

SEA-WATER INTRUSION IN THE UPPER PART OF THE FLORIDIAN AQUIFER IN COASTAL PASCO COUNTY, FLORIDA, 1969

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INTRODUCTION

The population of western Pasco County has grown 266 percent in the decade 1960-70. In a recent census (1970) the population of the western half of the county was 43,000 persons. Accompanying this rapid growth is the demand for more water from the Floridian aquifer, the ground-water reservoir which supplies nearly all water users in coastal Pasco County.

As the demand for ground water in the western area of the county increases, the threat of sea-water intrusion into the Floridian aquifer also increases. The chloride content of fresh ground water in the area is less than 20 mg/l (milligrams per liter). Substantially higher chloride content indicates sea-water intrusion. Salt water has been reported in private wells in the New Port Richey area, and chloride increases were noted in the city's well in 1949 (Black, Brown, and Pearce, 1953, p. 20). In 1969, five of the nine wells owned by the city of New Port Richey yielded water whose chloride content was in excess of 250 mg/l (water from one well had increased in chloride content more than 200 mg/l since 1949). The U. S. Public Health Service recommends that chloride not exceed 250 mg/l in public water supplies in areas where other more suitable water supplies can be made available (U. S. Department of Health, Education, and Welfare, 1962, p. 7).

Because of the threat of sea-water intrusion, the Southwest Florida Water Management District and Pasco County officials requested that the U. S. Geological Survey furnish information concerning the extent of intrusion in the coastal parts of the county (area shown on inset, fig. 1) to provide salt-water control. To supply the needed information, the Geological Survey made an investigation there starting in July 1969, in cooperation with the Southwest Florida Water Management District, the Pasco County Commissioners, and the Florida Bureau of Geology. This report defines the extent of the occurrence of salt water in the Floridian aquifer in 1969 and its relationship to fresh water in the aquifer. The report also depicts the potentiometric surface of the upper part of the Floridian aquifer, the elevation of the top of the aquifer, and the salinity of the lower reaches of the Anclote and Pithlachacote Rivers. This investigation was made under the general supervision of C. S. Conover, Florida District Chief, and the immediate supervision of J. S. Rosenheim and R. N. Cherry. The author acknowledges the generous cooperation of personnel of the Florida Bureau of Geology, in assisting in drilling and in collecting data. Appreciation is also extended to the personnel of the Southwest Florida Water Management District and the many city and county officials who generously provided information.

HYDROLOGY OF COASTAL PASCO COUNTY

In the coastal part of Pasco County, land surface ranges in elevation from sea level to about 60 feet above sea level inland. In general, the land surface ranges in elevation from 5 to 40 feet.

In west-central Florida, the Floridian aquifer is composed of a sequence of limestone and dolomite more than 1,000 feet thick. The geologic and hydrologic properties of the aquifer in west-central and coastal Florida have been described by Wetherhall (1964), Hyde (1965), Stringfield (1966), and Cherry and others (1970).

The top of the Floridian aquifer lies near land surface in the western part of the County. The top of the aquifer ranges in elevation from near sea level to about 50 feet below (fig. 1) and is overlain by a thin cover of sand and mixed sand and clay. Elsewhere, the aquifer lies beneath as much as several hundred feet of sediments. North of Port Richey, the top of the Floridian aquifer generally lies within 20 feet of land surface. South of Port Richey, the top of the aquifer is generally deeper than 20 feet below land surface.

Throughout much of coastal Pasco County the water in the Floridian aquifer is unconfined, so that the potentiometric surface is the water table. The potentiometric surface (fig. 2) generally conforms to the land surface. The term "potentiometric surface" is defined as the imaginary surface to which water will rise in tightly cased wells that penetrate the aquifer. The potentiometric surface is high in areas of recharge and low in areas of discharge. The potentiometric surface also is high in areas of lower permeability or in areas surrounded by zones of lower permeability that prevent or retard the movement of water away from an area of recharge.

Over much of the area, water percolates through the sandy soil and through sinkholes and recharges the aquifer (Cherry and others, 1970, p. 56). The fresh water recharging the Floridian aquifer moves from the inland areas of higher water levels generally coastward toward areas of lower water levels (fig. 2). Along the coast, the aquifer is discharged either naturally or as a result of man's activities. Natural discharge occurs as surface seepage and springs, where the potentiometric surface intersects the earth's surface, and as evapotranspiration. Man-induced discharge occurs as pumping from wells tapping the aquifer or seepage to drainage canals. These canals make possible the reclamation of waterlogged areas, and they also reduce flooding during the wet season.

GENERAL ASPECTS OF SEA-WATER INTRUSION

Sea-water intrusion is the landward movement of sea water into aquifers, where the sea water displaces the fresh water. Where seaward movement of fresh water in the aquifer is indicated by a seaward gradient on the potentiometric surface, that movement and the higher fresh-water levels oppose sea-water intrusion.

The salt water-fresh water interface is the transition zone between the salt water and fresh water in the aquifer. The two water types merge gradually through the processes of mechanical dispersion and chemical diffusion. Chloride concentrations across the interface range from less than 50 mg/l to greater than 15,000 mg/l. Because of the difference in densities between fresh water and sea water, the interface slopes downward and inland with the sea water intruding beneath the less dense fresh water in the aquifer. The shape and movement of the sloping interface are governed by the hydrodynamic balance between the two water types and are subject to the influence of varying fresh-water levels in the aquifer and tidal fluctuations.

The Ghyben-Herzberg principle expresses the relationship between sea water and fresh water in a static condition in a coastal aquifer (Cooper and others, 1964). This principle indicates that in a coastal aquifer sea water of specific gravity 1.025 is theoretically depressed about 40 feet below sea level for each 1 foot of fresh-water elevation above sea level, as shown in figure 3. This concept of a 40:1 ratio, with modifications to account for the dynamic nature of the moving water involved, provides the following rule of thumb useful to estimate the effect of depressed ground-water levels on the position of the salt water-fresh water interface in the aquifer. For each foot that the potentiometric surface is lowered in an aquifer, the salt water below has

the potential to rise as much as 40 feet over a period time, in the absence of confining layers that would inhibit such rise. This upward movement of salt water acts to reestablish a balance between the fresh-and salt-water heads. Sea-water intrusion can be reversed if ground-water levels near the coast are raised.

The Ghyben-Herzberg principle illustrates that the landward extent of sea-water intrusion into the Floridian aquifer is directly influenced by the elevation of the potentiometric surface, as reflected in ground-water levels in wells penetrating the upper part of the aquifer. Generally, in coastal areas where ground-water levels are sufficiently elevated, the sloping salt water-fresh water interface intersects the earth's surface either at or seaward of the coast, and sea-water intrusion is not a problem. In coastal areas where ground-water levels have declined the seaward gradient of the potentiometric surface may be significantly reduced or even reversed. This allows the salt water-fresh water interface to shift upward and landward and salt water to penetrate the aquifer at increasingly shallow depths inland, thereby causing some ground-water supplies to become salty.

The behavior of the water levels in the upper part of the Floridian aquifer near the coast is an important indicator of the potential for salt-water intrusion. Figures 3 and 4, when compared, show that, theoretically, the effect of widespread lowering of the potentiometric surface is to induce the salt water-fresh water interface to move landward and upward, with the result that some wells will yield salty water.

In coastal Pasco County, the potentiometric surface of the upper part of the Floridian aquifer (fig. 2) slopes toward the coast at a gradient of about 5 feet per mile. The contour indicating zero head, or zero elevation above mean sea level, of the potentiometric surface is inferred to be adjacent to or just inland from the coast and generally parallel with it.

The location of the zero contour marks the seaward extent of fresh water in the upper part of the aquifer; therefore, it marks the seaward extent of fresh-water discharge from the aquifer. The position of the zero contour somewhat inland from the coast in Pasco County indicates that all discharge of fresh water occurs inland from the coast. Such discharge occurs only in areas where the potentiometric surface is at or above land surface. As an example of the volume discharged from January 1964 to June 1966, aquifer discharge contributed about 15 percent of the average flow of the Pithlachacote River, measured at the mouth, and about 10 percent of the average flow of the Anclote River measured 15 miles upstream from the mouth. Total seepage to the two rivers from the Floridian aquifer during the period was about 18 cubic feet per second, or 11.6 million gallons per day, (Cherry and others, 1970, p. 29).

The potentiometric surface of the upper part of the Floridian aquifer exhibits both seasonal and long-term fluctuations. Generally, water levels in the upper part of the aquifer are highest in September and October after the rainy season and lowest usually in May just preceding the rainy season. Local variations from this pattern may be expected near areas of substantial ground-water withdrawal. When recharge (input from precipitation) exceeds discharge, water levels in the upper part of the aquifer rise, the location of the contour of zero head on the potentiometric surface shifts toward the Gulf, and the salt water-fresh water interface is depressed. Conversely, when discharge exceeds recharge, water levels decline, the zero contour shifts landward, and the interface moves upward.

Tidal drainage canals and the tidal reaches of streams that have no salt-water control structures influence the position of the salt water-fresh water interface in the aquifer in two ways. First, the lowered fresh-water head in the vicinity of such canals or streams allows upward movement of salt water in the underlying aquifer, and the canals and streams are avenues for sea-water intrusion. Second, during certain times of the year when fresh water head in the aquifer is reduced, high tides allow salt water in the canals and streams to intrude downward and laterally into the aquifer (compare the idealized block diagrams of figures 5 and 6).

In many coastal areas in Florida, including coastal Pasco County, drainage canals enhance property values by draining waterlogged land in some places creating waterfront conditions. However, the canals also will facilitate sea-water intrusion of the aquifer, as illustrated in figures 5 and 6.

LOCATION OF SALT WATER-FRESH WATER INTERFACE

To locate the salt water-fresh water interface in the upper part of the Floridian aquifer in coastal Pasco County, 13 salinity-monitoring wells were constructed at 11 sites along the coast to monitor salinity in the aquifer. The wells were spaced 1 mile apart on each of four lines extending inland from the coast, and data were collected during drilling of the wells to show the variation of chloride concentration in water in the aquifer with increasing depth. In addition, stratigraphic information obtained during drilling was used to prepare a map depicting the limestone surface of the aquifer.

The salinity-monitoring wells were drilled with hydraulic rotary equipment. Water samples were collected from the bottom of the hole as drilling progressed. These samples were analyzed to determine chloride content.

A chloride concentration greater than 250 mg/l was used as the criterion indicating that the well had contacted the salt water-fresh water interface zone.

Each well was then cased to within several feet of the bottom of the hole with 4-inch polyvinyl chloride well pipe. The casing was sealed in place by forcing cement grout up from the bottom around the outside of the pipe. This grouting was intended to prevent waters from shallower depths mixing in the annular space between the casing and the well bore and entering the open end of the well. The grout thus assured that samples withdrawn from the well for analysis represented water from only that part of the aquifer open to the bottom few feet of the well.

Data collected from the salinity-monitoring wells were supplemented by analyses of samples from selected public-supply wells and private wells near the coast. Only those wells were selected for which reliable information on casing depth and drilled depth was available. Determination of the exact depth range from which water samples were withdrawn was important to the investigation; salinity typically varies with depth in the aquifer. Water samples collected from the salinity-monitoring wells were from a small depth range, usually only a few feet. Samples from public-supply and other wells are mixtures of water through a considerable depth range and include in the mixture not only water from the deepest part of the range penetrated but also the fresher water from the shallower part of the aquifer open to the well bore. Hence, the salinity-monitoring wells were more useful in detecting the position of the salt water-fresh water interface. Chloride concentrations higher than those reported herein probably would have been observed from some wells if it had been feasible to isolate and withdraw water samples from only the bottom several feet of open hole. In coastal Pasco County, the salt water-fresh water interface slopes landward beneath the fresh water in the aquifer at a gradient of about 200 feet per mile, a slope that is in apparent agreement with both the Ghyben-Herzberg concept and the seaward gradient of about 5 feet per mile on the potentiometric surface. The general slope of the interface in parts of coastal Pasco County is shown on three sections (fig. 7).

The position of the salt water-fresh water interface at a depth of 100 feet below mean sea level in the upper part of the Floridian aquifer in coastal Pasco County is depicted in figure 8. The line represents that part of the interface in which chloride concentrations of 250 mg/l occur 100 feet below mean sea level, based on interpretation of data collected before November 1969.

As stated earlier, the 250 mg/l chloride concentration was chosen as a criterion to indicate that a well had penetrated the salt water-fresh water zone. The depth of 100 feet below land surface was chosen arbitrarily because wells less than 100 feet deep generally are considered to be shallow and those more than 100 feet to be deep. Along the line shown in the map (fig. 8), which represents the position of the interface at a depth of 100 feet, the fresh-water head theoretically is 2.5 feet above mean sea level. Coastward from this line, salty water occurs at depths less than 100 feet, and the fresh-water head in the aquifer is generally less than 2.5 feet, declining to zero at the coast, where the interface approaches land surface. Inland from this line, water in the upper part of the Floridian aquifer containing more than 250 mg/l of chloride occurs generally at a depth greater than 100 feet.

Figure 9 defines the extent to which salty water migrates upstream under varying tidal and streamflow conditions. Profiles of chloride concentrations in the two rivers were constructed from samples collected near the surface and near the bottom of each stream at high and low tides during high streamflow conditions in 1969 (flows expected to be equal or exceeded only 10 to 20 percent of the time). At each sampling site the chloride concentration was greater near the bottom of the stream than at the surface. Water with a chloride concentration of 250 mg/l or more was detected farther up each stream during high tide than during low tide.

One such profile made in 1964 during low streamflow conditions (flows that would be exceeded 80 to 90 percent of the time) showed that water with a chloride concentration of 250 mg/l was detected in the Pithlachacote River as far as 4 miles upstream from the mouth and in the Anclote as far as 8 miles upstream from the mouth. These distances do not necessarily represent extremes of sea-water penetration upstream, but do indicate a range of conditions likely to be common to either river. Undoubtedly, sea water will migrate farther upstream at those times when conditions of low fresh-water discharge coincide with exceptionally high tides.

CONTROL OF SEA-WATER INTRUSION

The Ghyben-Herzberg principle indicates that sea-water intrusion into the Floridian aquifer in coastal Pasco County is directly influenced by the relation between sea-water and fresh-water levels. Maintaining high ground-water levels inland from the coast would be a desirable step in controlling intrusion of salt water in the aquifer because the high fresh-water head would act to oppose both the lateral and vertical movement of sea water into the Floridian aquifer. Over a long period of time maintenance of elevated water levels would force the salt water-fresh water interface seaward, with the result that chloride content in the aquifer would be reduced.

The erection of salinity-control structures on tidal streams and canals would prevent the upstream movement of salt water and would raise the fresh-water levels in and along the channels. Such controls have been erected in Broward County and have successfully retarded salt-water intrusion caused by heavy pumping of wells and the widespread construction of uncontrolled tidal canals in some areas (Sherwood and Grantham, 1966).

A program of close observation of chloride content of water withdrawn from selected salinity-monitoring wells would allow the detection of changes in the salt water-fresh water interface, as development of coastal Pasco County continues. An expansion of the network of wells along the coast would permit a more comprehensive representation of the salt water-fresh water relationship in west central Florida. With the inclusion of the entire coastline of Florida in the network, information gained would provide the basis for evaluating the effects of man's activities, as related to salt-water intrusion.

SUMMARY AND CONCLUSIONS

Sea water intrusion is evident in coastal Pasco County. Data collected indicate that the salt water-fresh water interface (as defined by a chloride concentration of 250 mg/l at 100 feet below mean sea level) closely parallels the Gulf Coast 1 to 2 miles inland. Landward from the interface, ground water containing chloride in concentrations greater than 250 mg/l lies deeper than 100 feet below mean sea level, and the elevation of the potentiometric surface exceeds 2.5 feet above mean sea level.

Salt water encroaches upon the fresh-water supply in the upper part of the Floridian aquifer in coastal Pasco County by three principal avenues: (1) laterally through the permeable limestone of the aquifer, where it is in contact with sea water offshore, (2) by way of the tidal streams and canals in which salt water is free to move upstream and inland, from which to intrude the aquifer, and (3) the upward movement of salt water through the aquifer as a result of the lowering of the fresh-water head in the coastal part of the aquifer.

Sea-water intrusion would be countered by placing salt-water control structures on tidal streams and canals and by maintaining high fresh-water head in the aquifer.

Construction of a network of salinity-monitoring wells would provide a means of detecting changes in the location of the salt water-fresh water interface in Florida.

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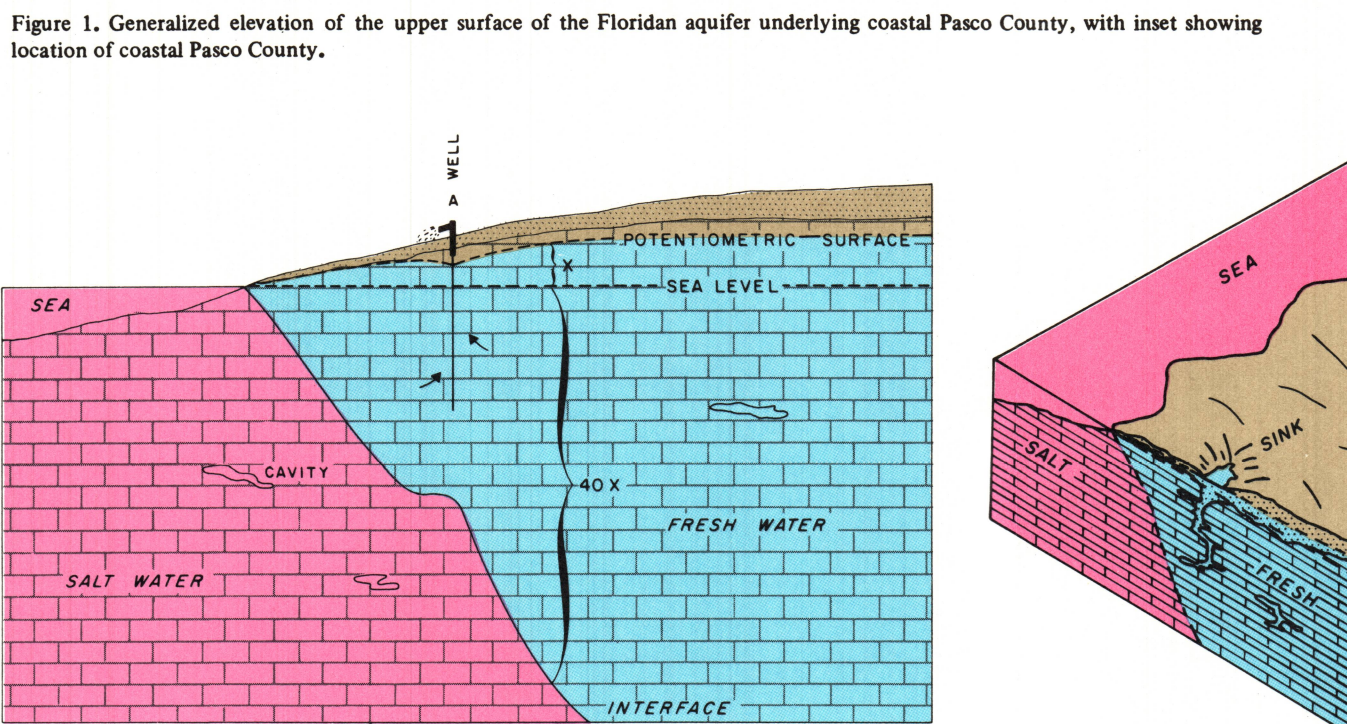
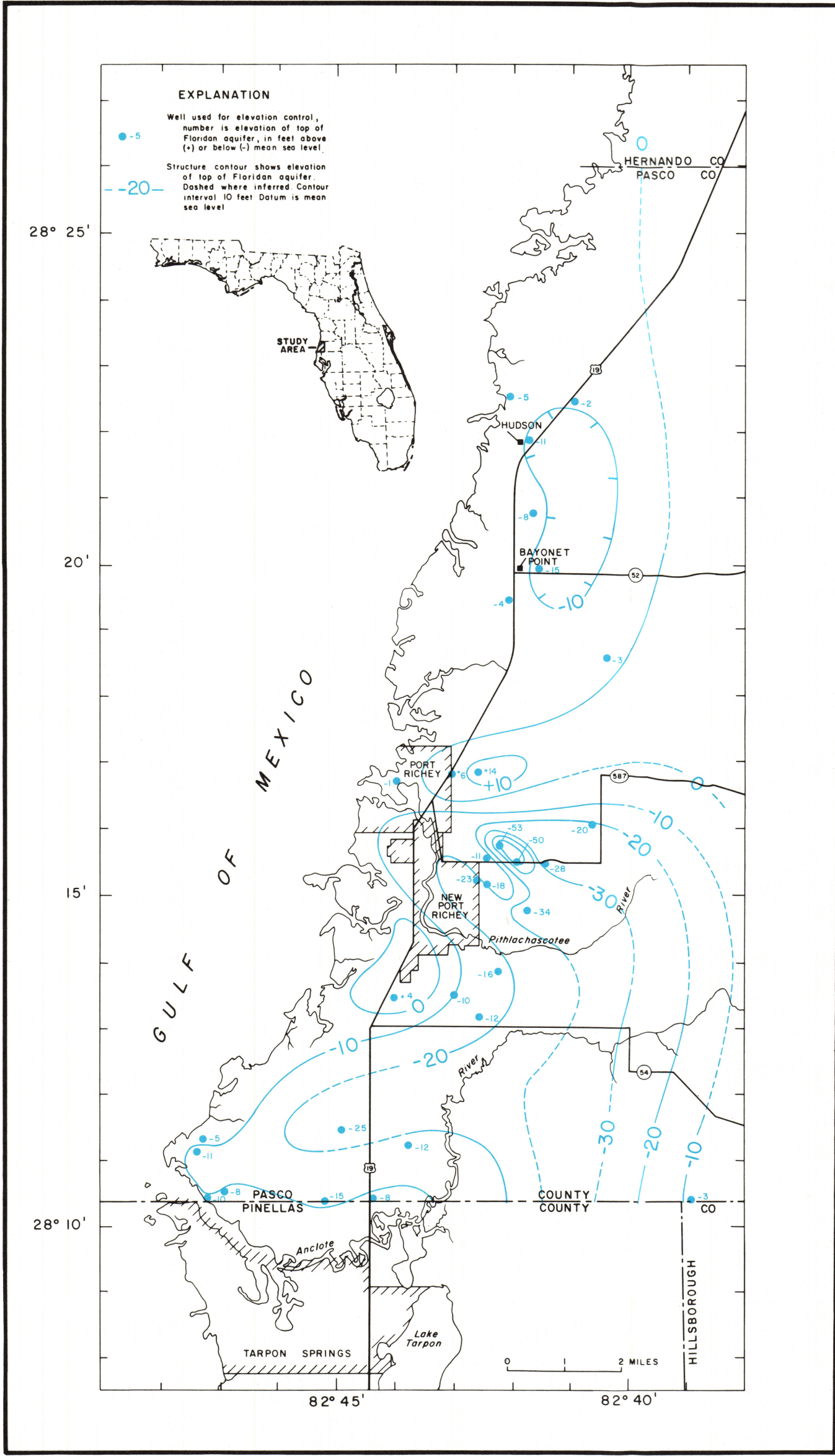


Figure 3. Generalized section across a salt water-fresh water interface, showing the Ghyben-Herzberg principle.

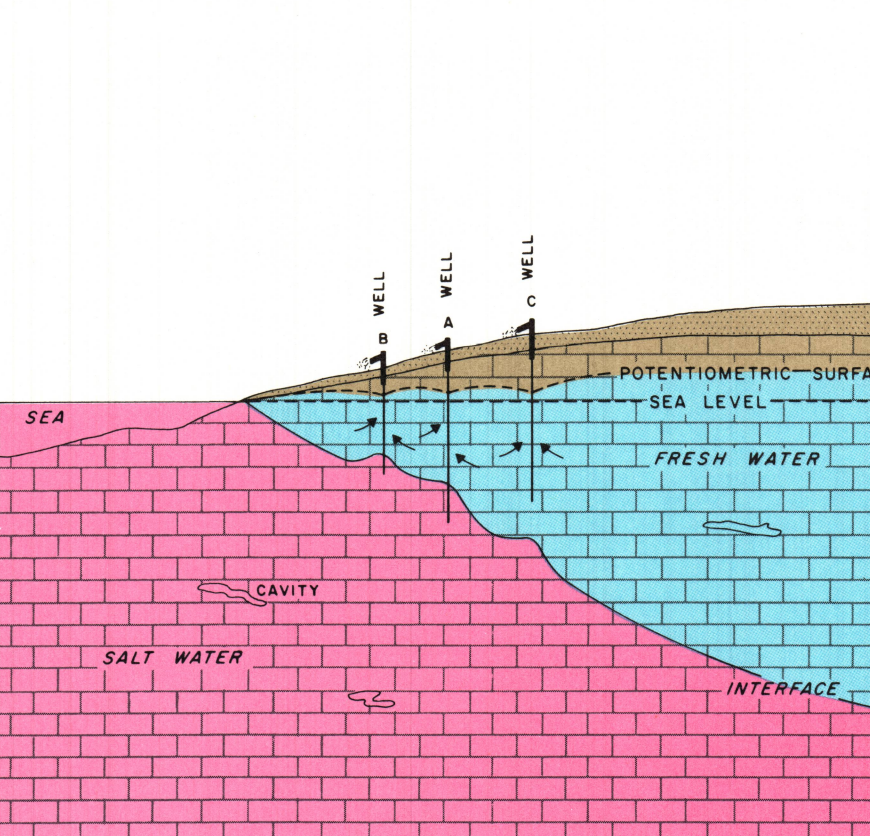


Figure 4. Generalized section across a salt water-fresh water interface, showing the effect of a substantially lowered potentiometric surface (compare to fig. 3).

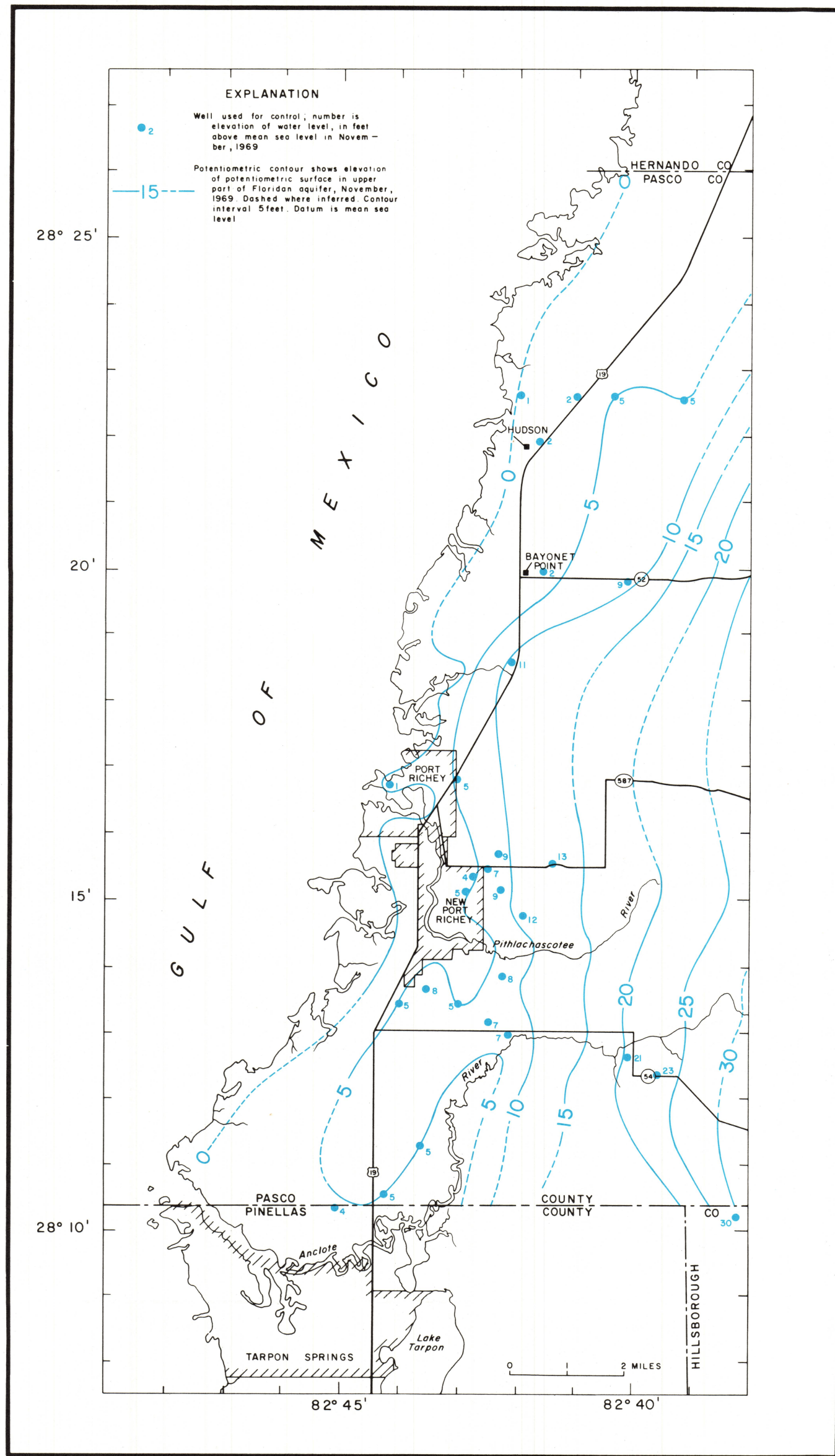


Figure 2. Elevation of the potentiometric surface of the upper part of the Floridian aquifer underlying coastal Pasco County, November, 1969.

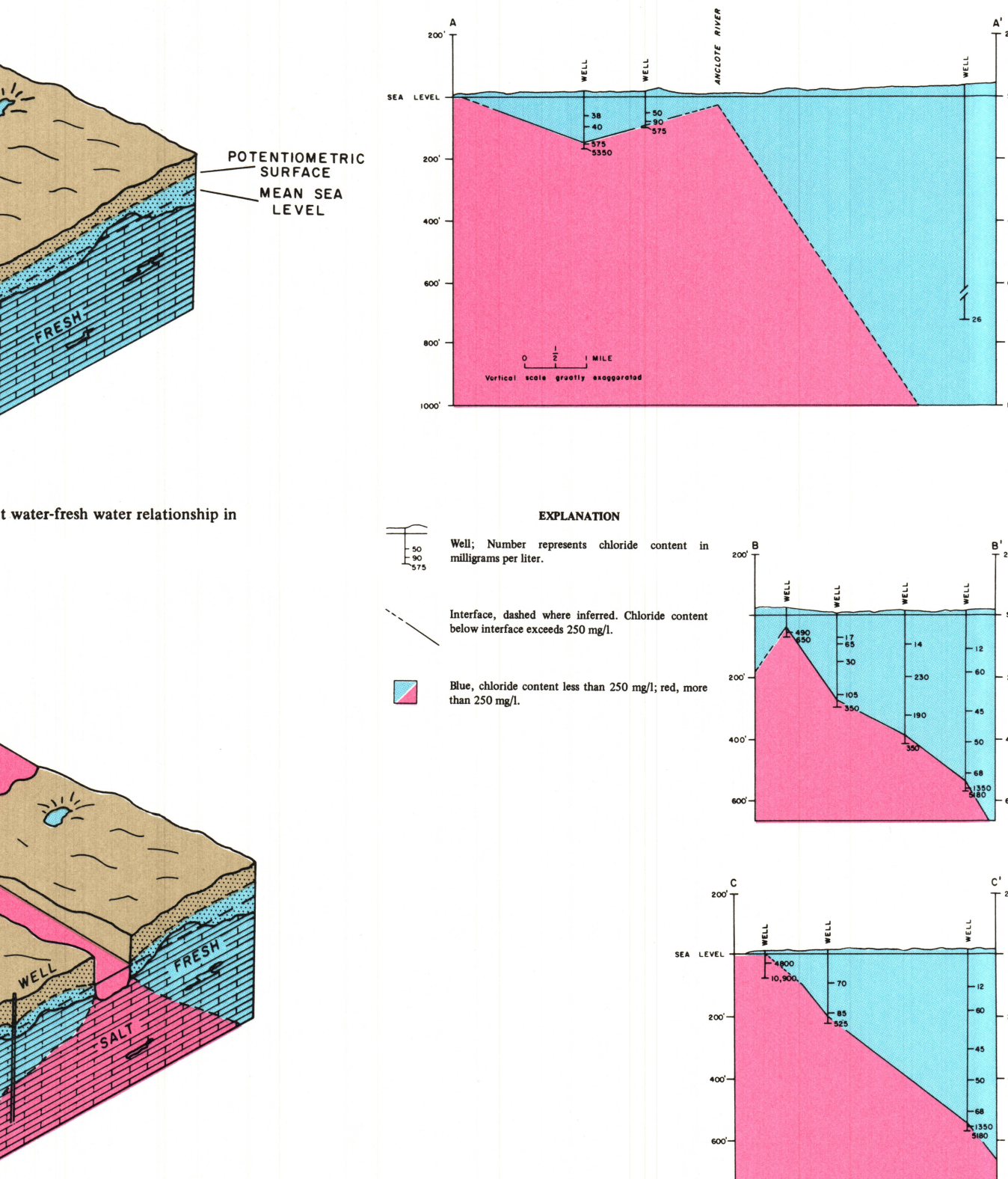


Figure 6. Generalized block diagram showing salt-water intrusion induced by uncontrolled tidal stream or canals.

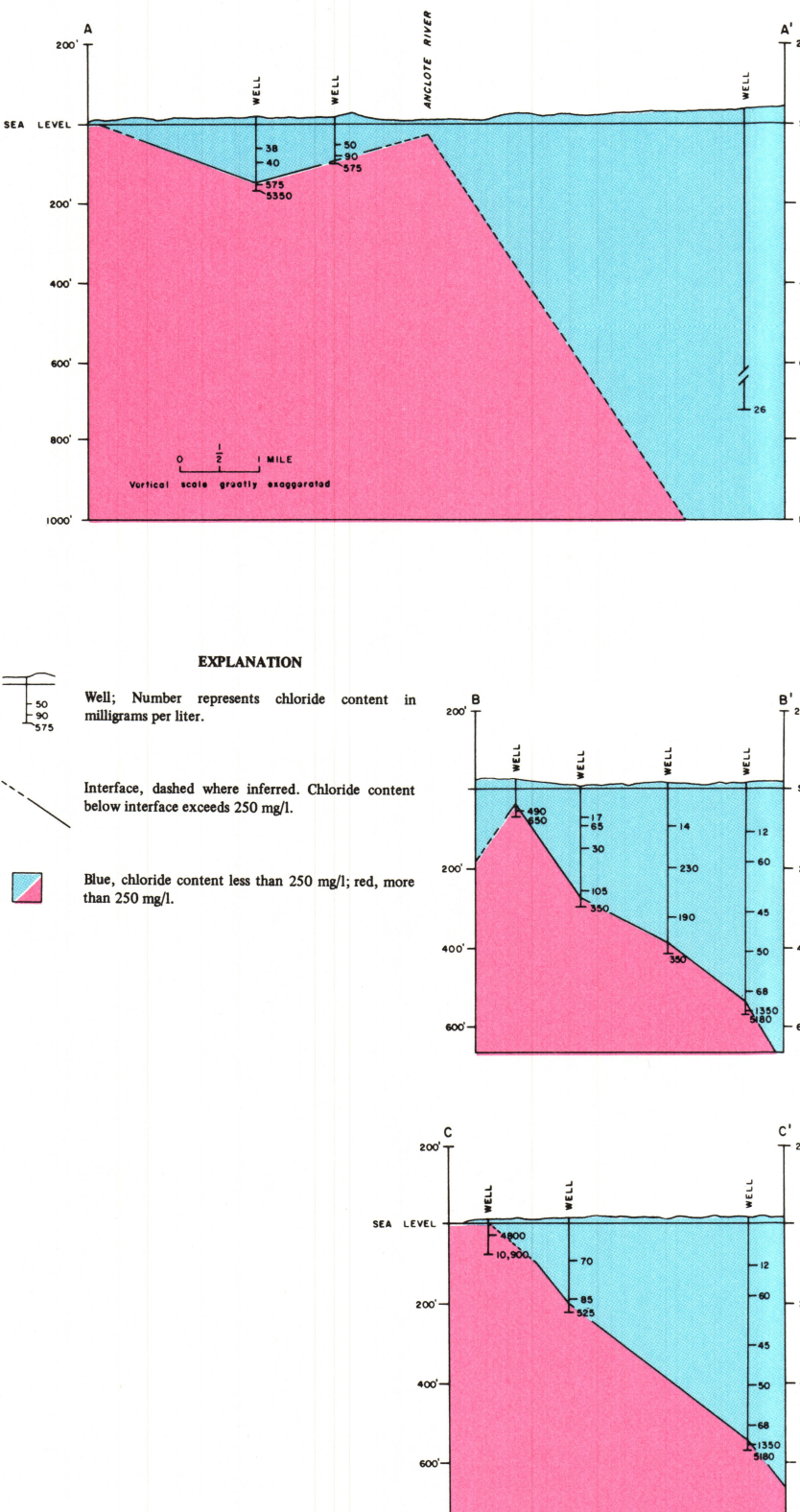


Figure 7. Three sections across the salt water-fresh water interface in the upper part of the Floridian aquifer underlying coastal Pasco County, November 1969. See map, fig. 8, for key to section location.

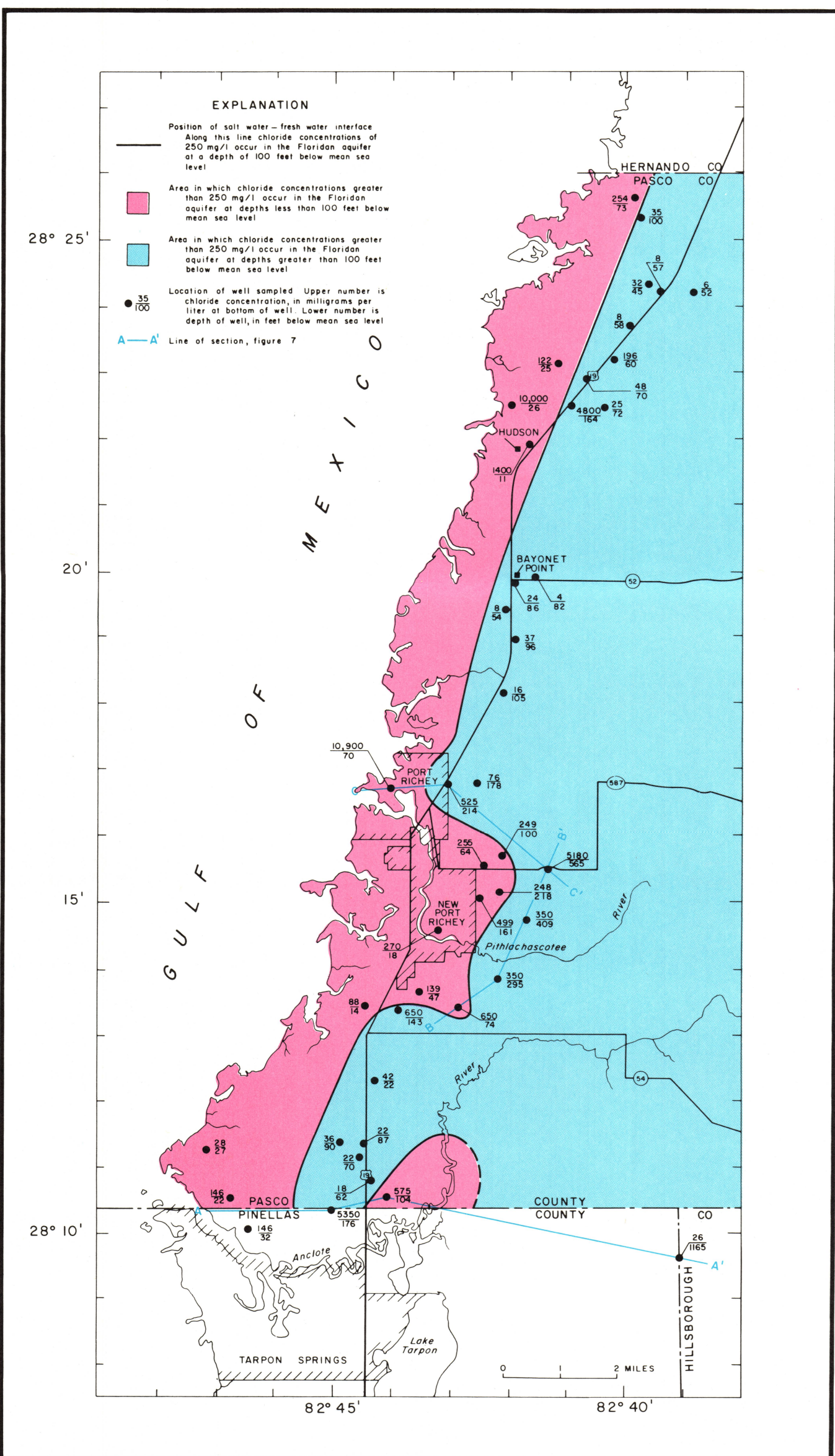


Figure 8. Position of the salt water-fresh water interface at a depth of 100 feet below mean sea level in the Floridian aquifer underlying coastal Pasco County, November 1969.

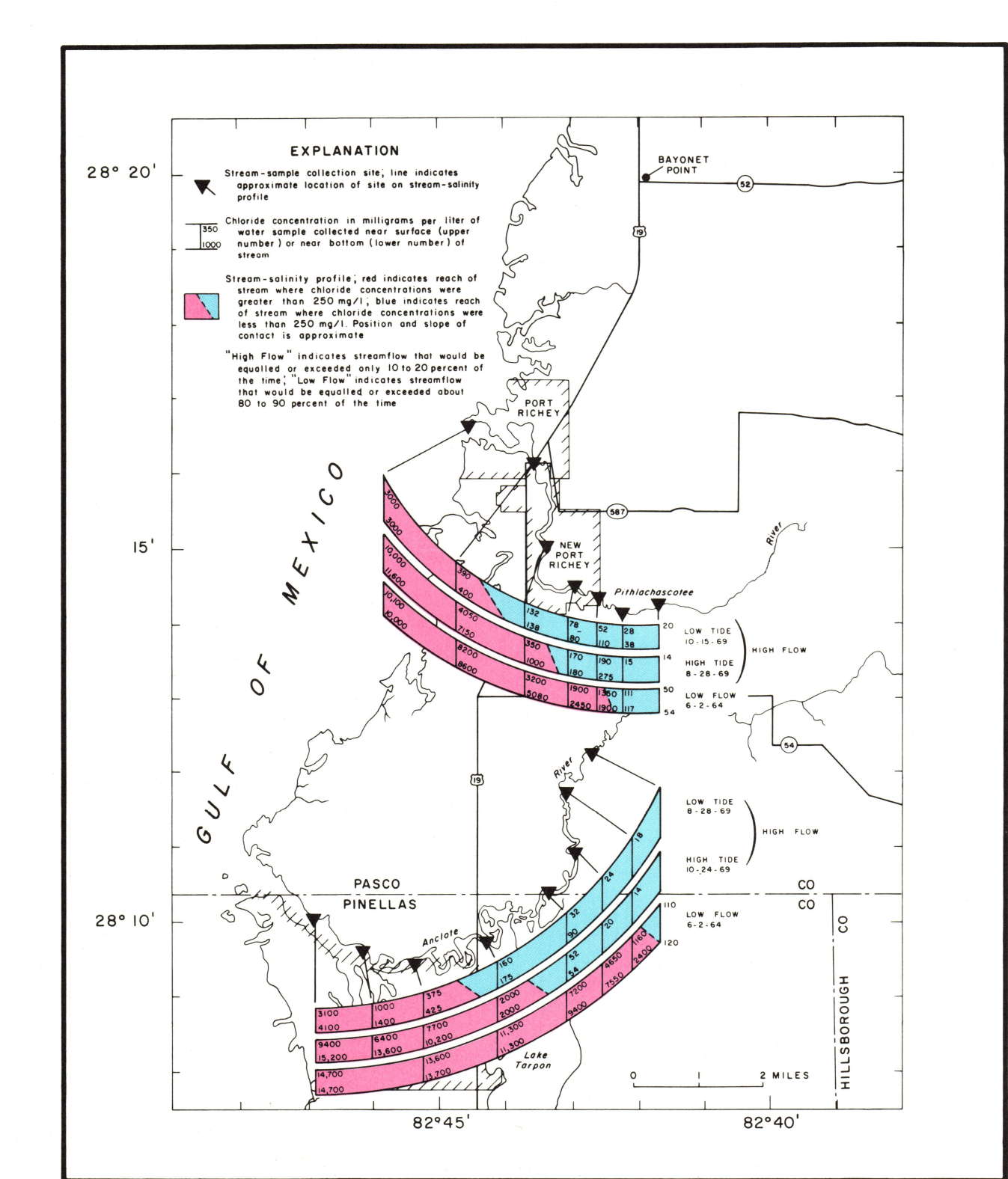


Figure 9. Chloride concentrations at selected locations in the lower reaches of the Pithlachacote and Anclote Rivers in 1964 and 1969.