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SEAWAT: A Computer Program for Simulation of Variable-Density Groundwater Flow and Multi-Species Solute and Heat Transport

SEAWAT is a MODFLOW-based computer program designed to simulate variable-density groundwater flow coupled with multi-species solute and heat transport. The program has been used for a wide variety of groundwater studies including saltwater intrusion in coastal aquifers, aquifer storage and recovery in brackish limestone aquifers, and brine migration within continental aquifers. SEAWAT is relatively easy to apply because it uses the familiar MODFLOW structure. Thus, most commonly used pre- and post-processors can be used to create datasets and visualize results. SEAWAT is a public domain computer program distributed free of charge by the U.S. Geological Survey.

SEAWAT Design and Strengths

The SEAWAT design is based on the concept of combining two well-established and proven groundwater programs, MODFLOW and MT3DMS, into a single program that simulates variable-density groundwater flow and transport. This design concept leverages the substantial capabilities of MODFLOW and MT3DMS, and extends those capabilities to coastal aquifers and other environments where density variations are important. For example, MT3DMS has an option to simulate zero-order decay and growth, which can be used for groundwater age simulations. This functionality is also available in SEAWAT, making it possible to simulate groundwater age for variable-density problems. The SEAWAT design concept has the following associated strengths:

- *Accuracy*—The program builds on the thoroughly tested MODFLOW and MT3DMS methods for solving groundwater flow and transport, respectively. Variable-density functionality is tested with most benchmark problems.
- *Computational Efficiency*—SEAWAT includes standard MODFLOW solvers for flow and flexible MT3DMS methods for solving transport. The modular structure allows capabilities to be activated as needed.
- *Familiarity*—Users familiar with the constant-density versions of MODFLOW and MT3DMS can transition to variable-density simulations with few difficulties. Furthermore, the program can be used with existing groundwater software pre- and post-processors, as well as other MODFLOW-related programs (MODPATH, ZONEBUDGET, Modelviewer, and so forth).
- *Modularity*—The SEAWAT program design makes it easy to modify or add new processes and packages.
- *Support*—SEAWAT is actively maintained and developed to include new features and capabilities and to support new MODFLOW and MT3DMS packages and processes.

Selected SEAWAT Applications

With the increase in demand for fresh groundwater resources, the number of studies that require explicit representation of fluid density variation has increased. Although many of these studies focus on saltwater intrusion issues in coastal areas, dense saline brines can also threaten freshwater resources in continental aquifers. USGS investigators have developed expertise in applying the SEAWAT computer program to a wide variety of groundwater problems. The following list demonstrates the breadth of these investigations, and provides examples of the types of hydrologic issues that have been addressed.

Saltwater Intrusion and Upconing

- Upconing was identified to be a greater threat near Bonita Springs, Florida, than lateral saltwater intrusion (Shoemaker and others, 2003).
- The effects of groundwater pumping and sea-level rise on the freshwater-saltwater interface were simulated as part of a study of freshwater availability on Cape Cod, Massachusetts (Masterson, 2004; Masterson and Garabedian, 2007).
- The relative importance of drought, well-field pumping, sea-level rise, and canal management on saltwater intrusion were evaluated for the Biscayne aquifer in southern Florida (Dausman and Langevin, 2005).
- Saltwater intrusion patterns were simulated for the Coastal Plain aquifer system of Virginia (Heywood and Pope, 2009).
- Areas susceptible to saltwater intrusion were identified for the Eastern Shore of Virginia (Sanford and others, 2009).
- Aquifer salinization rates and thermal plume migration were simulated for an extensive hypersaline cooling canal system in southern Florida (Huges and others, 2009).

Submarine Groundwater Discharge

- The rate of fresh groundwater discharge into Biscayne Bay was estimated to be about 10 percent of the measured surface-water discharge (Langevin, 2001; 2003).
- A SEAWAT model was developed to help guide data collection efforts for submarine groundwater discharge studies (Dausman and others, 2007).

Coastal Wetland Hydrology

- FTLOADDS, a program that combines SEAWAT with a two-dimensional hydrodynamic surface-water model, was applied to the southern Everglades of Florida (Langevin and others, 2005).
- Water-management strategies were optimized using a FTLOADDS model (Swain and James, 2007).

- A FTLOADDS model was used to evaluate the hydrologic effects of Everglades restoration (Wang and others, 2007).

Deep-Well Injection

- Upward migration of injected treated effluent was simulated for a wastewater-treatment plant in Florida (Dausman and others, in press).

Brine Transport

- A dense brine pool near Syracuse, New York, was determined to have migrated to its present position from a distant salt source (Yager and others, 2007).
- Upward brine migration through a collapse feature was simulated for a flooded salt mine in Livingston County, New York (Yager and others, 2009).

SEAWAT Version 4

Since its first release by the USGS in 2002, SEAWAT has continued to evolve by supporting additional MODFLOW and MT3DMS packages and by adding new functionality. The most recent SEAWAT revision, Version 4, contains new features that allow users to simulate multi-species solute and heat transport (Langevin and others, 2007). One of the benefits of these added capabilities is that temperature effects on fluid density and viscosity can be simulated. Dausman and others (2009) demonstrate the use of SEAWAT Version 4 by simulating a set of complex variable-density benchmark problems. Langevin and others (2009) test the simultaneous solute and heat transport capabilities by simulating a laboratory experiment involving warm freshwater flowing over cold saltwater (fig. 1).

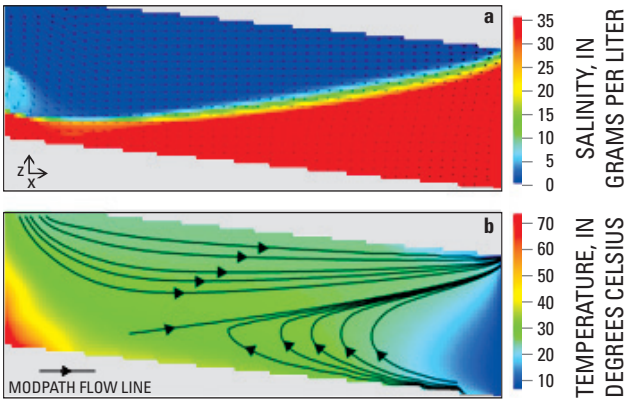

Figure 1. Results from a simultaneous solute and heat transport simulation (Langevin and others, 2009).

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