INTRODUCTION

Geophysical well logs from over 150 oil test and water wells in Mississippi, Alabama, and Georgia were examined and calculations of the dissolved-solids concentration in ground water were made using the spontaneous potential deflection as a measure of ionic activity. The values derived from these calculations were used to prepare a map (fig. 1) showing the altitude relative to sea level at which the concentration of dissolved solids in the ground water reached 10,000 mg/L (milligrams per liter) within a regionally extensive aquifer in Mississippi, Alabama, and Georgia. This map was prepared as part of a study of the Southeastern United States Coastal Plain aquifer system conducted by the U.S. Geological Survey Regional Aquifer-System Analysis (RASA) program.

A dissolved-solids concentration of 10,000 mg/L is used by the Survey to delineate the interface between moderately saline and saline water. In this report, 10,000 mg/L dissolved solids was designated to delineate the freshwater-saltwater interface. For the finite-difference computer flow model being used in the RASA study, this interface represents the location where horizontal flow of freshwater is greatly diminished. 10,000 mg/L also is the lower limit for dissolved-solids concentrations for water in target zones for injection wells (U.S. Environmental Protection Agency, 1982).

The 10,000 mg/L dissolved solids line is of value as a water-quality indicator. Although water containing 3,000 to 10,000 mg/L or more of dissolved solids is too saline for agricultural use (upper limit approximately 3,000 mg/L, or for drinking water (upper limit approximately 1,000 mg/L), it may be useful for some industrial purposes. Waters containing dissolved-solids concentrations greater than 10,000 mg/L have little potential for any use involving human activities.

HYDROGEOLOGIC FRAMEWORK

The sediments comprising the Southeastern United States Coastal Plain are predominantly clastic. Sediments range in age from Jurassic to Cretaceous and Tertiary. These sediments are important sources of ground water in the southeastern United States. The Floridan aquifer system, which is mostly limestone, overlies the clastic sediments in northern Florida and parts of Georgia and Alabama (Miller, 1984). In some areas of the southeastern United States, surficial aquifers overlie the Floridan and may provide water locally.

In the Southeastern Coastal Plain, Renken (1984) has defined seven regional hydrogeologic units (fig. 2). Four of these are aquifers, and they are confined by three zones of clay, marl, chalk and low-permeability limestones. The aquifers are poorly consolidated to unconsolidated sequences of gravel, sandstone and clayey sand. These units are defined on the basis of contrasts in permeability rather than time, lithology, or environment of deposition. Due to their regional nature, and because they do not necessarily coincide with present stratigraphic nomenclature, they are given the alphanumeric designation of A1, A2, A3, and A4 (for aquifers, youngest to oldest) and C1, C2, and C3 (for confining zones, youngest to oldest). Some of these units extend throughout most of the Coastal Plain; others are less extensive.

This study is restricted to the lowermost aquifer unit (A4) in Mississippi, Alabama, and Georgia because water-quality data indicated that water containing more than 10,000 mg/L dissolved solids is found in parts of this aquifer throughout most of the study area. The overlying aquifer units contain water with dissolved-solids concentrations of less than 10,000 mg/L throughout most of the three States.

The A4 aquifer is the most extensive of the four regional aquifers that comprise the Southeastern United States Coastal Plain (R. A. Renken, U.S. Geological Survey, written commun., 1985). These Cretaceous age sediments crop out in a 40 to 50-mile wide band in western Alabama and western Alabama, decreasing in outcrop width eastward into Georgia. At outcrop, the base of the A4 represents the updip boundary of the Southeastern United States Coastal Plain. It slopes seaward with a gradient of 15 to 30 feet per mile in Georgia, and 30 to 50 feet per mile in Alabama and Mississippi.

The A4 aquifer unit includes quartzose, glauconitic, and feldspathic, fine to coarse-grained sands and local confining zones of Early and Late Cretaceous age. Permeable parts of six rock-stratigraphic units—the Coffee Sand, the Eutaw Formation, the McShan Formation, the Gordo Formation and Coker Formation of the Tuscaloosa Group, and the Atkinson Formation—comprise important aquifer zones in the A4 aquifer unit.

RELATION OF DISSOLVED-SOLIDS CONCENTRATION AND SPONTANEOUS POTENTIAL

The magnitude of the spontaneous potential of a water is a function of the dissolved-solids content of that water. A quantitative relationship for electrochemical (spontaneous) potential was developed by Wyllie, (1963), using the electrochemical activities of the drilling mud and the interstitial water:

$$SSP = -K \log \frac{[\text{activity of interstitial water}]}{[\text{activity of mud filtrate}]} \quad (1)$$

where SSP is the electrochemical (spontaneous) potential in millivolts and K is an empirical value related to formation temperature. The value used for K in these calculations is $K = 60 + 0.133 \ T_f$, where T_f is the formation temperature in degrees Fahrenheit. The relation above is often expressed in terms of the resistivity of the interstitial water, which is inversely related to the spontaneous potential and, hence, to the dissolved-solids concentration. The relation, based on resistivity, is as follows:

$$SSP = -K \log \left(\frac{R_{mf}}{R_w} \right) \quad (2)$$

where R_{mf} is the resistivity of the mud filtrate and R_w is the resistivity of the interstitial water contained in the formation.

METHODS

The concentration of dissolved solids was calculated from the spontaneous potential (SP) curve of calibrated electric logs using a program written by L. M. MacCary, formerly of the U.S. Geological Survey (written commun., 1982). The program was adapted for use on the Survey's PRIME computer system by J. M. Pulford of the U.S. Geological Survey. Using an SP value for a given depth, the program calculates a dissolved-solids concentration at that depth.

Logs used in this study were predominantly from oil test wells because the data (drilling-mud resistivity and bottom-hole temperature) necessary to perform the calculations are recorded on these types of logs. Ideally, the zones within the aquifer suitable for the calculations were permeable sand beds of at least 100 feet in thickness and not less than 20 feet thick (calculations of dissolved-solids concentrations were made at the midpoint of the unit). The Southeastern Coastal Plain aquifer system is defined on a regional scale and a sand bed less than 20 feet thick cannot be described as a discrete water-bearing unit on such a scale. Moreover, the SP value recorded in thin sand and shale beds is less than the true potential because a significant amount of the flow of electricity between thin beds of sand and shale is diverted through the drilling mud into the borehole and the invaded zones (Davis and DeWiest, 1966).

After a sand bed was selected, the SP deflection (in millivolts) adjacent to the sand layer was read. The bottom-hole temperature, which is used to calculate the formation temperature (T_f) at a given depth, and resistivity of the drilling mud (R_m) were obtained from the log heading. When available, the resistivity of the mud filtrate (R_{mf}) was also taken from the log heading. If the R_{mf} was not given, it was approximated by the empirical relation:

$$R_{mf} = R_m \times 0.85 \quad (3)$$

After R_{mf} was determined, equation 2 was solved for R_w by a computer program or by published charts (Schlumberger Limited, 1972, p. 9). After R_w was determined it was converted to milligrams per liter of sodium chloride in solution by computer program.

To ascertain the quality of water over the entire thickness of the aquifer, calculations of dissolved-solids concentrations were made at a point not more than 50 feet below the top of the regionally defined unit. This was usually the first calculation done, and the selection of subsequent zones was based on the value obtained at that point. If the dissolved-solids concentration calculated for the initial zone was greater than 10,000 mg/L, a visual check of the SP deflection was done on the remainder of the log to ensure that there were no freshwater-saltwater reversals in the well. Calculations were not made unless reversals were obvious. Wells with logs indicating that the calculated dissolved-solids concentration reached 10,000 mg/L somewhere above the top of the regional aquifer were designated with the prefix "A" on the map. The initial value calculated was less than 10,000 mg/L, calculations were made on deeper sands. If the well contained water having a dissolved-solids concentration of less than 10,000 mg/L throughout the entire thickness of the aquifer, it was designated with the prefix "B". This indicated that the dissolved-solids concentration would not reach 10,000 mg/L until some point below the bottom of the regional aquifer, if at all.

Within the aquifer, the depth at which the 10,000 mg/L dissolved-solids interface was plotted for any given well was determined by linear interpolation between two calculated dissolved-solids concentrations, unless the interpolated depth occurred in a shale bed. In that case, the location of the interface was placed at the top of the first thick sand bed (>20 feet) below the shale. If the interpolated depth occurred within 100 feet of the top of the regional aquifer unit, it was placed at the altitude of the top of the aquifer.

THE FRESHWATER-SALTWATER INTERFACE

Figure 1 shows the altitude of the freshwater-saltwater interface in each well. In northeastern Mississippi and most of central Alabama and Georgia, all water in the A4 regional aquifer has a dissolved-solids concentration less than 10,000 mg/L. Within a zone approximately 30 to 95 miles wide through the three States, the freshwater-saltwater interface occurs within the aquifer. The heavy solid line designated as "Updip Limit of Saltwater" represents the intersection of the freshwater-saltwater interface with the top of the A4 regional aquifer. All ground water within the A4 aquifer south, southeast, and southwest of this line contains dissolved-solids concentrations greater than 10,000 mg/L. The heavy solid line designated as "Downdip Limit of Freshwater" represents the intersection of the freshwater-saltwater interface with the base of the A4 aquifer unit. All ground water within the A4 aquifer system north and northeast of this line contains dissolved-solids concentrations less than 10,000 mg/L. Between these lines, the altitude of the freshwater-saltwater interface has been delineated as shown by the contours in figure 1.

The utility of the freshwater-saltwater interface as a physical flow boundary for hydrologic models is illustrated by the Ghyben-Herzberg principle (Henry, 1964), which postulates that no significant ground-water flow occurs across the interface between saltwater and freshwater. In nature, this interface is usually not sharp; that is, a zone of mechanical dispersion and chemical diffusion is present. If this zone is narrow, then it can be treated as a discrete interface through which little or no flow between freshwater and saltwater occurs. Because ground-water flow is continuous, freshwater movement is assumed to be upward relative to saltwater due to difference in density. In many hydrologic models, the freshwater-saltwater interface is considered to be the downdip limit of significant horizontal flow of freshwater.

Two cross sections (figs. 3 and 4) show the relation between the freshwater-saltwater interface and the top and base of the A4 aquifer unit in Alabama and Georgia, respectively (for location, see fig. 1). The nonuniform shape of this interface indicates that the permeability of the A4 aquifer unit is variable, both vertically and horizontally. The shape of the interface is probably due to contrasting rates of water movement in the discrete sand aquifers that make up the A4 aquifer unit.

SELECTED REFERENCES

Applin, P. L., and Applin, E. R., 1967, The Gulf Series in the subsurface in northern Florida and southern Georgia: U.S. Geological Survey Professional Paper 524-G, 35 p.

Boswell, E. H., 1963, Cretaceous aquifers of northeaster Mississippi: Mississippi Board of Water Commissioners Bulletin 63-10, 202 p.

———, 1977, The Eutaw-McShan aquifer in Mississippi: U.S. Geological Survey, Water-Resources Investigation 76-134, map, 3 sheets.

———, 1978, The Tuscaloosa aquifer system in Mississippi: U.S. Geological Survey Water-Resources Investigations Report 78-98, map, 3 sheets.

Brown, D. L., 1971, Techniques for quality of water interpretations for calibrated geophysical logs, Atlantic Coast Area: Groundwater, July-August, v.9 no.4, p. 25–38.

Davis, S. N., and DeWiest, R. J. M., 1966, Hydrogeology, New York, John Wiley and Sons, Inc., 298 p.

Henry, H. R., 1964, Interfaces between saltwater and freshwater in coastal aquifers: U.S. Geological Survey Water-Supply Paper 1613-C, p. C35.

Miller, J. A., 1984, Geohydrologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p.

Renken, R. A., 1984, The hydrogeologic framework for the Southeastern Coastal Plain aquifer system of the United States: Water Resources Investigations Report 84-4243, 26 p.

Renken, R. A., Mahon, G. L., and Davis, M. E., in press, Geometry and extent of Tertiary and Cretaceous regional aquifer and confining units in the Southeastern Coastal Plain Aquifer System of the United States: U.S. Geological Survey Hydrologic Investigations Atlas HA-701.

Schlumberger Limited, 1972, Log interpretation charts, Houston, Texas, 92 p.

U.S. Environmental Protection Agency, 1982, Underground injection control program criteria and standards: U.S. Code of Federal Regulations, Title 40, Parts 122 and 146, revised as of February 3, 1982, p. 4992.

Wait, R. L., and Davis, M. E., 1986, Hydrology and configuration of the rocks underlying the Southeastern Coastal Plain Aquifer: Water-Resources Investigations Report 86-4010.

Wyllie, M. R. J., 1963, The fundamentals of well log interpretation, New York, Academic Press, 238 p.

ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System of units (SI) and abbreviations of units

Multiply	By	To obtain
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, square (mi²)	2.590	kilometer, square (km²)
square foot per day (ft²/d)	0.0929	square meter per day (m²/d)
cubic foot per second (ft³/s)	0.02832	cubic meter per second (m³/s)
gallon (gal)	0.003785	cubic meter (m³)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m³/s)
degree Fahrenheit (°F)	°F-32)/1.8	degree Celsius (°C)

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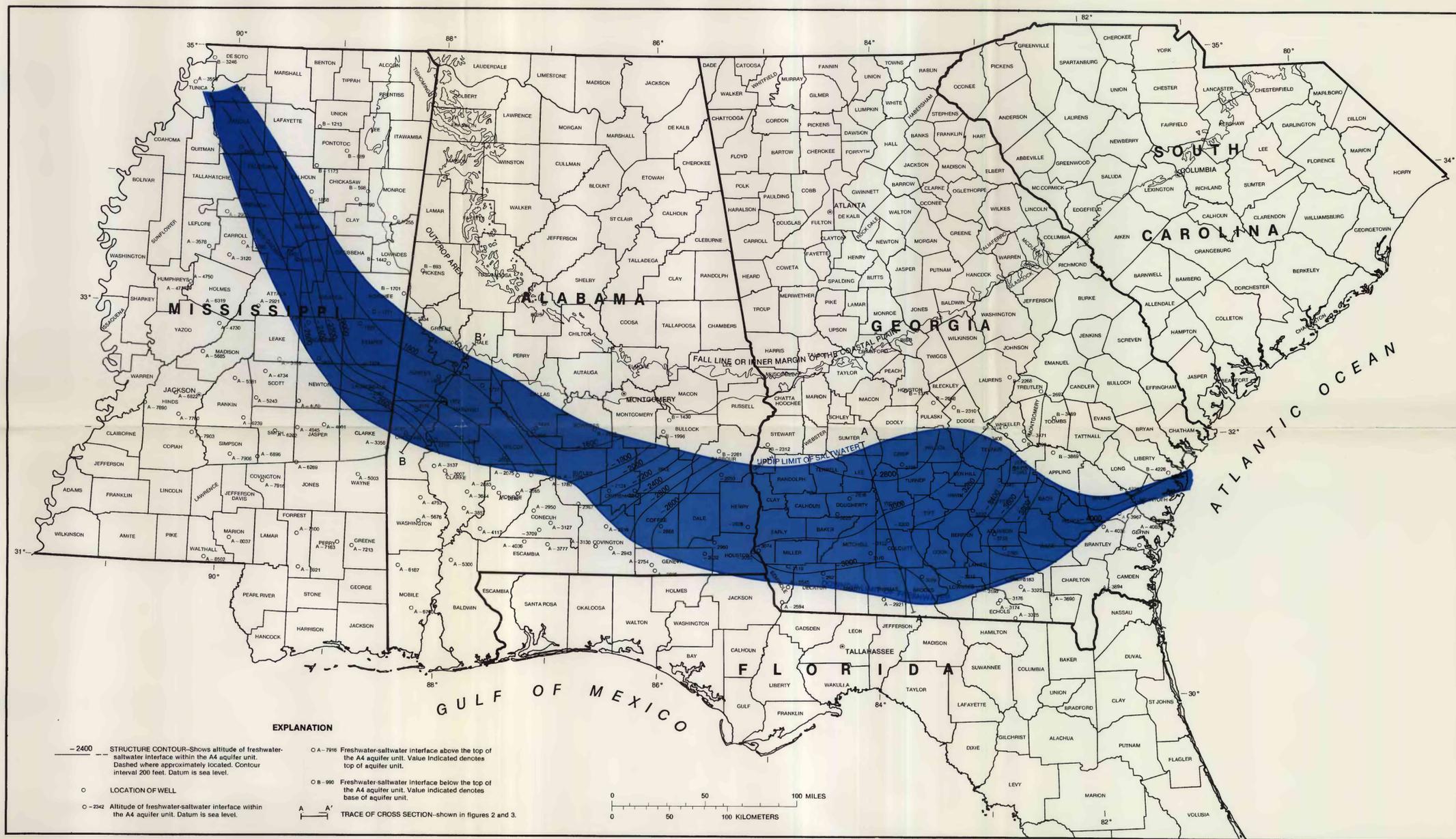

EXPLANATION

—2400— STRUCTURE CONTOUR–Shows altitude of freshwater-saltwater interface within the A4 aquifer unit. Dashed where approximately located. Contour interval 200 feet. Datum is sea level.

○ LOCATION OF WELL

○ –2342 Altitude of freshwater-saltwater interface within the A4 aquifer unit. Datum is sea level.

○ A –7916 Freshwater-saltwater interface above the top of the A4 aquifer unit. Value indicated denotes top of aquifer unit.

○ B –990 Freshwater-saltwater interface below the top of the A4 aquifer unit. Value indicated denotes base of aquifer unit.

A———A' TRACE OF CROSS SECTION–shown in figures 2 and 3.

Figure 1.–Altitude of freshwater-saltwater interface in the basal sands of Cretaceous sediments of the Southeastern United States Coastal Plain.
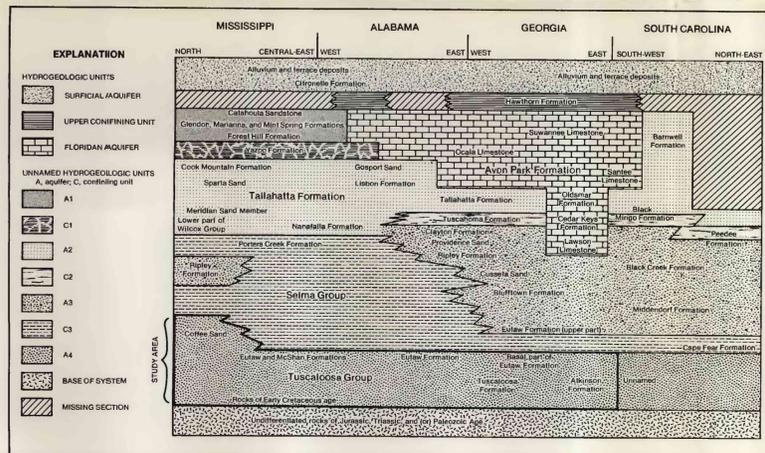

Figure 2.–Extent of study area within the Southeastern United States Coastal Plain aquifer system (modified from Renken, 1984).
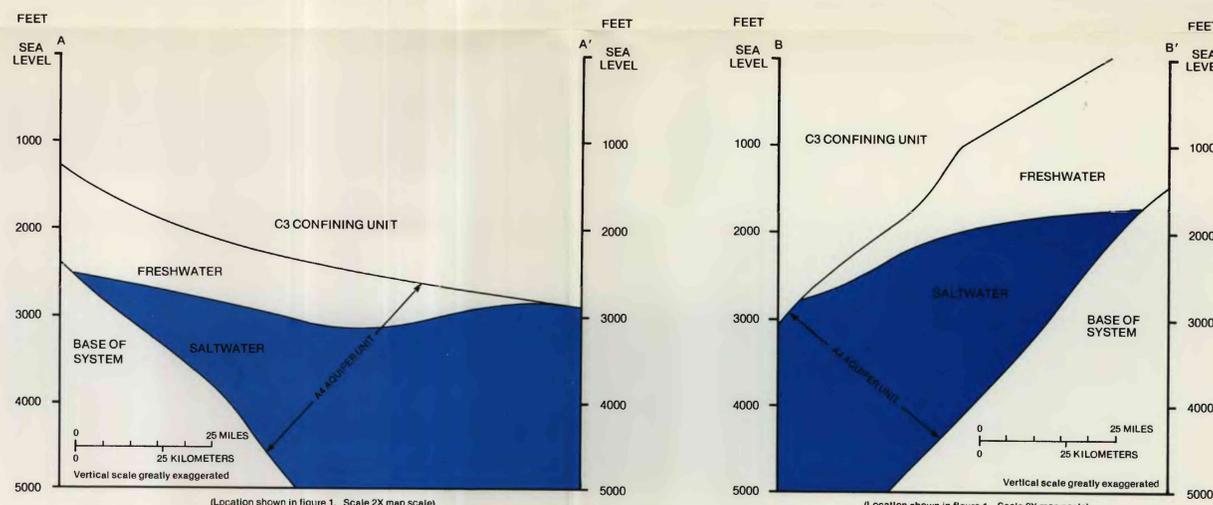

Figure 3.–Cross section A-A' showing the 10,000 milligrams per liter dissolved solids surface in the A4 aquifer unit in south-central Georgia.

Figure 4.–Cross section B-B' showing the 10,000 milligrams per liter dissolved solids surface in the A4 aquifer unit in southwestern Alabama.

ALTITUDE OF THE FRESHWATER-SALTWATER INTERFACE IN A REGIONALLY EXTENSIVE COASTAL PLAIN AQUIFER OF MISSISSIPPI, ALABAMA, AND GEORGIA

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