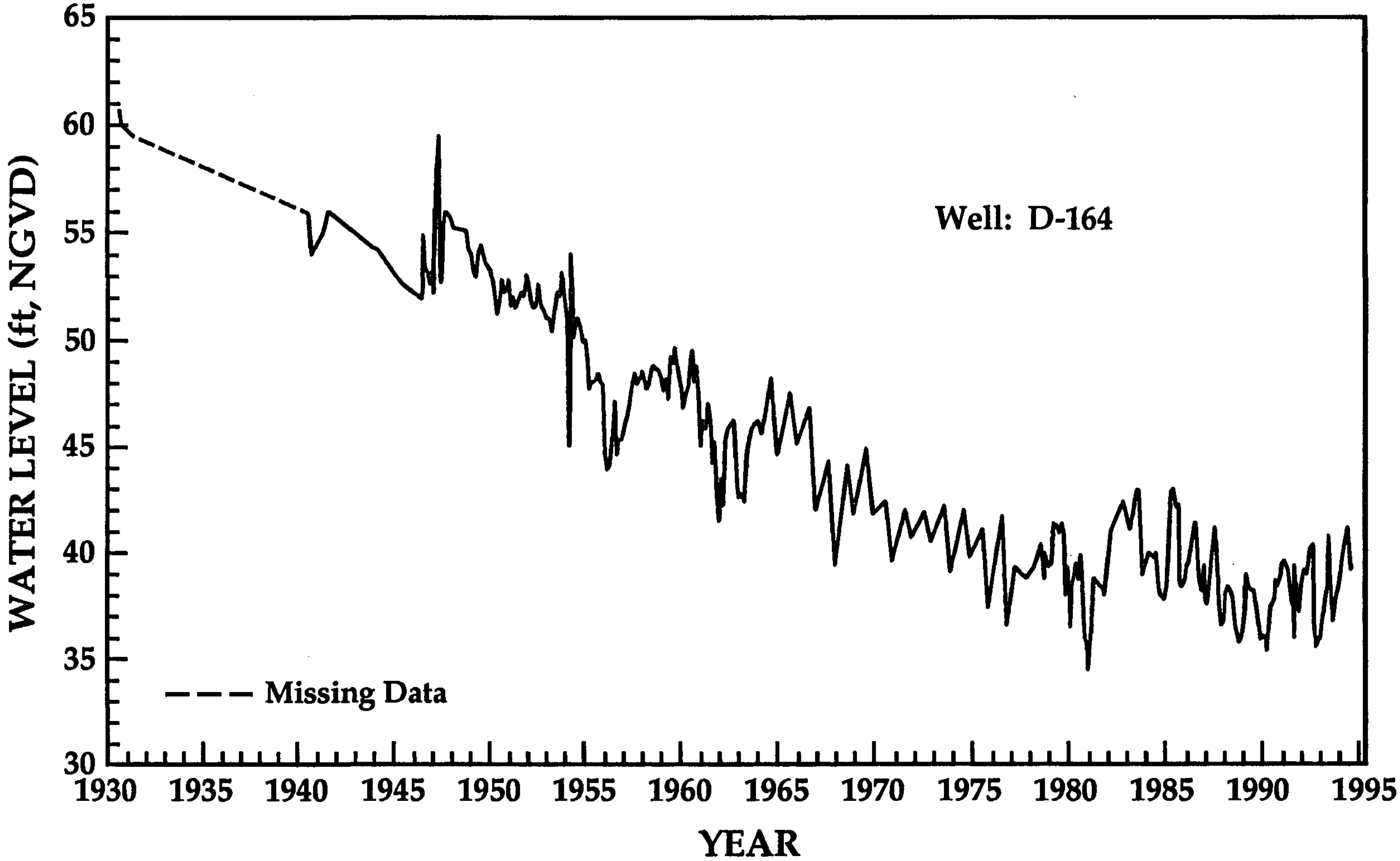


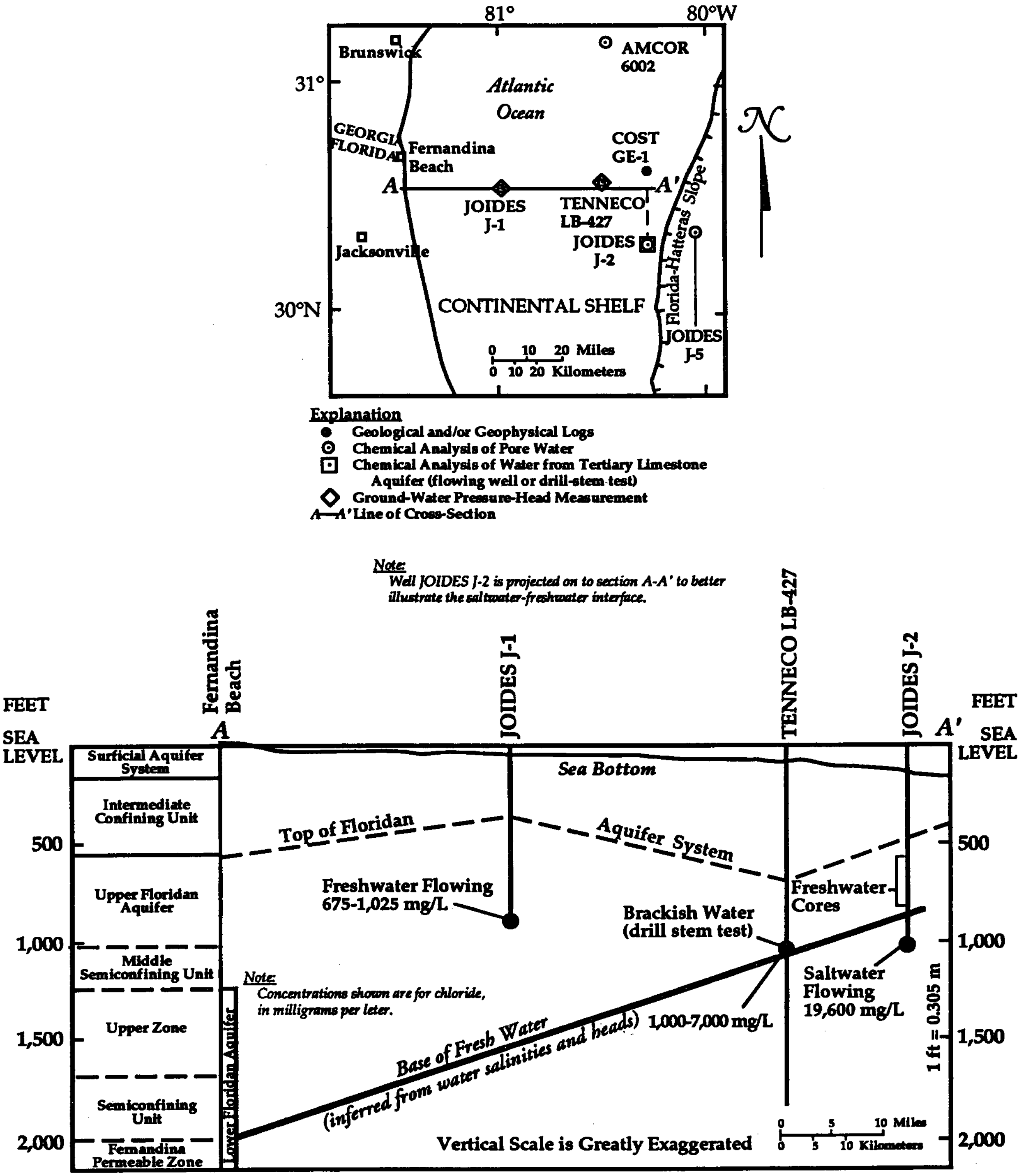
Figure 12. Hydrograph for well D-164

Crescent Beach area in southeastern St. Johns County. Chloride concentrations exceed 30 mg/L in parts of east-central and coastal Duval County. Regionally, the saltwater-freshwater interface is at a depth of 2,000 ft or more along the coast and at progressively shallower depths eastward beneath the Atlantic Ocean (Johnston et al. 1982)(see Figure 13).

Locally, chloride concentrations were greater than 50 mg/L between 1960 and 1984 in areas along the coast and near north-south trending faults described by Leve (1978) and Miller (1980) (see Figure 14). The occurrence of high chlorides in localized areas along these faults suggests that these faults may be the mechanism for the upward movement of more mineralized water from deeper zones within the Floridan aquifer (Toth 1990).

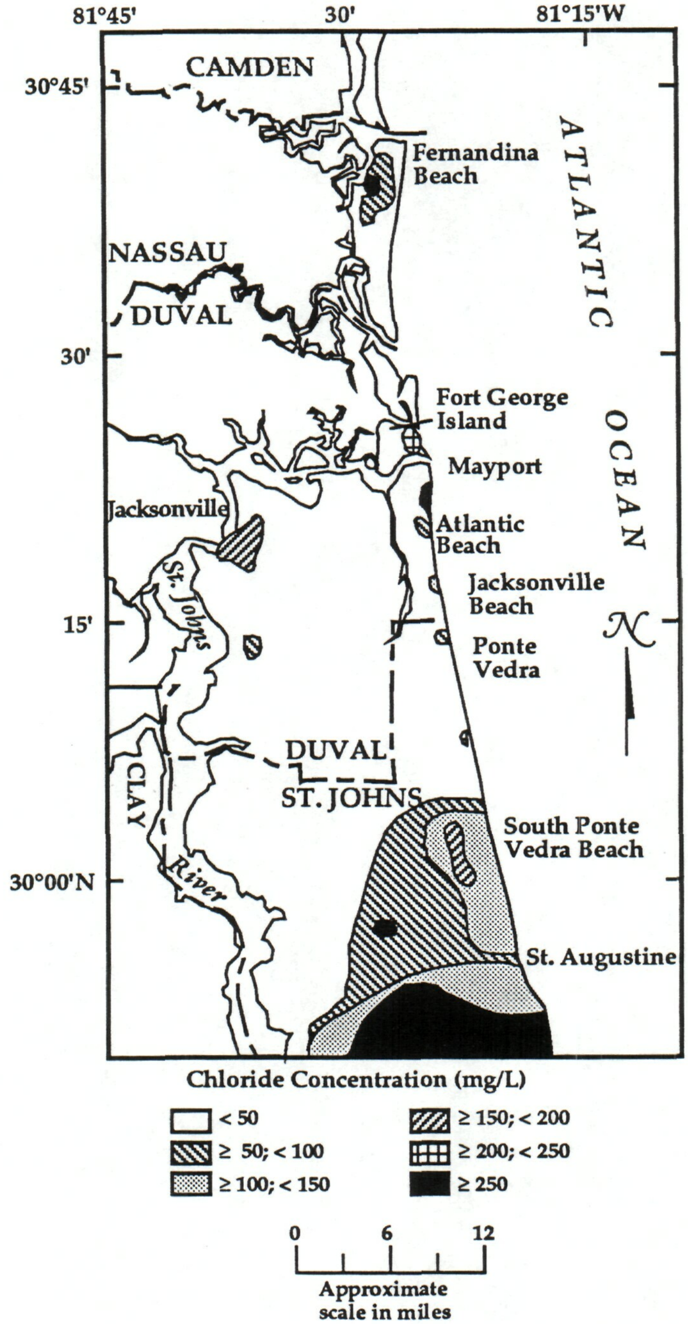
In the study area in the vicinity of Jacksonville Beach, chloride concentrations have increased progressively over time in some wells tapping the upper Floridan aquifer. For example, in well D-164 on Fort George Island, the chloride concentration has increased from 63 mg/L in 1930 to 340 mg/L in 1994 (see Figure 15). Also, in well D-484 in the Jacksonville Beach wellfield, the chloride concentration has increased from 84 mg/L in 1974 to 220 mg/L in 1995 (see Figure 16). On Fort George Island, available data indicate that saltwater might be moving upward into the upper Floridan aquifer from a deeper zone along a vertical, or nearly vertical, conduit(s) (Environmental Science and Engineering, Inc. 1985; Spechler 1994).

The most plausible mechanism for the movement of higher chloride water into the fresh-water zone of the Floridan aquifer system in parts of east-central Duval County is the upward leakage of salt water along joints, fractures, collapse features, faults, or other structural



Source: Spechler 1994 (from Johnston et al. 1982)

Figure 13. Inferred position of the saltwater-freshwater interface



Source: Toth 1990

Figure 14. Chloride concentration in water from the Floridan aquifer for samples collected after 1979

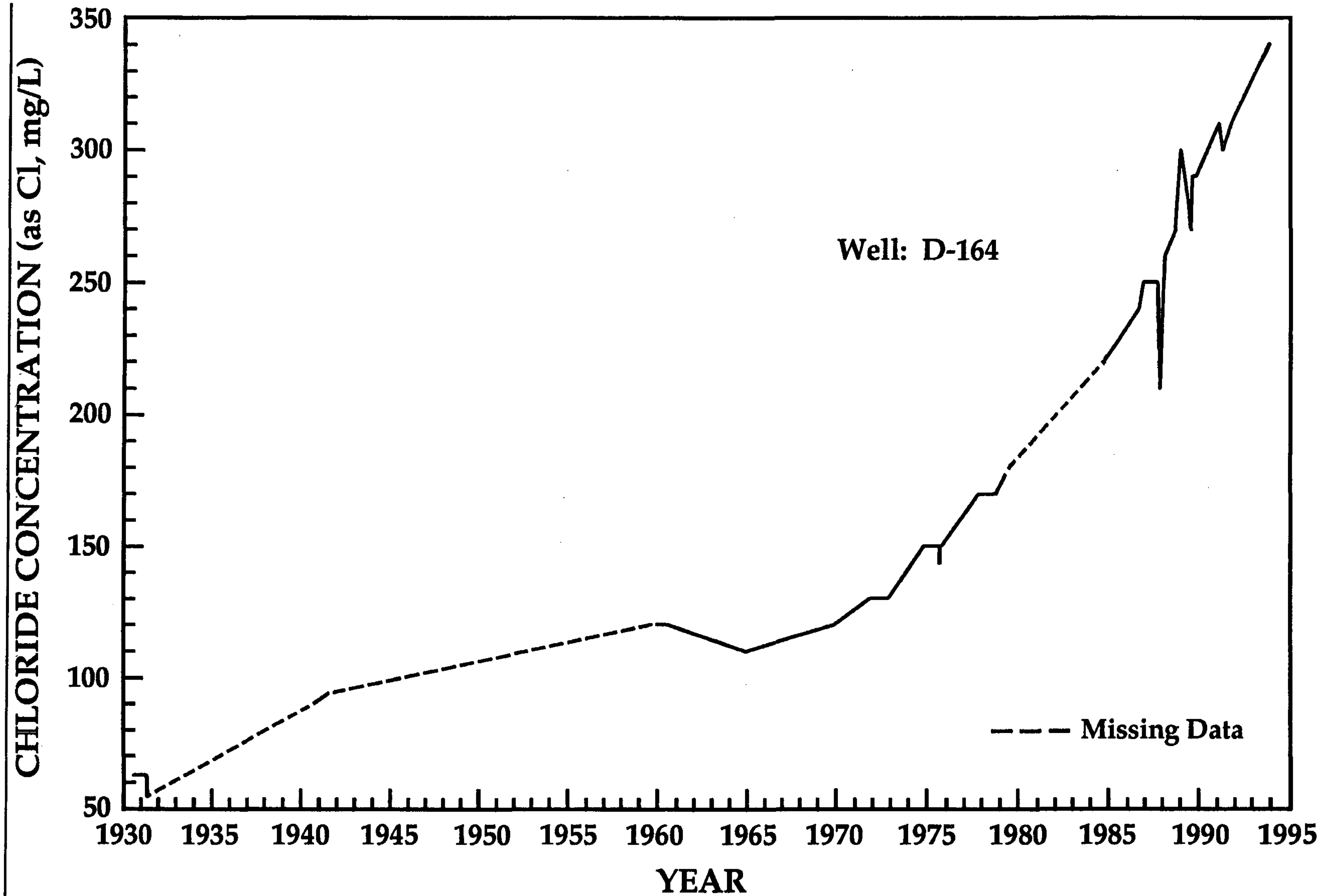


Figure 15. Chloride concentration versus time for well D-164

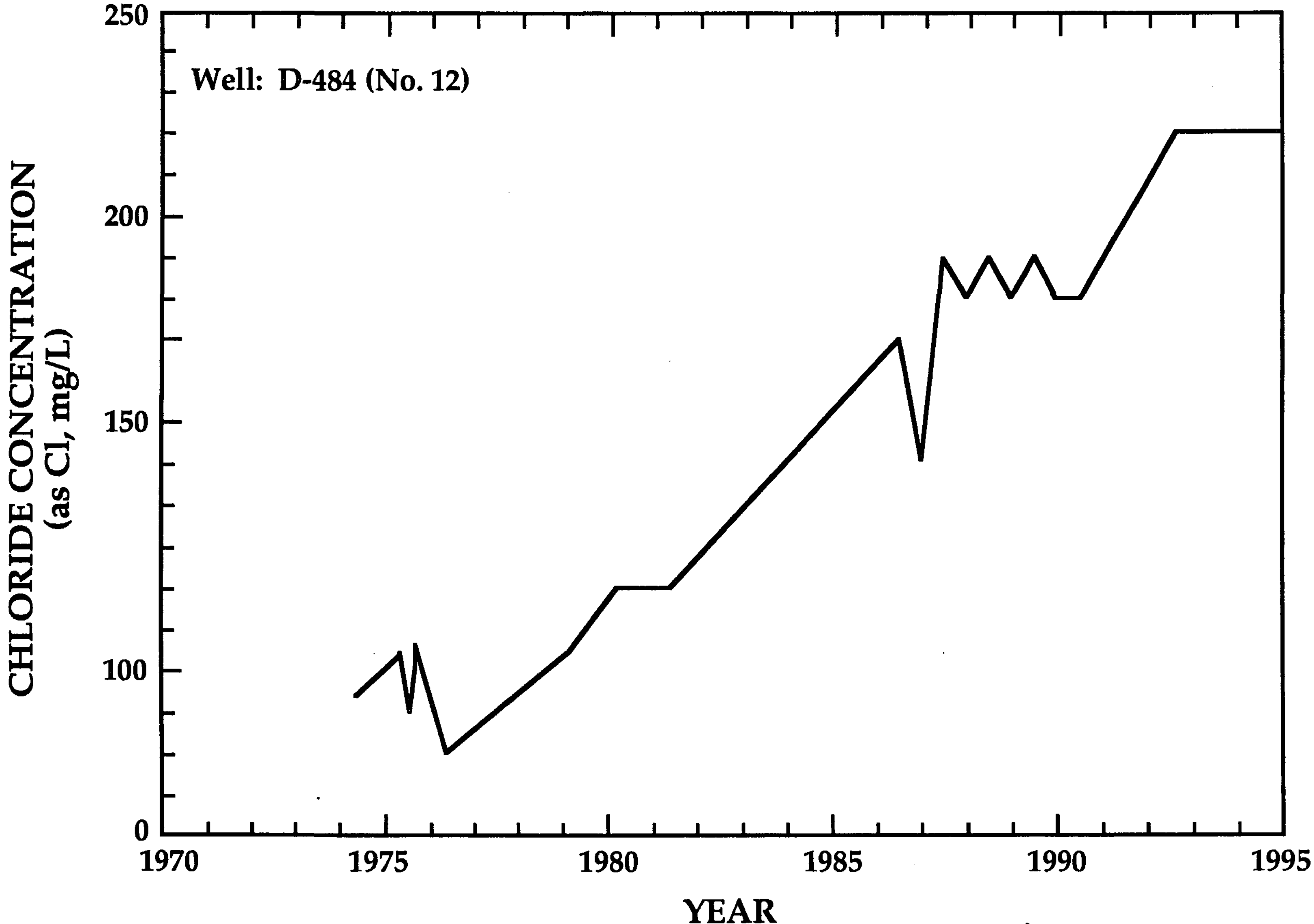
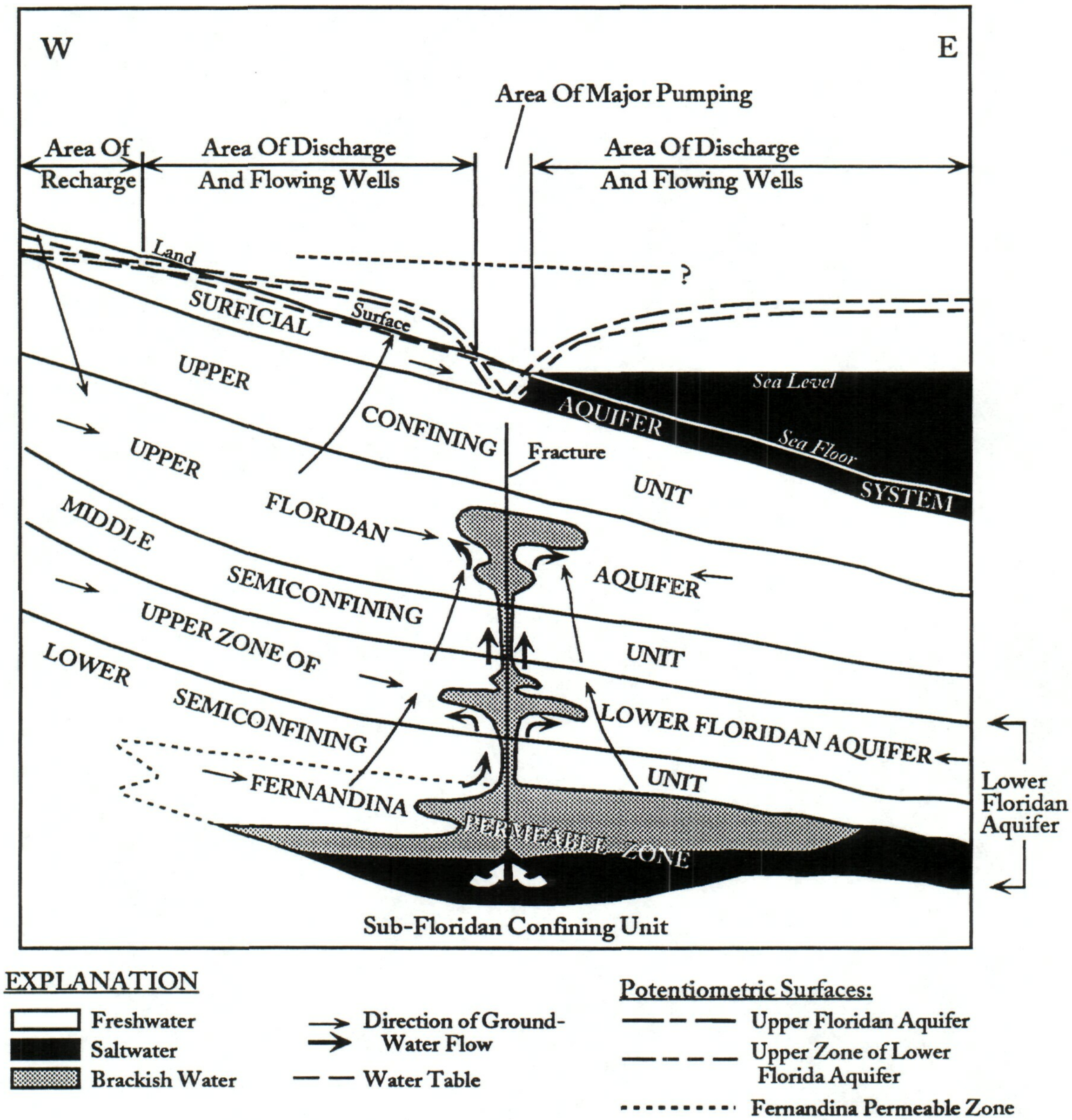


Figure 16. Chloride concentration versus time for well 12 (D-484)

deformities (Spechler 1994)(see Figure 17). These features can provide a vertical hydraulic connection between freshwater zones and deeper, more saline zones. Decreasing heads in the shallower freshwater zones of the aquifer can result in an increase in the potential for upward leakage of salt water through nearly vertical zones of preferential permeability. Once salt water reaches the freshwater zone, it can move laterally downgradient toward pumping centers.



Source: Spechler 1994

Figure 17. Conceptualization of the vertical movement of salt water in localized areas in northeastern Florida

3.0 JACKSONVILLE BEACH WELLFIELD

3.1 JACKSONVILLE BEACH WELLS

Six wells are used for water supply by the City of Jacksonville Beach (see Figure 18 and Table 4). Wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) are approximately 1,200 ft deep and are open to both the upper Floridan aquifer (upper water-bearing zone) and the upper part of the lower Floridan aquifer (middle water-bearing zone)(see Figure 19). Wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23) are approximately 900 ft deep and open only to the upper Floridan aquifer. Wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) are free-flowing wells, and wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23) are equipped with down-hole turbine pumps.

3.2 WATER USE

The total water use from the Jacksonville Beach wells has been approximately 3 million gallons per day (mgd) (400,000 ft^3/day) since 1985 (see Figure 20). In 1993, the average water use ranged from 0.021 mgd (2,800 ft^3/day) at well D-484 (no. 12) to 0.952 mgd (127,000 ft^3/day) at well D-2707 (no. 22) (see Figure 21). In 1995, the average water use ranged from 0.007 mgd (935 ft^3/day) at well D-2747 (no. 21) to 0.907 mgd (121,000 ft^3/day) at well D-482 (no. 11) (see Figure 22).

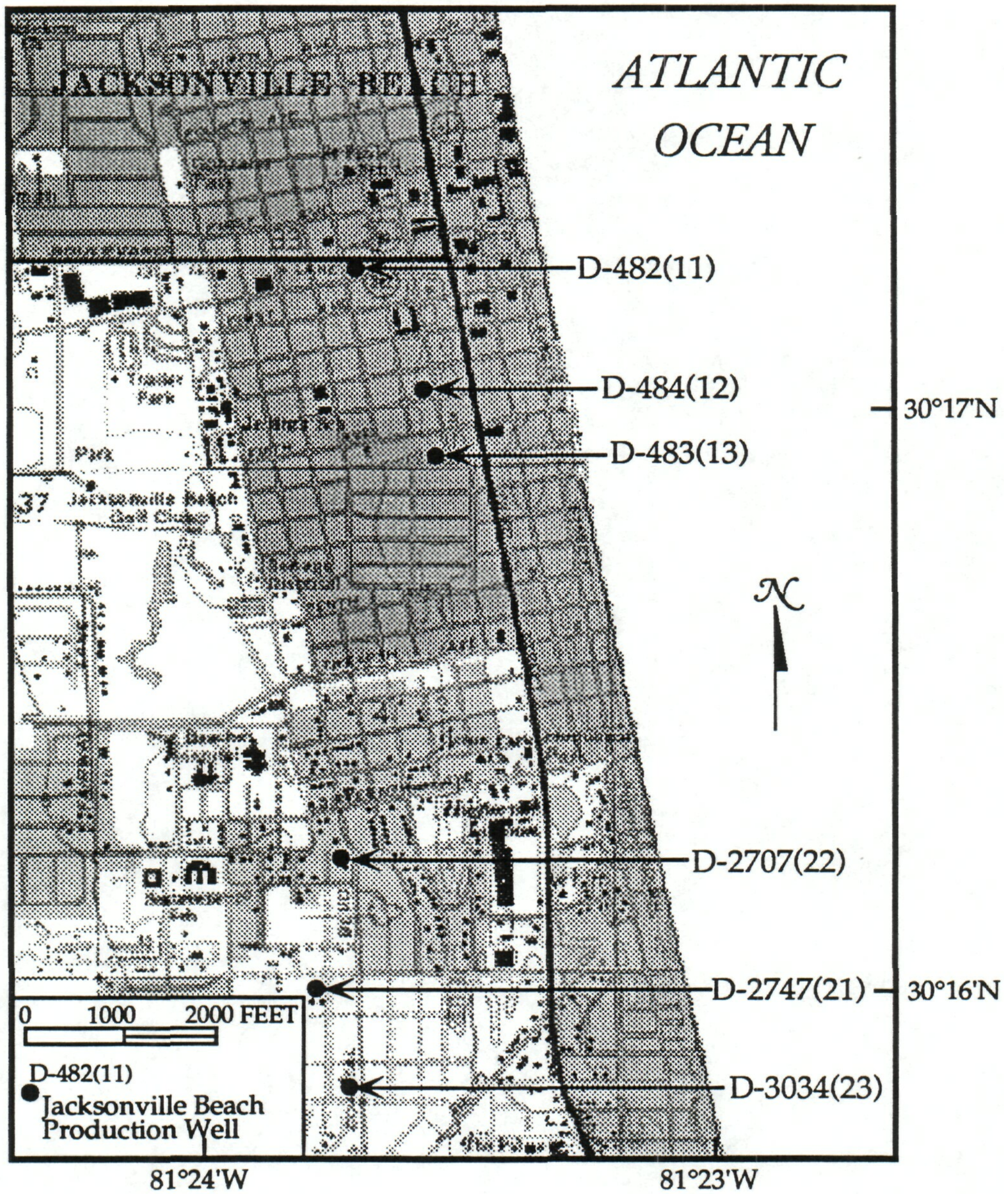


Figure 18. Locations of Jacksonville Beach wells

Table 4. Details of Jacksonville Beach wells

USGS Site Identification Number	Local Number	Jacksonville Beach No.	Aquifer	Altitude of Land Surface (ft, NGVD)	Diameter of Casing (inches)	Depth of Casing (ft)	Depth of well (ft)
301716-081234301	D-482	11	b	11	12	375	1,212
301704-081233401	D-484	12	b	8	12	357	1,181
301657-081233301	D-483	13	b	8	12	372	1,220
301604-081234601	D-2747	21	u	10	16	402	920
301620-081234201	D-2707	22	u	10	16	400	900
301552-081234301	D-3034	23	u	20	16	400	900

Notes: u = upper Floridan aquifer well; and
b = well tapping both the upper Floridan aquifer and the upper zone of the lower Floridan aquifer.

Source: Spechler, 1994

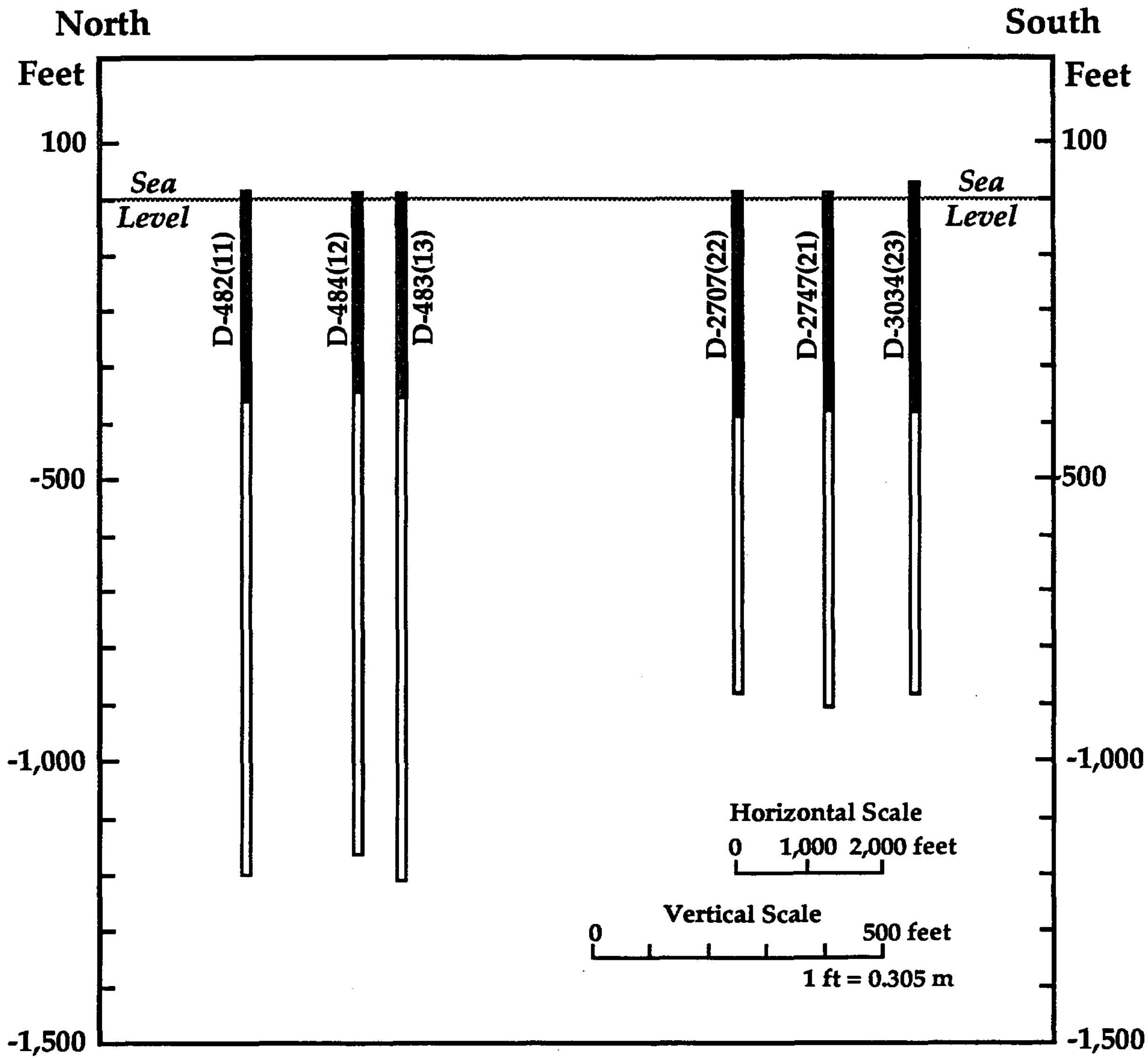


Figure 19. Cross-section through Jacksonville Beach wellfield

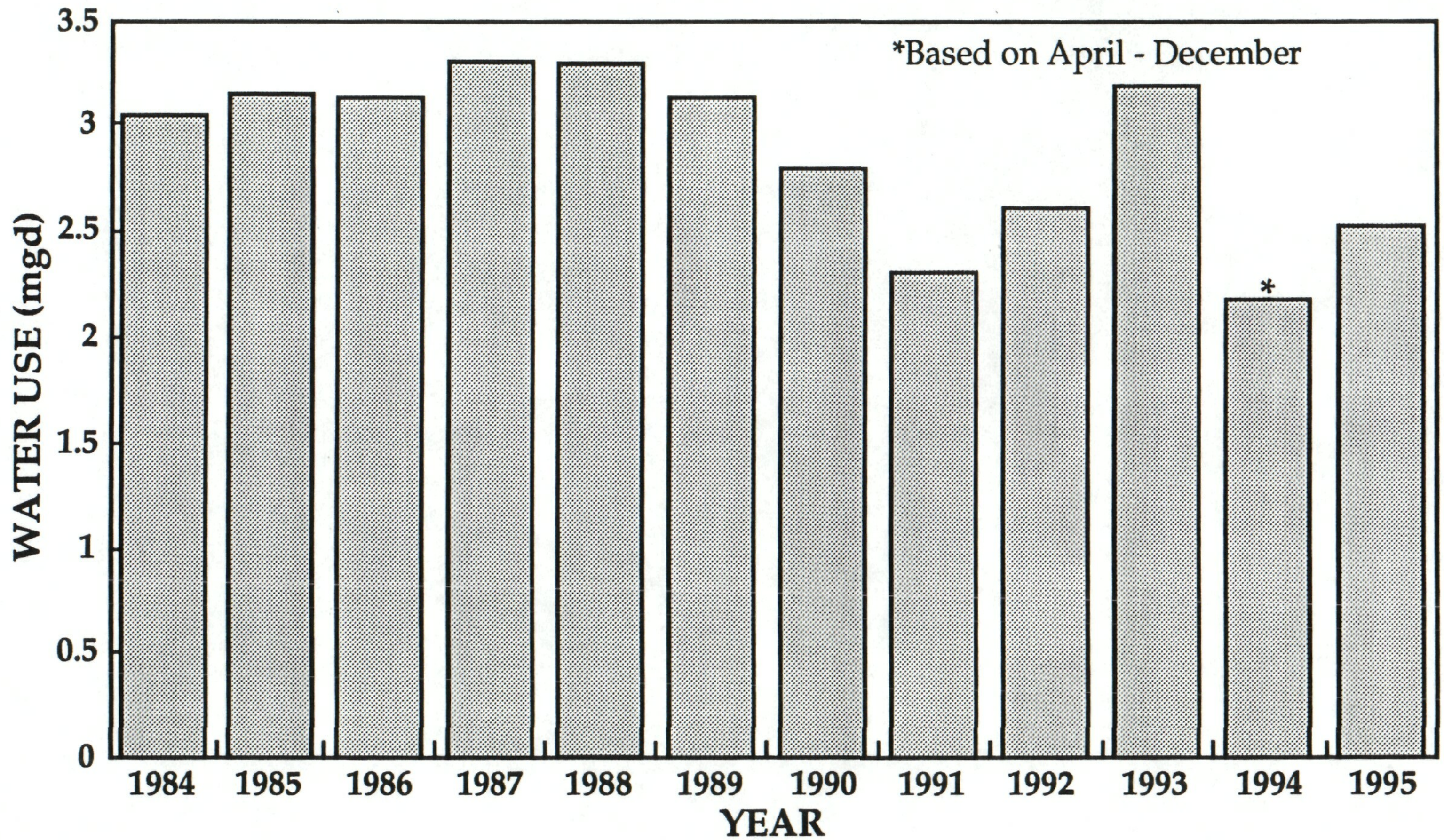


Figure 20. Average water use from Jacksonville Beach wellfield for 1984-1995

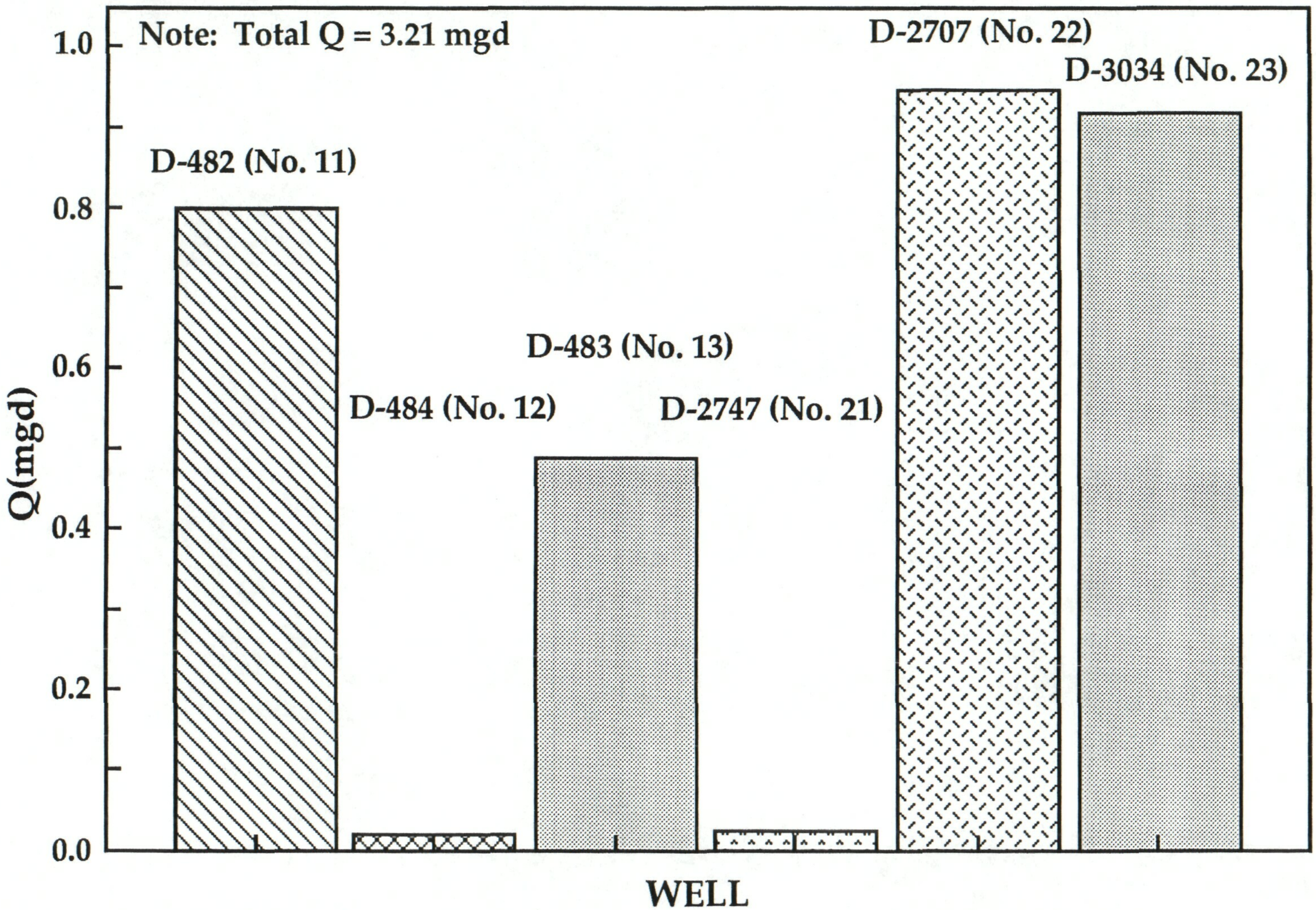


Figure 21. Average water use from Jacksonville Beach wells for 1993

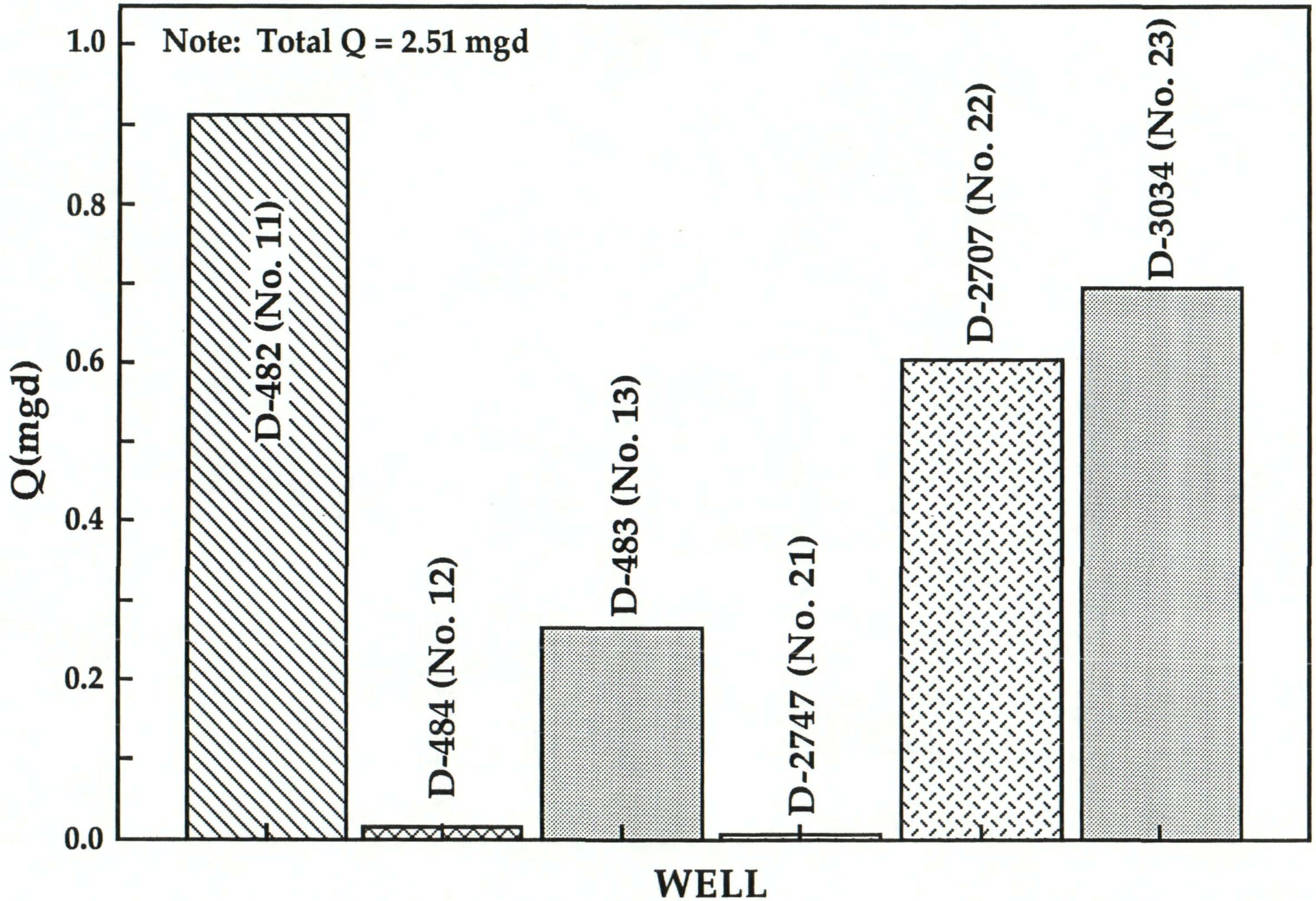


Figure 22. Average water use from Jacksonville Beach wells for 1995

3.3 Chloride Levels

Chloride concentrations for all six of the Jacksonville Beach wells are available from 1986 to 1995 (see Figures 23 through 28). Chloride concentrations in wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13), which are open to both the upper and middle water-bearing zones, are significantly greater than the chloride concentrations in wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23), which are open only to the upper water-bearing zone. During part of the period from 1993 to 1995, the chloride concentrations reported by the City of Jacksonville Beach for well D-484 (no. 12) (Figure 24) were greater than the chloride concentrations reported by the USGS for the same period (Figure 16). By comparing Figures 16 and 24, it can be seen that the most recent data for 1995 are in good agreement, however. The chloride concentration reported by the USGS for February 14, 1995 for well D-484 (no. 12) was 220 mg/L. Chloride concentrations in well D-483 (no. 13) measured on September 19, 1995 by SJRWMD ranged from 143 to 149 mg/L (see Table 5).

3.4 Pumping Tests

Data are available from three pumping tests that have been performed at two wells in the Jacksonville Beach wellfield. Well D-2747 (no. 21) was pumped at a constant rate of 2,000 gallons per minute (gpm) (385,000 ft^3/day) on March 8 and 9, 1984, and the drawdown was 15.5 ft at 1,440 minutes (see Figure 29). A step-drawdown test also was performed at well D-2747 (no. 21) on September 15 and 16, 1982, in which the pumping rate was increased from 2,000 gpm

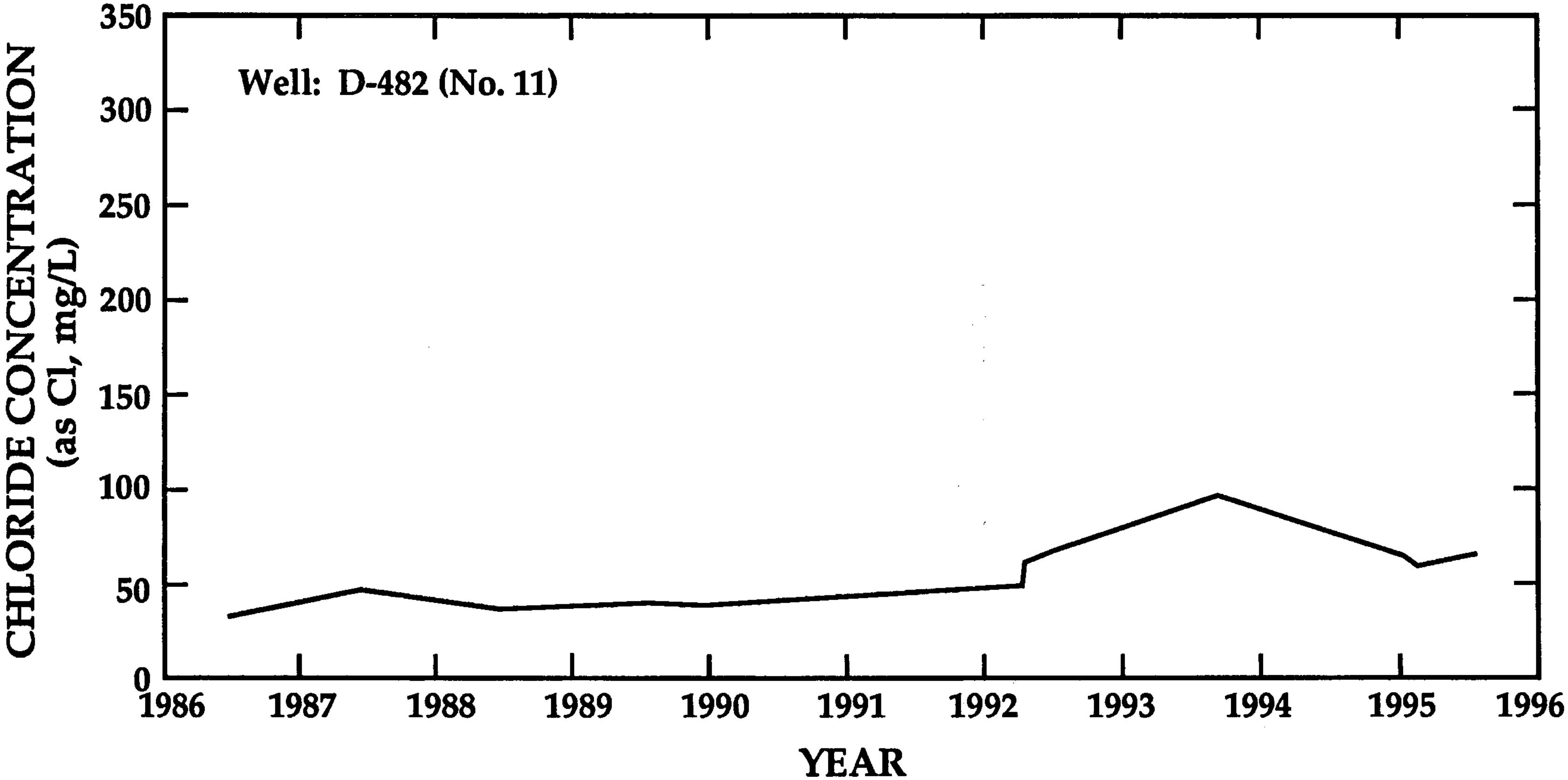


Figure 23. Chloride concentration for well 11 (D-482) from 1986 to 1995

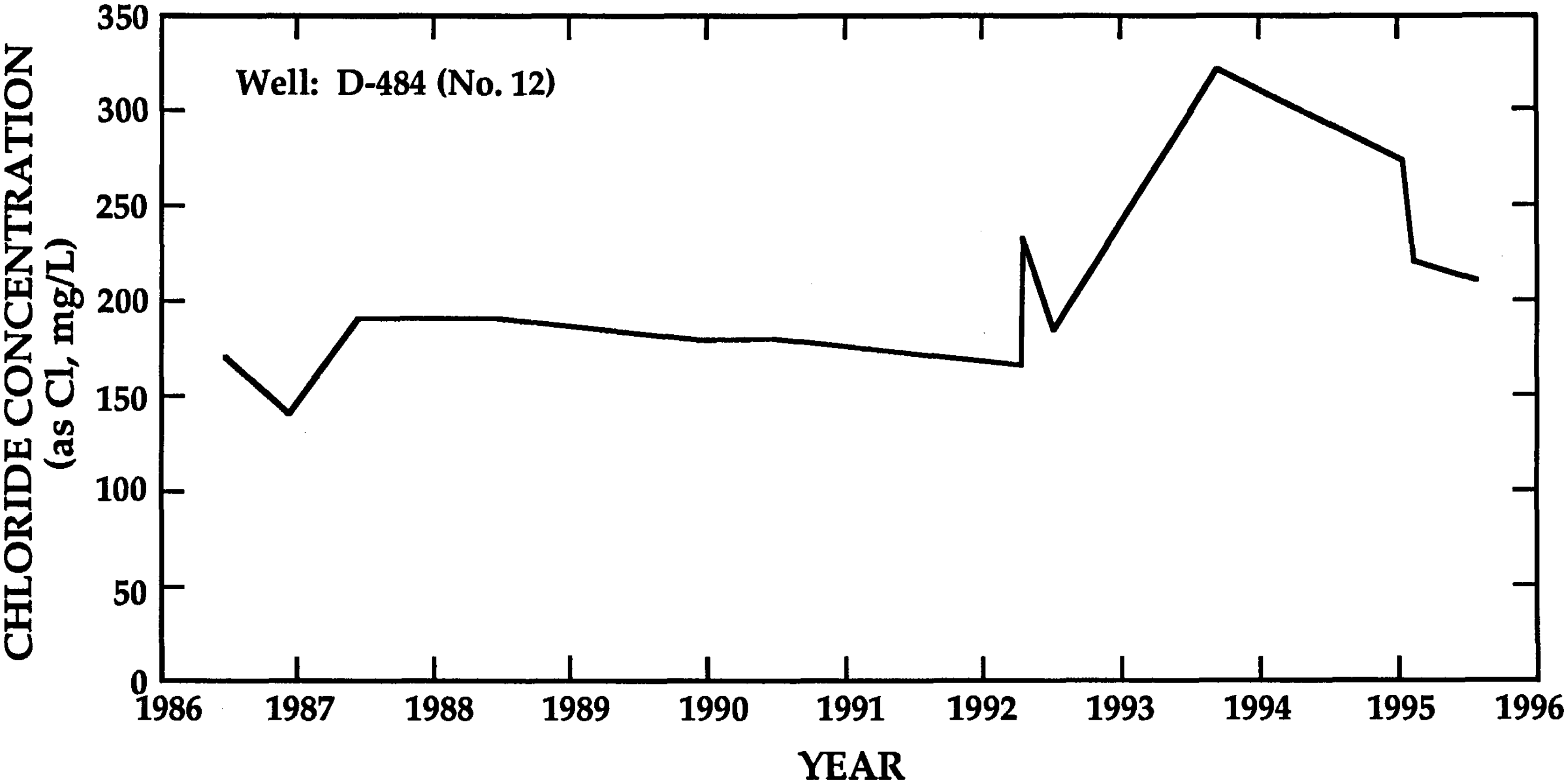


Figure 24. Chloride concentration for well 12 (D-484) from 1986 to 1995

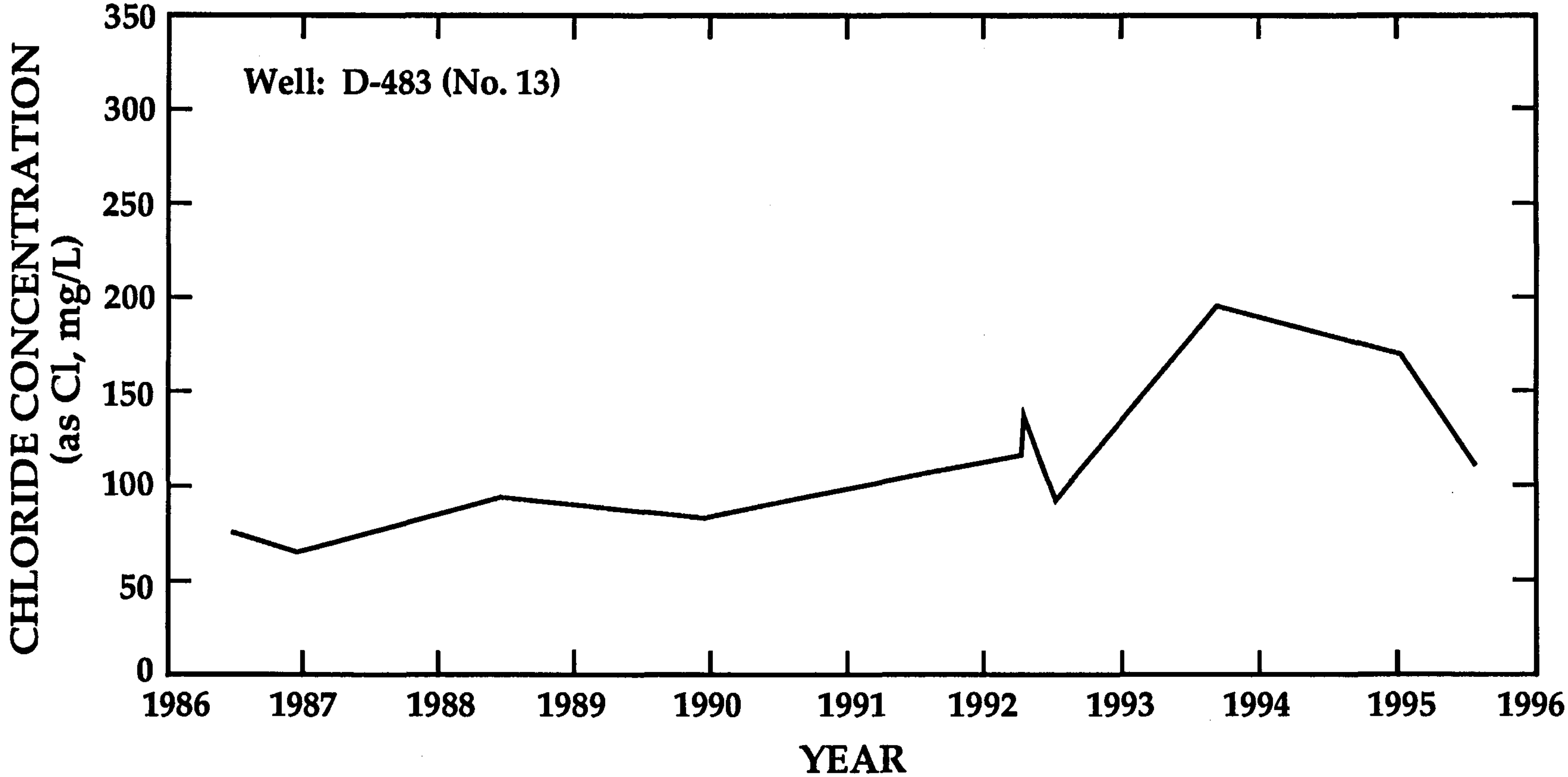


Figure 25. Chloride concentration for well 13 (D-483) from 1986 to 1995

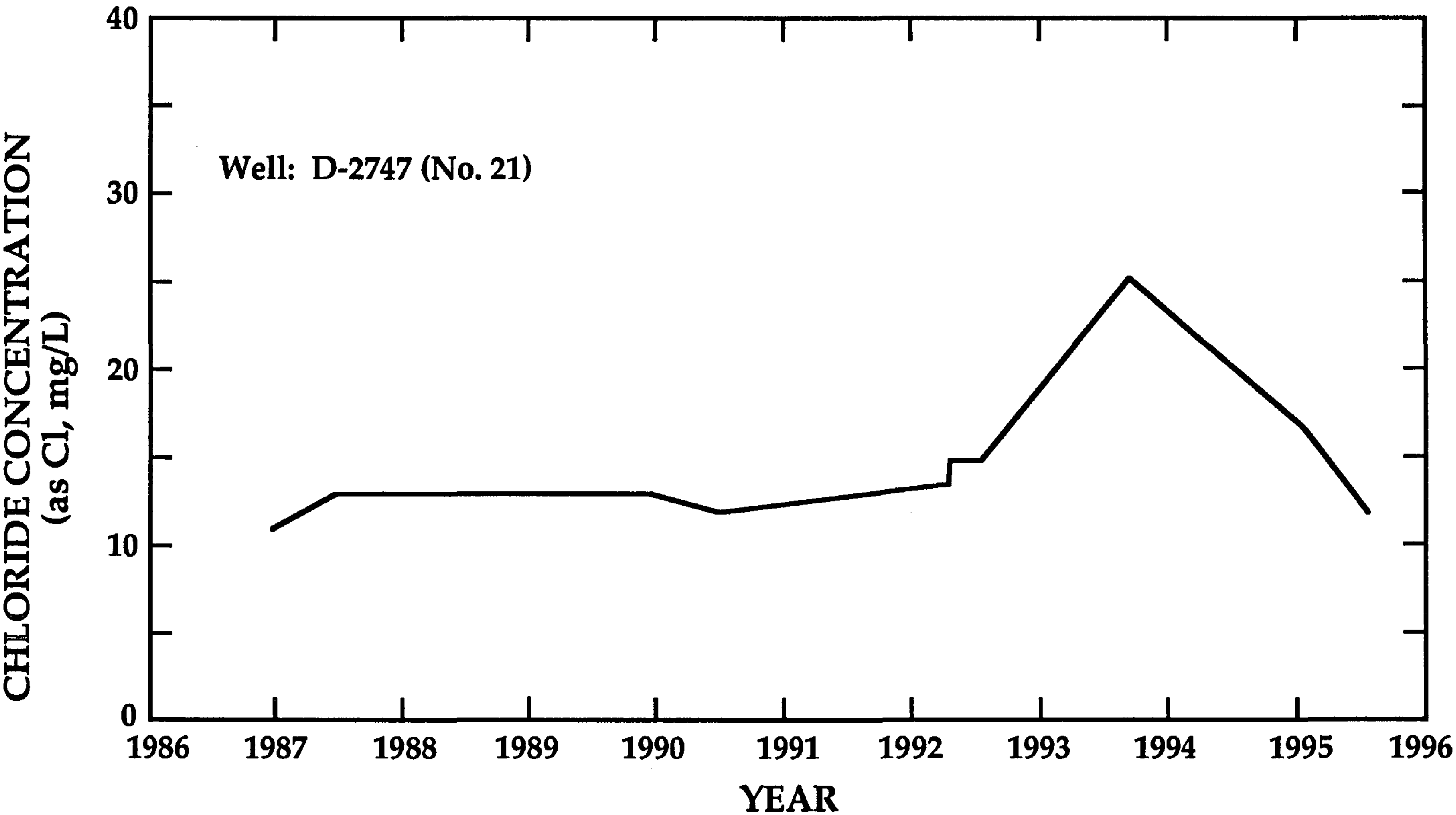


Figure 26. Chloride concentration for well 21 (D-2747) from 1986 to 1995

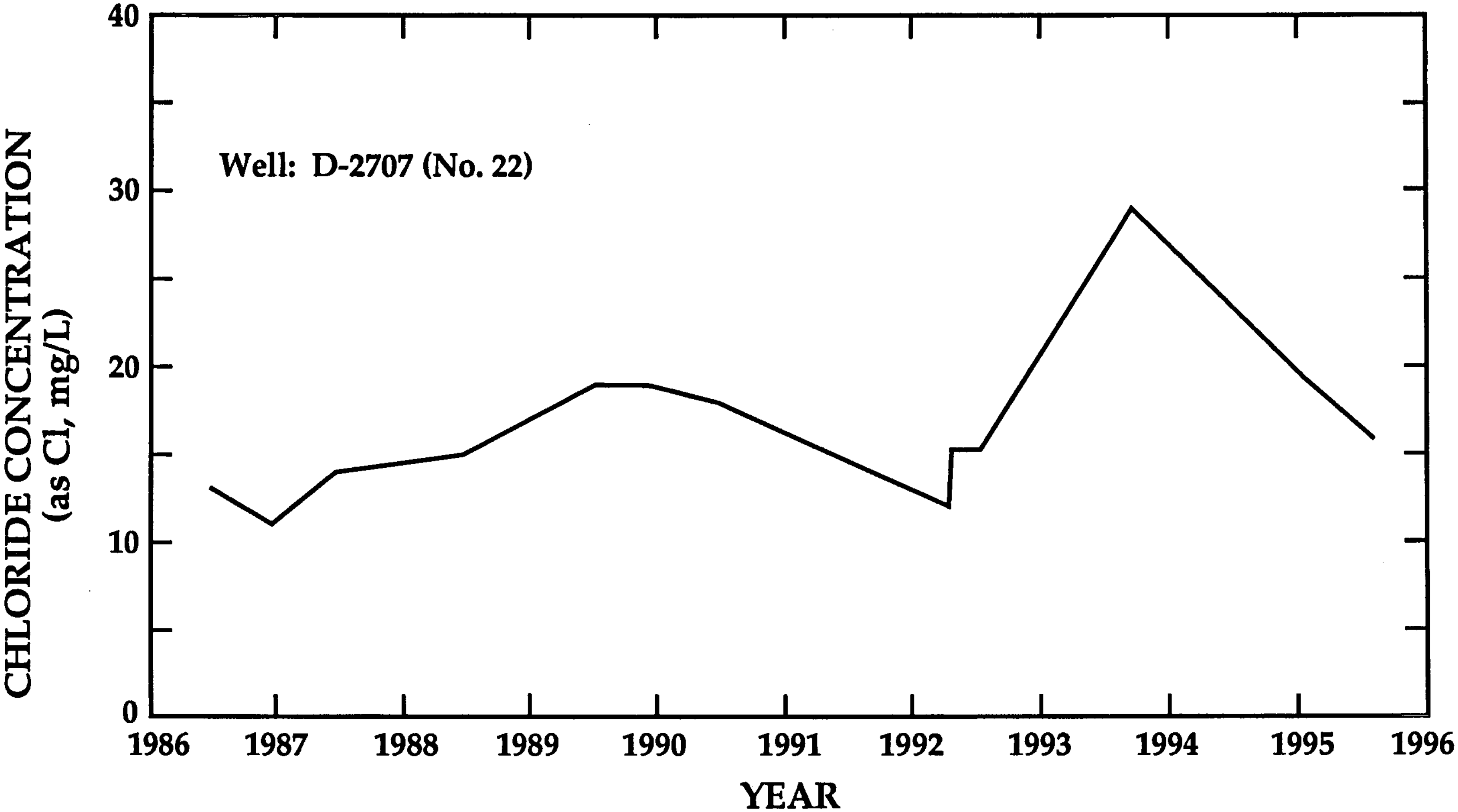


Figure 27. Chloride concentration for well 22 (D-2707) from 1986 to 1995

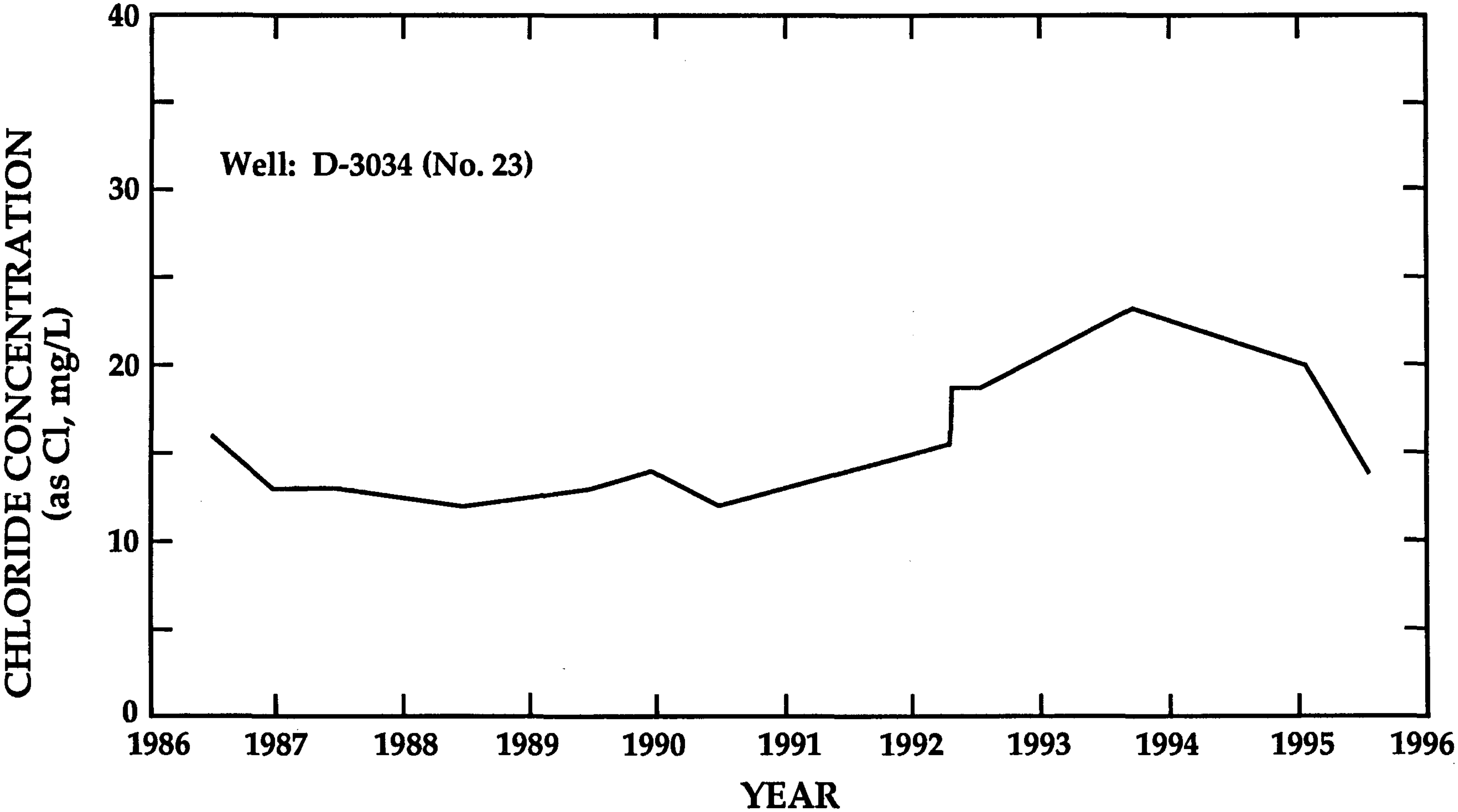


Figure 28. Chloride concentration for well 23 (D-3034) from 1986 to 1995

Table 5. Chloride concentrations in well D-483 (no. 13)

Depth (ft)	Chloride Concentration (mg/L as chloride)
0	143
550	144
850	143
1,125	149

Note: Samples taken by SJRWMD September 19, 1995

Source: J. Davis, SJRWMD, October 31, 1995

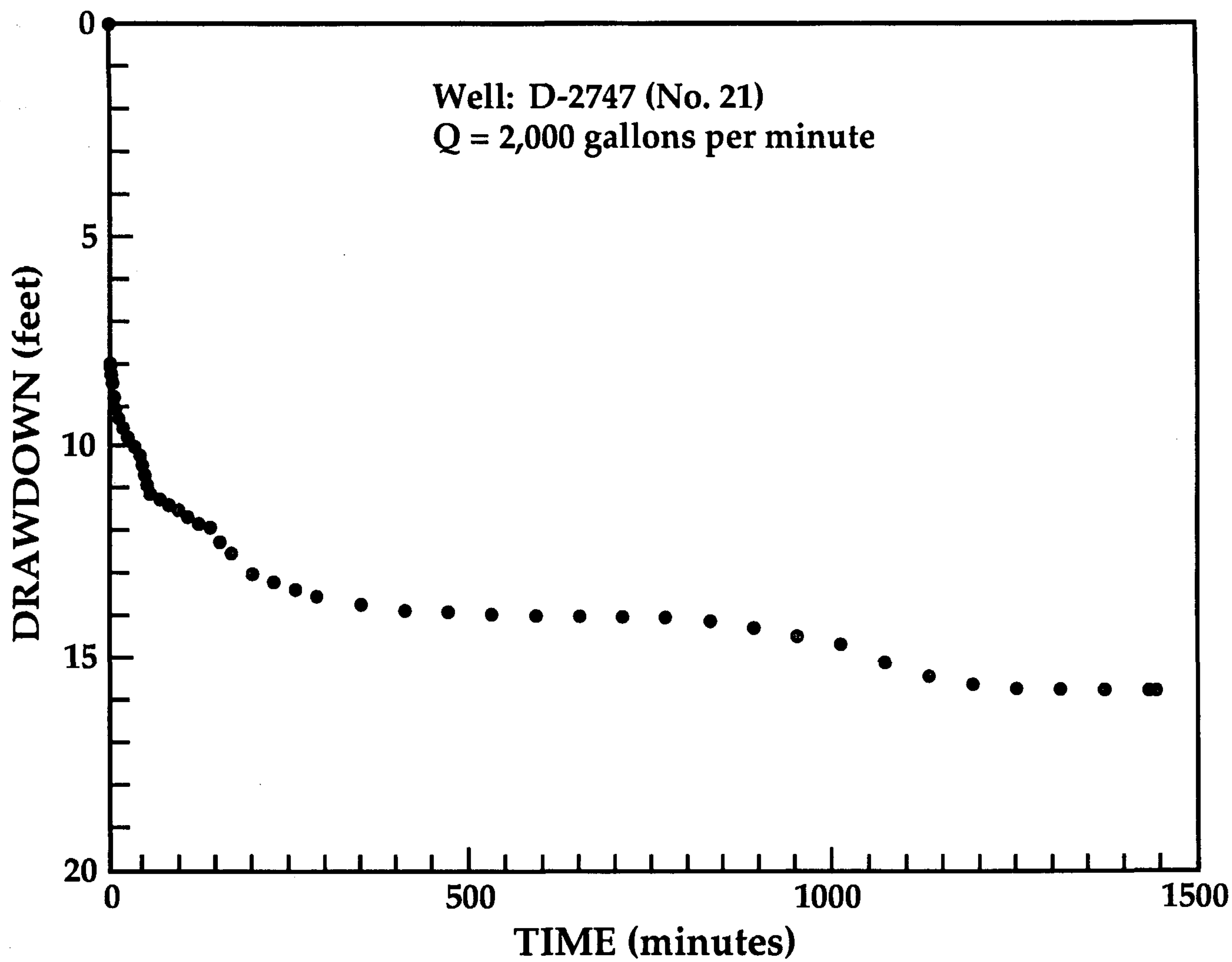


Figure 29. Drawdown versus time at well 21 (D-2747) on March 8 and 9, 1984

(385,000 ft^3/day) to 3,500 gpm (674,000 ft^3/day) and in which the drawdown was 44.6 ft at 355 minutes (see Figure 30). Another step-drawdown test was performed at D-2707 (well no. 22) on October 5 and 6, 1982, in which the pumping rate was increased from 2,000 gpm (385,000 ft^3/day) to 3,500 gpm (674,000 ft^3/day) and in which the drawdown was 29.3 ft at 720 minutes (see Figure 31).

The drawdown versus time data were analyzed as part of this investigation to estimate values for transmissivity at these wells. Based on Walton (1970), the Theis (1935) nonequilibrium equation was used to estimate the transmissivity from the specific capacity (gpm/ft) observed at 1,440 minutes at well D-2747 (no. 21) (Figure 29). In using the specific capacity data from a pumped well, it is necessary to assume a range for the storage coefficient (S) in order to estimate the transmissivity. For an assumed range of $S = 1.0 \times 10^{-3}$ to 1.0×10^{-4}, the transmissivity was determined to range from 37,800 to 42,500 ft^2/day (see Table 6). Based on Bear (1979), the specific capacity values at the end of the first time steps in the two step-drawdown tests also were used to estimate transmissivities. Using these data and the Theis (1935) nonequilibrium equation, the transmissivity at well D-2747 (no. 21) was determined to range from 39,800 to 45,500 ft^2/day, and the transmissivity at well D-2707 (no. 22) was determined to range from 92,500 to 105,000 ft^2/day at well 22 (see Table 6). Thus, based on these pumping data, transmissivity ranges from about 37,800 to 45,500 ft^2/day at well D-2747 (no. 21) and from about 92,500 to 105,000 ft^2/day at well D-2707 (no. 22).

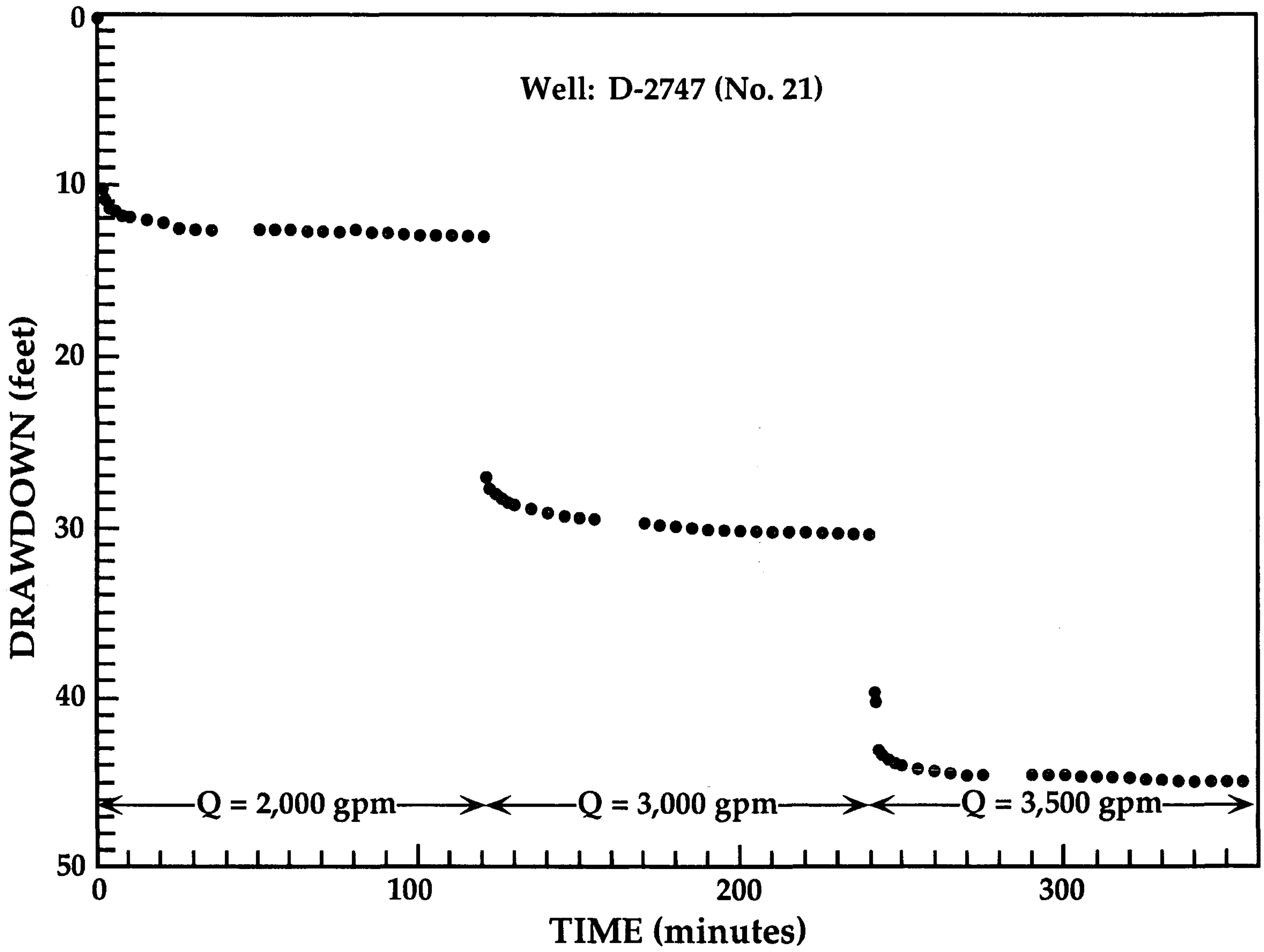


Figure 30. Step-drawdown test at well 21 (D-2747) on September 15 and 16, 1982

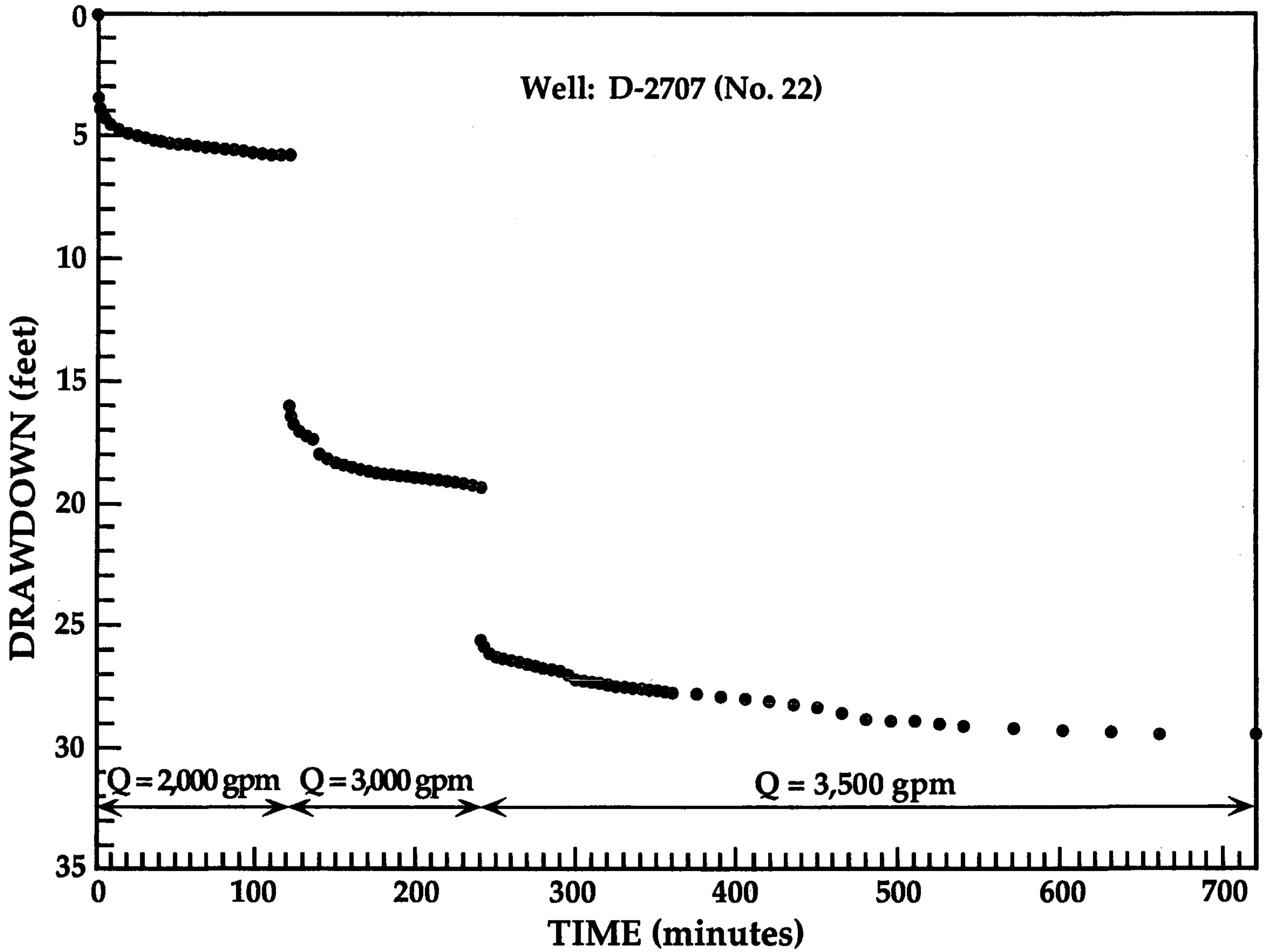


Figure 31. Step-drawdown test at well 22 (D-2707) on October 5 and 6, 1982

Table 6. Analysis of pumping tests at wells D-2747 (no. 21) and D-2707 (no. 22)

Well	Pumping Rate (gpm)	Draw-down (ft)	Specific Capacity (gpm/ft)	Time (min)	Assumed Storage Coefficient: 1.0×10^{-3}	1.0×10^{-4}
					Transmissivity (ft^2/day):	
D-2747 (no. 21)	2,000	15.5	129.0	1,440	37,800	42,500
D-2747 (no. 21)	2,000	12.8	155.9	120	39,800	45,500
D-2707 (no. 22)	2,000	5.79	345.4	120	92,500	105,000

3.5 GEOPHYSICAL LOGS

Geophysical logs have been run in three wells in the Jacksonville Beach wellfield (see Table 7 and Appendix A). Logs for wells D-484 (well no. 12) and D-482 (well no. 11) were run by the USGS on February 13-14 and 15-16, 1995, respectively. As interpreted by the USGS (Appendix A, written communication, Trudy G. Phelps, March 29, 1995), the logs of well D-484 (well no. 12) indicate that most of the flow from this well enters from one or two fractures at a depth of 1,140 to 1,151 ft below land surface. The temperature and fluid resistivity logs indicate that the source of salty water is one or both of these fractures that are near the bottom of the well. Logs of well D-482 (well no. 11) indicate that most of the flow enters this well at a depth between about 1,120 and 1,150 ft. The caliper log does not show the presence of a large single fracture such as was noted in well D-484 (well no. 12), however. A major water-quality change in well D-482 (well no. 11) occurs at a depth of about 1,125 ft. A water sample collected at a depth of 1,160 ft had a specific conductance of 600 microSiemens, and a wellhead sample had a specific conductance of 680 microSiemens. Water with the highest chloride concentration probably is entering the well between 1,125 and 1,150 ft, and the water is slightly fresher at 1,160 ft.

Well D-483 (well no. 13) was logged by SJRWMD on September 19, 1995 (see Appendix A). The temperature and resistivity logs do not change significantly with depth in this well. Apparently, nearly all of the water from this well enters the well at or near the bottom of the well at a depth of about 1,220 ft.

Table 7. Summary of geophysical logs run in Jacksonville Beach wellfield

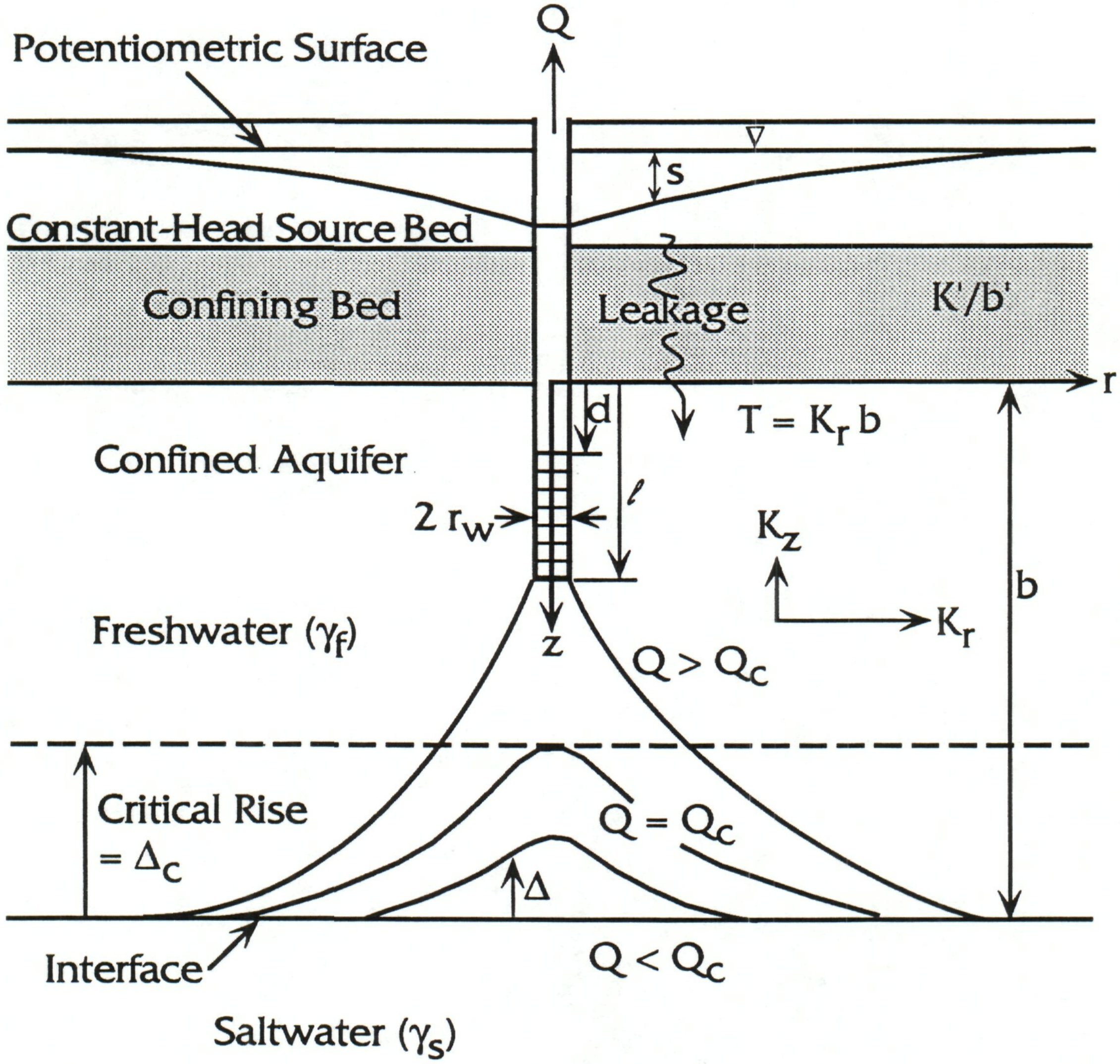
Logs	Well D-482 (no. 11)	Well D-484 (no. 12)	Well D-483 (no. 13)
Run By	USGS	USGS	SJRWMD
Dates	February 15-16, 1995	February 13-14, 1995	September 19, 1995
Caliper	x	x	x
Temperature	x	x	x
Resistivity	x	x	x
Flow Meter	x	x	x
Gamma	x	x	x
Sonic Television	x	x	-

4.0 SALTWATER UPCONING

4.1 ANALYTICAL SOLUTION

Saltwater upconing that occurs in an aquifer that is overlain by a leaky confining bed can be described in terms of an analytical model that assumes the existence of a sharp interface between the fresh water and salt water and the occurrence of a critical rise in the interface, above which only an unstable cone can exist (Motz 1992)(see Figure 32). Drawdown is calculated along the saltwater-freshwater interface due to pumping from a well that partially penetrates the freshwater zone, and then the Ghyben-Herzberg relation is used to calculate the steady-state rise in the interface. The interface rise and the critical pumping rate are determined in terms of aquifer and confining bed properties and the degree of penetration of the pumped well into the freshwater zone. The critical rise is assumed to occur when the calculated interface rise is equal to 0.3 times the distance from the original interface location to the bottom of the well. Based on the analytical model, the critical pumping rate increases as the ratio of vertical to horizontal hydraulic conductivity is decreased, and it decreases as the degree of well penetration is increased.

By considering the interference effects of other nearby pumped wells, the single-well solution can be extended to determine the critical pumping rate due to pumping from multiple wells in a wellfield (Motz 1994). For this case, the critical pumping rate is obtained from:



Source: Motz 1992

Figure 32. Saltwater upconing due to pumping from a well in a leaky confined aquifer

$$Q_c = \frac{2\pi(0.3)T(b - \ell)}{\delta\left\{\left[K_0\left(\frac{r_w}{B}\right) + \frac{f_w}{2}\right] + \sum_{m=2}^{m=M} \alpha_m \left[K_0\left(\frac{r_m}{B}\right) + \frac{f_m}{2}\right]\right\}} \tag{1}$$

where: b = thickness of aquifer; b' = thickness of confining bed; $1/B = (K'/b'T)^{½}$; f = partial penetration correction factor; K_0 = modified Bessel function of the second kind, zero order; K' = vertical hydraulic conductivity of the confining bed; K'/b' = leakance of the confining bed; ℓ = distance from the top of aquifer to the bottom of the well screen; M = number of multiple wells; m,n = summation indices; Q_c = critical pumping rate of well; r = radial distance; r_w = radius of pumped well; s = drawdown; T = transmissivity; z = vertical coordinate; α_m = pumping rate coefficient; γ_f = specific weight of fresh water; γ_s = specific weight of salt water; Δ = rise of the saltwater-freshwater interface; Δ_c = critical rise of the saltwater-freshwater interface; $\delta = [\gamma_f/(\gamma_s - \gamma_f)$; and:

$$f = \frac{4b}{\pi(\ell - d)} \sum_{n=1}^{\infty} \frac{(-1)^n}{n}\left[\sin\left(\frac{n\pi\ell}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right] \cdot K_0\left[\left(\frac{K_z}{K_r}\right)^{1/2}\left(\frac{n\pi r}{b}\right)\right] \tag{2}$$

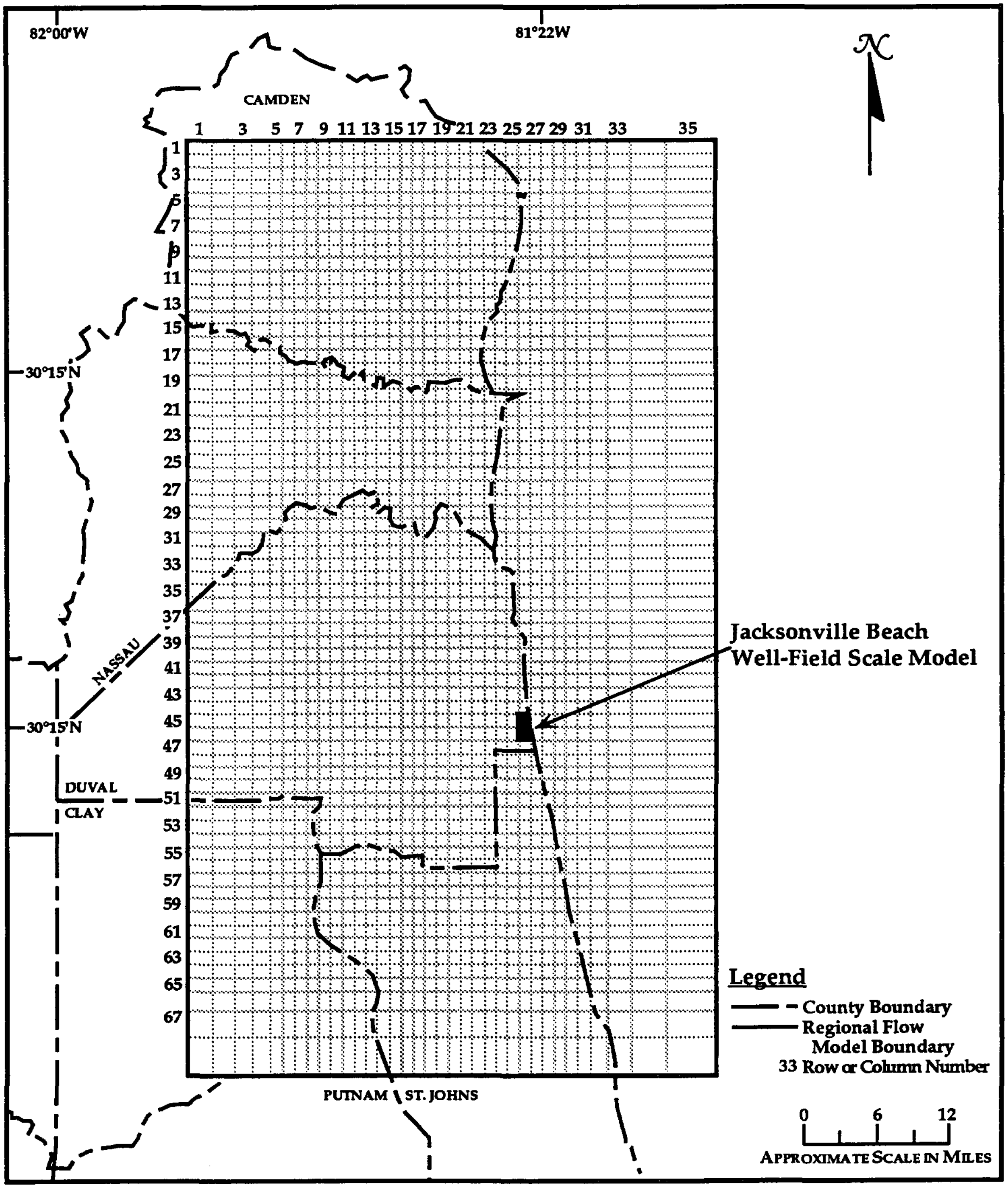
where: d = distance from the top of aquifer to the top of the well screen; K_r = horizontal hydraulic conductivity of the aquifer; K_z = vertical hydraulic conductivity of the aquifer; and:

$$\alpha_m = \frac{Q_m}{Q_c} \tag{3}$$

The first bracketed term in the denominator of Equation 1 represents the effects of pumping from the pumped well under consideration, and the terms in the summation represent the interference effects from the other pumped wells in a wellfield. The coefficients α_m in Equation 3 express the ratios of the pumping rate of each of the other pumped wells to the pumping rate of the well under consideration at r_w.

An analysis of the effects of pumping from the Jacksonville Beach wells was made using the analytical solution. Initial estimates for aquifer and confining bed properties were obtained from SJRWMD's northeast regional ground water flow model (Durden 1995). In the regional ground water flow model, one of the Jacksonville Beach wells (D-482) is located in the cell at row 45, column 26, and the other five wells are in the cell at row 46, column 26 (see Figure 33). Based on the regional model calibration, transmissivities for the upper, middle, and lower water-bearing zones are 45,000 - 46,000 ft^2/day, 600,000 ft^2/day, and 35,000 ft^2/day, respectively, and leakances for the upper, middle, and lower semiconfining units are 5.0×10^{-7} day^{-1}, 1.0×10^{-6} to 1.0×10^{-5} day^{-1}, and 4.32×10^{-6} to 6.57×10^{-6} day^{-1}, respectively.

For this analysis, values used for α_m represented the actual distribution of pumping among the wells that occurred in 1993 (based on Figure 21). For each of the three deeper wells that extends into the middle water-bearing zone, the critical pumping rate was calculated using Equations 1 through 3 to calculate the drawdowns due to the pumped well and the drawdowns due to the other five wells. Based on the aquifer parameters from SJRWMD's ground water flow model, values of $T = 680{,}000$ ft^2/day and $K'/b' = 5.0 \times 10^{-7}$ day^{-1} were used in Equations 1 through 3 to represent the aquifer and overlying confining bed in the analytical model, along with $K_z/K_r = 1.0 \times 10^{-6}$ to represent the effects of the lower semiconfining unit and $\delta = 40$ to represent the effects



Modified from Durden 1995.

Figure 33. Location of Jacksonville Beach wellfield relative to SJRWMD regional ground water flow model

of the density difference between salt and fresh water. It was determined that the minimum critical pumping rate (and thus the limiting pumping rate) occurred at well D-483 (no. 13). For this case, drawdowns were calculated at well D-483 (no. 13) and at the other five wells located at distances of 700 to 6,900 ft from well D-483 (no. 13), and values of α_m ranged from 0.043 to 1.939 (see Table 8). For this initial set of parameters, the total critical pumping rate for the six wells is approximately 5×10^7 ft^3/day (see Table 9), which is significantly greater than the actual pumping rate (400,000 ft^3/day) at Jacksonville Beach that apparently is already causing critical or near critical conditions to occur.

A sensitivity analysis was performed by varying the hydraulic parameters. First, the value for K_z / K_r was increased to represent discontinuities that apparently occur in the lower semiconfining unit in the vicinity of the Jacksonville Beach wells, causing saltwater upconing in the middle water-bearing zone. For $K_z / K_r = 1.0$, the critical pumping is approximately 4×10^6 ft^3/day (see Table 9), a value that is smaller than the first estimate for the critical pumping rate but still an order of magnitude greater than the actual pumping rate.

Next, the values used for transmissivity and leakance were re-evaluated based on pumping test results in the Jacksonville area. These values may be more representative of wellfield-scale conditions at Jacksonville Beach than values obtained from SJRWMD's regional ground water flow model. At nearby Fort George Island, for example, transmissivity values for the upper and middle water-bearing zones are nearly equal, or 34,360 and 35,560 ft^2/day, respectively (Environmental Science and Engineering, Inc. 1985). Also, the value of leakance is 7.49×10^{-6} day^{-1} for

Table 8. Input Parameters Used to Calculate Initial Critical Pumping Rate at Well 13

Well	T (ft^2/day)	K'/b' (day^{-1})	r_w (feet)	b (feet)	ℓ/b	d/b	K_z/K_r	α_m
D-483 (no. 13)	680,000	5.0×10^{-7}	0.5	1,600	0.5	0.0	1.0×10^{-6}	1.000
D-484 (no. 12)	680,000	5.0×10^{-7}	700	1,600	0.5	0.0	1.0×10^{-6}	0.043
D-482 (no. 11)	680,000	5.0×10^{-7}	2,150	1,600	0.5	0.0	1.0×10^{-6}	1.629
D-2707 (no. 22)	680,000	5.0×10^{-7}	4,450	1,600	0.3	0.0	1.0×10^{-6}	1.939
D-2747 (no. 21)	680,000	5.0×10^{-7}	5,950	1,600	0.3	0.0	1.0×10^{-6}	0.057
D-3034 (no. 23)	680,000	5.0×10^{-7}	6,900	1,600	0.3	0.0	1.0×10^{-6}	1.877

Table 9. Results of sensitivity analysis at well D-483 (no. 13)

T (ft^2/day)	K'/b' (day^{-1})	(K_z/K_r)	Total Critical Pumping Rate at Six Wells (ft^3/day)
680,000	5.0×10^{-7}	1.0×10^{-6}	5×10^{7}
680,000	5.0×10^{-7}	1.0	4×10^{6}
90,000	7.5×10^{-6}	1.0	9×10^{5}

the upper semiconfining unit and 1.87×10^{-5} day^{-1} for the middle semiconfining unit. Based on these values, values of $T = 90{,}000$ ft^2/day and $K'/b' = 7.49 \times 10^{-6}$ day^{-1} were used in Equations 1 through 3, along with $K_z/K_r = 1.0$ to represent the apparent discontinuities in the lower semiconfining unit at Jacksonville Beach. The resulting critical pumping rate was determined to be 900,000 ft^3/day (see Table 9), a value that is consistent with the actual pumping rate (400,000 ft^3/day) that apparently is beginning to cause salty water to occur in the middle water-bearing zone at Jacksonville Beach.

4.2 Numerical Solution

4.2.1 Wellfield-scale Models

Input and output files for SJRWMD's northeast regional saltwater intrusion model were obtained (Durden, personal communication 1995) to investigate whether the localized upconing observed at Jacksonville Beach could be quantified by developing a model that is subset of SJRWMD's regional model. First, a wellfield-scale model was developed by discretizing aquifer parameters from an area that is a subset of the regional saltwater intrusion model and which represents the Jacksonville Beach wellfield. In this first model, the aquifer parameters were the same as the aquifer parameters in SJRWMD's regional model for corresponding locations. Next, a revised wellfield-scale model was developed by adjusting the aquifer parameters to be more consistent with the parameters used in the analytical model (Table 9) to predict vertical upconing beneath some of the Jacksonville Beach wells.

4.2.2 SIMLAS Code

SJRWMD's regional saltwater intrusion model and the wellfield-scale models developed as part of this investigation use the SIMLAS code developed by HydroGeoLogic, Inc. (Huyakorn et al. 1993). SIMLAS (e.g., a Saltwater-Intrusion Model for Layered Aquifer Systems) simulates simultaneous saltwater and freshwater flows that are separated by a sharp interface, and it can represent both single aquifers and multiple aquifers separated by confining units. Boundary conditions that can be treated include prescribed head and flux conditions, vertical leakages through confining units, and head-dependent fluxes at coastal boundaries. A modified Galerkin finite-element procedure is used to approximate the vertically averaged differential equations for sharp-interface flow in each aquifer layer, and the numerical procedure incorporates an optional upstream weighting of fluid (phase) mobilities and storage matrix lumping for linear rectangular elements. The resulting system of algebraic equations is solved iteratively using a matrix solver.

In SJRWMD's regional saltwater intrusion model and the wellfield-scale models developed in this investigation, the Floridan aquifer system is represented by three layers in the SIMLAS code (see Figure 34). The lower water-bearing zone is represented by layer one, the middle water-bearing zone by layer two, and the upper water-bearing zone by layer three. The surficial aquifer is represented by a constant-head source bed. The lower semiconfining unit for the Floridan aquifer system is represented by a confining unit between layers one and two, the middle semiconfining unit by a confining unit between layers two and three, and the upper confining unit by a confining unit between layer three and the overlying constant-head source bed.

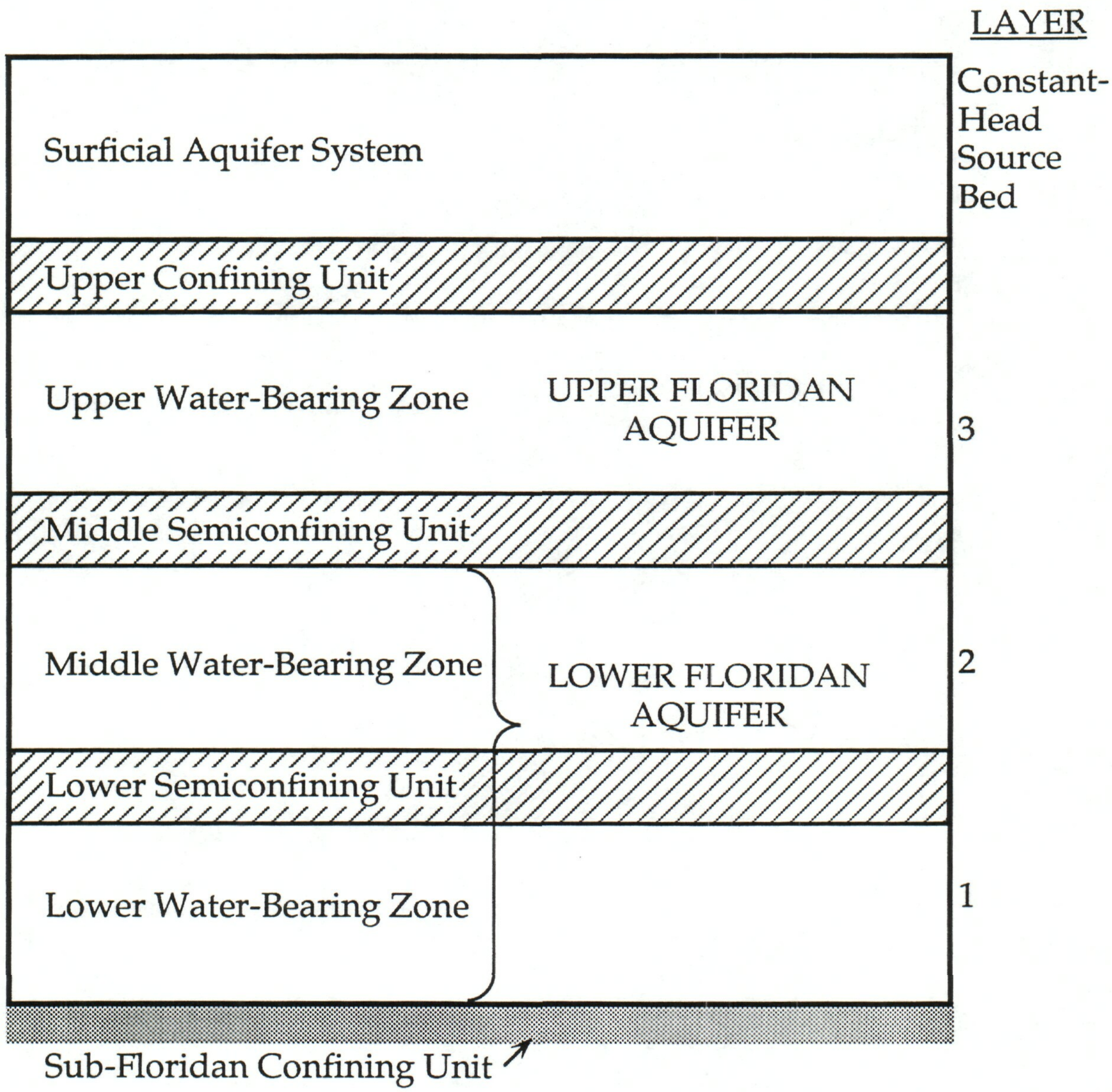


Figure 34. Conceptualization of hydrogeologic system in Jacksonville Beach area

4.2.3 Wellfield-scale Model Using Regional Parameters

The wellfield-scale model was constructed by utilizing the aquifer parameters in the SJRWMD regional saltwater intrusion model. The wellfield-scale model covers an area 5,000 ft by 13,000 ft as a subset of the regional model (see Figure 35). Fifty-three rows and 21 columns of nodes were spaced at regular intervals 250 ft apart. The total number of nodes was 3,339, with 1,113 nodes in each of the three aquifer layers. Parameters in each aquifer layer were obtained for the nodes in the wellfield-scale model by interpolating linearly (using Surfer® for Windows) from the 12 nearest nodes in each layer in the regional saltwater intrusion model to construct a regularly-spaced grid with 53 rows and 21 columns, the intersecting coordinates of which correspond to the locations of the nodes in the wellfield-scale model (see Figure 35).

In the wellfield-scale model, values for the intrinsic permeability in layers one, two, and three are on the order of 0.7×10^{-10} ft^2, 0.6×10^{-8} ft^2, and 0.3×10^{-9} ft^2, respectively, based on the values interpolated from SJRWMD's regional saltwater intrusion model. In the confining units, values for vertical intrinsic permeability divided by confining unit thickness are on the order of 0.3×10^{-16} ft between layers one and two, 0.3×10^{-16} ft between layers two and three, and 0.2×10^{-17} ft between layer three and the overlying constant-head source bed. The corresponding transmissivities in layers one, two, and three are on the order of 20,000 ft^2/day, 660,000 ft^2/day, and 40,000 ft^2/day, respectively, and leakance (K'/b', e.g., vertical hydraulic conductivity divided by thickness) is on the order of 7.0×10^{-6} day^{-1} between layers one and two, 8.0×10^{-6} day^{-1} between

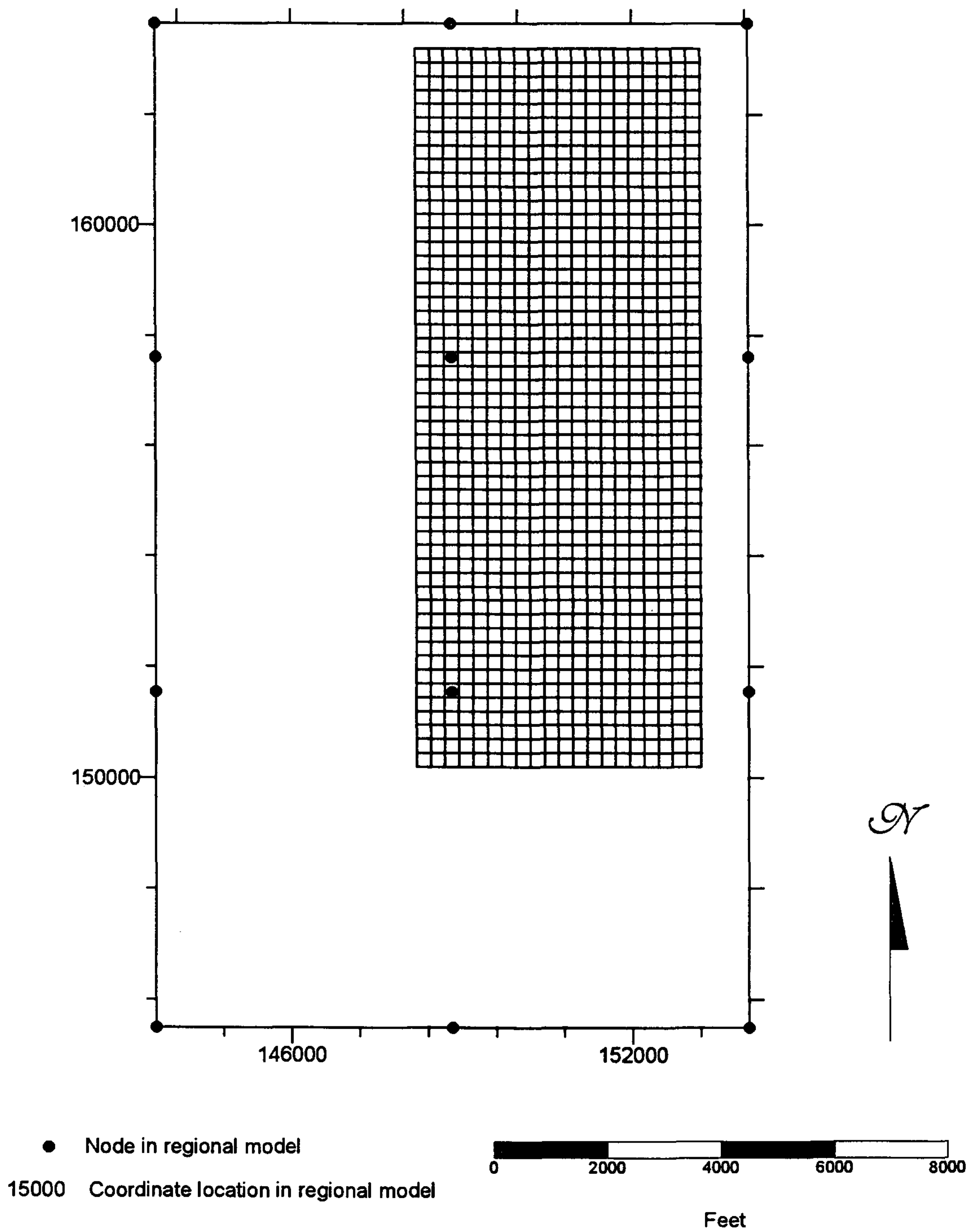


Figure 35. Discretization of Jacksonville Beach wellfield-scale model area

layers two and three, and 5.0×10^{-7} day^{-1} between layer three and the overlying constant-head source bed.

In SJRWMD's regional saltwater intrusion model, pumping from the Jacksonville Beach wells is represented by pumping from four nodes. In the wellfield-scale model, the pumping occurs at nine nodes that represent the six production wells. Pumping from the deeper wells [D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13)] is from three nodes (nodes 2046, 1943, and 1881, respectively) in layer two and from three nodes (nodes 3159, 3056, and 2994) at the same coordinate locations in overlying layer three, and pumping from the shallower wells [D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23)] is from three other nodes (nodes 2527, 2633, and 2423) in layer three. The pumping rates used for the wells in the model are the actual 1993 pumping rates, which total 3.21 mgd (based on Figure 21), or 8.33×10^5 slugs/day in the mass and time units used in SIMLAS. The distribution of pumping at each of the three deeper wells between layers two and three was assumed to be the same as the distribution used in SJRWMD's regional saltwater intrusion model.

The nodes around all three layers in the wellfield-scale model were designated as general-head boundaries. Head values for the distant fixed-head nodes were obtained from the output file of SJRWMD's regional saltwater intrusion model. The values were obtained by extrapolating north, south, east, and west from the location of the wellfield-scale model boundary nodes to nodes that were approximately 50,000 to 110,000 ft from the wellfield-scale model. The distances were selected so that the distant nodes were unaffected by pumping in the smaller area that was being modeled but also so that the distant nodes had the same saltwater-freshwater boundary characteristics as the boundary nodes in the wellfield-scale model. This resulted in assigning both saltwater and freshwater heads to the general-head boundaries in layer one, because a saltwater-freshwater interface occurs on the regional scale in layer one, but only assigning freshwater heads to the general-head boundaries in layers two and three, because there is no interface in these layers on a regional scale within the model area. Starting values for lumped conductance, which is the product of the intrinsic permeability and the cross-sectional area at the general-head boundary node through which flow is occurring divided by the distance from the fixed-head node to the general-head boundary node, were estimated from the regional model parameters.

The wellfield-scale model was calibrated by matching the freshwater piezometric heads in layers one, two, and three and the saltwater-freshwater interface location in layer one that had been calculated by SJRWMD's regional saltwater intrusion model for present-day conditions. The calibration was achieved by adjusting the lumped conductance terms at the general-head boundaries. The intrinsic permeabilities, leakances, and pumping distributions were not changed during the calibration runs. By comparing the regional model and wellfield-scale model results, it can be seen that very good matches were obtained for the freshwater heads in all three layers and the interface location in layer one (see Figures 36 through 39). Differences in the locations and numbers of the pumping well nodes in the regional and wellfield-scale models probably account for most of the remaining differences between the freshwater heads in layers two and three in the two models.

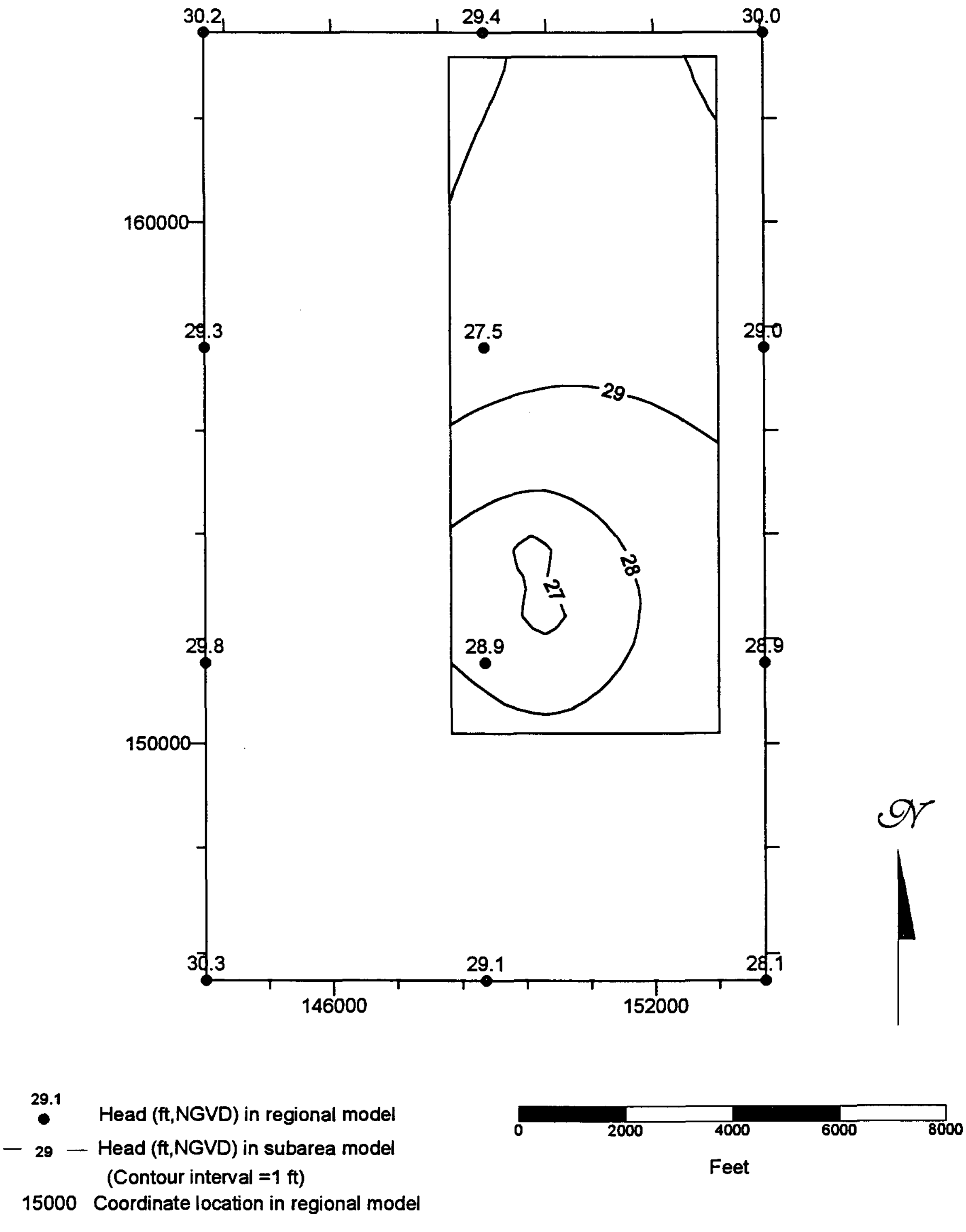


Figure 36. Calculated freshwater heads in layer three in SJRWMD regional saltwater intrusion model and Jacksonville Beach subarea model

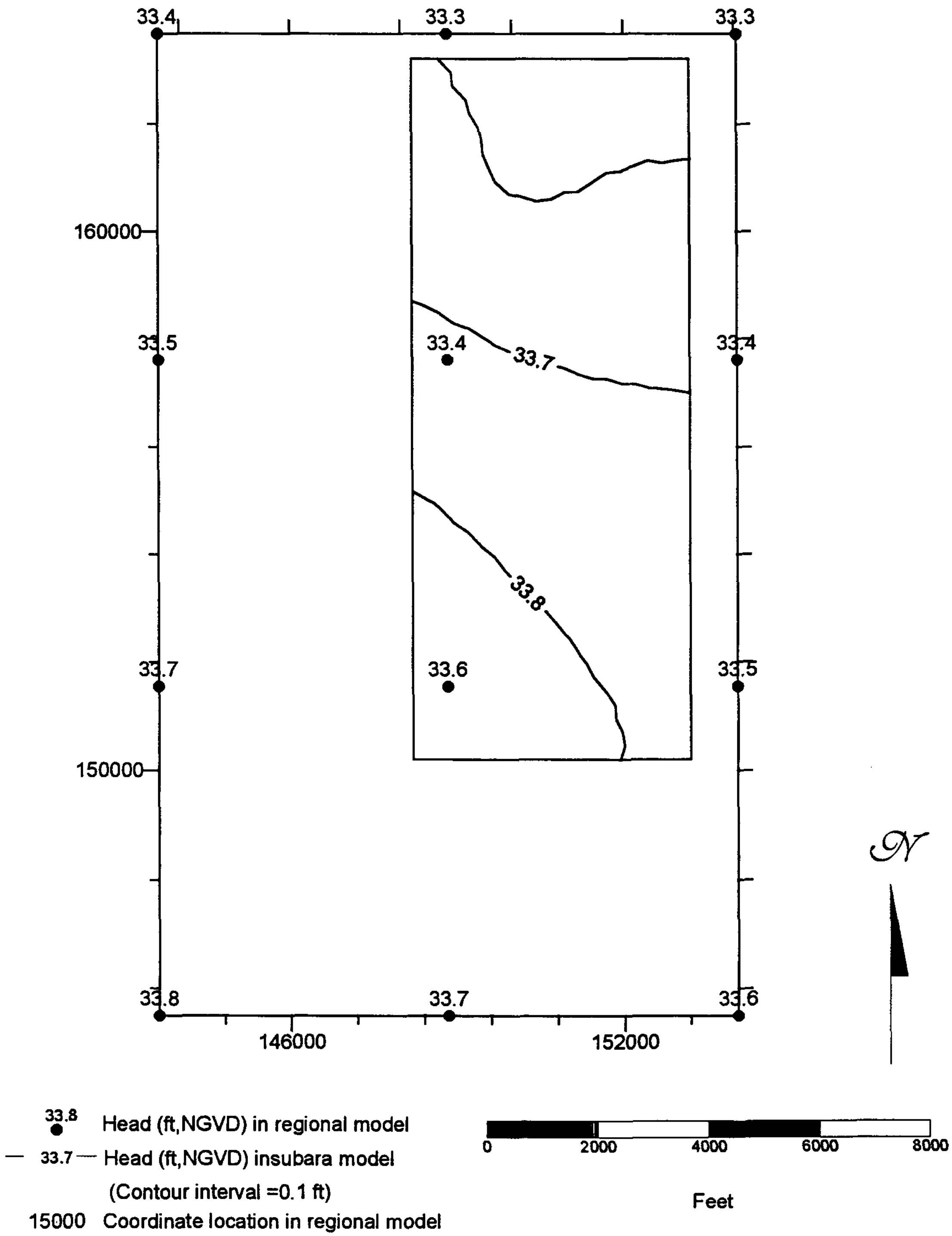


Figure 37. Calculated freshwater heads in layer two in SJRWMD regional saltwater intrusion model and Jacksonville Beach subarea model

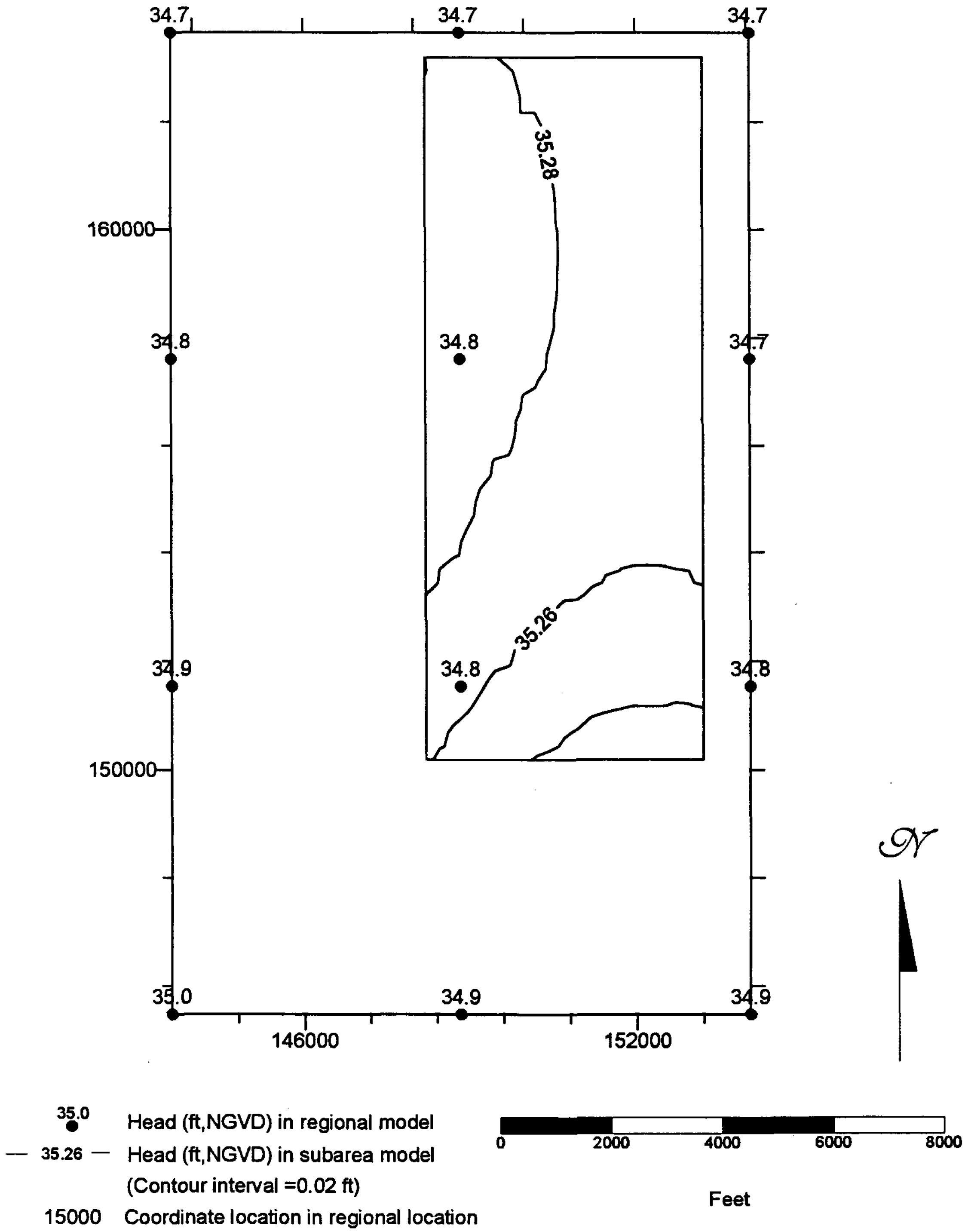


Figure 38. Calculated freshwater heads in layer one in SJRWMD regional saltwater intrusion model and Jacksonville Beach subarea model

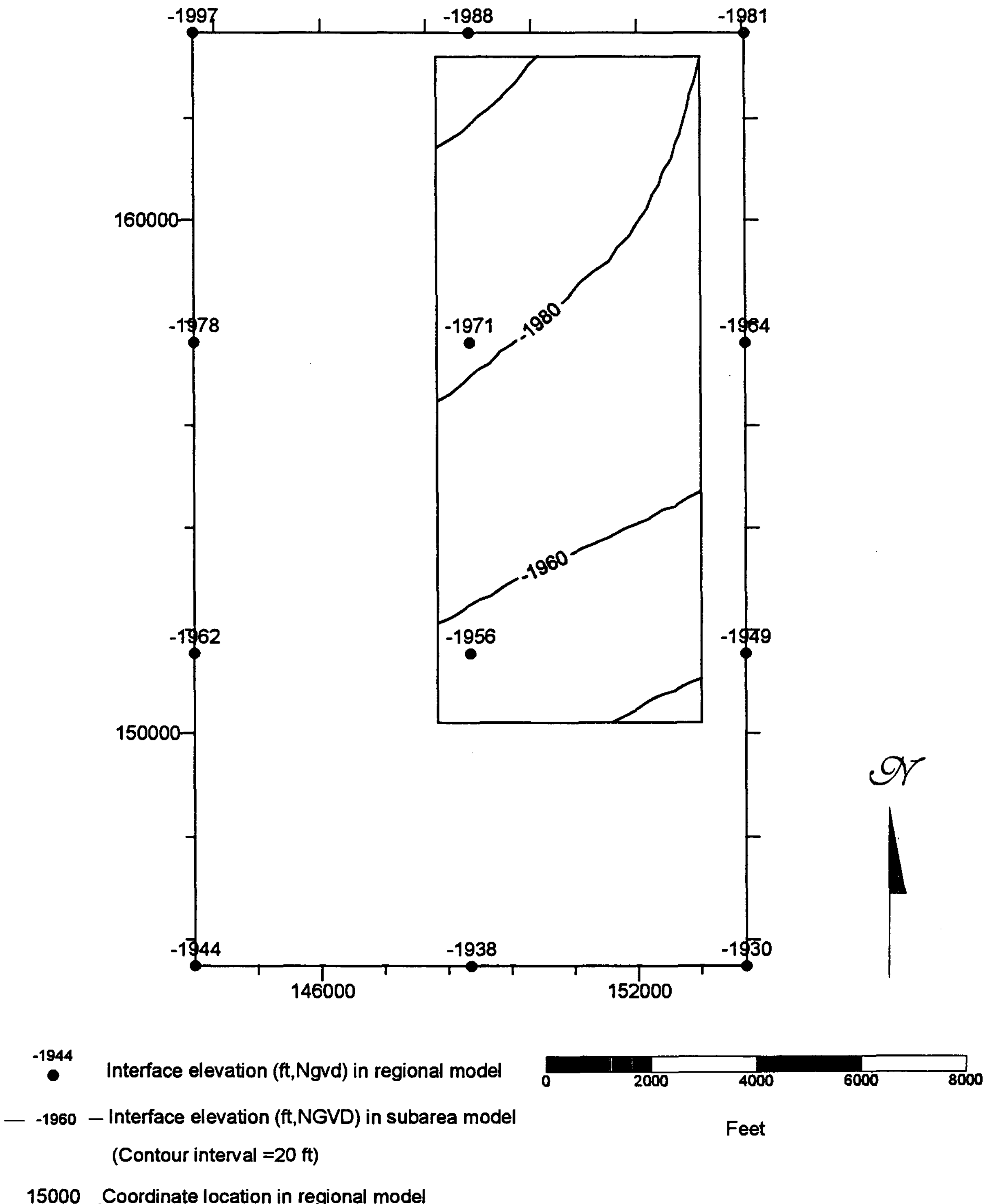


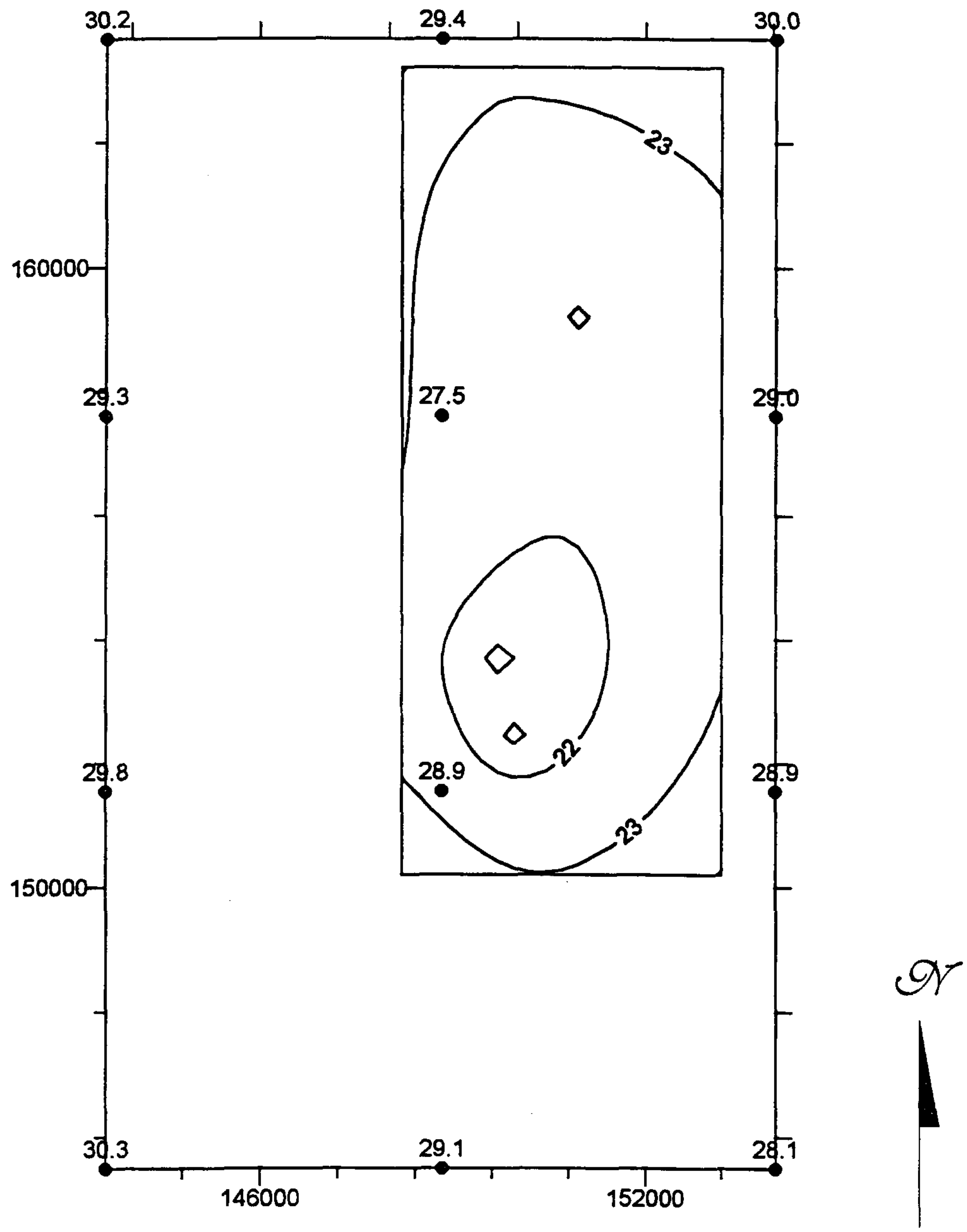
Figure 39. Calculated saltwater-freshwater interface in layer one in SJRWMD regional saltwater intrusion model and Jacksonville Beach subarea model

4.2.4 Revised Wellfield-scale Model

In the wellfield-scale model, the aquifer parameters were the same as the aquifer parameters in SJRWMD's regional saltwater intrusion model for corresponding locations, and the freshwater heads and saltwater-freshwater interface location were in close agreement (Figures 36 through 39). However, the results from these models did not match the localized upconing in layer two that has been observed in the Jacksonville Beach wellfield. Accordingly, the wellfield-scale model was revised by adjusting the aquifer parameters to be more consistent with the analytical model results that predicted upconing could occur beneath the Jacksonville Beach wells in the middle water-bearing zone. Pumping from the Jacksonville Beach wells in the revised wellfield-scale model was the same as in the wellfield-scale model, e.g., pumping occurs from nine nodes that represent the six production wells. A number of runs were made in which aquifer parameters were adjusted to cause a saltwater-freshwater interface to occur in layer two beneath the nodes that represent the Jacksonville Beach wells.

In the revised wellfield-scale model, final values for the intrinsic permeability in layers one, two, and three are on the order of 0.15×10^{-9} ft^2, 0.4×10^{-9} ft^2, and 0.3×10^{-9} ft^2, respectively. In the confining units, final values for vertical intrinsic permeability divided by thickness are on the order of 0.3×10^{-13} ft between layers one and two, 0.3×10^{-13} ft between layers two and three, and 0.5×10^{-14} ft between layer three and the overlying constant-head source bed. The corresponding transmissivities in layers one, two, and three are all on the order of 40,000 ft^2/day, and leakance is on the order of 7.0×10^{-3} day^{-1} between layers one and two, 8.0×10^{-3} day^{-1} between layers two and three, and 1.3×10^{-3} day^{-1} between layer three and the overlying constant-head source bed. The values for lumped conductance in the revised wellfield-scale model along the general head boundaries range approximately from 0.1×10^{-9} to 0.4×10^{-8} ft^3.

In the revised wellfield-scale model, the freshwater heads in layers three and two are generally consistent with, but lower than, the corresponding freshwater heads in SJRWMD's regional model (see Figures 40 and 41). Part of the reason for this is because the leakance of the upper confining unit between layer three and the constant-head source bed in the revised wellfield-scale model, which represents the localized wellfield area, is larger than the corresponding leakance in the regional saltwater intrusion model, which is calibrated over a much larger area. The area represented is a discharge area, and, thus, greater discharge occurs vertically upward and lower heads result in layers two and three due to the greater leakance of the upper confining unit in the revised wellfield-scale model. Also, pumping effects in the revised wellfield-scale model are more localized than in the regional model, which probably results in greater drawdowns and lower heads in the wellfield area in the revised model. In the revised wellfield-scale model, saltwater completely occupies layer one, a saltwater-freshwater interface occurs in layer two, and freshwater occupies layer three (see Figures 42 and 43). The interface in layer two in the revised model occurs at the bottom of the production wells in layer two, which is consistent with the chloride increases that have been observed in the deep wells in the Jacksonville Beach wellfield.



30.3
● Head (ft,NGVD) in regional model

— 23 — Head (ft,NGVD) in revised subarea model
(Contour interval =1 ft)

15000 Coordinate location in regional model

0 2000 4000 6000 8000
Feet

Figure 40. Calculated freshwater heads in layer three in SJRWMD regional saltwater intrusion model and revised Jacksonville Beach subarea model

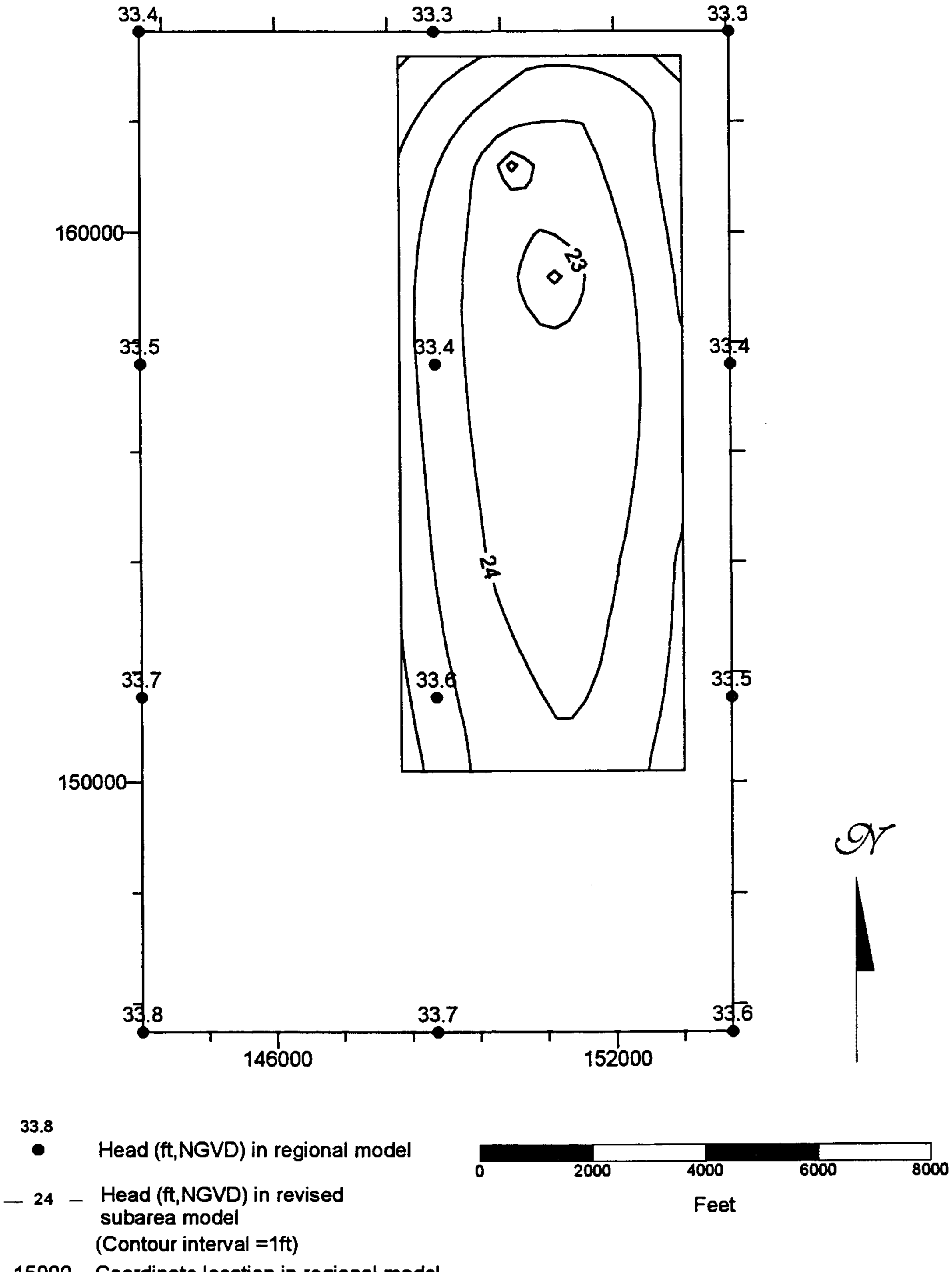
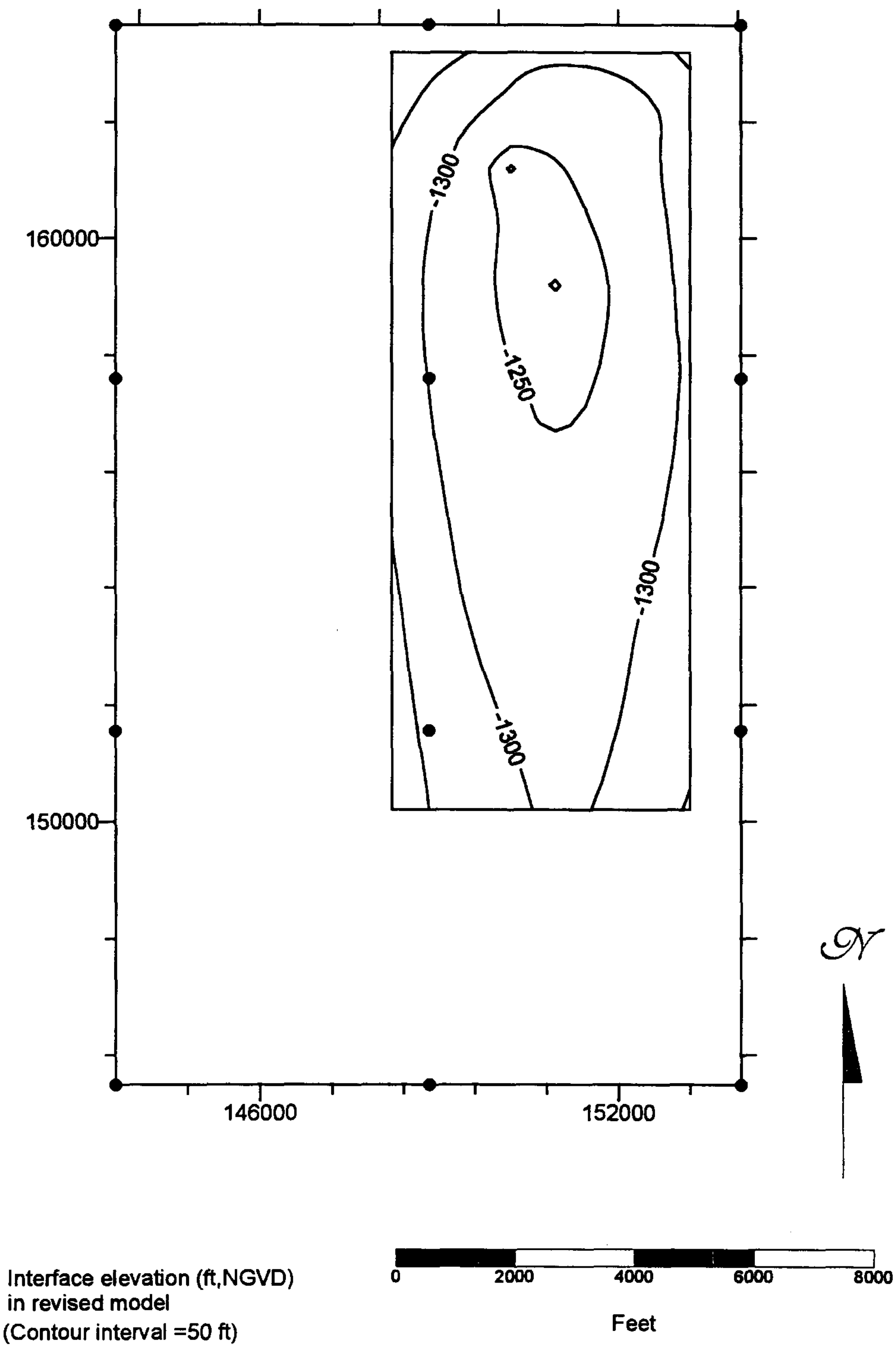


Figure 41. Calculated freshwater heads in layer two in SJRWMD regional saltwater intrusion model and revised Jacksonville Beach subarea model



— -1250 — Interface elevation (ft,NGVD) in revised model (Contour interval =50 ft)

15000 Coordinate location in regional model

Figure 42. Calculated saltwater-freshwater interface in layer two in the revised Jacksonville Beach subarea model

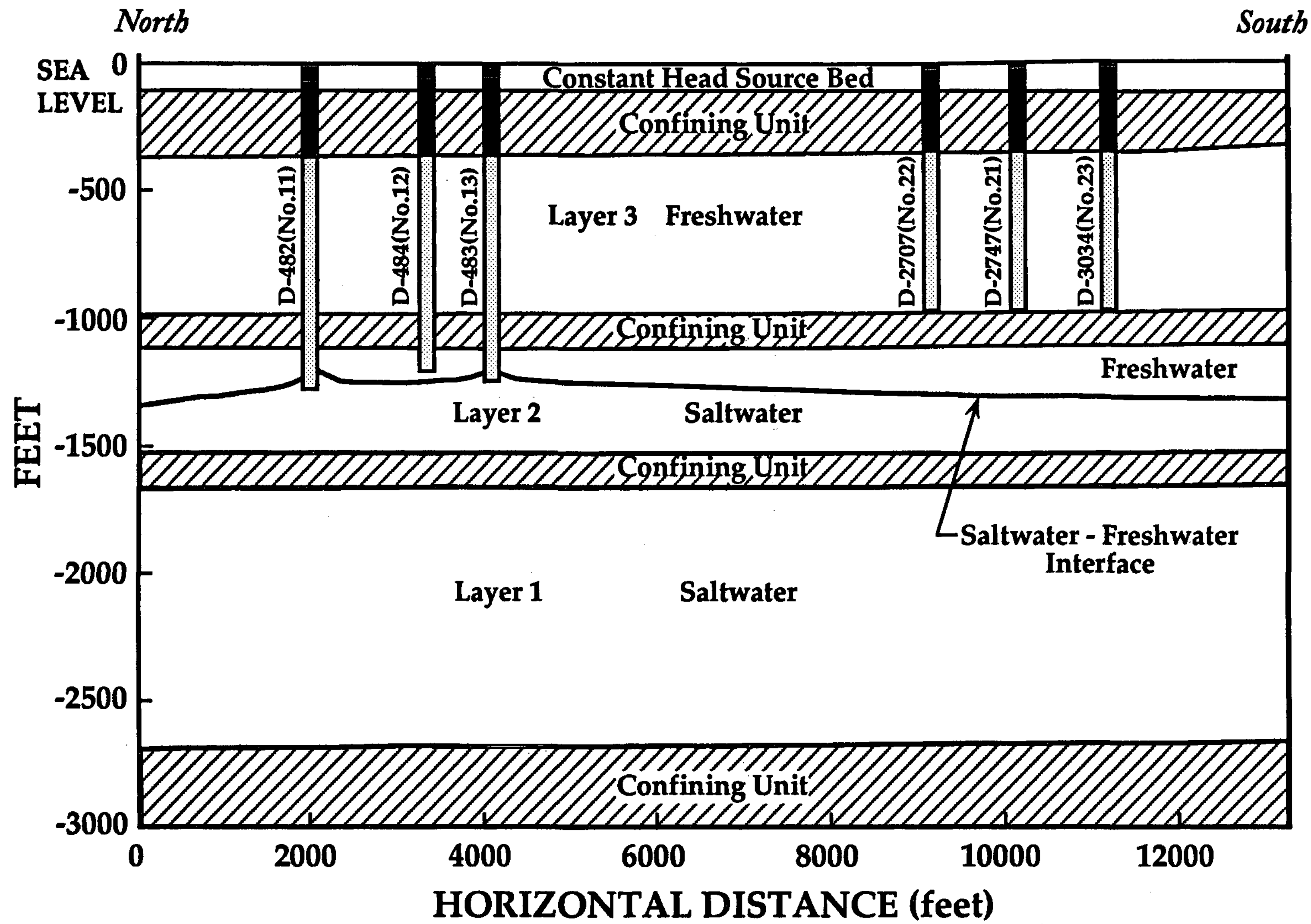


Figure 43. **Calculated saltwater-freshwater interface in cross-section through Jacksonville Beach well-field under present pumping conditions (see Figure 18 for locations of wells in cross-section)**

5.0 LOCATIONS AND PUMPING RATES FOR JACKSONVILLE BEACH WELLS

5.1 ANALYTICAL SOLUTION

The analytical model was used to investigate the hypothesis that an increased pumping rate could be achieved by pumping from only the upper water-bearing zone to avoid the upconing that apparently is occurring in the middle water-bearing zone. The aquifer parameters resulting from the sensitivity analysis were used (Table 9), and the depths of penetration of the three deeper wells [D-482(no. 11), D-484(no. 12), and D-483(no. 13)] were reduced from $\ell/b = 0.5$ to 0.3 to represent plugging these wells in the middle water-bearing zone. With these parameters (see Table 10), a critical pumping rate of 1.3×10^6 ft^3/day was calculated using Equations 1 through 3. This value is approximately 40 percent greater than the critical pumping rate of 900,000 ft^3/day calculated for the case that represents the existing condition of pumping from both the upper and middle water-bearing zones (section 4.1). In both of these calculations, it was assumed that $K_z/K_r = 1.0$, or that the middle and lower semiconfining units are not effective in retarding vertical upconing. This assumption probably is reasonable for the lower semiconfining unit because this is consistent with the occurrence of salty water in the middle water-bearing zone. However, it may be too conservative for the middle semiconfining unit since apparently no saltwater upconing has been observed to date in this zone in the Jacksonville Beach wellfield. Also, it is clearly an

Table 10. Input parameters used to calculate critical pumping rate with all pumping from the upper water-bearing zone

Well	T (ft^2/day)	K'/b' (day^{-1})	r_w (feet)	b (feet)	ℓ/b	d/b	K_z/K_r	α_m
D-483 (no. 13)	90,000	7.5×10^{-6}	0.5	1,600	0.3	0.0	1.0	1.000
D-484 (no. 12)	90,000	7.5×10^{-6}	700	1,600	0.3	0.0	1.0	0.043
D-482 (no. 11)	90,000	7.5×10^{-6}	2,150	1,600	0.3	0.0	1.0	1.629
D-2707 (no. 22)	90,000	7.5×10^{-6}	4,450	1,600	0.3	0.0	1.0	1.939
D-2747 (no. 21)	90,000	7.5×10^{-6}	5,950	1,600	0.3	0.0	1.0	0.057
D-3034 (no. 23)	90,000	7.5×10^{-6}	6,900	1,600	0.3	0.0	1.0	1.877

assumption that the same amount of pumping can be achieved from wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) after plugging the middle water-bearing zone.

In another set of calculations based on Equations 1 through 3, it was assumed that all of the pumping occurred from the upper water-bearing zone and that the pumping was distributed equally among the six wells, or that all of the α_m's = 1.0 (see Table 11). The results of these calculations indicated that the critical pumping rate would increase to 1.2×10^6 ft^3/day under these conditions, an increase of about 35 percent, which is consistent with the results of the first set of calculations.

5.2 NUMERICAL SOLUTION

The revised wellfield-scale model (Section 4.2.2) also was utilized to investigate the effects of pumping from only the upper water-bearing zone. It was assumed that the pumping rates at Jacksonville Beach wells were equal to the actual 1993 pumping rates, or 3.21 mgd (4.29×10^5 ft^3/day), and that pumping from wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) occurred only from the upper water-bearing zone. The results indicate that the saltwater-freshwater interface will remain in layer two under this scenario (see Figure 44).

5.3 CONCLUSIONS AND RECOMMENDATIONS

Chloride concentrations in wells in the Jacksonville Beach wellfield and the results of the analytical and numerical modeling conducted as part of this investigation indicate that salty water

Table 11. Input parameters used to calculate critical pumping rate with all pumping from the upper-water bearing zone (α_m's = 1.0)

Well	T (ft^2/day)	K'/b' (day^{-1})	r_w (feet)	b (feet)	ℓ/b	d/b	K_z/K_r	α_m
D-483 (no. 13)	90,000	7.5×10^{-6}	0.5	1,600	0.3	0.0	1.0	1.000
D-484 (no. 12)	90,000	7.5×10^{-6}	700	1,600	0.3	0.0	1.0	1.000
D-482 (no. 11)	90,000	7.5×10^{-6}	2,150	1,600	0.3	0.0	1.0	1.000
D-2707 (no. 22)	90,000	7.5×10^{-6}	4,450	1,600	0.3	0.0	1.0	1.000
D-2747 (no. 21)	90,000	7.5×10^{-6}	5,950	1,600	0.3	0.0	1.0	1.000
D-3034 (no. 23)	90,000	7.5×10^{-6}	6,900	1,600	0.3	0.0	1.0	1.000

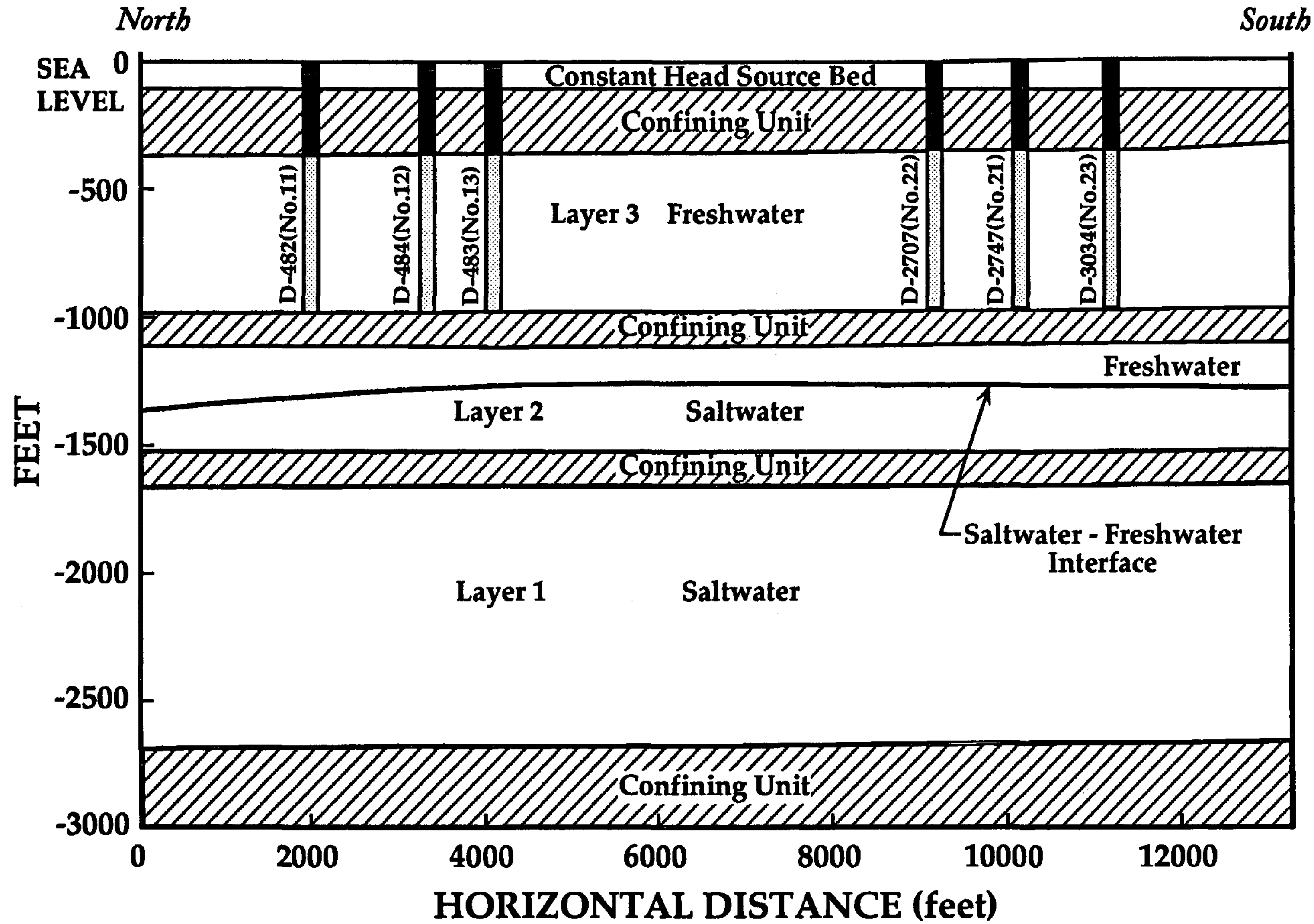


Figure 44. **Calculated saltwater-freshwater interface in cross-section through Jacksonville Beach wellfield with pumping only from the upper water-bearing zone (see Figure 18 for locations of wells in cross-section)**

is present in the in the middle water-bearing zone of the Floridan aquifer system in the vicinity of the Jacksonville Beach wellfield. Vertical upconing from the lower water-bearing zone through faults, fractures, or other conduits is the most likely mechanism by which the salty water is reaching the middle water-bearing zone. In the Jacksonville Beach wellfield, chloride concentrations are lowest in wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23), which are open only to the upper water-bearing zone, and highest in wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13), which are open to both the upper and middle water-baring zones. The chloride concentration in well D-484 (no. 12) is particularly high compared to the other wells (see Figures 23-28). The results of the analytical and numerical modeling also indicate that increased pumping rates can be achieved, relative to the upconing, by pumping only from the upper water-bearing zone.

Several options could be pursued to achieve the goal of pumping only from the upper water-bearing zone. One option, plugging existing wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) so that they pump water only from the upper water-bearing zone, does not appear to be practical, however. This is because the relatively small diameters (12 inches, see Table 4) of the casings of these wells would make it difficult to install down-hole pumps of sufficient capacity, based on the 16-inch casing diameters and larger capacity pumps that presently are installed in wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23). Also, the results of the geophysical logs run by the USGS and SJRWMD (see Appendix A) indicate that most of the water obtained from wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) comes from near the bottoms of these wells; significant reductions in flow could occur if the middle water-bearing zone were plugged in these wells.

Another option would be to abandon the existing deep wells and drill new wells that are open only to the upper water-bearing zone. One additional location for a new well is the area between existing wells D-483 (no. 13) and D-2707 (no. 22) or west of this area (see Figure 18). Additional locations are the areas west and northwest of the existing wells D-482 (no. 11), D-484 (no. 12), and D-483 (no. 13) as thee wells are phased out of production in response to increasing chloride concentrations. Among other factors, specific locations should be selected so that the drawdown interference between new wells and remaining existing wells is kept to a practical minimum. The construction specifications for new wells should be similar to wells D-2747 (no. 21), D-2707 (no. 22), and D-3034 (no. 23), which have 16-inch diameter casings and down-hole turbine pumps, and which are cased to approximately 400 feet and drilled open hole to about 900 feet (see Table 4 and Figure 19).

If wells D-482 (no. 11), D-484 (no. 12) and D-483 (no. 13) are abandoned, the potential will exist for salty water to move upward from the middle water-bearing zone into the upper water-bearing zone through the open boreholes, particularly at well D-484 (no. 12). Thus, if thee wells are abandoned, they should be grouted back to land surface so that both the middle and upper water-bearing zones in these wells are plugged.

An alternative to abandoning and plugging all three deep wells at the same time would be to abandon and initially plug well D-484 (no. 12), which has the worst water quality, and then abandon and plug wells D-482 (no. 11) and D-483 (no. 13) if this becomes necessary. If it is decided to use well D-484 (no. 12) as a long-term monitor well so that the USGS can continue to measure chloride concentrations in the middle water-bearing zone at this location, an inner casing should be installed and grouted back to land surface so that only the middle water-bearing zone is open to prevent movement of salty water into the upper water-bearing zone at this well.

Based on this investigation, pumping from only the upper water-bearing zone in the vicinity of the Jacksonville Beach wellfield appears to be the best solution to the problem of high chlorides in some of the wells open to the middle water-bearing zone. It must be clearly understood, however, that this may not be a permanent solution but that chloride concentrations could begin to increase in the future in the upper water-bearing zone in this area.

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APPENDIX A - GEOPHYSICAL LOGS

United States Department of the Interior

GEOLOGICAL SURVEY

WATER RESOURCES DIVISION
224 West Central Parkway, Suite 1006
Altamonte Springs, Florida 32714
(407) 865-7575

March 29,1995

Mr. John L. Birch
City of Jacksonville Beach
11 North 3rd Street
Jacksonville Beach Florida 32250

Dear John:

Enclosed are copies of the geophysical logs we recently ran in the wells at Jacksonville Beach and Atlantic Beach, along with our preliminary summary of important information for each well. We greatly appreciate your help during the logging effort and are confident that the information obtained will be as useful to you as it is to our efforts to gain a better understanding of the Floridan aquifer system in northeast Florida. The interpretations are preliminary and may be subject to revision. If you have any questions or need more information, please contact me or Rick Spechler. Again, thanks very much for your help.

Sincerely,

Trudy G. Phelps

Trudy G. Phelps, P.G.
Hydrologist

APR 03 1995

WELL D-484 SITE ID 301704081233401
4th St. and 4th Ave., Jacksonville Beach

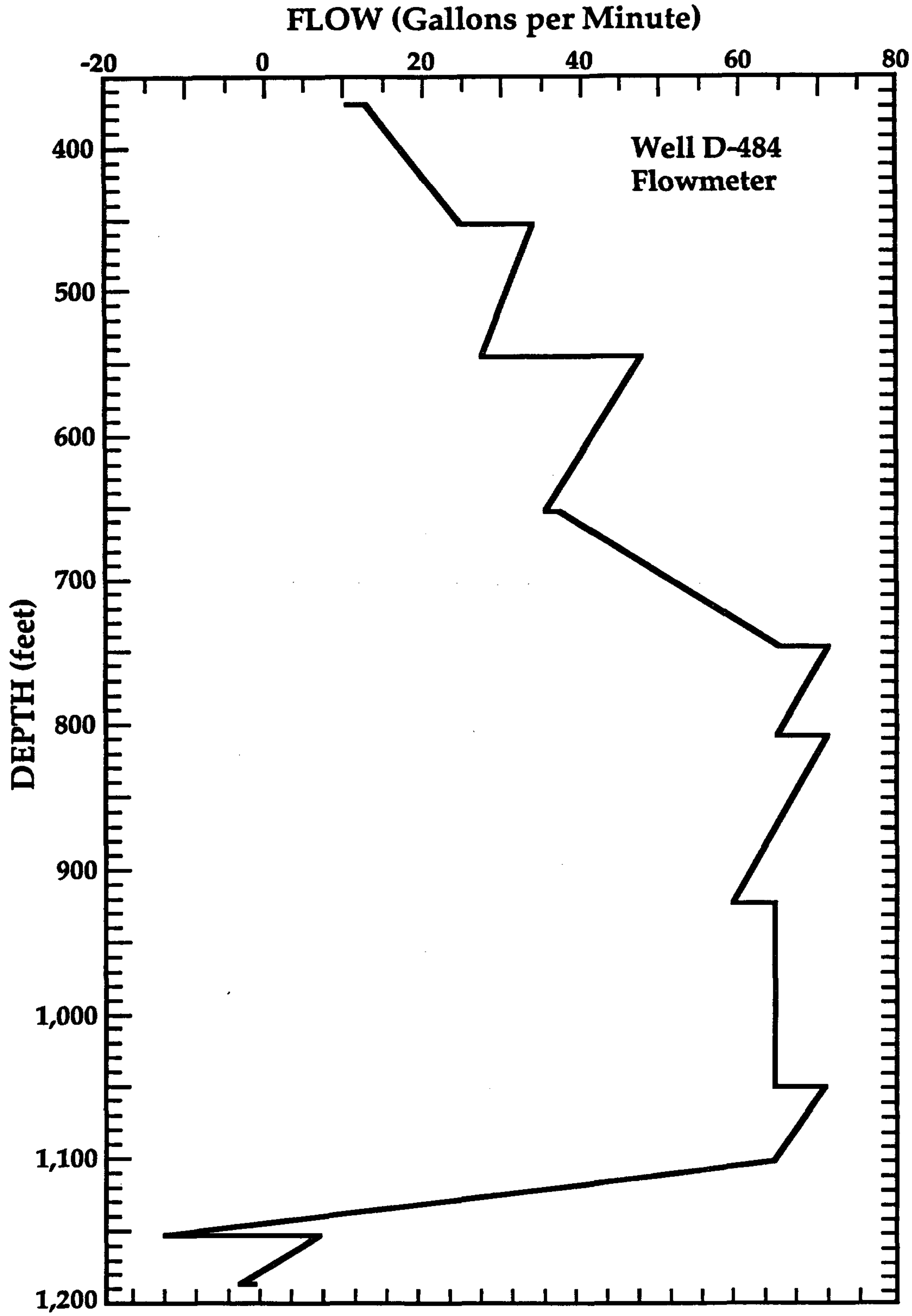
February 13-14, 1995
U.S. Geological Survey Southeast Region Logger

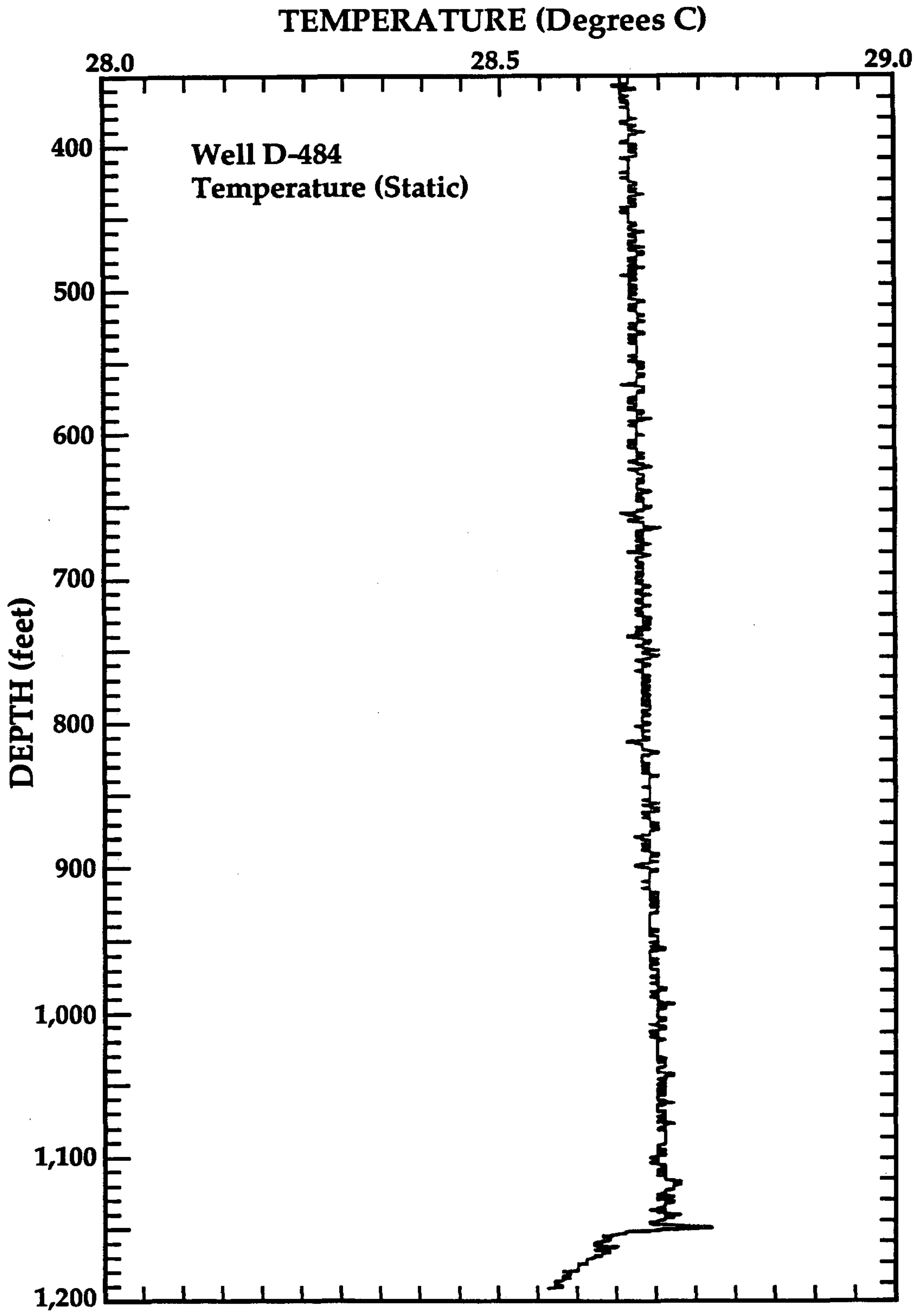
Logs of this well show that most of the flow from the well enters from one or two fractures at a depth of 1,140 to 1,151 ft below land surface. Under static conditions (and probably also under pumping conditions) water flows out into the formation near the bottom of the casing. A measured flow of about 18 gal/min when the well was shut-in could indicate a leak near the top of the casing or in the valve at the wellhead.

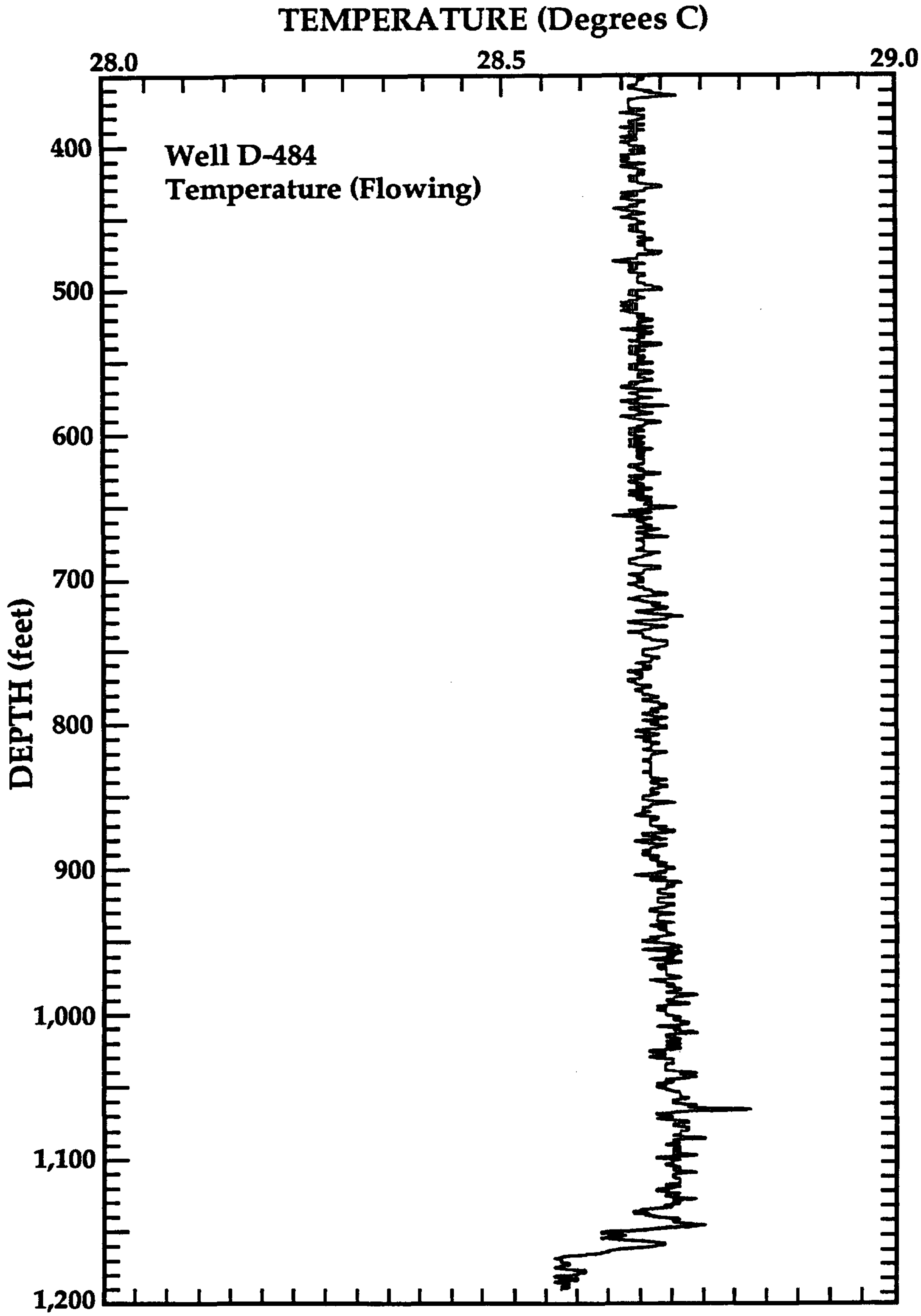
Temperature and fluid resistivity logs indicate that the source of salty water is one or both of the fractures near the bottom of the well, at a depth of about 1,140 to 1,151 ft. Water samples were taken at the wellhead and at 1,138 ft. The specific conductance of the wellhead sample and the sample from 1,138 ft were the same, 1,250 microSiemens/cm at 25 deg C., which also indicates that nearly all of the flow in the well comes from the fractures near the bottom of the well.

The fractures also show up well on the caliper and sonic televiewer logs. On the sonic televiewer, very dark areas mean that no signal was returned to the tool and indicate the presence of a void or fracture. Areas that are very light on the televiewer are very dense rock. The televiewer sequence from about 823 to 860 ft shows the alternating of very dense rock with fractures that is characteristic of the Avon Park Formation. The fractures at 1,139 and 1,151 also show up clearly on the sonic televiewer log.

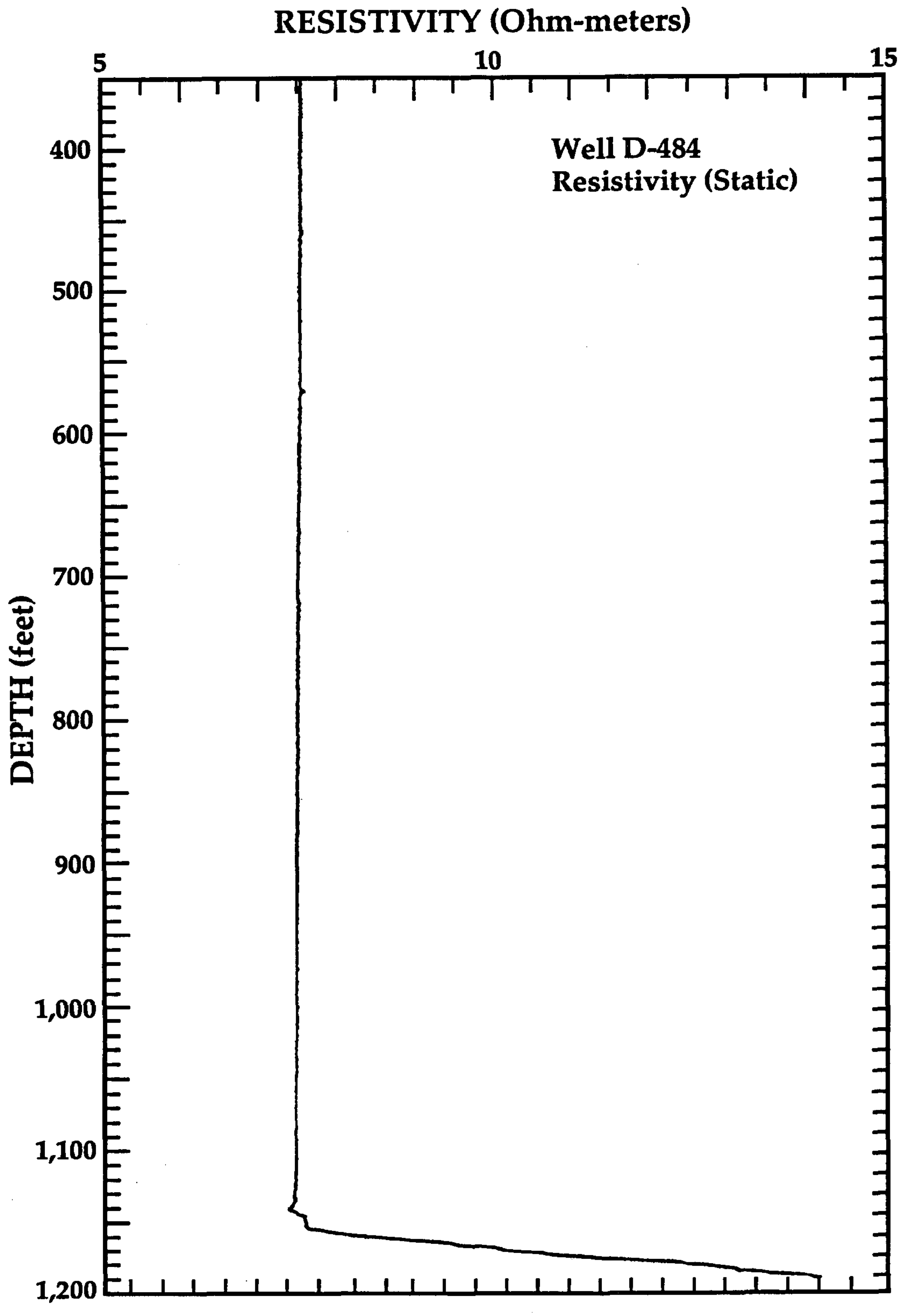
Heat pulse flowmeter logs are run when the well is shut in. The heat pulse flowmeter log for this well shows the importance of the fractures near the bottom of the well. When the flow in gallons per minute is a relatively large number, most of the flow is flowing in the borehole, indicating a relatively tight formation. When the number is smaller, the formation is more permeable and water is flowing from the borehole out into the formation. The fact that the flow is greater deeper in the well and becomes less toward the top indicates that most of the flow enters the well near the bottom and flow out into the formation is occurring above about 650 ft. The negative flow values at a depth of 1,153 are attributed to the effect of the pump in another nearby well being turned on while the data were being collected. Because of possible change in the borehole diameter, the flow rates shown on the heat pulse flow meter log may not be exact, but must be corrected for the diameter of the wellbore.


FLOW (Gallons per Minute)
-20
0
20
40
60
80
Well D-484
Flowmeter
400
500
600
700
800
900
1,000
1,100
1,200
DEPTH (feet)

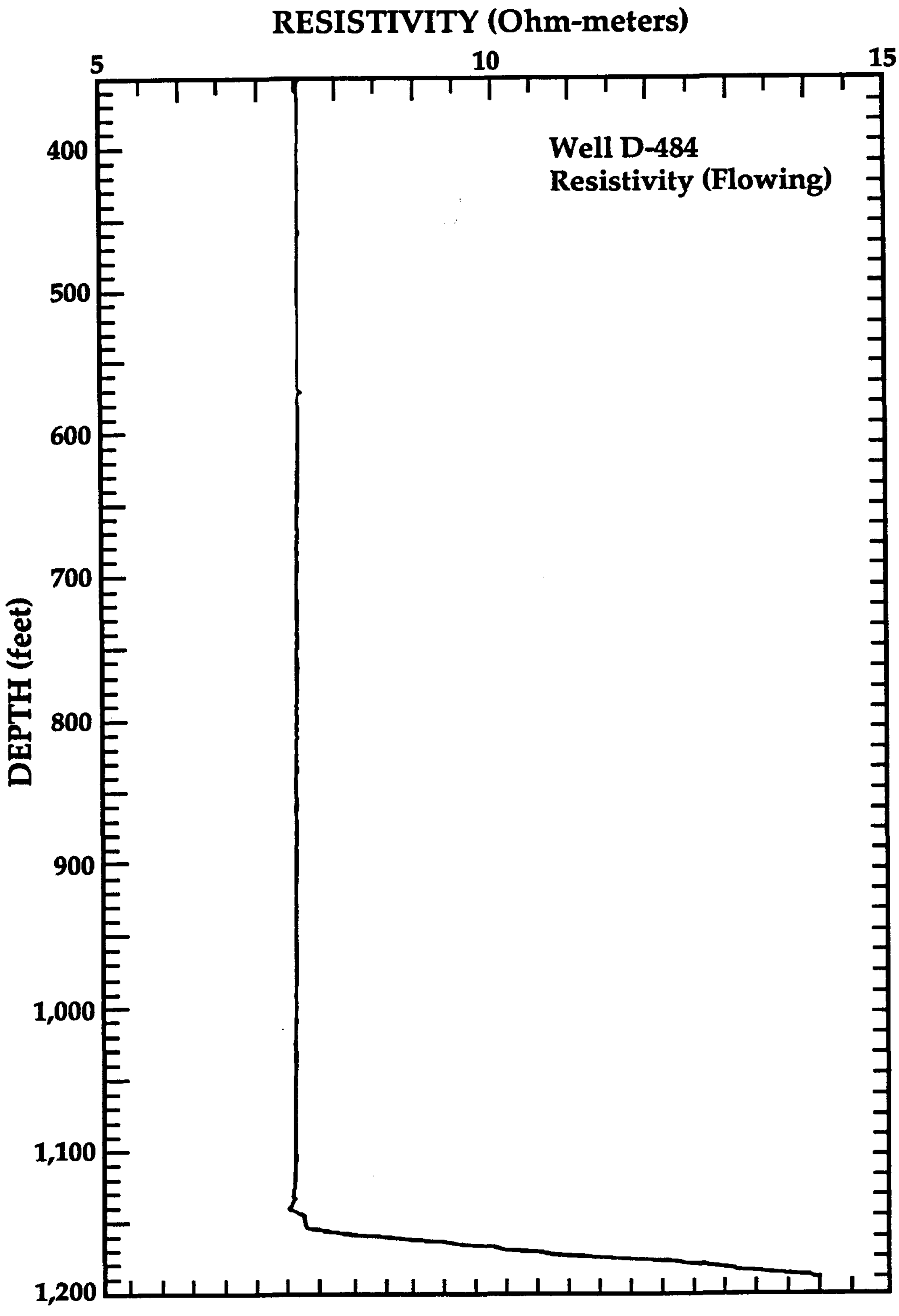

TEMPERATURE (Degrees C)
28.0
28.5
29.0
Well D-484
Temperature (Static)
400
500
600
700
800
900
1,000
1,100
1,200
DEPTH (feet)

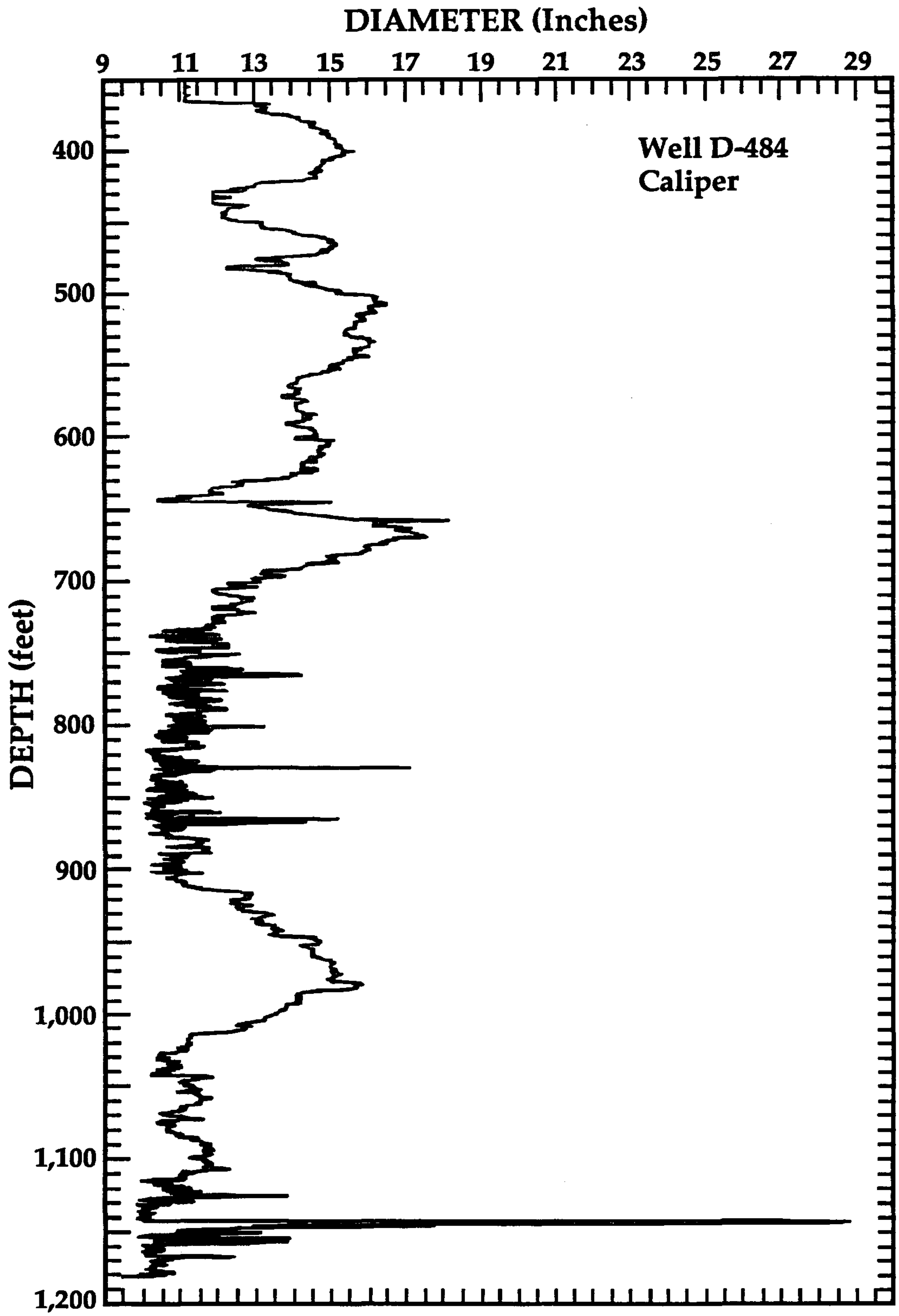


TEMPERATURE (Degrees C)
28.0
28.5
29.0
Well D-484
Temperature (Flowing)
DEPTH (feet)
400
500
600
700
800
900
1,000
1,100
1,200



RESISTIVITY (Ohm-meters)
5
10
15
Well D-484
Resistivity (Static)
DEPTH (feet)
400
500
600
700
800
900
1,000
1,100
1,200


RESISTIVITY (Ohm-meters)
5
10
15
Well D-484
Resistivity (Flowing)
DEPTH (feet)
400
500
600
700
800
900
1,000
1,100
1,200


DIAMETER (Inches)
9
11
13
15
17
19
21
23
25
27
29
Well D-484
Caliper
DEPTH (feet)
400
500
600
700
800
900
1,000
1,100
1,200

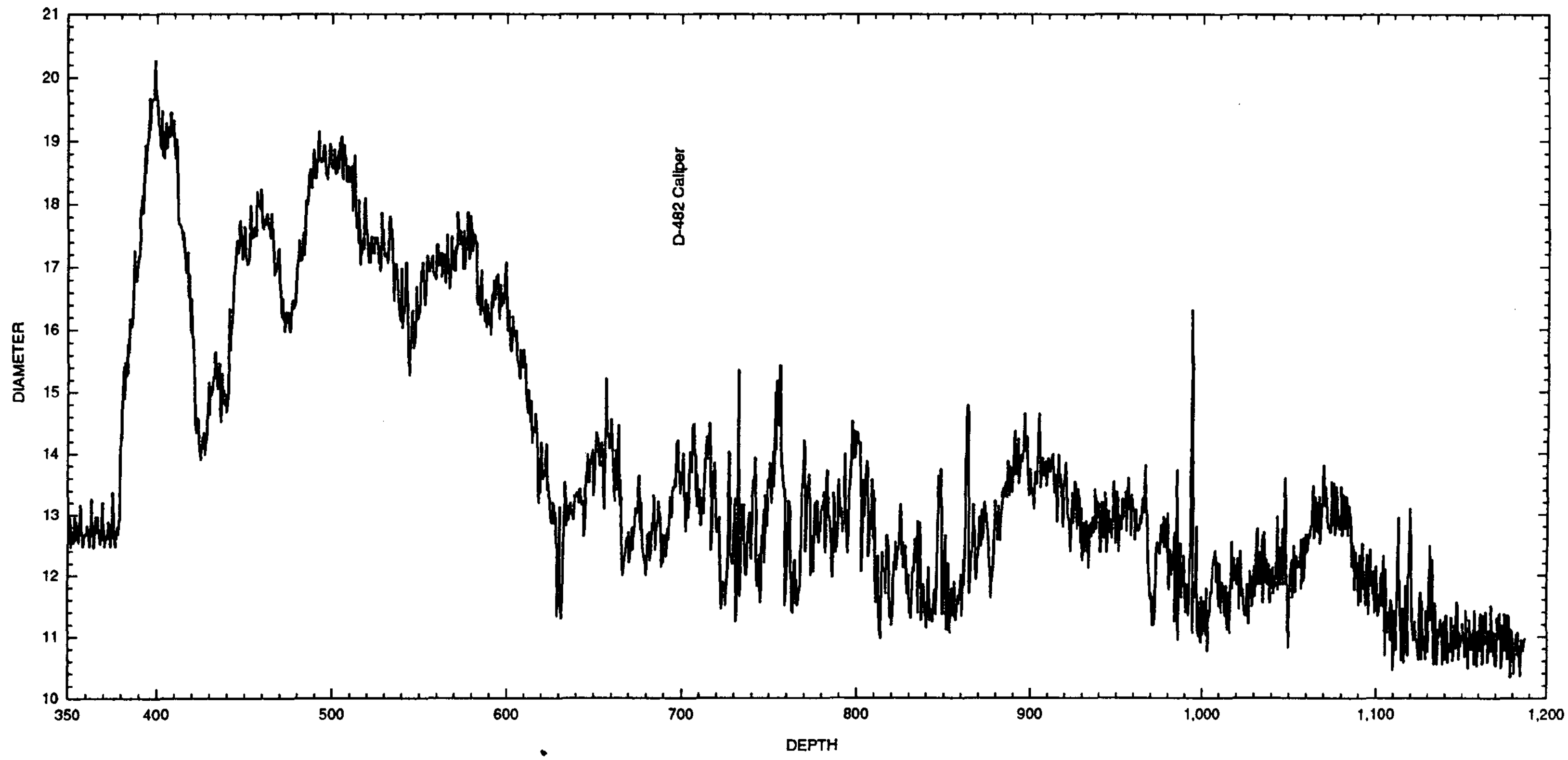
WELL D-482 SITE ID 301716081234301
6th St. S. near Wendy's, Jacksonville Beach

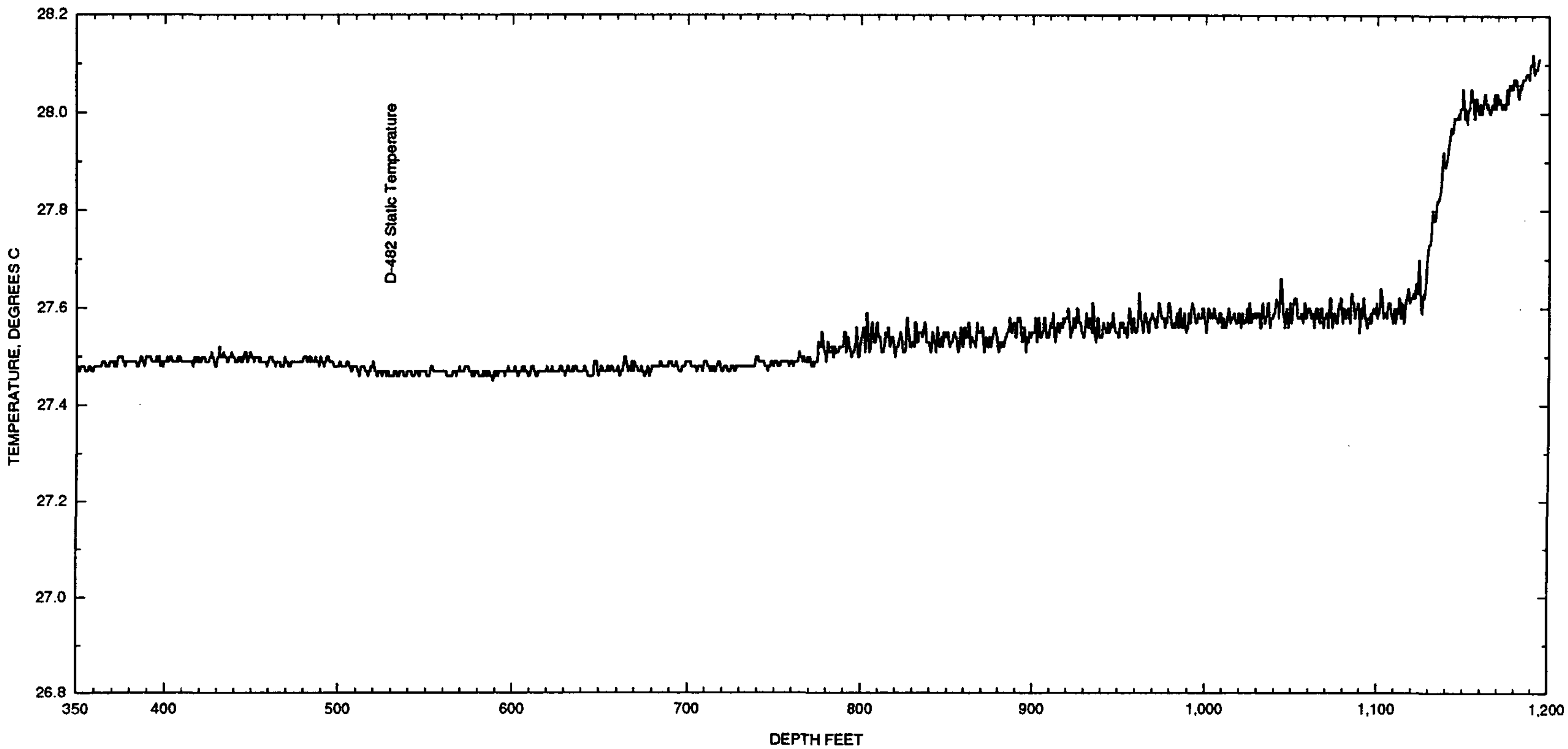
February 15-16, 1995
U. S. Geological Survey Southeast Region Logger

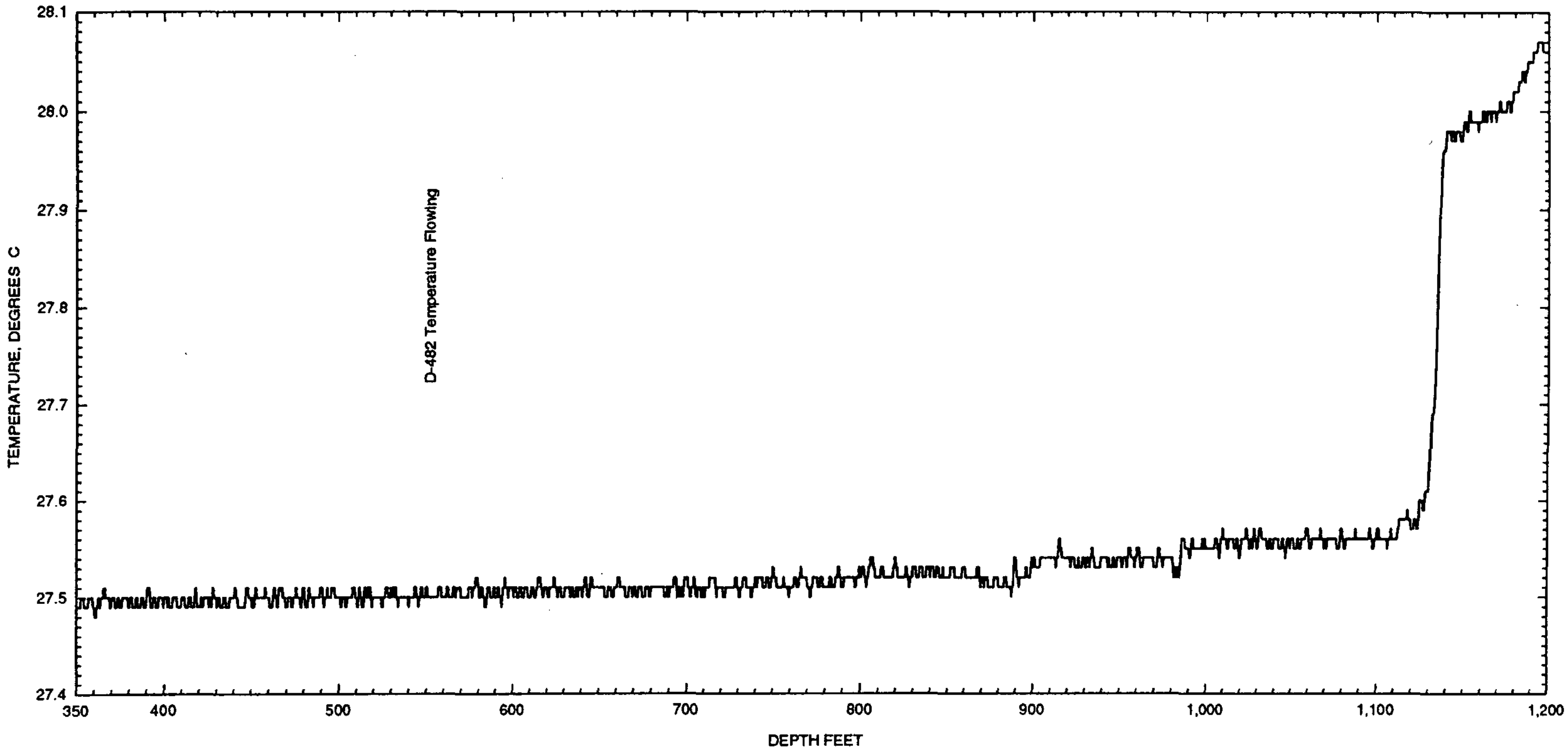
Logs of this well show that most of the flow enters the well between about 1,120 and 1,150 ft. The caliper log does not show the presence of a large single fracture such as was seen in other wells. Unfortunately, the sonic televiewer tool could not get past a depth of 1,002 ft, but it is possible that the formation near the bottom of the hole is like a honeycomb of small fractures that contribute a lot of flow. Other fractures, such as those at depths of about 995 ft, 865 ft, and 728-733 ft, do no appear to add to the net flow of the well. The temperature log indicates that water is entering the well at 995 ft but the water probably flows out into the formation within a few feet of where it enters, because the heat pulse flow meter shows no net gain of water up the borehole between 1,050 and 960 ft.

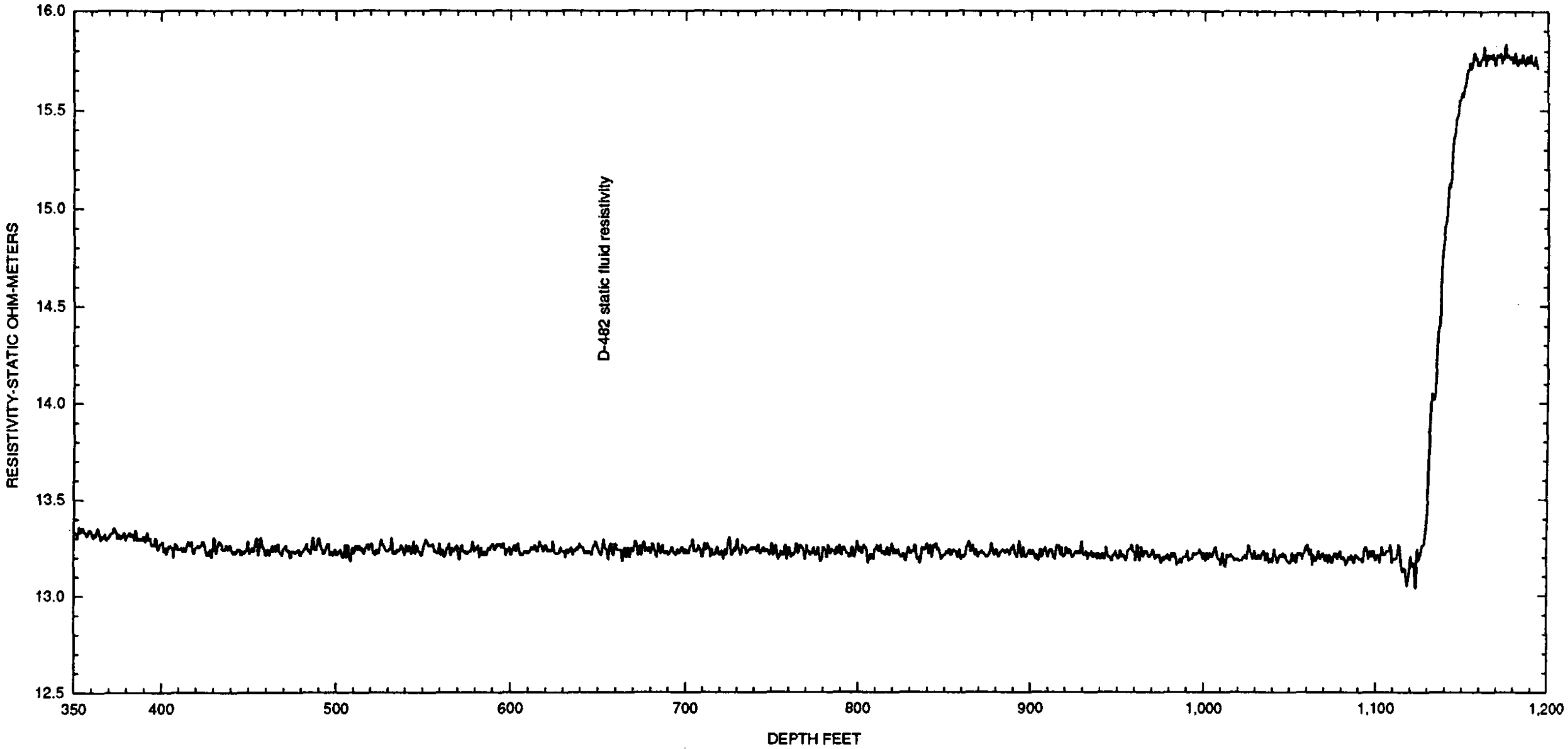
The major water-quality change occurs at about 1,125 ft. A sample was collected at a depth of 1,160 ft. It had a specific conductance of 600 microSiemens. The wellhead sample had a specific conductance of 680 microSiemens. Probably the water with the highest chloride concentration is entering the well between 1,125 and 1,150 ft and the water becomes slightly fresher at 1,160 ft.

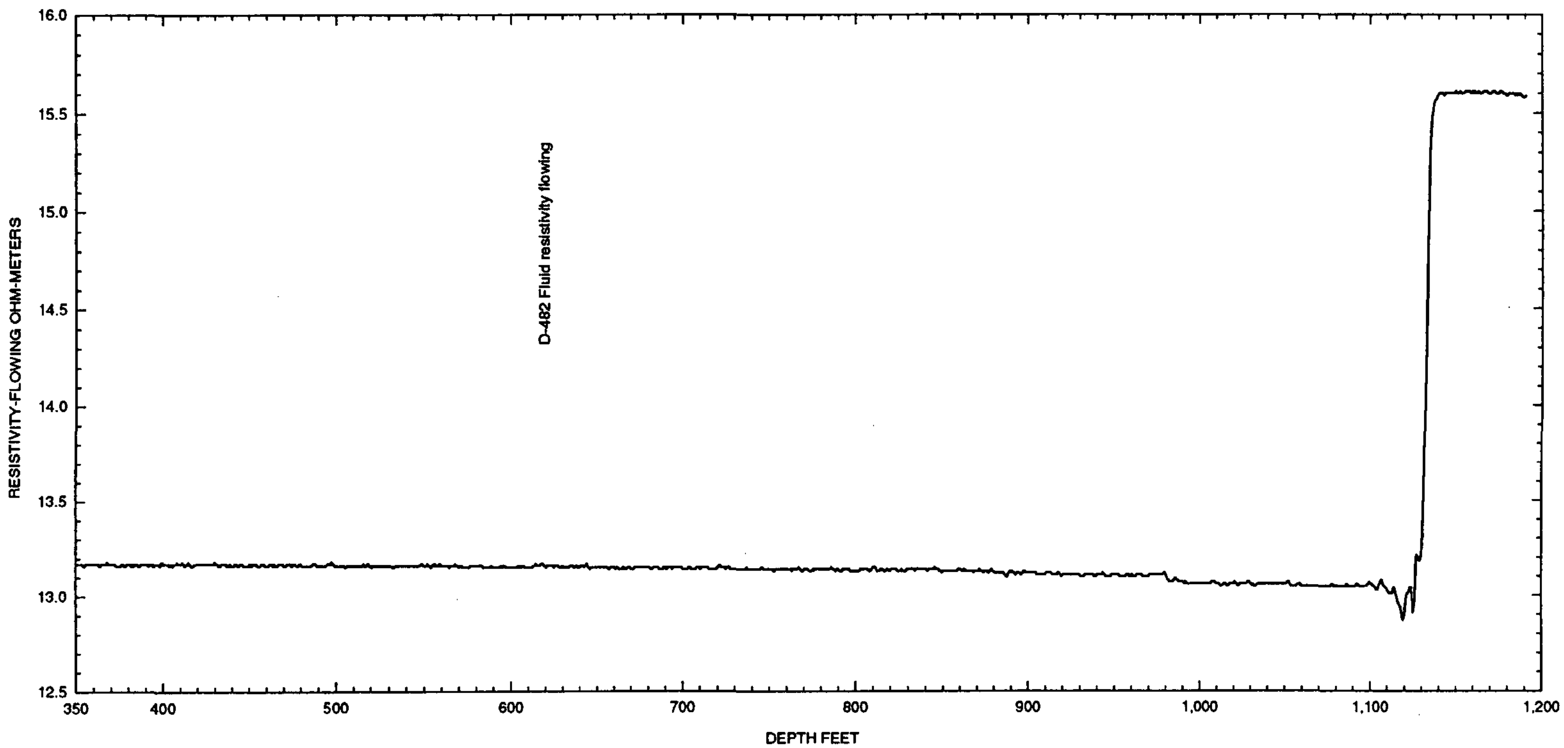
The heat pulse flow meter also shows that water that enters the well near the bottom is gradually being lost into the formation as it moves up the borehole. There are significant losses into a permeable formation between 635 and 538 ft and again between 538 and 425 ft. Nearly all of the flow goes out into the formation between 425 ft and the bottom of the casing. Heat pulse flowmeter logs are run when the well is shut in. The flow rates shown on the log must be corrected for changes in the borehole diameter.


D-482 Caliper
DIAMETER
DEPTH
21
20
19
18
17
16
15
14
13
12
11
10
350
400
500
600
700
800
900
1,000
1,100
1,200


D-482 Static Temperature
TEMPERATURE, DEGREES C
28.2
28.0
27.8
27.6
27.4
27.2
27.0
26.8
350
400
500
600
700
800
900
1,000
1,100
1,200
DEPTH FEET


D-482 Temperature Flowing
TEMPERATURE, DEGREES C
DEPTH FEET
28.1
28.0
27.9
27.8
27.7
27.6
27.5
27.4
350
400
500
600
700
800
900
1,000
1,100
1,200


D-482 static fluid resistivity
RESISTIVITY-STATIC OHM-METERS
DEPTH FEET
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
350
400
500
600
700
800
900
1,000
1,100
1,200


D-482 Fluid resistivity flowing
RESISTIVITY-FLOWING OHM-METERS
DEPTH FEET
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
350
400
500
600
700
800
900
1,000
1,100
1,200

GEOPHYSICAL LOGS FOR WELL D-0483

WELL ID AND LOCATION

Log Source: SJRWMD

County: Duval	Topo Quad: JACKSONVILLE BEACH
Station Name: D-0483	Well ID: D-0483
FGS ID: un	Other ID: Jax Beach #13
Latitude: 30 16 57	Longitude: 81 23 33
Township: 2S	Range: 29
Section: 33	1/4, 1/4, 1/4:
Owner: City of Jax Beach	Driller: un
Completion Date: un	Date logged: 9/19/95
Elevation (msl): 10 ft.	

WELL CONSTRUCTION

Drilling method: un	Total Depth Driller: un ft.
Total Depth Logger: 1155'	T.O.C.:
Open Hole Bit Size:	Cased Hole Bit Size:
CSG String 1 Dia.: 12"	CSG String 2 Dia:
CSG 1 Interval: 0" - 365'	CSG 2 Interval:
CSG 1 Type: Steel	CSG 2 Type:

Screened ( ) Open (X) Interval: 365' to 1155'

Screen Type:	Well Use: Public supply

Comments 1: Log set A

Comments 2: Chlorides @ 550'= 144; @ 850' = 143; @ 1125' = 149.

Comments 3:

LOGGING INFORMATION

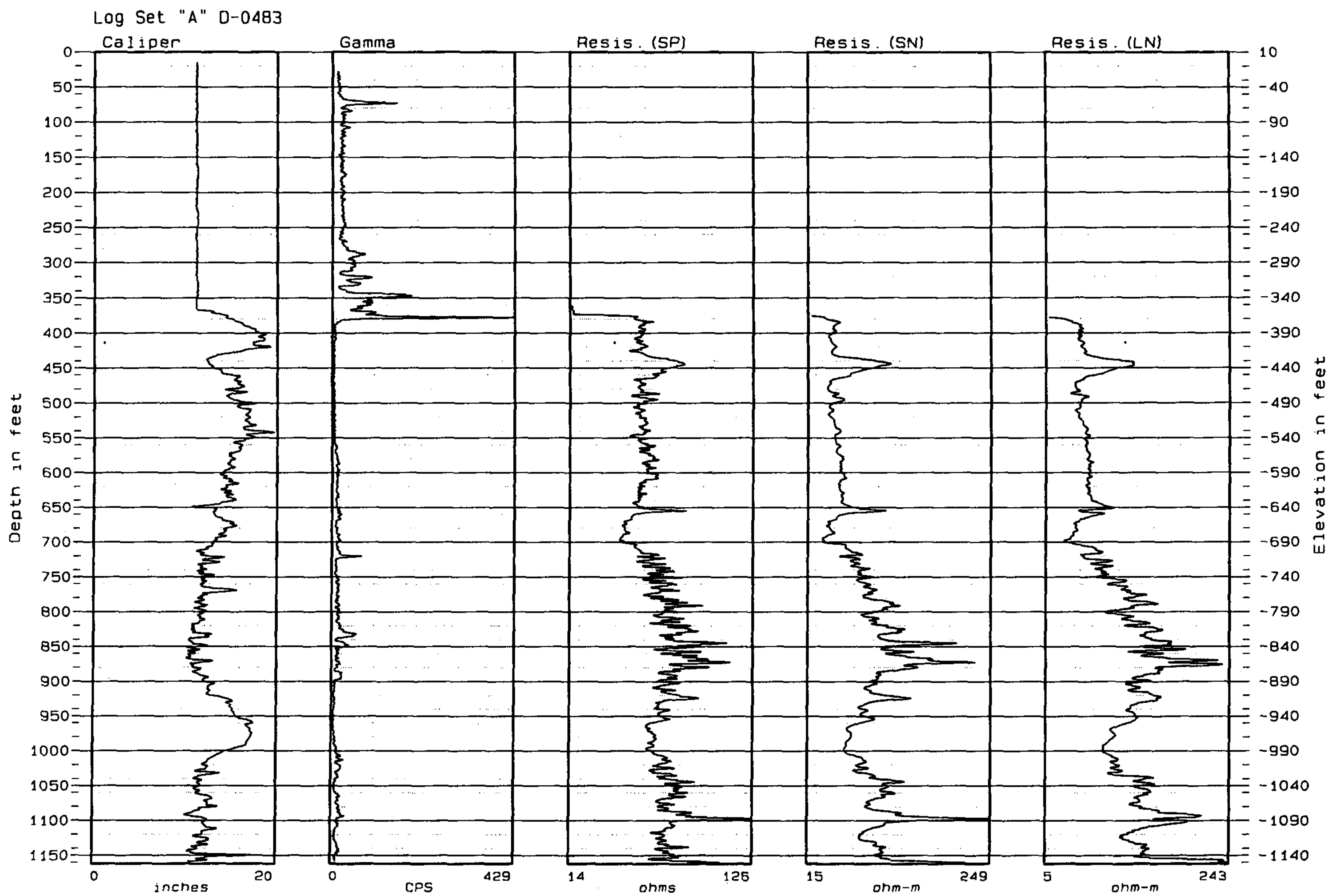
Logged by: S. Dossat	Witnessed by: J. Davis
Logging Unit: MGXII	Tool Zero: Land Surface
Location Method: Topo	Elevation Method: Topo
Digitized by: Logshell	Digitize Method: Real Time

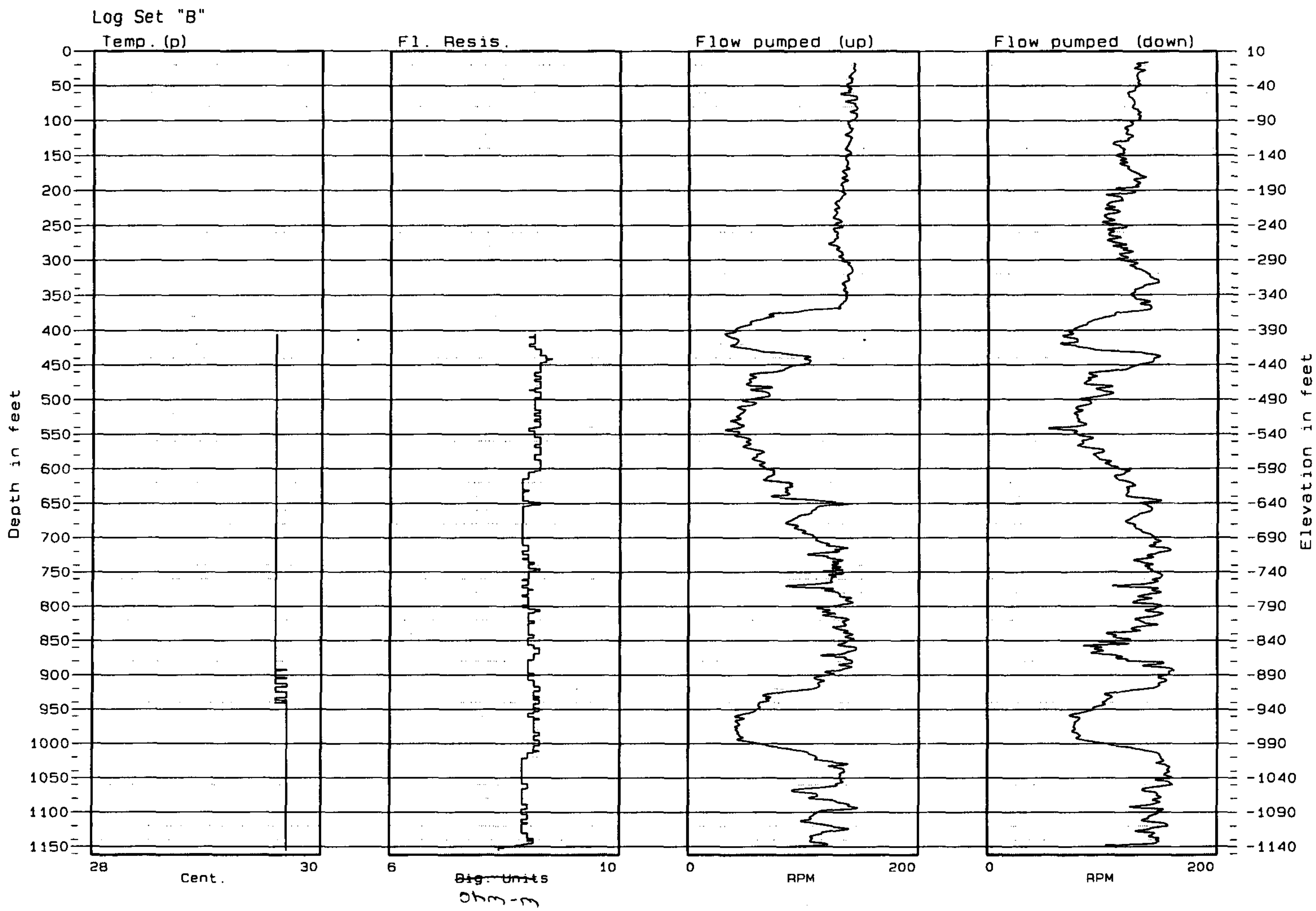
FLUID INFORMATION

Water Level (msl):	
Sample Source:	Sampler ID: MLS 1 Liter
Sample Depths: 0', 550', 850', 1125	Sample dates: 9/19/95
Conductivity:	Temperature:
Density:	Chloride: 143 mg/l @ 0'
Sulfate: 130 mg/l @ 0'	T.D.S.:

TYPE OF LOGS RUN

Caliper	Gamma
Resis. (SP)	Resis. (SN)
Resis. (LN)	


Log Set "A" D-0483
Caliper
Gamma
Resis. (SP)
Resis. (SN)
Resis. (LN)
Depth in feet
Elevation in feet
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
10
-40
-90
-140
-190
-240
-290
-340
-390
-440
-490
-540
-590
-640
-690
-740
-790
-840
-890
-940
-990
-1040
-1090
-1140
0 inches 20
0 CPS 429
14 ohms 126
15 ohm-m 249
5 ohm-m 243



Log Set "B"
Temp. (p)
Fl. Resis.
Flow pumped (up)
Flow pumped (down)
Depth in feet
Elevation in feet
28
Cent.
30
6
~~Dig. Units~~
ohm-m
10
0
RPM
200
0
RPM
200

STATIC FLOW DATA FROM D-0483 WHILE WELL WAS PUMPED ~1250 gpm

DEPTH (FEET)	FLOW (CPS)
325	104
400	39
425	88
450	50
600	58
650	84
800	87
900	87
940	53
975	47
1050	96
1150	23