Using Numerical Models to Simulate Surface-Water and Ground-Water Movement in South Florida

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This paper presents current numerical modeling efforts of the U.S. Geological Survey in south Florida. The efforts summarized here include the development of numerical models designed to simulate (1) a deep well injection in Miami-Dade County, (2) saltwater interface movement in Broward County, (3) submarine ground-water discharge to Biscayne Bay, and (4) coupled surface-water and ground-water exchange in the southern Everglades.

The South District Wastewater Treatment Plant (SDWWTP) in Miami-Dade County, Florida began operation in 1983. The facility contains 17 Class I underground injection wells for disposal of treated effluent. The treated effluent is injected into the saline Boulder Zone, a highly permeable dolomite unit located at the base of the Lower Floridan aquifer. In 1994, the Miami Dade Water and Sewer Department (MDWASD) detected ammonia and total Kjeldahl nitrogen (TKN) above background levels in samples taken above the injection zone in Floridan aquifer system monitoring wells at the SDWWTP. Two possible explanations for the ammonia plumes have been suggested: 1) treated wastewater may be flowing upward around poorly cemented well casings; or 2) the middle confining unit, located between the Boulder zone and Upper Floridan aquifer, does not provide enough confinement to restrict the upward movement of injectate. Regardless of the pathway, the density difference between the native aquifer water and the injectate probably contributes to the observed flow pattern caused by the buoyancy of less dense freshwater injected into more dense saline water. The USGS, in cooperation with MDWASD, is developing a variable-density ground-water flow and solute-transport model to: (1) evaluate movement of injected waters within the Floridan aquifer system, (2) estimate the current extent of the injectate within the Upper Floridan aquifer, and (3) predict the future movement of injected fluids under a range of different injection scenarios.

The USGS conducted a study to relate movement of the freshwater/saltwater interface to fluctuations in canal stage in an effort to better manage saltwater intrusion in a shallow aquifer system. In support of the modeling, water levels and fluid variables were measured and recorded at 15-minute intervals at six monitoring wells in Broward County, Florida. The field data suggest tidal fluctuations, rainfall, and changes in canal stage have a measurable effect on ground-water levels and fluid conductance. Data from the field study were used to guide the development and calibration of transient, three-dimensional, variable-density, ground-water flow models based on the SEAWAT code. The model was calibrated by adjusting values of hydraulic conductivity, specific yield, porosity, and dispersivity. Additional simulations have suggested that canal stage changes can have a long-term effect on interface location and intrusion rates in southeastern Florida. Modeling this phenomenon can aid in defining appropriate canal stages to prevent saltwater intrusion under a wide range of hydrologic conditions.

Biscayne National Park (BNP) is the largest national marine park in the United States. Hydrologic investigations have shown that terrestrially derived ground-water is discharging into Biscayne Bay and possibly to the offshore coral reef tract. The quantification of ground-water discharge rates, location of discharge areas, and delineation of ground-water recharge areas is important for reliable water management. The current project is using a previously developed USGS ground-water model of Biscayne Bay to simulate ground-water discharge patterns to the bay under a variety of conditions. It is expected that simulated flow patterns will correlate with ecological indicators of stressed communities, providing managers with insight into the causes of ecosystem degradation. The ground-water model simulates transient ground-water discharge to Biscayne Bay in three dimensions using a horizontal cell spacing of 1000m x 1000m, and 11 vertical layers. The simulation period for the original model was 10 years, from January 1989 to September 1998, with monthly time steps. For the present study, the model will be linked with the South Florida Water Management District (SFWMD) Natural Systems Model (NSM) and South Florida Water Management Model (SFWMM) to simulate ground-water discharge into the bay under predevelopment conditions, present conditions, and the future alternative management conditions proposed under the Comprehensive Everglades Restoration Plan (CERP).

The USGS began modeling the southern Everglades and northeastern Florida Bay hydrology in 1995 with the development of the Southern Inland and Coastal Systems (SICS) hydrodynamic surface-water flow and solute-transport model. The original surface-water model did not include a ground-water component which was a limitation, considering the documented importance of surface-water and ground-water exchange in southern Florida. Subsequently, the FTLOADDS (Flow and Transport in a Linked Overland Aquifer Density Dependent System) program was designed by linking the SWIFT2D surface-water code with the SEAWAT ground-water code. The integrated simulation was extended to 7 years, representing the period from January 1996 to December 2002. The integrated model was used to evaluate the dominant hydrologic processes, including surface-water and ground-water interactions, and to synthesize a wide range of hydrologic data collected for the area. The specific objective of the model application was to develop a numerical tool that could be used to quantify freshwater discharges to northeastern Florida Bay, predict temporal and spatial variations in coastal salinity patterns, and represent wetland hydroperiods. Presently, this numerical tool is being used to evaluate the effects of CERP on future hydrologic conditions (heads, flows, and salinities) in the coastal wetlands and adjacent Florida Bay estuary. Additionally, the model is being combined with various stochastic schemes in order to enhance its capabilities. Two of these techniques include (1) a fourier-transform method to determine hydrologic forcings on the system and model input errors, and (2) an optimization scheme that will allow the model to be used to assist in the design of water delivery scenarios that meet restoration performance measures.

The methodology used for the SICS model is being expanded and improved for the development of the TIME (Tides and Inflows in the Mangroves of the Everglades) model. The TIME model is coarser in resolution (500-m cell size) than SICS (305-m cell size), but covers a much larger area of the Everglades, including Shark River and Taylor Sloughs that drain to the Gulf of Mexico and northern Florida Bay respectively. The TIME model also is being developed using the FTLOADDS computer program; therefore, the type of output from both models is similar, consisting of discharge, stage, and salinitiy in the wetlands and underlying aquifer system. As with the SICS model, TIME is being developed as a tool to evaluate the effects of CERP scenarios on freshwater flows to Florida Bay and the Gulf of Mexico. The model is currently simulating the period from 1996 to 2002.