

# USING MARINE REFLECTION SEISMICS TO IDENTIFY POTENTIAL SEAWATER INTRUSION SITES IN THE UPPER FLORIDAN AQUIFER OF COASTAL GEORGIA AND SOUTH CAROLINA

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**Abstract.** The Upper Floridan aquifer (UFA) is the principal source of groundwater for coastal Georgia and South Carolina. A progressive increase in groundwater use since the late 1800s has resulted in a large (~30-mile radius) cone of depression on the aquifer's potentiometric surface that is centered on Savannah, GA. In coastal and inner shelf areas where the overlying Miocene aquitard is absent, the UFA is susceptible to seawater recharge. As part of the Sound Science Initiative (SSI), the Georgia Environmental Protection Division (EPD) recently funded geophysical mapping to identify those locations where the Miocene aquitard is thin or absent.

Geophysical surveys identified ten Areas of Concern (AOCs) where the UFA is susceptible to seawater intrusion. At each AOC, the aquifer is present at shallow depth, erosion has removed the aquitard, the overlying water column is saline, and the area lies within or adjacent to the Savannah cone of depression. Research results are contributing to a database of information being developed under SSI that will provide input necessary for managing groundwater resources in southeast Georgia.

## INTRODUCTION

As part of the SSI Interim Strategy for managing saltwater intrusion in the UFA, Georgia EPD is conducting a multi-year investigation into saltwater intrusion on the GA-SC coast. A significant component of this initiative concerns the identification of sites of potential seawater intrusion into the uppermost parts of the aquifer in northern coastal Georgia and southern South Carolina. The principal concern arises from downward and lateral movement of saline waters from estuaries, sounds, and shelf areas in locations where subsurface geologic structure and hydrogeologic conditions are conducive to the transport of seawater from the water column through

the seabed and into the UFA. This paper describes the application of marine seismic reflection data as a tool to facilitate this cross-disciplinary environmental study.

The UFA is a major source of high-quality groundwater for the southeastern United States and seawater intrusion into the aquifer is known or suspected to occur on parts of the GA-SC coast. This process may allow contamination of drinking water wells and degradation of groundwater quality in an area that is heavily dependent on groundwater for public supply and industrial uses. This applied geophysics study utilizes stratigraphic data from the coast and inner shelf to identify sites of potential seawater intrusion into the UFA. The research results will facilitate development of appropriate management practices and intrusion mitigation strategies for the UFA as part of ongoing and future management of water resources by the State of Georgia.

## BACKGROUND AND RELATED WORK

The study area covers about 1400 square miles of nearshore and estuarine areas between Wassaw Sound, GA, and Port Royal Sound, SC (Fig. 1). Most of the study area lies within the northeastern quadrant of the Savannah cone of depression on the UFA. The cone of depression developed, and continues to persist, because pumped groundwater cannot be replaced quickly enough through natural inflow from other parts of the aquifer; the inverted apex of the cone now lies about 100 feet below sea level (Peck et al., 1999).

The UFA consists of limestone that was deposited more than 25 million years ago and now underlies the lower coastal plain and continental shelf. In coastal GA-SC, it lies between 19 and 200 ft below mean sea level (-19 to -200 ft MSL) and ranges from 50 to 200 ft in thickness (Hughes et al., 1989; Clarke et al., 1990; Foyle et al.,

1999). Previous studies show that most groundwater used for public water supply and industrial needs in coastal GA-SC is supplied from the UFA (Krause and Randolph, 1989; Garza and Krause, 1996). The aquifer provides approximately 350 million gallons/day of water, a volume that has increased steadily since water was first pumped from the aquifer at Savannah about 115 years ago (Fanning, 1999). When groundwater is pumped out of the UFA in the coastal area, there is the potential for sea water to recharge the aquifer and move towards the pumping sites to replace the water being withdrawn.

The Miocene aquitard overlying the UFA consists mostly of sands, silts, and clays that were deposited 5 to 25 million years ago. While porous and permeable, transmissivities of the aquitard are significantly lower than those of the aquifer and the unit essentially behaves as a "cap rock" for the UFA. The aquitard can be as much as 160 ft thick, but in localized areas it can be thin or absent as a result of two natural processes and one possible anthropogenic process. Firstly, in coastal creeks and sounds, tidal currents are of sufficient strength to erode the channel bottoms and cut into or through the aquitard and expose the UFA to seawater intrusion. Some of these tidal-scour holes are as much as 70 feet deep and are potential intrusion sites in Beaufort County, SC, where the aquifer is shallow and lies on the edge of the Savannah cone of depression.

Secondly, several times over the past 2 million years, sea level was as much as 300 ft lower than it is today. During these times of lowered sea level, the most recent of which occurred about 18,000 years ago, the Savannah paleoriver and other coastal streams flowed across the exposed continental shelf to a paleo-shoreline located 60 to 80 miles seaward of where it is today. At certain points along its route, the Savannah paleoriver channel cut down into, and locally through, the aquitard. While the paleochannels have since been filled with post-Miocene sands and gravels, these younger sediments are not as efficient an aquitard as the Miocene strata. These paleochannels are potential seawater intrusion sites seaward of Hilton Head Island where the aquifer is relatively shallow and lies within the Savannah cone of depression.

Thirdly, dredging for navigation purposes in parts of the Savannah and Beaufort Rivers is a potential, but as yet undocumented, cause of seawater intrusion. Dredging has removed either the uppermost parts of the aquitard (at Savannah; U.S. Army Corps of Engineers, 1998) or the uppermost parts of the aquifer where the aquitard is already absent (at Port Royal; Hayes, 1979; Hughes et al., 1989). Fig. 2 summarizes these scenarios and illustrates that the Miocene aquitard has the greatest probability of being thinnest where the underlying UFA occurs at shallow depth and either (1) modern tidal creeks (or dredged channels) cut down into or through the Miocene (Fig. 2a) or (2) paleochannels incised during glacioeustatic lowstands of sea level cut down into or through the Miocene (Fig. 2b).

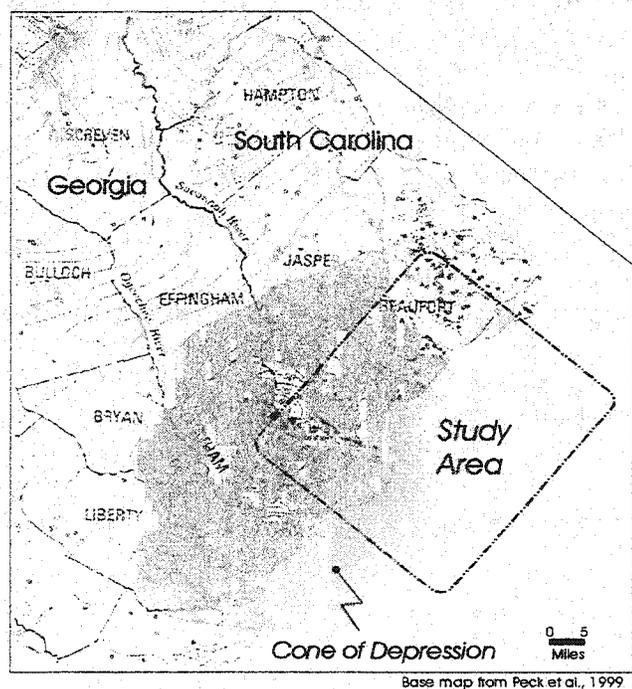


Figure 1: Study area.

## OBJECTIVE AND METHODS

### Study Objective

The principal objective of the study is to identify coastal areas where the Miocene aquitard overlying the UFA is thin or missing. In areas where the overlying water column is saline (i.e. in estuaries and on the inner shelf) and where the potentiometric head on the UFA is negative (i.e. within the Savannah cone of depression), there is enhanced susceptibility of seawater intrusion into the aquifer. The primary means of identifying these potential intrusion areas involves the use of marine seismic reflection profiling and seismic sequence stratigraphy.

### Methods

Approximately 1200 miles of sub-bottom, single-channel, seismic reflection data were collected and form the primary dataset for this investigation. Standard

methods of sequence stratigraphy were used in data interpretation (Payton, 1977; Vail, 1987). Seismic reflectors associated with major unconformities were identified at the top of the UFA and at the top of the Miocene aquitard and were used to map the thickness of the Miocene aquitard. Published borehole lithology-log and gamma-log data were used to ground-truth seismic-stratigraphic interpretations and to provide additional control in areas where seismic coverage was limited.

## RESULTS

### Aquifer Elevations

Depths to the top of the UFA range from as shallow as -19 ft MSL in the vicinity of Ladies Island north of Beaufort, S.C. (Hayes, 1979; Hughes et al., 1989), to as deep as -280 ft MSL offshore and to the southeast of Savannah. An irregular "karstic" erosional surface defines the top of the aquifer and local relief can be as much as 20 ft over horizontal distances of as little as 300 ft (1:15 slope). Throughout coastal and offshore Georgia, the aquifer everywhere lies at depths of at least -100 ft MSL. However, on the South Carolina shelf, the aquifer is locally as shallow as -48 ft MSL in an area located about 3.5 miles offshore and to the southeast of central Hilton Head Island.

### Thin-Miocene Areas

On the Georgia coast and inner shelf, seismic data indicate that the Miocene is almost everywhere thicker than 40 ft. The exception to this statement occurs at about

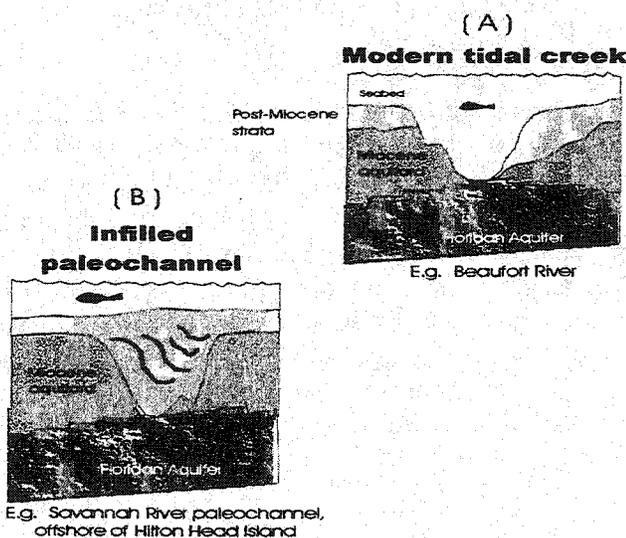
ten small localized areas on the lower Savannah River and Navigation Channel. These localized thin spots (arbitrarily defined as locations where less than 40 ft of Miocene are present) mark where buried Quaternary paleochannels occur.

The principal area of thinned Miocene strata occurs beneath the coastal and inner shelf region of South Carolina where approximately 560 square miles are underlain by less than 40 ft of Miocene. Of this area, approximately 145 square miles are underlain by less than 20 ft of Miocene and approximately 50 square miles are underlain by less than 10 ft of Miocene. Numerous no-Miocene zones also occur and are described below.

Over 50% of the thin-Miocene area (less than 40 ft of Miocene present) occurs south and southeast of the Broad River and within the northeastern quadrant of the Savannah cone of depression. Miocene strata locally crop out on the sea bed in Port Royal Sound in areas where present water depths are almost -70 ft MSL.

### No-Miocene Areas

A total of ten localized sites (AOCs) were identified where the Miocene aquitard is no longer preserved. Collectively, these ten AOCs comprise a total area of about 8 square miles and delineate where the UFA is believed to be most susceptible to seawater intrusion. However, the areal dimensions of these no-Miocene "windows" are not well constrained because the widths of several of the features are uncertain. Nine of the ten no-Miocene areas are within the northeastern quadrant of the Savannah cone of depression. At all of these sites, 10 to 55 ft of the post-Miocene non-confining unit overlies the aquifer and separates it from the seabed. The tenth and most extensive no-Miocene area, located along the axis of the Beaufort River, lies just outside the 0-ft contour on the Savannah cone of depression (see Ransom and White, 1999). At this site, the Miocene aquitard is absent for several miles along the thalweg of the Beaufort River between southern Parris Island and the town of Beaufort, SC. In this area, the UFA either crops out at the sea floor or is covered by a thin veneer (0-10 ft) of post-Miocene strata. This is the only part of the study area where the UFA was observed to be in direct contact with seawater.



## DISCUSSION

Each of the ten AOCs can be qualitatively ranked in terms of susceptibility to seawater recharge. Using an

Figure 2: Seawater intrusion scenarios.

inferred vertical permeability for the post-Miocene unit, a calculated vertical hydraulic gradient, and a normalized incision width, a modified Darcy's equation was used to calculate potential seawater recharge rates per unit width of incision zone. The ranking showed that the most susceptible site is located in Calibogue Sound southwest of Hilton Head Island, while the least susceptible site is located in the Beaufort River on the outer edge of the cone of depression. The ranking is as follows (where I = most susceptible and X = least susceptible): (I) Cooper River at Calibogue Sound, (II) Broad River near US Hwy 170 bridge, (III) Colleton River at Victoria Bluff, (IV) Confluence of May River and Bull Creek, (V) Beaufort Arch offshore Hilton Head, (VI) Beaufort Arch offshore Hilton Head, (VII) Beaufort Arch offshore Hilton Head, (VIII) Port Royal Sound at Hilton Head Island, (IX) Broad River north of Daws Island, and (X) Beaufort River north of Parris Island.

## CONCLUSIONS

Ten AOCs were identified in this study from geophysical surveys. Each AOC, when compared with areas where the Miocene aquitard is well developed, has an enhanced susceptibility to seawater intrusion because (1) the Miocene aquitard is absent, (2) the potentiometric surface for the UFA is near or below mean sea level (i.e. the potentiometric head is negative), and (3) the overlying water column is saline. The most susceptible site is located in Calibogue Sound about 17 miles from the center of the Savannah cone of depression, while the least susceptible site is located in the Beaufort River on the outer edge of the cone of depression.

The location and seawater intrusion susceptibility associated with each AOC will be utilized in aquifer monitoring and testing by state and federal agencies in order to better quantify and model the water and solute transport rates within the UFA. Approximately 5 years from now, an increased understanding of this coastal aquifer will form the sound scientific basis upon which coastal Georgia's future groundwater management plans can be constructed.

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