Presentation 2

Variable-Density Groundwater Modeling: Applications and Tools

Applications

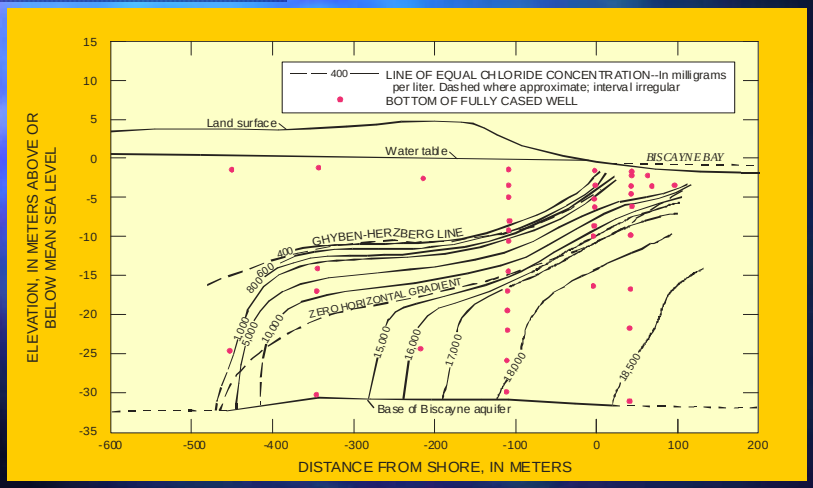
- Saltwater intrusion
- Upconing
- Aquifer storage and recovery (ASR)
- Deep well injection
- Submarine groundwater discharge
- Coastal wetland hydrology
- Brine migration
- Aquifer processes
- Heat transport

Saltwater Intrusion

- Defined as, inland movement of seawater into areas previously occupied by freshwater (Stewart, 1999)
- Causes
  - Natural
  - Anthropogenic

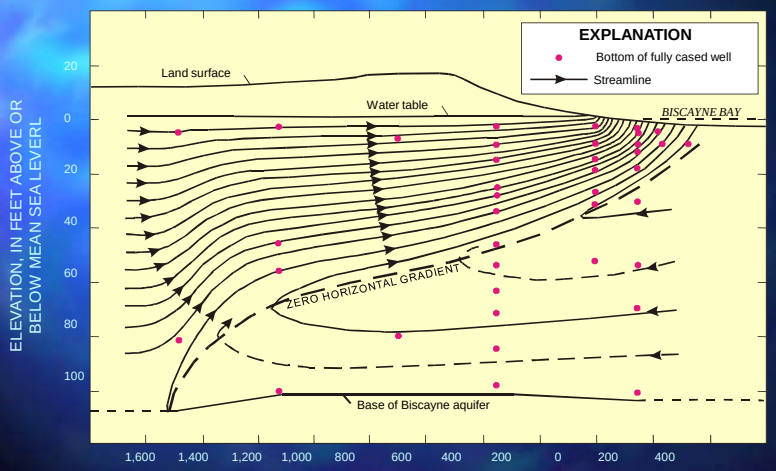
From Parker and others (1955)

Saltwater Intrusion (cont.)



Kohout (1964)

Saltwater Intrusion (cont.)



Saltwater Intrusion (cont.)

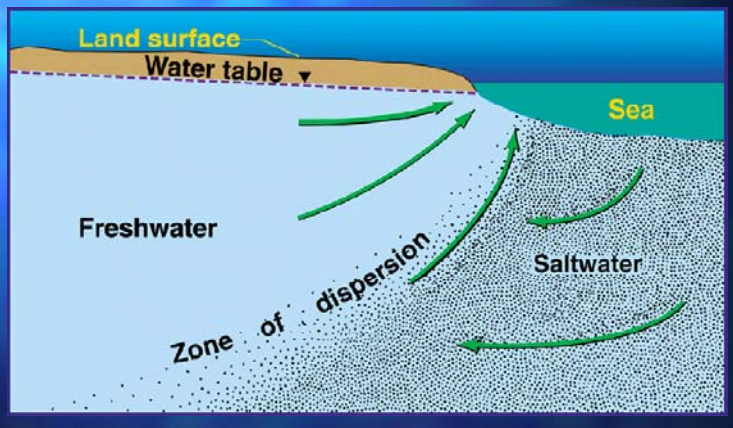


Figure modified from Cooper, H. H., 1964, A hypothesis concerning the dynamic balance of fresh water and salt water in a coastal aquifer: U.S. Geological Survey Water-Supply Paper 1613-C, p. 1-12

Saltwater Intrusion (cont.)

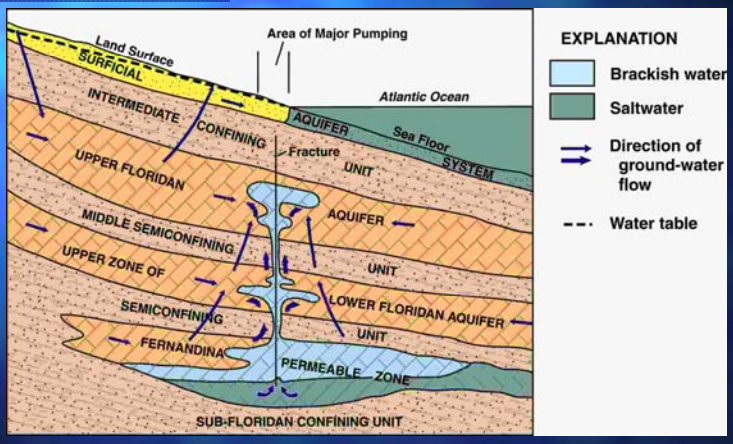
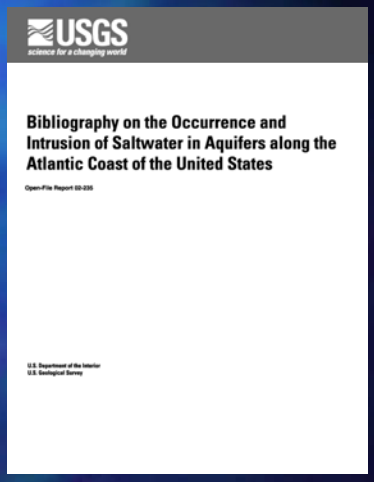


Figure modified from Spechler, R.M., 1994, Saltwater intrusion and quality of water in the Floridan Aquifer system, northeastern Florida: U.S. Geological Survey Water-Resources Investigations Report 92-4174, 76 p

Saltwater Intrusion (cont.)

- Bibliography
  - Bibliography on the Occurrence and Intrusion of Saltwater in Aquifers along the Atlantic Coast of the United States
  - By Paul M. Barlow and Emily C. Wild
  - Open-File Report 02-235
  - http://water.usgs.gov/pubs/of/ofr02235/

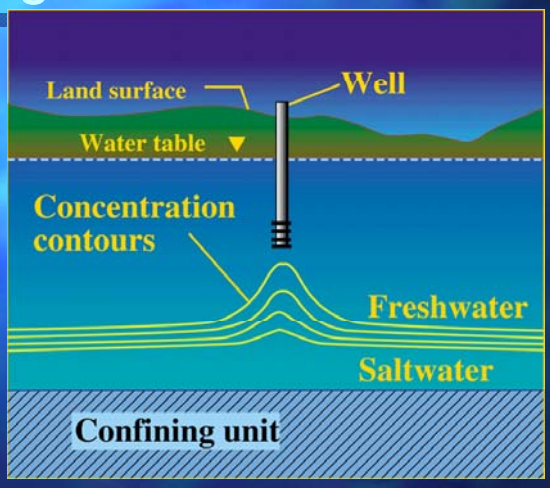

USGS
science for a changing world

Bibliography on the Occurrence and Intrusion of Saltwater in Aquifers along the Atlantic Coast of the United States

Open-File Report 02-235

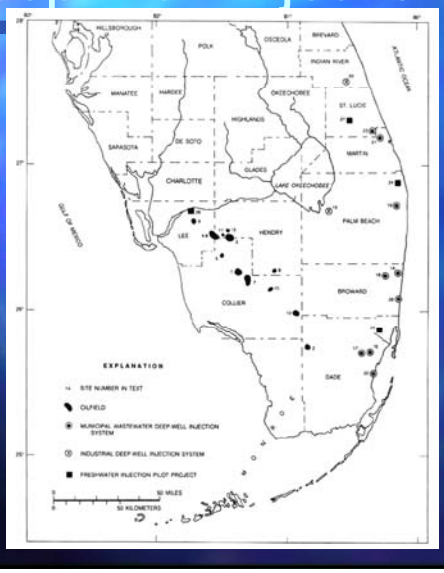
U.S. Department of the Interior
U.S. Geological Survey

Upconing



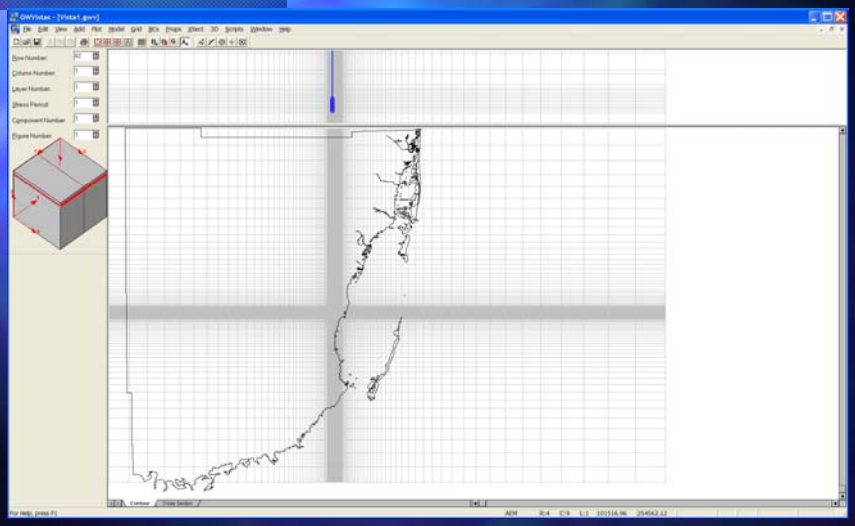
(Figure modified from Reilly, T.E., 1993, Analysis of ground-water systems in freshwater-saltwater environments, in Alley, W.M., ed., Regional ground-water quality: New York, Van Nostrand Reinhold, 634 p.)

Deep Well Injection

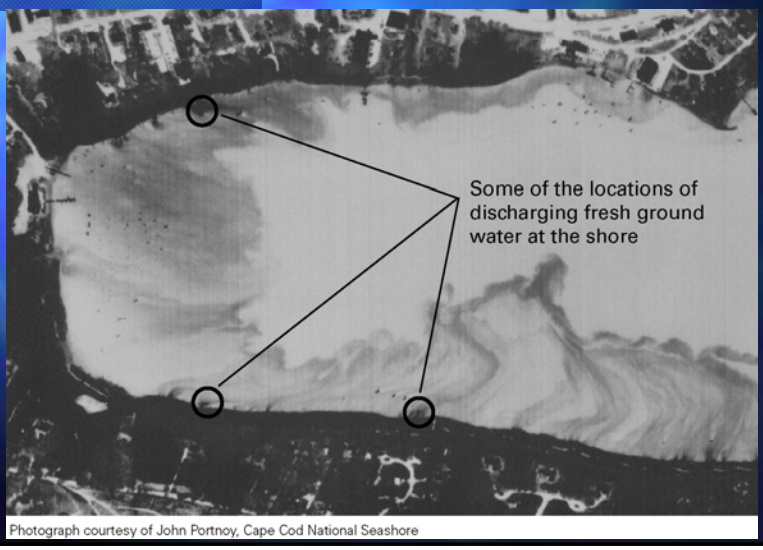


Hydrogeology, Ground-Water Movement, and Subsurface Storage in the Floridan Aquifer System in Southern Florida
By Frederick W. Meyer
Professional Paper 1403-G

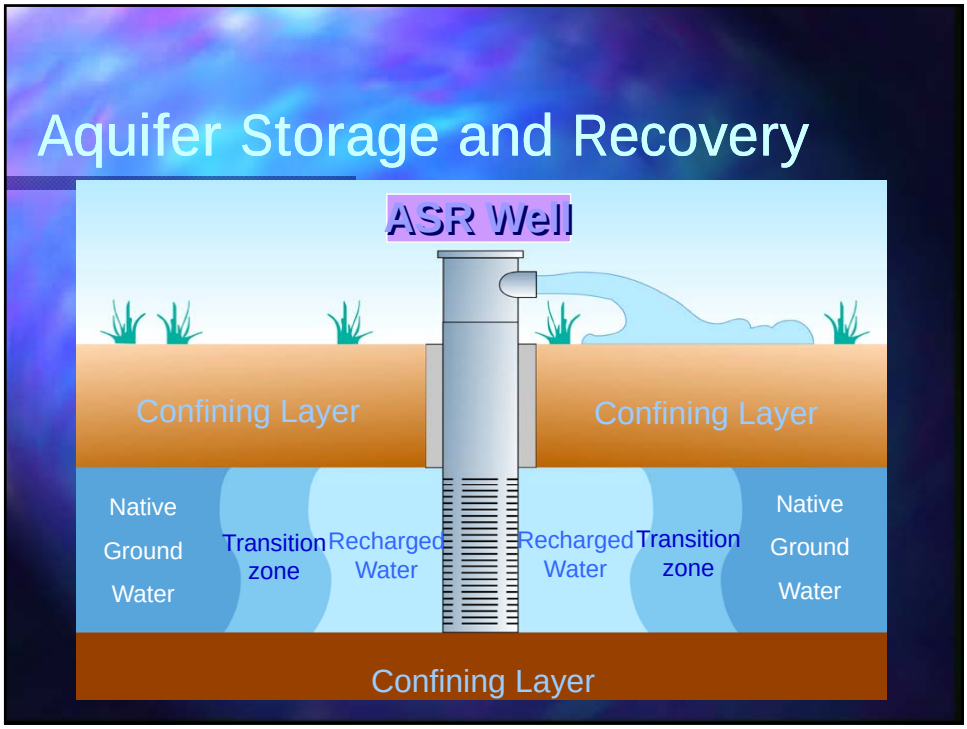
South District Wastewater Treatment Plant

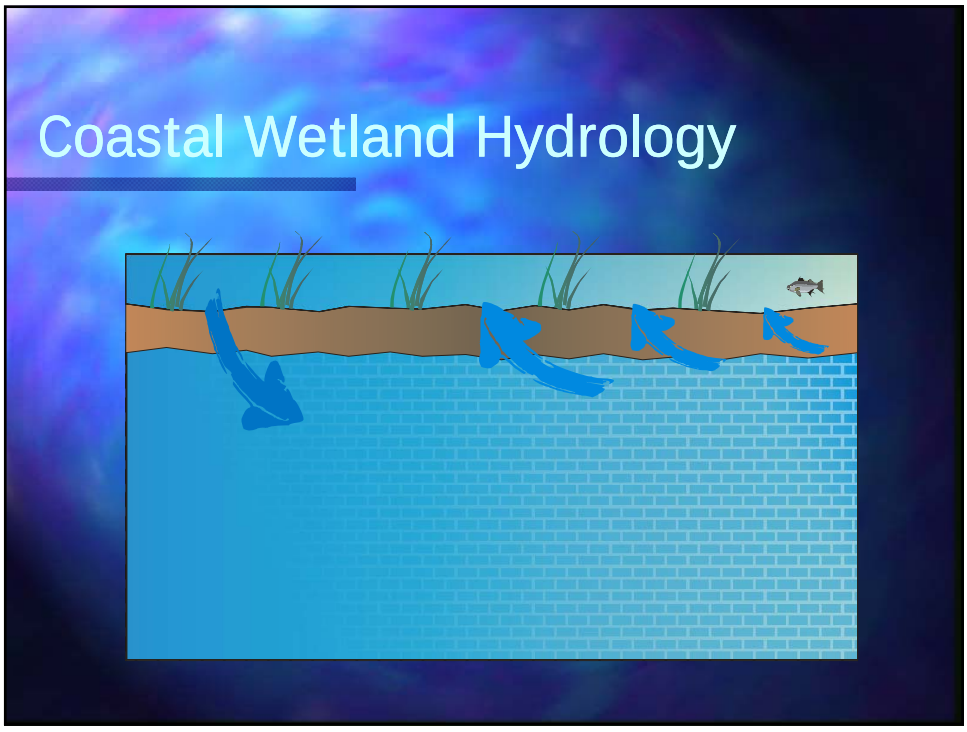


Submarine Groundwater Discharge



Photograph courtesy of John Portnoy, Cape Cod National Seashore

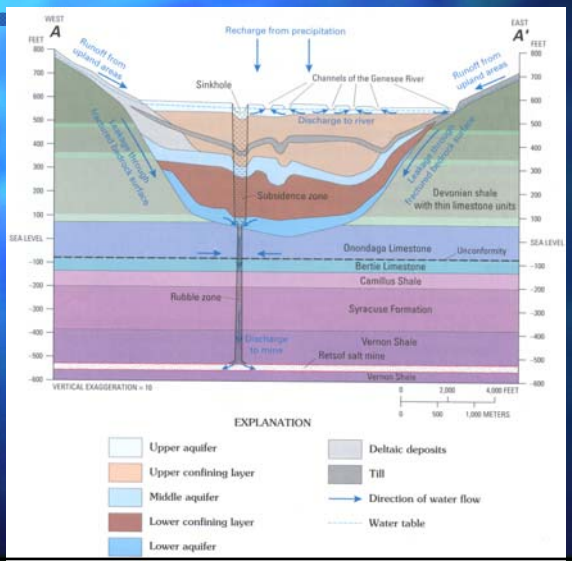

Aquifer Storage and Recovery
ASR Well
Confining Layer
Confining Layer
Native
Ground
Water
Transition
zone
Recharged
Water
Recharged
Water
Transition
zone
Native
Ground
Water
Confining Layer

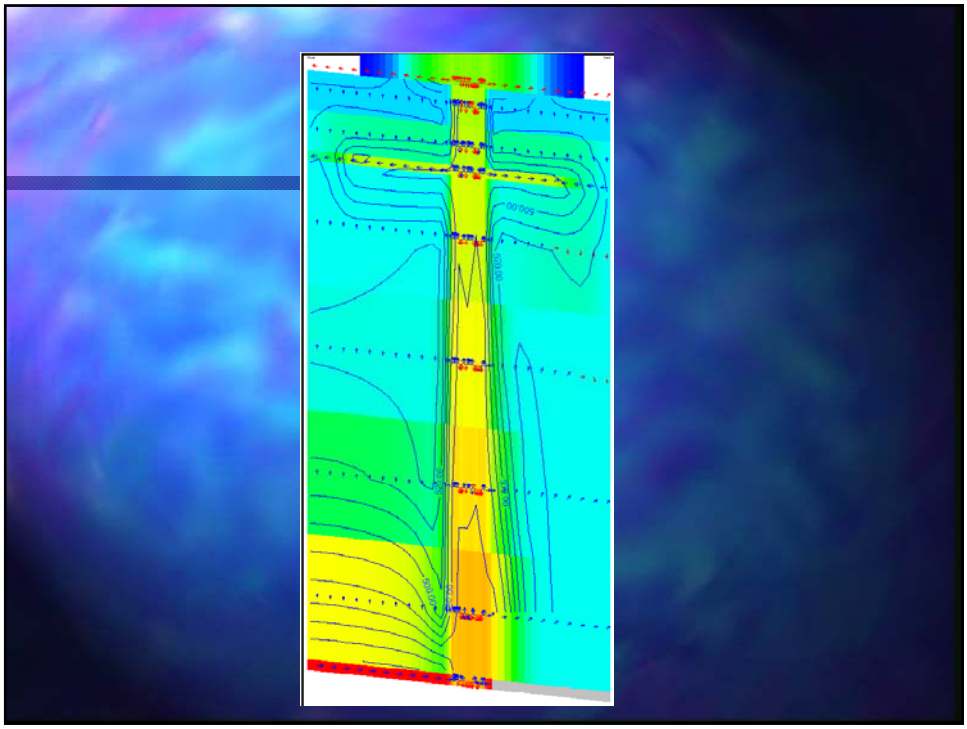

Coastal Wetland Hydrology

Brine Migration

- Salt mine subsidence (Yager 2001)

Salt Mine Cross Section



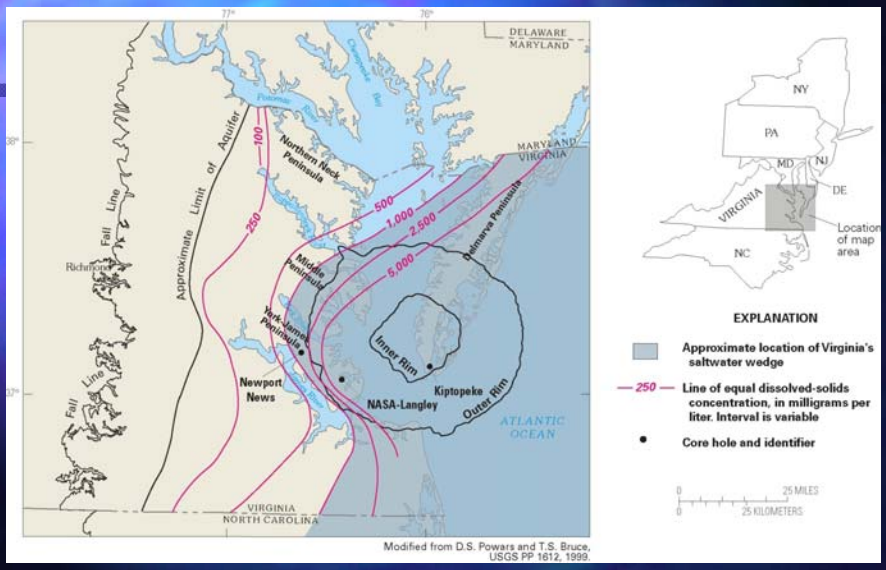


SEAWAT Computer Program

- Finite difference
- Combined version of MODFLOW and MT3DMS
- Designed to simulate transient, three-dimensional, isothermal, fully saturated, variable-density groundwater flow

Aquifer Processes

Heywood, C.E., and Pope, J.P., 2009, Simulation of groundwater flow in the Coastal Plain aquifer system of Virginia: U.S. Geological Survey Scientific Investigations Report 2009–5039, 115 p.



Virginia Coastal Plain

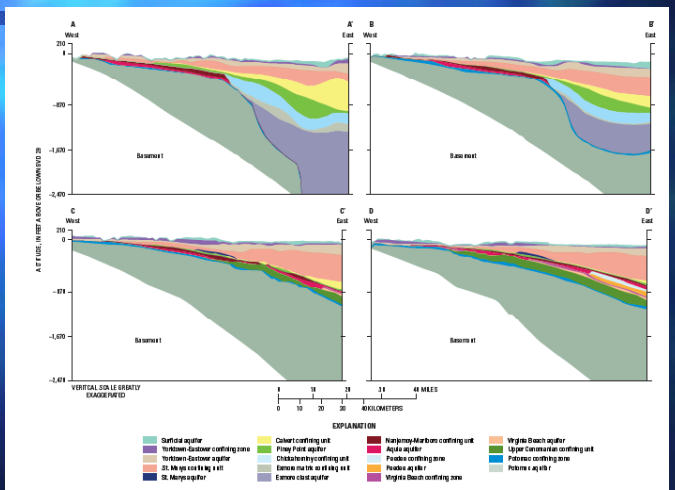
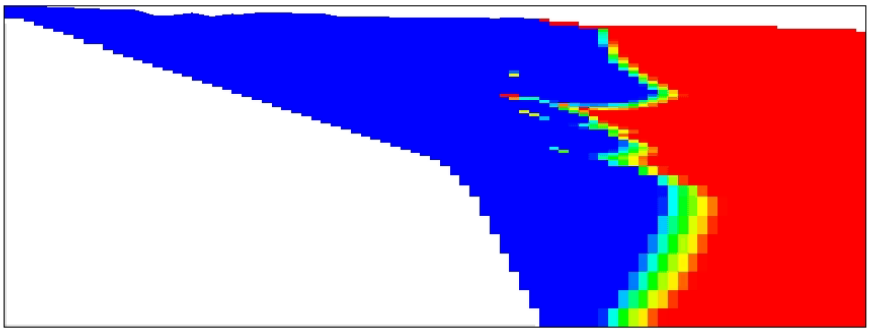
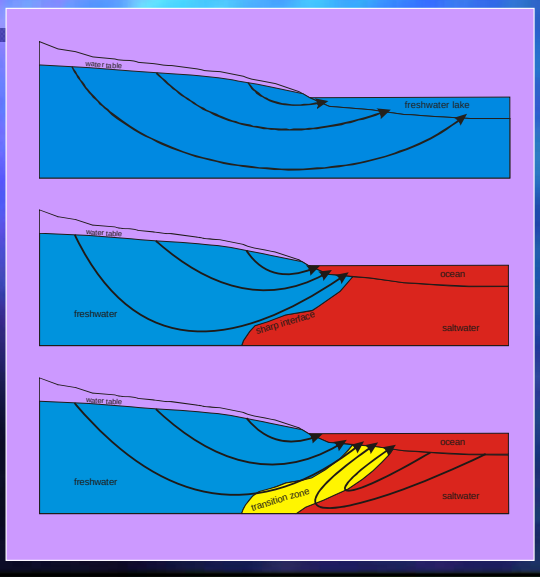


Figure 4. Vertical model cross sections showing distribution of hydrogeologic units from west to east along row 80 (A–A'), west to east along row 95 (B–B'), west to east along row 107 (C–C'), west to east along row 120 (D–D'), north to south along column 50 (E–E'), north to south along column 60 (F–F'), north to south along column 70 (G–G'), and north to south along column 87 (H–H'). (Locations of cross sections are shown in figure 3.)



Time = 1.19e+006 (1-1-924)

Approaches for Representing Variable-Density Flow



Ignore it!

Sharp interface approach

Fully coupled flow and dispersive transport approach

Classes of Variable-Density Models

- Sharp Interface Approach
  - Fast
  - No dispersion
- Dispersed Interface Approach
  - Can predict changes in concentration
  - Represent free convection processes
  - Slow

Selected Variable-Density Modeling Programs

Finite Element

- DYNFLOW, Camp Dresser McKee
- FEFLOW, WASY, Hans Diersch
- FEMWATER, Army Corps and George Yeh
- SUTRA, USGS, Cliff Voss
- WASH123, Army Corps and George Yeh

Finite Difference

- HST3D, USGS, Ken Kipp
- MOCDENSE, USGS, Ward Sanford
- MOCDENS3D, Gualbert Oude Essink
- MODHMS, Hydrogeologic Inc.

Sharp Interface

- Saltwater Intrusion Package for MODFLOW, Univ. Georgia, Mark Bakker
- SHARP, USGS, Hedeff Essaid

Why use SEAWAT?

- Accurate
- Documented
- Public domain
- Relatively easy to use
  - Based on MODFLOW and MT3D
  - Modular—Process/Package approach
- Compatible with existing pre and post processors
- Compatible with a wide range of utility programs (MODPATH, ZONEBUDGET, etc)

Accurate

Code has been tested with many benchmark problems (for example):

- Box problem—closed rectangular region with freshwater and seawater (Voss and Souza, 1987)
- Henry problem (Voss and Souza, 1987; Segol, 1993)
- Modified Henry problem (Simpson and Clement, 2003, 2004)
- Elder problem (Elder, 1967; Voss and Souza, 1987)
- HYDROCOIN problem (Konikow et al., 1997)
- Salt-lake problem (Simmons, 1997)
- Rotating saltwater interface (Bakker et al., 2004)

Documentation

Version 1

Guo, W., and Bennett, G.D., 1999, SEAWAT Version 1.2: A computer program for simulations of groundwater flow of variable density: Eastern Tech, Cape Coral, Florida.

Version 2

Guo, W., and Langevin, C.D., 2002, User's guide to SEAWAT: A computer program for simulation of three-dimensional variable-density ground-water flow: U.S. Geological Survey Techniques of Water Resources Investigations Book 6, Chapter A7, 79 p.

Version 3

Langevin, C.D., Shoemaker, W.B., and Guo, Weixing, 2004, MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model–Documentation of the SEAWAT-2000 Version with the Variable-Density Flow Process (VDF) and the Integrated MT3DMS Transport Process (IMT): U.S. Geological Survey Open-File Report 03-426, 43 p.

Langevin, C.D., and Guo, W., 2006. MODFLOW/MT3DMS-based simulation of variable density ground water flow and transport: Ground Water vol. 44, no. 3:339-351.

Version 4

Langevin, C.D., Thorne, D.T., Dausman, A.M., Sukop, M.C., and Guo, Weixing, 2008, SEAWAT Version 4: A computer program for simulation of multi-species solute and heat transport. U.S. Geological Survey Techniques and Methods Book 6, Chapter A22, 39 p.

Public Domain

http://water.usgs.gov/ogw/seawat

SEAWAT Concept

- Combine MODFLOW and MT3DMS into a single program
  - Insert MT3DMS into MODFLOW main program
- Modify MODFLOW routines to solve the variable-density groundwater flow equation


Programming Objectives
Accurate
Modular
Minimal changes to existing MODFLOW and MT3D subroutines