PRELIMINARY NUMERICAL MODELS OF SALTWATER TRANSPORT IN COASTAL GEORGIA AND SOUTHEASTERN SOUTH CAROLINA

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Abstract. Two preliminary saltwater transport models of the Savannah, Georgia—Hilton Head Island, South Carolina area and the Brunswick area were developed as part of a cooperative investigation by the U.S. Geological Survey (USGS) and the Georgia Department of Natural Resources, Environmental Protection Division (GaEPD) to assist the GaEPD in the development of management strategies for coastal ground-water resources. The Savannah-Hilton Head Island model was designed to test the effect of concentrated pumping on the steady-state, offshore, saltwater-freshwater interface. Results show that saltwater moves laterally from offshore and vertically downward through the confining unit toward the pumping site on a scale of 100,000 years. The Brunswick model was designed to test the movement of saltwater along a complex flow path toward a pumping well. Results show that saltwater moves upward from the source at depth through a vertical conduit, then laterally across the aquifer unit toward the pumping center, while mixing with freshwater. Future models will be refined to more accurately represent actual conditions.

INTRODUCTION

The Upper Floridan aquifer is the primary ground-water resource in coastal Georgia and adjacent parts of South Carolina and Florida; the aquifer is extremely permeable and high-yielding. Saltwater has encroached into the Upper Floridan aquifer on the northern end of Hilton Head Island, S.C.; and a saltwater plume exists in the Upper Floridan aquifer beneath downtown Brunswick, Ga., as a result of pumping and consequent reduction in hydraulic head. At some locations, the Upper Floridan aquifer contains dissolved chloride concentrations exceeding the U.S. Environmental Protection Agency secondary maximum contaminant level of 250 milligrams per liter (mg/L) (U.S. Environmental Protection Agency, 1994).

As part of the Georgia Coastal Sound Science Initiative, the USGS, in cooperation with the GaEPD, is developing numerical models of the regional ground-water flow system and intrusion of saltwater in coastal Georgia and South Carolina to: (1) better define mechanisms of ground-water flow and saltwater intrusion in the Floridan aquifer system, and in aquifer units that affect the Floridan aquifer system or that may be considered as alternative ground-water supplies; (2) delineate paths and rates of ground-water flow and changes in chloride concentration in water in the Upper Floridan aquifer; and (3) evaluate various water-management scenarios that may alleviate saltwater contamination.

Preliminary saltwater transport models in the Savannah—Hilton Head Island and Brunswick areas are part of the first phase of the modeling program that will include development of a regional flow model and refined, predictive models of the focus areas. The preliminary models are designed to generally test the sensitivity to model input and boundary conditions, and the physical controls on the system. Results of the preliminary models are presented herein.

Approach

Saltwater transport models of the Savannah, Ga.–Hilton Head Island, S.C., area and Brunswick, Ga., area are being developed using the SUTRA3D simulator, a three-dimensional version of the SUTRA program (Voss, 1990). A concurrently developed regional-scale flow model will provide boundary conditions for and encompass these two smaller-scale models. SUTRA3D is a three-dimensional variable-density finite-element model that simulates density-dependent saturated-unsaturated ground-water flow and transport of a solute in ground water. SUTRA3D calculates fluid pressures and solute concentrations as they vary with time. These preliminary models are not calibrated and should not be used to evaluate saltwater movement. Subsequent models will be refined from the preliminary models, calibrated, and used to test the effects of various management scenarios.

Savannah-Hilton Head Island Model

Chloride concentration in ground water in the Upper Floridan aquifer beneath Port Royal Sound—north of Hilton Head Island—indicates that saltwater has intruded into the aquifer (Smith, 1988). Recent unpublished chloride concentrations in the aquifer on the north end of the island suggest that saltwater is moving south toward Hilton Head Island (Camille Ransom III, South Carolina Department of Health and Environmental Control, oral commun., 2000). Withdrawal of water from the Upper Floridan aquifer in the Savannah area since the late 1800's has resulted in the development of a large cone of depression in the potentiometric surface that extends from Savannah northeastward across Hilton Head Island. This situation, combined with pumping on Hilton Head Island, has resulted in reversal of the normally seaward hydraulic gradients (fig. 1). Offshore of the Savannah-Hilton Head Island area, erosion has partially or completely removed the confining unit overlying the Upper Floridan aquifer (Vernon Henry, Clark Alexander, and Anthony Foyle, Georgia Southern University, written commun., 1999) exposing the aquifer directly to seawater. These conditions allow seawater to enter the aquifer and migrate laterally downgradient toward pumping centers (fig. 1).

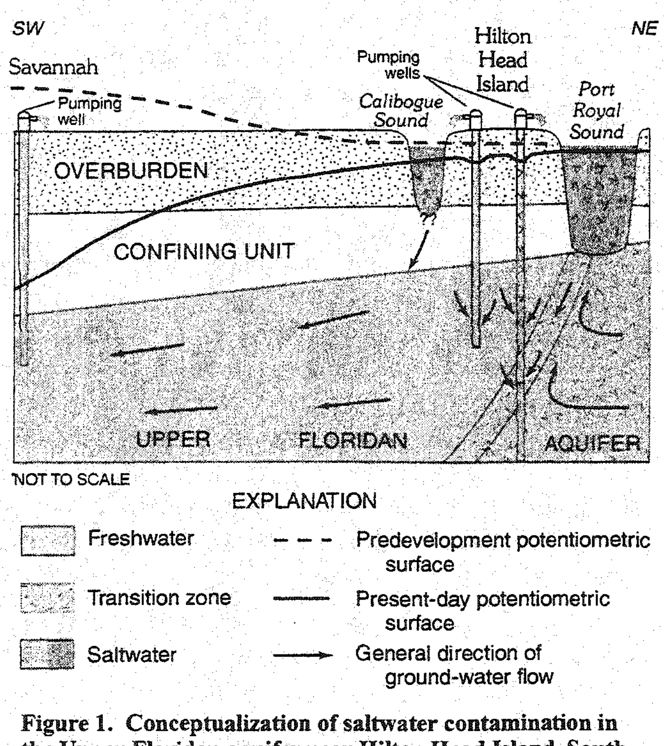

Figure 1. Conceptualization of saltwater contamination in the Upper Floridan aquifer near Hilton Head Island, South Carolina (R.E. Krause, written commun., 2000).

The saltwater transport model for the Savannah-Hilton Head Island area represents five aquifers and three confining units, and includes Chatham and surrounding Counties in Georgia and South Carolina and the adjacent offshore area—an area of approximately 11,000 square miles (mi^2). The model vertically represents aquifer units with five cell layers and confining units with three cell layers. Horizontally, each layer consists of 40 rows by 35 columns of cells. Intrinsic permeability values assigned to the layers range from 10^{-16} feet squared (ft^2) for the confining units, to 10^{-9} ft^2 for the aquifer units. The hydraulic boundary conditions are as follows: the bottom boundary is no flux; the top offshore boundary is hydrostatic seawater; the top onshore boundary is atmospheric or zero pressure; the northwest vertical boundary is hydrostatic freshwater; the southeast vertical boundary is hydrostatic seawater; and the southwest and northeast vertical boundaries are no flux. A stress is applied to three vertical cells representing a pumping site that withdraws 80 million gallons per day (Mgal/d) from the Upper Floridan aquifer at Savannah. This preliminary model is designed to test the effect of concentrated pumping on the steady-state offshore saltwater-freshwater interface and is not intended to simulate actual conditions.

The model was run to simulate steady-state conditions prior to development, and transient conditions after 100,000 years of pumping. The steady-state simulation was used as the initial condition for transient simulations. Preliminary modeling results after simulated pumping for 100,000 years simulation time from the initial condition are shown in figure 2. For the preliminary model, this time scale is required to move the saltwater-freshwater interface to the pumping site. Over the course of the simulation, the saltwater-freshwater interface migrates toward the Savannah pumping center as saltwater moves both laterally from the offshore steady-state position and downward through the confining unit. The preliminary model was designed with a grid resolution that does not capture local areas where the confining unit above the Upper Floridan aquifer is thin or has been eroded. In spite of this, the simulated saltwater intrusion is partly the result of downward vertical transport of seawater through the confining unit. As the model is refined, these areas of thinning confining unit will be more precisely and accurately simulated, and it is expected that these will act as more direct conduits for seawater entry into the Upper Floridan aquifer, and thus decrease the time scale of saltwater intrusion.

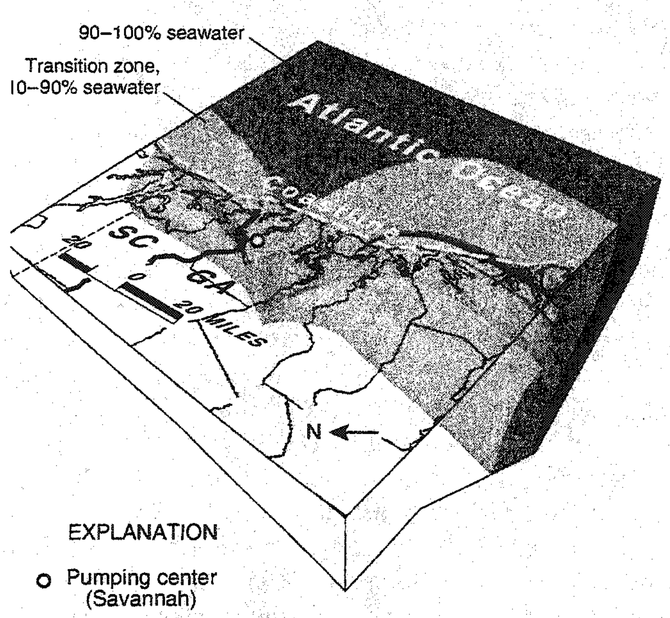

Figure 2. Preliminary modeling results, Savannah-Hilton Head Island model, after simulated pumping for 100,000 years.

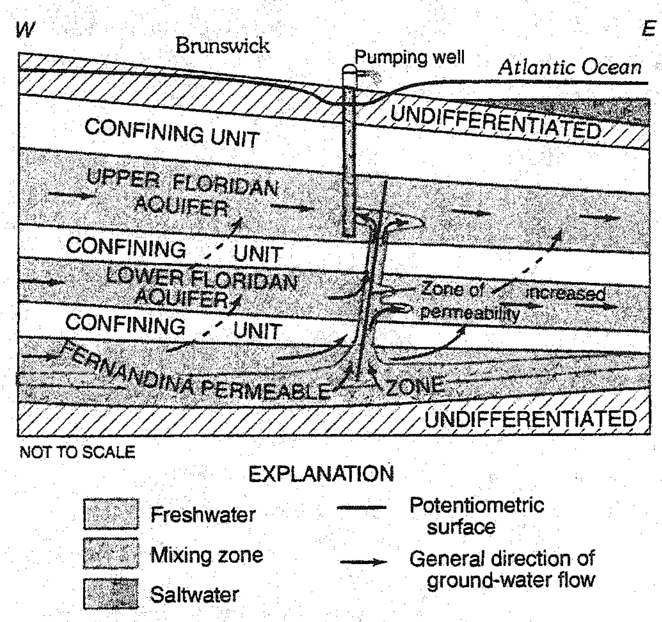

Figure 3. Conceptualization of saltwater contamination in the Floridan aquifer system at Brunswick (R.E. Krause, written commun., 2000).

Brunswick Model

Beneath downtown Brunswick, the occurrence of saltwater in the Upper Floridan aquifer has been known for several decades (Krause and Randolph, 1989). Water from about 2,400 feet below land surface in the lower part of the Lower Floridan aquifer (Fernandina permeable zone) has chloride concentrations greater than 30,000 mg/L, suggesting that this is brine or connate water and is a likely source of saltwater in the Upper Floridan aquifer at Brunswick (Krause and Randolph, 1989). The presence of steeply dipping fractures and zones of abundant solution features in the Floridan aquifer system in one of these wells (Maslia and Prowell, 1990) suggests that saltwater is transported vertically upward into the Upper Floridan aquifer from depth (fig. 3). The geometry and distribution of possible conduits that allow saltwater to move upward are poorly defined in this area, limiting the model's ability to accurately predict future movement of the plume. The model, however, may be used to test conceptual models for the area.

The saltwater transport model for the Brunswick area represents four hydrologic units and covers an area of about 50 mi^2 encompassing downtown Brunswick. The model is discretized into 19 cell layers, with increased cell layer density in the Upper Floridan aquifer. A narrow vertical zone of increased permeability extends from the lowermost unit into the upper aquifer unit; inclusion of this feature in the model roughly simulates conduits probably present in the Floridan aquifer system (Maslia and Prowell, 1990). In plan view, the model area is discretized into 437 cells with increased cell density in the vertical zone of increased permeability. Intrinsic permeability values assigned to the layers range from 10^{-16} ft^2 in the confining units to 10^{-10} ft^2 in the Upper Floridan aquifer. The vertical zone of increased permeability is represented by five closely spaced rows of cells assigned a permeability of 10^{-7} ft^2. Vertical boundaries are all hydrostatic for freshwater conditions for the upper three units, and for saltwater conditions at the sides of the lowermost unit. The top and bottom boundaries are no-flux. These boundaries allow the lowermost unit to supply unlimited saltwater, and the other units to supply unlimited freshwater. Initially, the lowermost unit contains saltwater (35,000 mg/L total dissolved solids), and the other units contain freshwater. The model simulates 36 and 9 Mgal/d withdrawal from the Upper Floridan aquifer at two locations in downtown Brunswick. This model is designed to test the movement of saltwater along a complex flow path toward a pumping well, and is not intended to accurately represent all aspects of the flow system.

After a 47-year simulated pumping period, the saltwater in the lowermost unit mixes with freshwater as the saltwater migrates upward through the vertical zone of increased permeability, then laterally within the Upper Floridan aquifer toward pumping centers (fig. 4). The total dissolved-solids concentration of the water reaching the pumping center is 250 mg/L. The lower-most unit continues to supply saltwater, so as pumping continues, the saltwater continues to follow the indirect path toward the pumping sites. Despite the uncertainty in the geometry and transport properties of the zones of increased permeability, these preliminary results suggest that this conceptual model may result in the type of saltwater contamination observed at Brunswick.

DISCUSSION

These models are preliminary—future models will require considerable refinement of input data and model construction. Boundary conditions will need to be refined by imposing flow conditions calculated from a larger, regional-scale flow model that encompasses the areas in the saltwater transport models. More accurate and precise distributions of aquifer properties will need to be assigned, as appropriate. Once developed, the models will be calibrated against water-level and chloride-concentration data within acceptable ranges of uncertainty. Finally, changes in water level and chloride concentration may be estimated based on scenarios of future changes in pumping rates or aquifer-management practices.

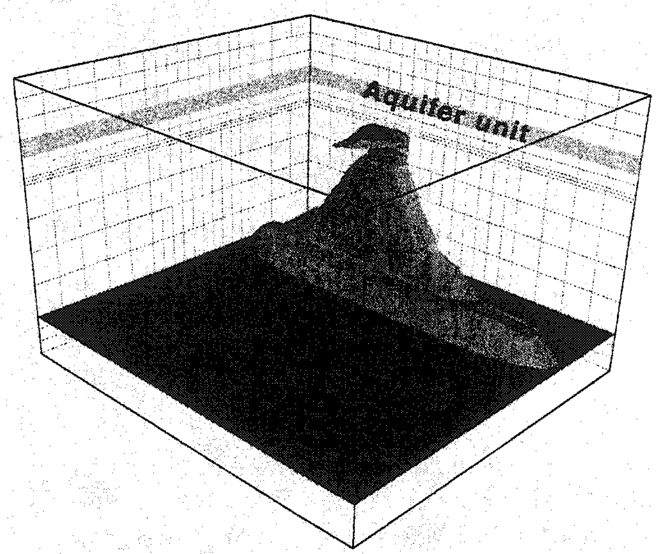

Figure 4. Preliminary modeling results, Brunswick model, after simulated pumping for 47 years. The gray isosurface represents approximately 250 mg/L total dissolved solids.

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