GROUND-WATER AVAILBILITY IN THE ATLANTIC COASTAL PLAIN AQUIFERS OF NORTH AND SOUTH CAROLINA

Bruce G. Campbell[1] and Alissa L. Coes[2]

AUTHORS: [1]Hydrologist, U.S. Geological Survey, 720 Gracern Rd., Suite 129, Columbia, SC, 29210, SC bcampbel@usgs.gov; and [2]Hydrologist, U.S. Geological Survey, Arizona Water Science Center, 520 North Park Avenue, Suite 221, Tucson, AZ 85719-5035

REFERENCE: *Proceedings of the 2008 South Carolina Water Resources Conference*, held October 14-15, 2008, at the Charleston Area Event Center

Abstract. The hydrologic system of the Coastal Plain of North Carolina and South Carolina and parts of Georgia and Virginia was evaluated in order to update and combine two existing regional ground-water models that simulate ground-water flow and water-use in the aquifers of the study area. Revision of the models was deemed necessary because additional hydraulic, geologic, water-level, and water-use data are available for use in model calibration, and hydrogeologic inconsistencies at the North Carolina – South Carolina border have been reconciled since the development of the previous models. Revision of the flow model includes active simulation of the Coastal Plain aquifer system within the study area and incorporation of hydraulic properties, water-level and water-use data, and river base-flow data acquired since the previous investigations.

Overall, ground-water availability within the Atlantic Coastal Plain aquifers of North and South Carolina is good. Locally, the ground-water flow system is modified by drawdowns from pumping centers but high-quality ground water is available from one or several aquifers at most locations within the Coastal Plain.

Introduction

The Coastal Plain of North Carolina and South Carolina encompasses approximately 42,500 square miles and is part of the Atlantic Coastal Plain Physiographic Province. The study area extends from the Fall Line, the northwestern extent of the Province, to areas offshore that contain fresh ground water (fig. 1). The Coastal Plain is underlain by seaward-thickening layers of unconsolidated to poorly consolidated gravel, sand, and clay, with lesser amounts of marine limestone. These geologic layers form a layered hydrogeologic system consisting of aquifers composed of permeable sand or limestone separated by confining units of silt, clay, or low-permeability limestone.

Ground-water withdrawals from Atlantic Coastal Plain aquifers in North Carolina (NC) and South Carolina (SC) have increased over the past 100 years in response to demands for water from a rapidly increasing population. In 2000, the combined populations of Coastal Plain counties in NC and SC totaled nearly 6 million people, with 3.2 million located in NC and 2.5 million in SC (U.S. Census Bureau, 2007). These respective populations represented about 40 percent of the total population in NC and about 63 percent of the total population in SC. Overall, the populations of both States increased rapidly between 1990 and 2000. In NC, the population increased during this decade by 21.4 percent from 1990-2000 (Perry and Mackun, 2001) and is projected to increase another 13.7 percent by 2015 (Campbell, 1997). The numbers are similar in SC where the population increased by 15.1 percent from 1990 to 2000 (Perry and Mackun, 2001) and is projected to increase 13.2 percent by 2015 (Campbell, 1997). While

Figure 1. Location Map of the Atlantic Coastal Plain of North and South Carolina.

both NC and SC endeavor to increase development of surface-water supplies to meet increasing demands in coastal communities, both States recognize the need for additional information regarding ground-water supplies. For instance, the effects of ground-water withdrawals on the quantity of freshwater discharge to streams, estuaries, and wetlands are unknown. Further complicating these issues are regional concerns about saltwater intrusion, which is already occurring in some areas along the SC coast.

Inadequate ground-water supplies and declining water levels have been a problem locally in the Coastal Plain of NC and SC since the early 1900s. The Charleston aquifer was used to supply water to the Charleston, SC, area from 1879 until water levels and production began to decline in the 1920s when Charleston was forced to abandon use of the aquifer and switch to a surface-water source to ensure sufficient water supply for its increasing population.

In response to declining water levels, SC instituted Capacity Use Areas (CUA). In 1979, a CUA was established in the Myrtle Beach, SC, area because of 200-foot drawdowns from predevelopment levels in the Black Creek aquifer. In 1981, the Hilton Head, SC, area was designated as a CUA because of a 130-foot-deep cone of depression centered at Savannah, Georgia (GA), which is thought to contribute to saltwater intrusion in the Upper Floridan aquifer (Payne and others, 2005). More recently, in 2002, the Charleston, SC, area was designated as a CUA because of 180-foot drawdowns in the Charleston aquifer.

The 1998-2002 drought experienced in the eastern United States further exacerbated the declining water levels. During the drought, ground-water levels in the Coastal Plain of the Carolinas declined to some of the lowest levels on record.

Increased ground-water withdrawals related to population growth and drought-related conditions have emphasized the need for accurate, detailed information describing the ground-water resources in the Coastal Plain region. In this study, two existing U.S. Geological Survey (USGS) models for NC and SC (Aucott, 1988, 1996; Giese and others, 1997) have been combined and updated. The new model provides a valuable tool to assess ground-water availability in the Atlantic Coastal Plain. The new model also is useful in addressing interstate ground-water issues, such as the subregional water-level declines that result from the development of the Cretaceous aquifers in Horry County, SC, the Castle Hayne aquifer in Brunswick County, NC, and the Upper Cape Fear aquifer in the NC Bladen County area.

Methods

The methods of investigation included conceptual model evaluation and revision, data compilation, model construction and calibration, and sensitivity analysis. The existing conceptual models were evaluated to determine the appropriateness of boundary conditions, model layering, and methods of approximating field conditions. Hydraulic, water-use, and water-level data for 1900 to 2004 were compiled from various State agencies and other USGS investigations for inclusion in the model. These data also included synoptic ground-water elevation and ground-water base-flow measurements made in the fall of 2004. The model was calibrated by approximating steady-state predevelopment ground-water conditions for year 1900 and simulating transient conditions through 2004. The sensitivity of the calibrated model to the modeled parameters was evaluated to determine the relative importance of the parameters to simulated results.

The updated version of the USGS three-dimensional finite-difference modular flow model MODFLOW-2000 (Harbaugh and others, 2000) provided a more robust method for simulating field conditions than the numerical codes used in the previous NC and SC Coastal Plain models. Revision of the flow model included active simulation of the Coastal Plain aquifer system and major confining units in the study area and incorporation of hydraulic properties, water-level and water-use data, and ground-water base-flow data to rivers acquired since the previous study.

The USGS code MODFLOW-2000 was used to simulate the ground-water flow system of the NC and SC Coastal Plain. A grid of 130 rows, 275 columns, and 16 layers consisting of 2-mile by 2-mile cells was constructed to represent the Coastal Plain aquifers and confining units. Cell thicknesses ranged from a minimum of 2 feet to a maximum of 5,004 feet. The upper boundary for model layer 1 was designated a specified-head boundary in areas where the surficial aquifer is underlain by confining units, and recharge was defined in areas where the hydrogeologic units crop out. The specified-head boundaries in layer 1 are derived from land-surface elevations and depth to the water-table. Historical precipitation data from the inner Coastal Plain were used to vary recharge over time within the model. The lower no-flow model boundary simulates the top of the bedrock underlying Coastal Plain sediments. The northwestern and southeastern boundaries of all layers were simulated as no-flow boundaries and were located along the Fall Line and the freshwater/saltwater divide, respectively. The northeastern and southwestern boundaries were simulated as specified-head boundaries and are located along the James River in Virginia to the northeast and the Altamaha River in Georgia to the southwest in layer 1 and along ground-water flow paths in layers 2 through 16. Water-use data reported from 1900 to 2004 by State regulatory agencies and in previous model investigations were used to specify pumping rates and locations. Horizontal hydraulic conductivity and specific storage values for the aquifers were derived from published transmissivity and storage coefficient data and adjusted during model calibration. No data were available for horizontal hydraulic conductivity of the confining units, specific storage of the confining units, specific yield of the surficial aquifer, or vertical anisotropy of the aquifers or confining units; these properties were estimated during model calibration. Ground-water levels prior to 1980 were used as the predevelopment steady-state hydraulic-head observations, and ground-water levels from 1980 and 2004 were used as the transient hydraulic-head observations. Historical river base-flow data from streamgages were used to estimate ground-water discharge to the rivers.

Conclusions

The NC–SC Coastal Plain model began with a steady-state stress period representing predevelopment conditions prior to 1900. Transient conditions began in 1900 and simulate pumping and variable recharge through 2004. The model was calibrated to three conditions-- assumed steady-state conditions of pre-1900 and transient conditions in 1980 and 2004. The model was calibrated with a technique of parameter estimation using pilot points and regularized inversion. Mean calibrated horizontal hydraulic conductivity values for the aquifers ranged from 18.3 to 176 feet per day; calibrated horizontal hydraulic conductivity values for the confining units ranged from 2.18×10^{-5} to 2.29×10^{-2} feet per day; calibrated specific storage values were 1.5×10^{-6} inverse foot for all aquifers and confining units except the surficial aquifer which had a calibrated specific yield of 0.1 inverse foot; calibrated vertical anisotropies ranged from 1.0 to 3.0 for the aquifers and from 1.3 to 3.0 for the confining units.

Residuals for the simulated water levels in all layers produced an overall coefficient of determination (R^2) of 0.96 for the pre-1900 simulation, 0.95 for the 1980 simulation, and 0.89 for the 2004 simulation. The percentages of simulated water levels within the 20-foot calibration target for all of the layers were 64 percent for the pre-1900 simulation, 70 percent for the 1980 simulation, and 55 percent for the 2004 simulation. Simulated transient heads were similar to observed continuous ground-water levels in all areas except those where water-use data were not available.

Simulated annual mean stream base flows were substantially lower than calculated annual mean base flows at most of the streamgage sites. Only three of the streams had percentages of simulated base flows within the calibration criteria and the percentages were 50 percent or less. The model cannot accurately simulate stream base flow because the 2-mile by 2-mile cell size cannot accurately represent small-area streams.

The sensitivity of the model to the calibrated aquifer parameters and the boundary conditions was evaluated with composite sensitivity analysis and the perturbation method, respectively. Of the aquifer parameters, the model was relatively most sensitive to the horizontal hydraulic conductivity of the confining units in layers 10, 12, and 14 and of the aquifer in layer 1 and to the specific storage of the aquifers and confining units in layers 11, 12, 13, 14, and 15. Of the boundary conditions, the model was very sensitive to changes in ground-water withdrawals. Increasing the pumping rate substantially decreased model error, illustrating the known under-representation of pumping in the model. The model was not very sensitive to the lateral specified heads in layers 2 through 16, the upper specified head in layer 1, the recharge applied to layer 1, or to streambed conductance.

Analysis of the simulated predevelopment and 2004 ground-water flow budgets of the Atlantic Coastal Plain aquifers of North and South Carolina indicates that the largest component of flow is vertical interlayer flow to and from the aquifers and confining units. The next largest component of ground-water flow is the volume of water that moves into and out of the specified-head boundaries within the modeled area. The outflow and inflow from these specified-head boundaries is approximately equal. The net difference between inflow and outflow to the specified-head boundaries switches from a net outflow prior to about 1940 to a net inflow after 1940 as more water is pumped from the wells. The next largest components of the water budget are recharge and leakage to rivers. The recharge rate varies over time with differences in precipitation rates recorded at six climate stations in the upper Atlantic Coastal Plain of Georgia, North Carolina, and South Carolina. Other budget components are ground-water storage changes and withdrawals. Ground-water flow budgets for three discrete areas, the 15-county Central Coastal Plain Capacity Use Area in North Carolina and in Aiken and Sumter Counties, South Carolina, areas are analyzed for predevelopment and 2004 conditions.

Overall ground-water availability in the aquifers generally exceeds demand in most areas. Although some aquifers have experienced ground-water level declines in the vicinity of large-scale, concentrated pumping centers, large areas of the Atlantic Coastal Plain contain substantial, unused quantities of high-quality ground water.

Literature Cited

Aucott, W.R., 1988, The predevelopment ground-water flow system and hydrologic characteristics of the Coastal Plain aquifers of South Carolina: U.S. Geological Survey Water-Resources Investigations Report 86-4347, 66 p.

Aucott, W.R., 1996, Hydrology of the Southeastern Coastal Plain aquifer system in South Carolina and parts of Georgia and North Carolina: U.S. Geological Survey Professional Paper 1410-E, 83 p.

Campbell, P., 1997, Population projections: States, 1995-2025: Current population reports, U.S. Census Bureau P25-1131, 6 p.

Giese, G.L., Eimers, J.L., and Coble, R.W., 1997, Simulation of ground-water flow in the Coastal Plain aquifer system of North Carolina: U.S. Geological Survey Professional Paper 1404-M, 142 p.

Harbaugh, J.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey's modular ground-water flow model—User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Payne, D. F.; Rumman, M. A.; Clarke, J. S., 2005, Simulation of ground-water flow in coastal Georgia and adjacent parts of South Carolina and Florida-predevelopment, 1980, and 2000: U.S. Geological Survey Scientific Investigations Report 2005-5089, 92 p.

Perry, M.J., and Mackun, P.J., 2001, Population change and distribution - 1990 to 2000: U.S. Census Bureau, Census 2000 brief, 7 p.

U.S. Census Bureau, 2007, 2000 census, accessed May 12, 2007, at www.census.gov/main/www/cen2000.html.