

# Coastal Sound Science Initiative Modeling of Salt Water Intrusion

## *Conclusions About Salt Water Intrusion Into The Upper Floridan Aquifer in Coastal Georgia and South Carolina*



# **Coastal Sound Science Initiative Modeling of Salt Water Intrusion**

## **Objectives of Salt Water Intrusion Modeling**

The modeling of salt water intrusion at Hilton Head Island, South Carolina, was conducted as part of the Coastal Sound Science Initiative (CSSI) to assist the Georgia Environmental Protection Division (EPD) and the South Carolina Department of Health and Environmental Control (DHEC) in identifying feasible options for managing the Upper Floridan aquifer with respect to salt water intrusion at the island. The model is one of several tools that can be used to support exploration and examination of technically feasible options for managing the aquifer and for future management decision-making.

In a Memorandum of Agreement (MoA) signed by the Georgia EPD and the South Carolina DHEC during October 2007 the Georgia EPD and the South Carolina DHEC agreed to undertake, in good faith, the management steps necessary to accomplish objectives in the MoA including, as required, reductions in pumping of groundwater from the aquifer. The MoA also described how salt-water intrusion modeling would be critiqued and accepted by the Georgia EPD and the South Carolina DHEC.

## **Executive Summary**

The Georgia EPD conducted the CSSI modeling of salt-water intrusion into the Upper Floridan aquifer at Hilton Head Island and the South Carolina DHEC conducted modeling of vertical downward migration of salt water through the upper confining unit and into the underlying Upper Floridan aquifer in the areas of Savannah, Georgia, and Hilton Head Island. Following are key aspects of the CSSI modeling results and of the preliminary results of vertical migration modeling:

### **Conclusions of Modeling Scenarios**

- If groundwater withdrawals continue at the current rates in the Savannah area or on Hilton Head Island, salt water will continue to move into the aquifer contaminating more water supply wells.
- Eliminating further salt-water intrusion or movement of existing salt water plumes would require greater than 90% reduction in pumping in both the Savannah area and on Hilton Head Island.
- Eliminating all large withdrawals in the Savannah area and on Hilton Head Island would not immediately remove salt-water from the aquifer. Salt water would continue to exist in the aquifer well into the future, but would begin to slowly diminish as groundwater flow reverses and discharges into Port Royal Sound.
- Groundwater withdrawals in both the Savannah area and on Hilton Head Island were needed to create the inland extent of the current salt-water plume on Hilton Head Island. The pumping in Savannah has had the greatest effect on verall plume growth beneath Port Royal Sound and southwest of the Colleton River compared to the pumping on Hilton Head Island.

## Downward Movement of Salt Water

- Pore-water analyses of samples from the upper confining unit overlying the Upper Floridan aquifer showed trends indicating downward migration of saltwater through the upper confining unit.
- The model simulation of vertical salt water migration for the year 2050 showed that downward migration of salt water will first contaminate the aquifer where the upper confining unit is thinner.
- The model of vertical salt water migration has not yet simulated what impacts downward migration of saltwater through the upper confining unit could have on the overall quality of groundwater in the Upper Floridan aquifer at water supply wells.

## Methods of Salt water Intrusion Modeling

The Georgia EPD conducted modeling to reasonably match 2007 chloride contours on Hilton Head Island, Pinckney Island, and in the area of the Colleton Island generated by the South Carolina DHEC. The modeling included the following general steps:

- The CSSI salt water intrusion model was refined from the Savannah Harbor Expansion (SHE) model developed for the U.S. Army Corps of Engineers Savannah District
- The area of highest node density in the SHE model was shifted from the Savannah River channel to Hilton Head Island
- A Middle Floridan aquifer layer was added to the model beneath Hilton Head Island
- Horizontal and vertical hydraulic conductivities (permeabilities) of the aquifers and confining units were modified to better-match field permeability measurements

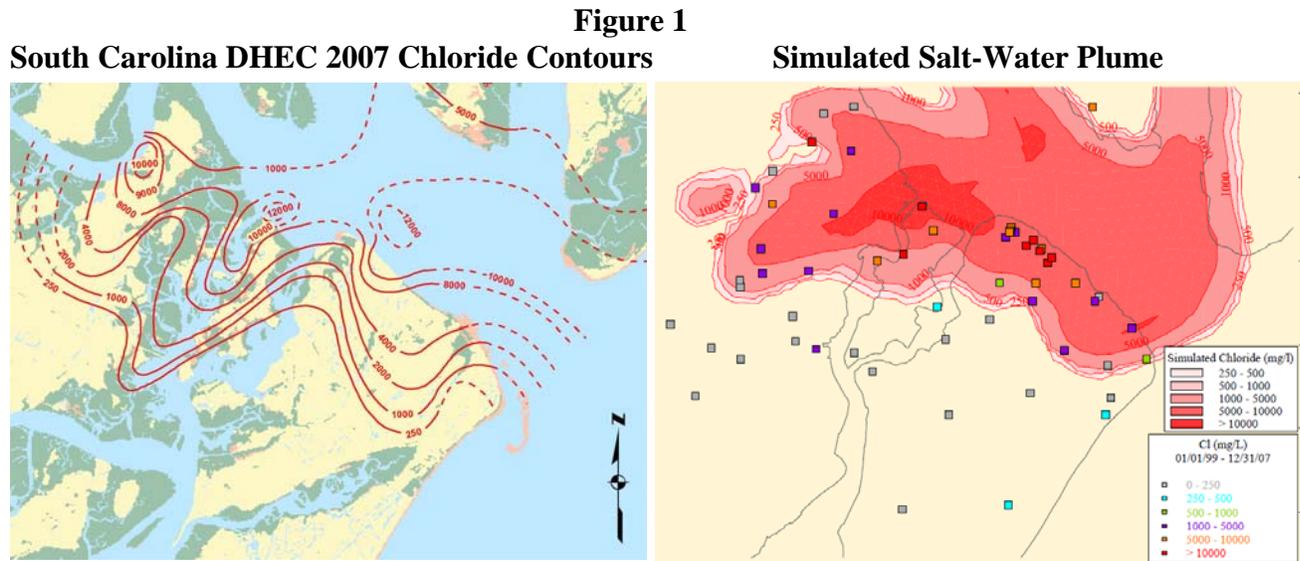
The groundwater flow portion of the model was calibrated for steady state and transient conditions. The calibration was done using baseline groundwater withdrawals considered to be the most appropriate spatial and temporal values that would not over express the impacts of withdrawals on salt water intrusion. The baseline withdrawals were:

- 69 million gallons per day (MGD) during 2000 in the area of Savannah, Georgia
- 9 MGD during 2007 on Hilton Head Island

The 2000 data for the Savannah area were the most complete on pumping locations and rates and the 69 MGD withdrawal was close to the withdrawal during 2007. The 2000 withdrawal from Hilton Head Island was not used because it was about 14 MGD and could have caused the model to over-predict effects of withdrawals on Hilton Head Island. Therefore the smaller 2007 withdrawal from Hilton Head Island was used in the model.

The flow portion of the model was calibrated by adjusting hydraulic properties of the aquifers and confining units until simulated steady state potentiometric surfaces and simulated transient well hydrographs closely matched water levels measured in wells on Hilton Head Island and in the Savannah area. Simulated historical potentiometric surfaces closely matched historical potentiometric surfaces in published literature.

The simulated salt-water plume was calibrated against 2007 chloride contours provided by the South Carolina DHEC. Figure 1 shows the South Carolina DHEC 2007 chloride contours and the simulated initial plume. The contours and plume were shown to a chloride concentration of 250 milligrams per liter (mg/L), the secondary maximum contaminant level for chloride in drinking water. Simulated time-sequence movements of the salt-water plume closely matched historical measurements of plume movement. The model closely replicated when the salt-water plume arrived at wells on Hilton Head Island and the range of chloride concentrations at the wells.



The model was critiqued by means of a Technical Advisory Committee (TAC) that included representatives from the Georgia EPD, the South Carolina DHEC, and the South Carolina Department of Natural Resources. The Georgia EPD and the South Carolina DHEC approved the model before it was used to simulate initial options for aquifer management and future management decision-making. The TAC accepted calibration of the simulated salt-water plume during September 2009.

**Simulation of Theoretical Plume Movement**

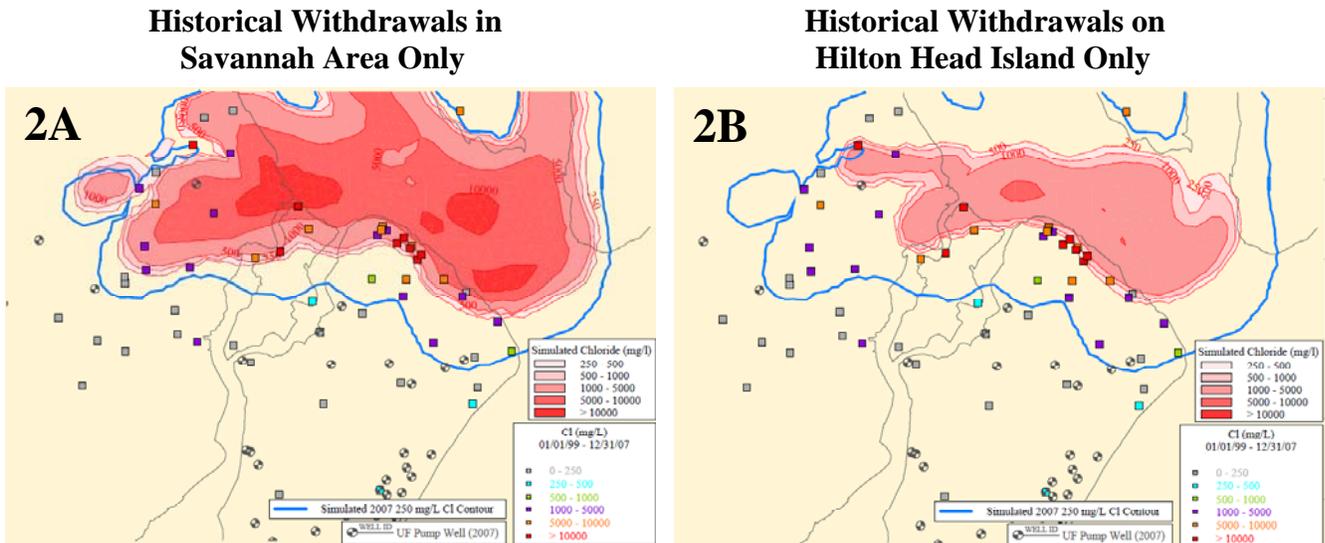
The refined calibrated model was used to simulate two theoretical salt-water plumes by 1) maintaining historical withdrawals in the Savannah area with no withdrawals on Hilton Head Island (Figure 2A), and 2) no withdrawals in the Savannah area and maintaining historical withdrawals on Hilton Head Island (Figure 2B).

With historical withdrawals only in the Savannah area the theoretical plume closely matched the simulated initial plume, shown by the blue lines on Figures 2A and 2B, on the northern side of Port Royal Sound and southwest of the Colleton River. The theoretical plume did not extend as far inland on the northern end of Hilton Head Island as the blue line.

With withdrawals only on Hilton Head Island the theoretical plume did not extend as far north and southwest as the blue line and overall chloride concentrations were smaller. This was

because historical withdrawals on Hilton Head Island were at lower rates and for a shorter period than historical withdrawals in the Savannah area. The theoretical plume did not extend as far inland on the northern end of the island as the blue line.

**Figure 2**



Neither of the theoretical salt-water plumes extended as far inland on the northern end of Hilton Head Island as the South Carolina DHEC 2007 chloride contours or the simulated initial plume. The theoretical salt-water plumes simulated using independent historical groundwater withdrawals did not recreate the chloride contours shown in Figure 1 indicating that historical withdrawals in the Savannah area Hilton Head Island acted together to create the South Carolina DHEC 2007 chloride contours and the simulated initial plume. Withdrawals in both the Savannah area and on Hilton Head Island were needed to create the inland extent of the plume on the northern end of the island indicated by the South Carolina DHEC 2007 chloride contours and the simulated initial plume.

### Simulation of Aquifer Management Scenarios

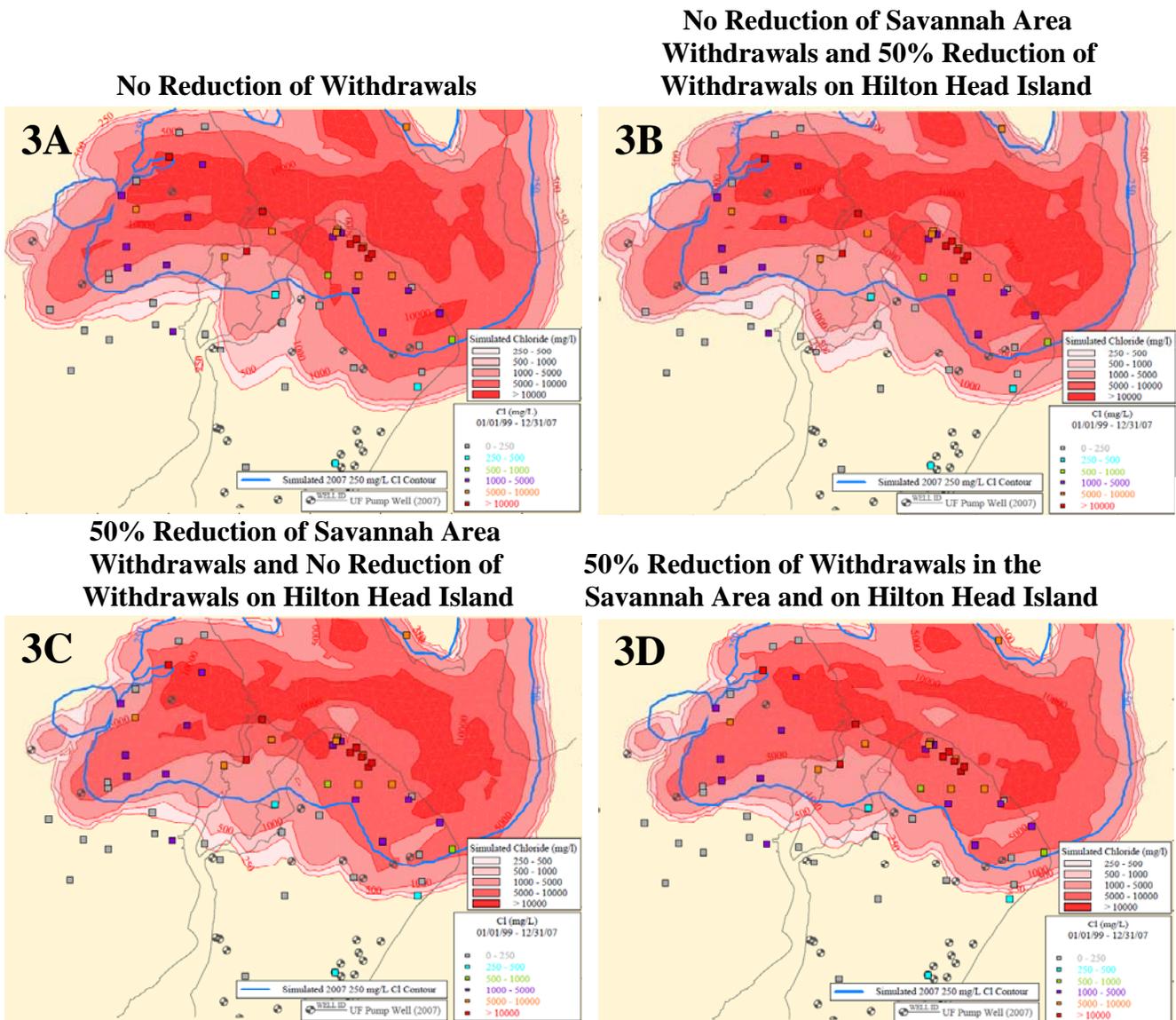
Simulations of possible future aquifer management scenarios were run using the refined calibrated model. The simulated plume shown in Figure 1 was used as the initial plume for the management scenario simulations. Each simulation was for a time of 30 years after the initial plume simulation.

Simulated management scenarios included four combinations of reductions of baseline groundwater withdrawals. Results of the management scenario simulations are shown on Figure 2. The following management scenarios were simulated:

- No reduction of withdrawals in either the Savannah area or on Hilton Head Island (Figure 3A)
- No reduction of withdrawals in the Savannah area and a 50 percent reduction of withdrawals on Hilton Head Island (Figure 3B)

- A 50 percent reduction of withdrawals in the Savannah area and no reduction of withdrawals on Hilton Head Island (Figure 3C)
- A 50 percent reduction of withdrawals in both the Savannah area and on Hilton Head Island (Figure 3D)

**Figure 3**



The scenario simulations indicated that with no reduction of groundwater withdrawals in either the Savannah area or on Hilton Head Island the simulated 30-year plume extended further inland on the northern end of Hilton Head Island and further southwest from the Colleton River than the initial simulation. With a 50 percent reduction of withdrawals in both the Savannah area and on Hilton Head Island the simulated 30-year plume still extended further inland on the northern end of Hilton Head Island and further southwest from the Colleton River than the initial simulation, though not as far as the simulation with no reduction of groundwater withdrawals.

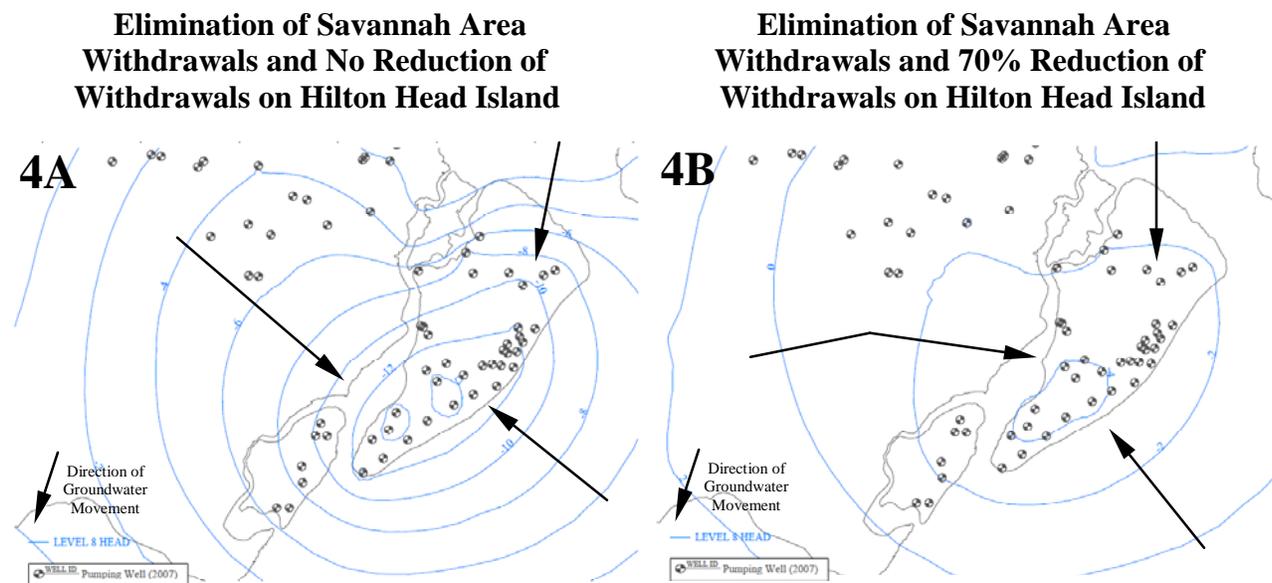
Extents of the simulated 30-year plumes for the other two scenario simulations were between the extents of simulated plumes with no reduction of groundwater withdrawals and with 50 percent reductions in both the Savannah area and on Hilton Head Island. Even with 50 percent reductions of withdrawals in both the Savannah area and on Hilton Head Island the simulated 30-year plume captured pumping water supply wells not currently impacted by salt water.

Additional metrics of salt water plume movement under the various management scenarios included the total mass of chloride in the Upper Floridan aquifer at Hilton Head Island and the total volume of groundwater with a chloride concentration greater than 250 mg/L. While the simulated rates at which the metrics increased got smaller as simulated withdrawals were reduced, the metrics continued to increase even with 50 percent reductions of withdrawals in both the Savannah area and on Hilton Head Island.

The refined calibrated model was used to simulate hydraulic heads on Hilton Head Island under the following conditions:

- Elimination of withdrawals in the Savannah area and no reduction of withdrawals on Hilton Head Island (Figure 4A)
- Elimination of withdrawals in the Savannah area and a 70 percent reduction of withdrawals on Hilton Head Island (Figure 4B).

**Figure 4**



Each simulation showed that with elimination of groundwater withdrawals in the Savannah area groundwater movement would be toward a cone of depression on Hilton Head Island. With groundwater movement toward a cone of depression on the island salt-water intrusion would continue to impact water supply wells. Even with no withdrawals in the Savannah area and a 70 percent reduction of withdrawals on Hilton Head Island to 2.7 MGD the direction of groundwater movement and salt water would be toward water supply wells and groundwater

movement would not be toward Port Royal Sound and the Atlantic Ocean as it was before the aquifer was developed.

The results of CSSI modeling of salt-water intrusion indicated that almost any groundwater withdrawals in the Savannah area or on Hilton Head Island would cause salt water to continue to move into the Upper Floridan aquifer and toward water supply wells. Decreasing groundwater withdrawals could reduce the movement of salt water into and within the aquifer but would not eliminate salt-water intrusion.

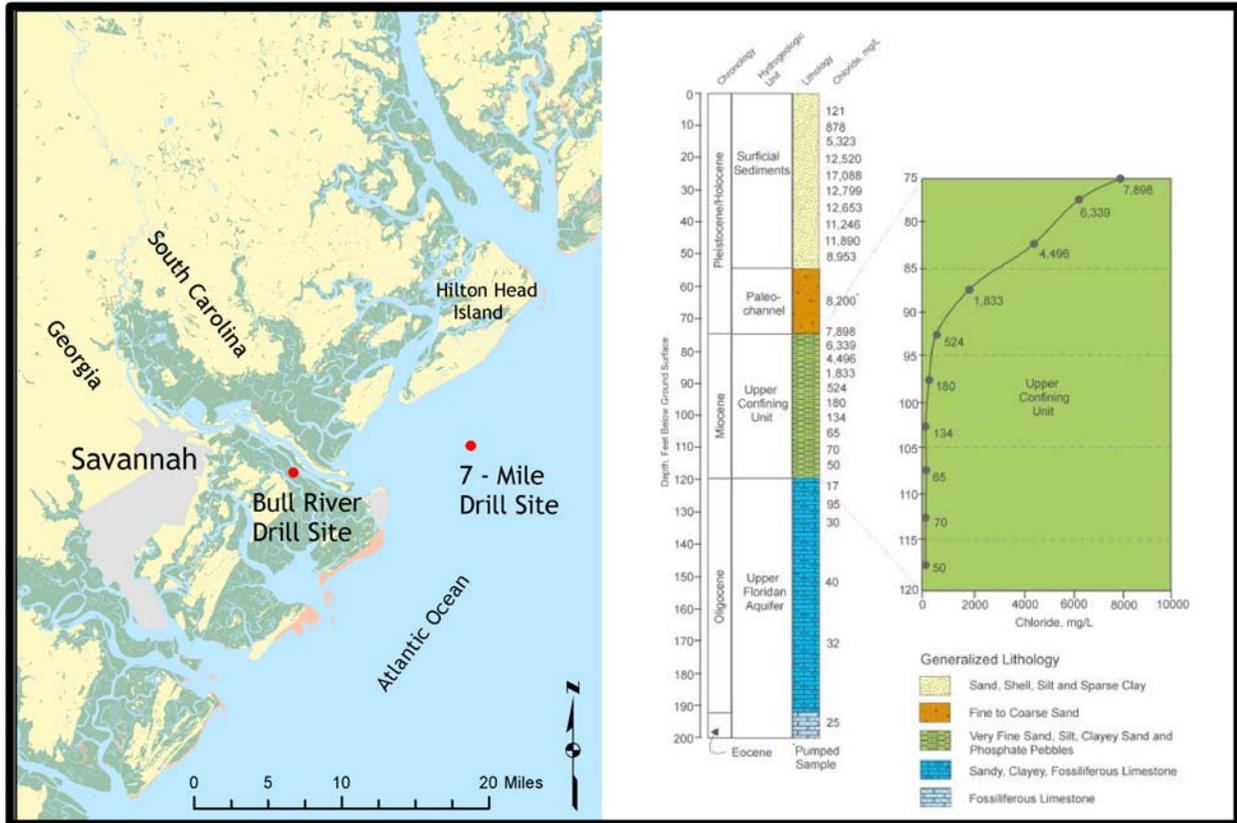
Previous CSSI salt-water intrusion modeling conducted by the U.S. Geological Survey indicated that even if all withdrawals in the Savannah area and on Hilton Head Island were eliminated salt-water plumes would continue to exist well into the future. One simulation showed that a salt-water plume would remain on the northern end of Hilton Head Island in 2104 even with elimination of withdrawals in both the Savannah area and on Hilton Head Island.

### **Simulation of Vertical Migration of Salt Water**

Saltwater is also migrating downward from surface sources through the upper confining unit and into the underlying Upper Floridan aquifer; surface sources include those areas overlain by saltwater marshes, tidal channels, and the Atlantic Ocean. The process of downward migration of saltwater from surface sources occurs within the cone of depression where the potentiometric surface is at or below mean sea level and includes an area of approximately 1,200 square miles.

Pore water was extracted from cores at two locations in the study area to obtain direct measurements of chloride concentrations (saltwater) in the sediments at selected depths. The first site (well BFT-2249) was located 7 miles offshore from Tybee Island, Georgia, and a second site was located onshore near Bull River between Tybee Island and the center of pumping at Savannah (Figure 5). Pore-water analyses showed a trend of high chloride concentrations near the top of the upper confining unit that decreased with depth at both the offshore and onshore locations indicating downward migration of saltwater through the upper confining unit (Figure 5). A previous model showed that the downward migration of saltwater was taking place over a large area.

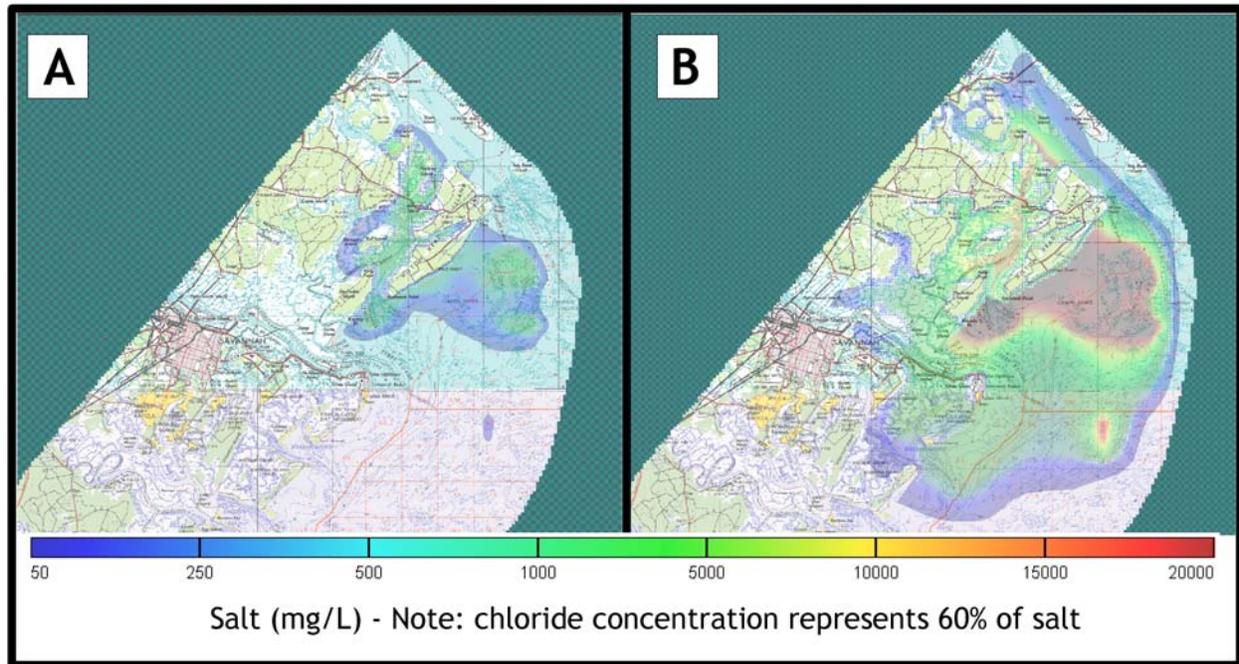
**Figure 5**  
**Map Showing Location of Drill Sites and the Vertical Chloride Profile From Pore Water Analyses at the Bull River Drill Site**



In 2009, a more complex model for the Savannah – Hilton Head Island area was completed by the South Carolina DHEC in cooperation with the City of Savannah and the Beaufort – Jasper Water & Sewer Authority. The three-dimensional numerical model is designed to simulate downward saltwater migration through the upper confining unit to (1) investigate the occurrence, distribution, and rate of downward migration of saltwater through the upper confining unit and into the Upper Floridan aquifer, and (2) to present projections through the year 2050.

The model simulation for the year 2050 showed that the areas of greatest saltwater contamination in the Upper Floridan aquifer occurred where the upper confining unit was thinnest (Figure 6A). Thinning of the unit is related to a geologic feature created by tectonic uplift known as the Beaufort Arch. The Beaufort Arch is an area of uplifted sediments that exposed the upper confining unit to erosion covering an area extending from the northern areas of Hilton Head Island, to the south near Tybee Island, and offshore east of Hilton Head Island. Saltwater migrating downward will first contaminate the aquifer where the upper confining unit is thinner, but other areas will be impacted later as the upper confining unit becomes saturated with increasing concentrations of saltwater throughout the Savannah – Hilton Head Island area. Figure 6B shows the estimated concentration of saltwater midway through the upper confining unit for the year 2050.

**Figure 6**  
**Model Simulation for the Year 2050 Simulating Saltwater in the (A) Upper Floridan Aquifer and (B) Midway Through the Upper Confining Unit Management**



## Conclusions

If no action is taken, salt water intrusion into the aquifer will continue, both horizontally and downward through the confining unit, resulting in larger salt water plumes that may make options for management of the aquifer more difficult in the future. Management options were not evaluated in the modeling conducted to date. Evaluations of options for managing the aquifer with respect to salt water intrusion, including options with reductions in pumping and the establishment of hydraulic barriers (e.g., injection of fresh water, removal of salt water) on Hilton Head Island, should quantify the short and long term costs and benefits of each management option. Options evaluated should also consider mitigating the effects of the vertical movement of salt water into the aquifer.