Modeling density dependent flow in shoreline aquifers

ERTH 656/CEE 623

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Ghyben-Herzberg Relation

Hydrostatic balance

ρ_s = saltwater density

ρ_f = freshwater density

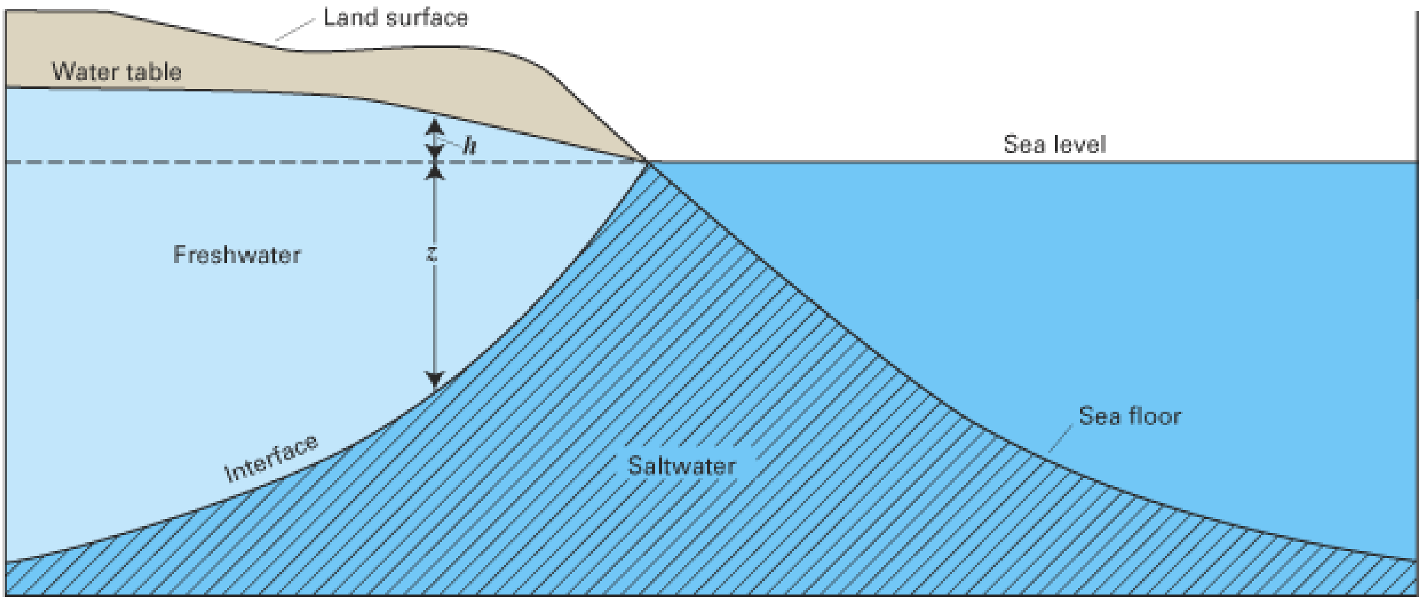
$$\rho_s g z = \rho_f g h$$

$$z = \frac{\rho_f}{\rho_s - \rho_f} h$$

$$\rho_f = 1.0 \text{ gm/cm}^3$$
$$\rho_s = 1.025 \text{ gm/cm}^3$$

$$z_s = 40 z_f$$

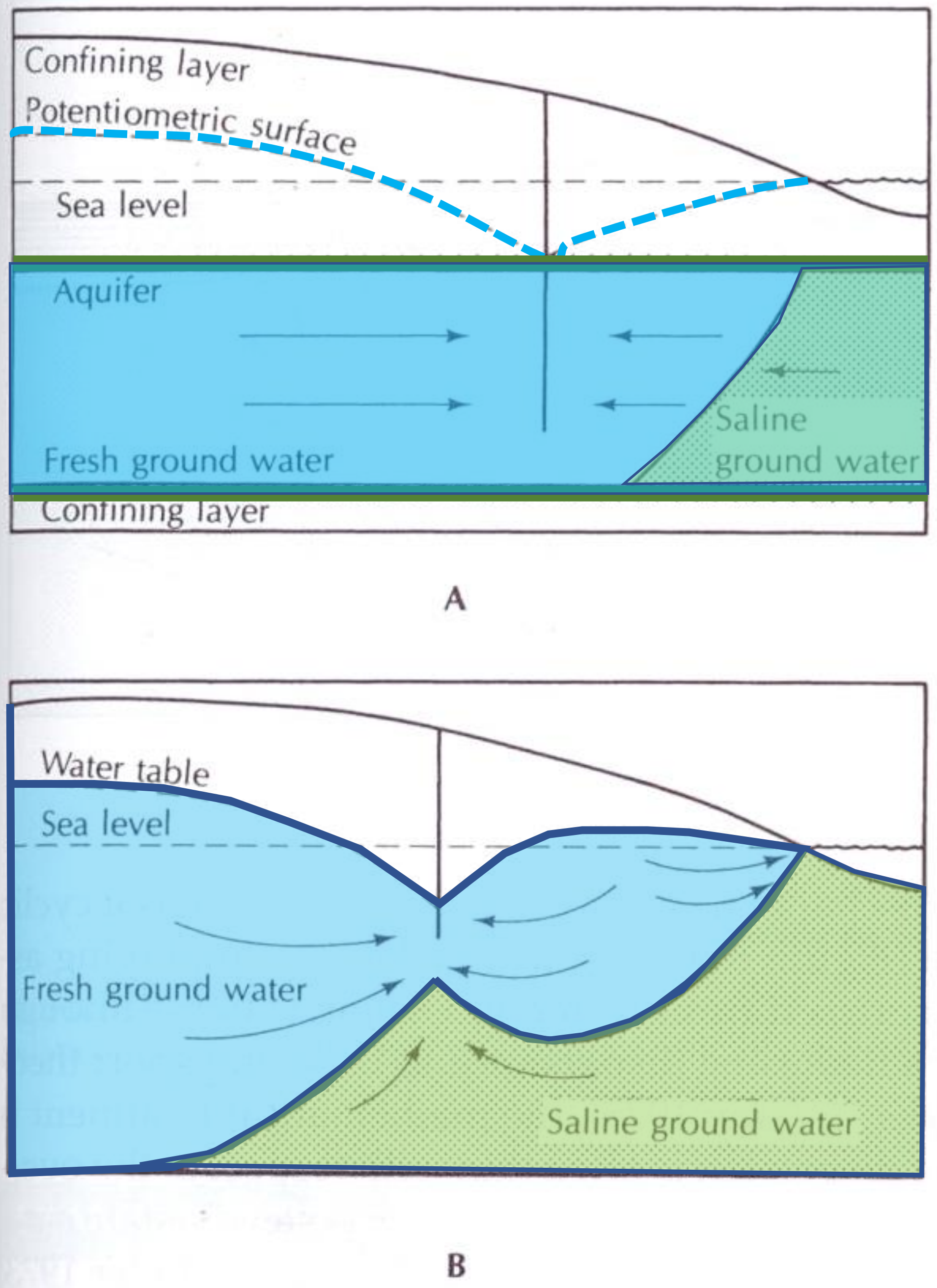
- Assumes no flow (hydrostatic situation); density consideration alone.
- It is applicable for horizontal flow away from shore line.



Confined aquifers

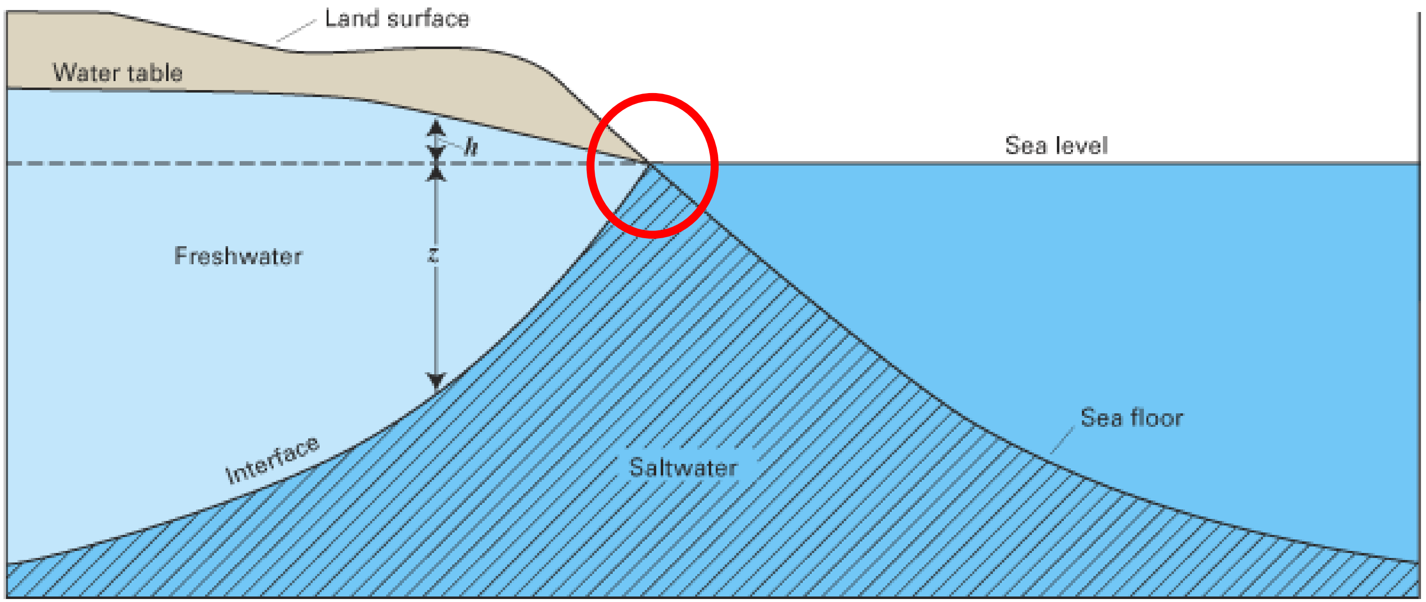
Use peizometric surface (Figure A) rather than water table (Figure B).

The slope of the water table or piezometric above MSL sets the flow to or from the ocean. See arrows in the figure where the flow field is drastically influenced by the pumping well.

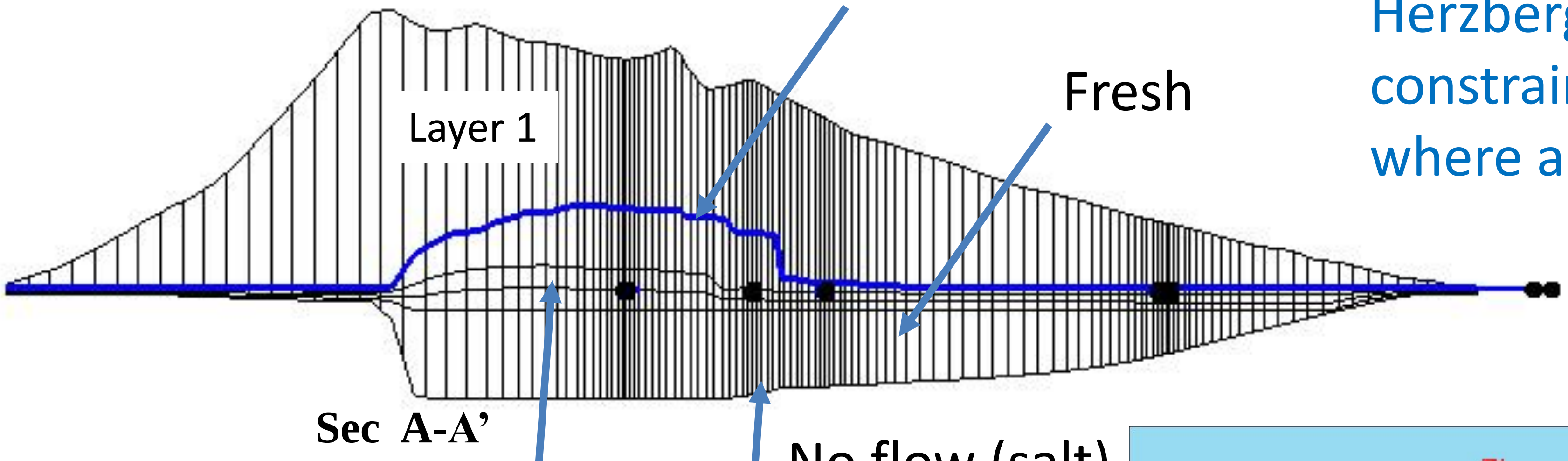


Approaches

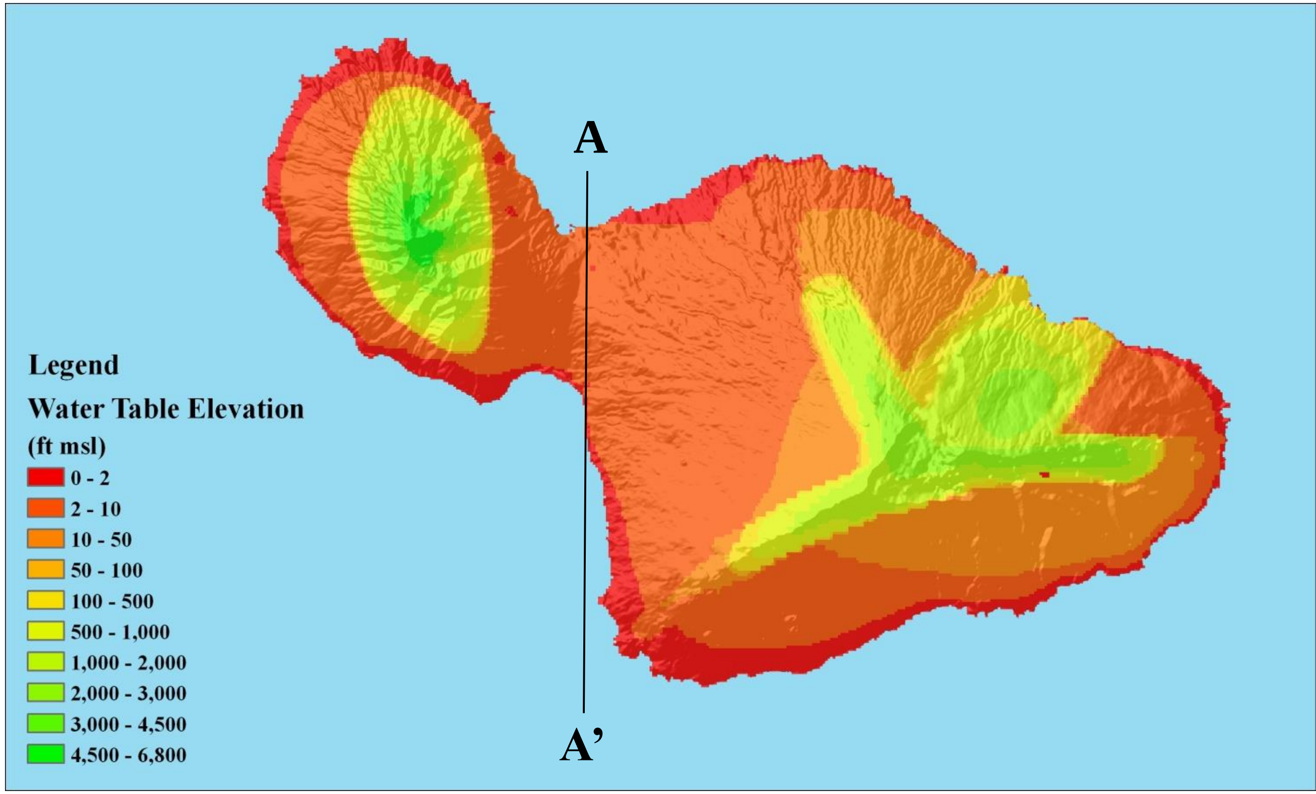
- Freshwater only (MODFLOW)
  - Assume sharp interface and treat saltwater zone as no flow zone
  - Aquifer bottom must be set first before running MODFLOW.



Using MODFLOW



Aquifer depth is based on the Ghyben-Herzberg (40:1) equation but constrained by certain value, say 2 km, where a no flow zone starts

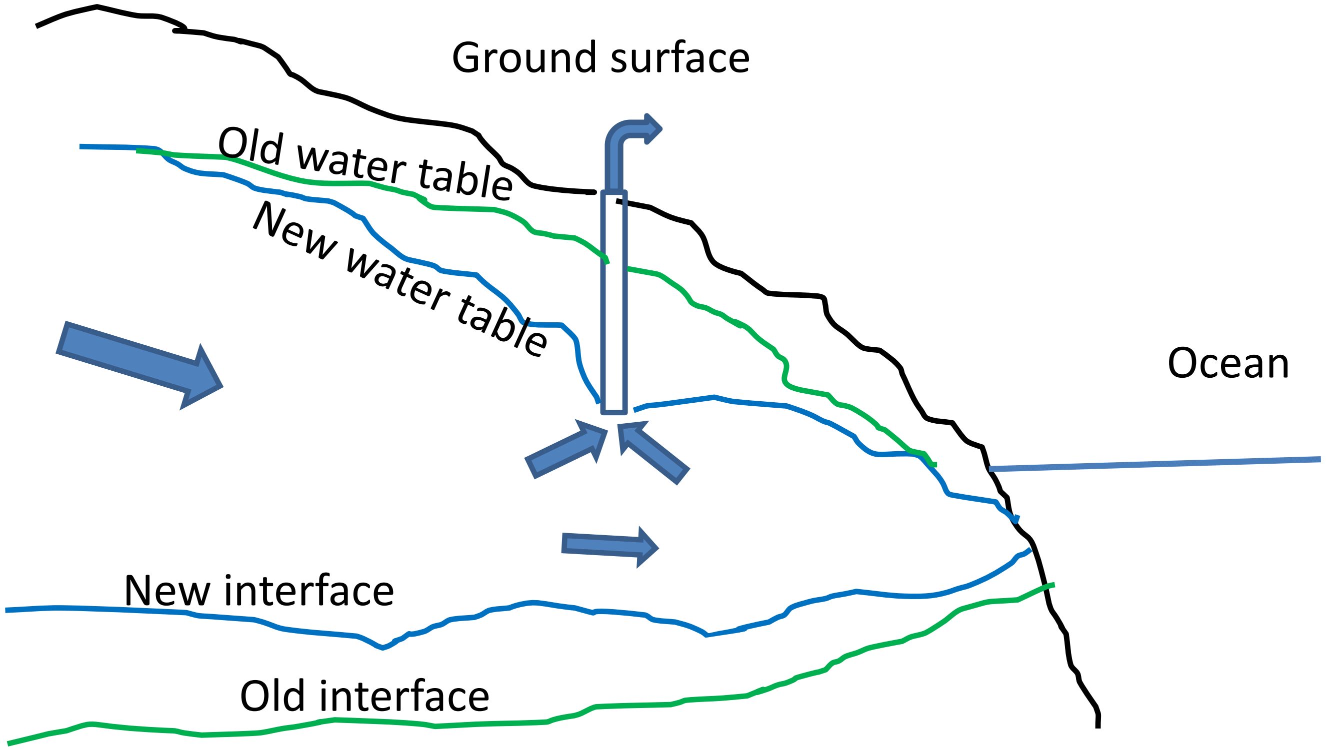


Important: Make sure bottom of layer 1 is below the water table

MODFLOW limitations by only simulating freshwater

- An aquifer bottom needs to be specified beforehand where freshwater is considered. A typical approach assumes a sharp interface with stagnant saltwater. Aquifer depth is estimated as forty times the fresh water height, by adopting the Ghyben-Herzberg equation.
- In reality, the freshwater zone is separated from the saltwater zone by a brackish zone, and all are of dynamic nature and can change based on aquifer condition, including pumping and recharge. Hence, developing scenarios with fixed aquifer bottom is not realistic.

The assumption of fixed aquifer bottom is not realistic



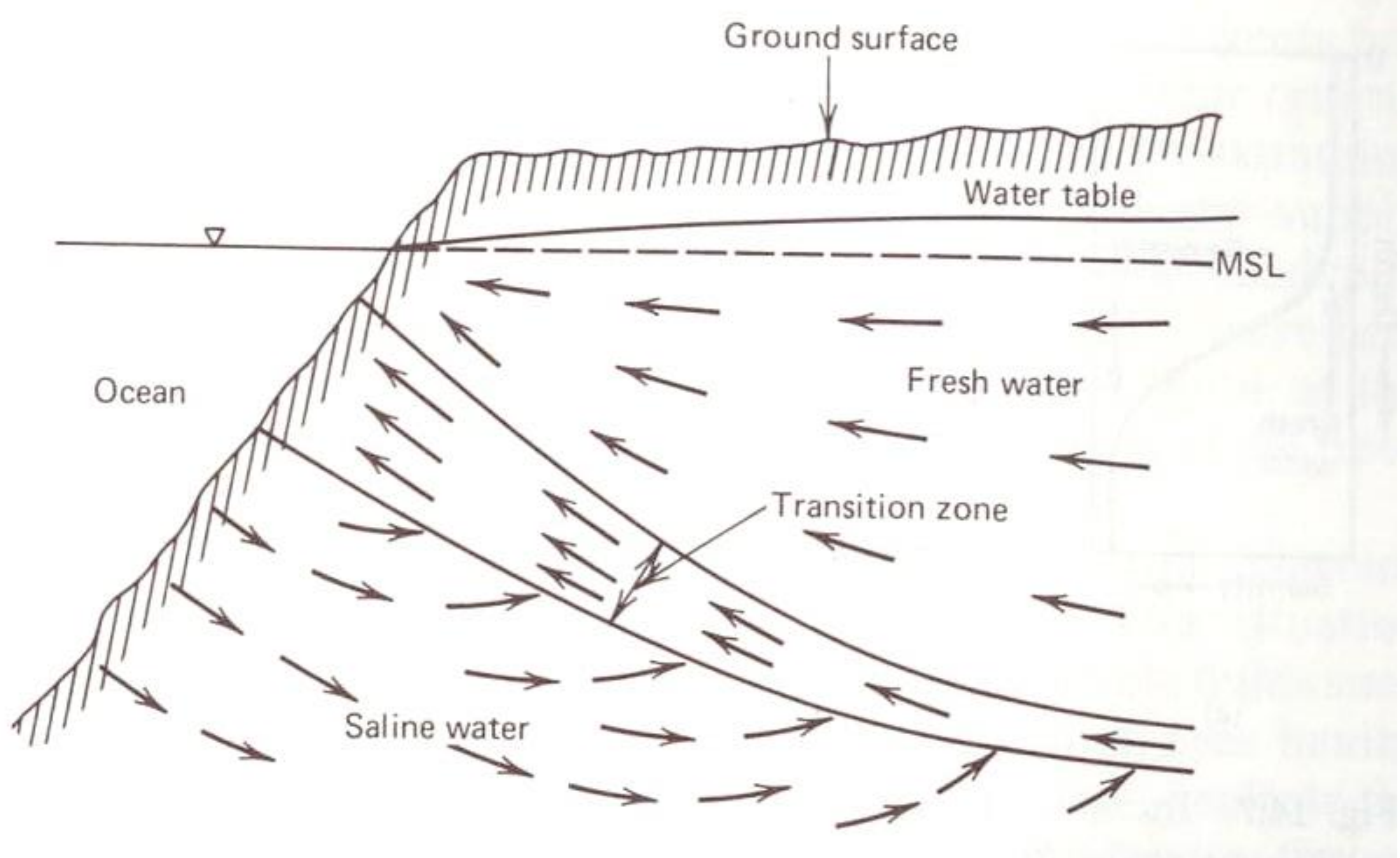
MODFLOW limitations by only simulating freshwater

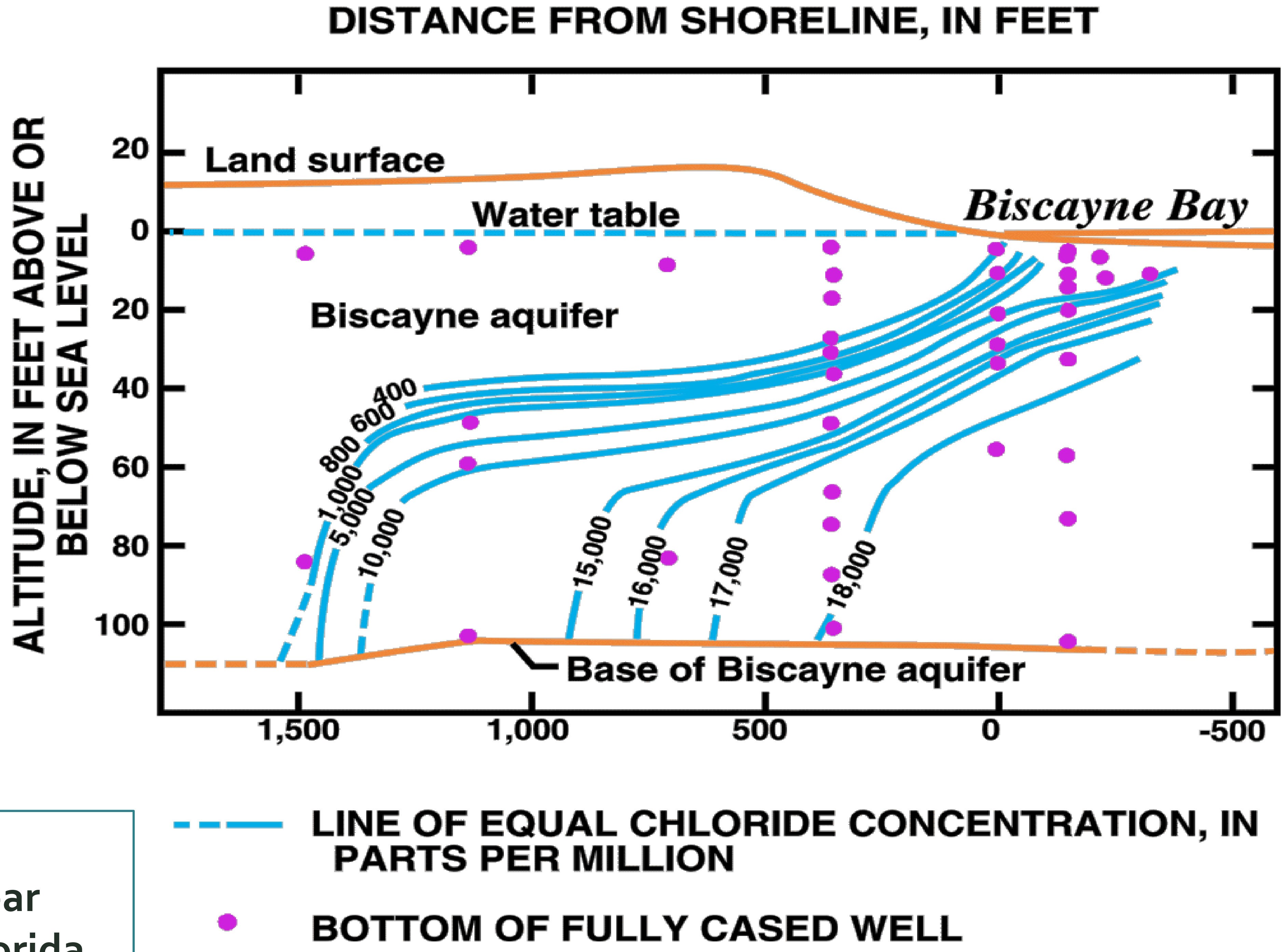
- Dynamics of the saltwater-freshwater zone and related circulation are not accounted for. Water and chemicals budgets and concentration of contaminants likely would be affected if salinity is overlooked.
- Groundwater sustainability would be likely misrepresented by ignoring the brackish zone influxes.
- Models only calibrated on freshwater flow do not provide accurate parameters for assessing chemical transport. A more accurate includes combining water flow and salinity measurements.
- A freshwater only model is not able to predict the effect of sea level rise, including expected increase saltwater intrusion.

Approaches

- Density-dependent flow (SEAWAT)
  - Simulates the interaction between saltwater and freshwater including the transition (brackish zone).
  - No need to set bottom for any of these zone because they are treated as one continuous zone. Aquifer bottom should be deep enough into the saltwater zone.

Vertical cross section showing flow patterr of fresh and saline water in an unconfin coastal aquifer





Biscayne aquifer near Miami, Florida.

Using SEAWAT

SEAWAT

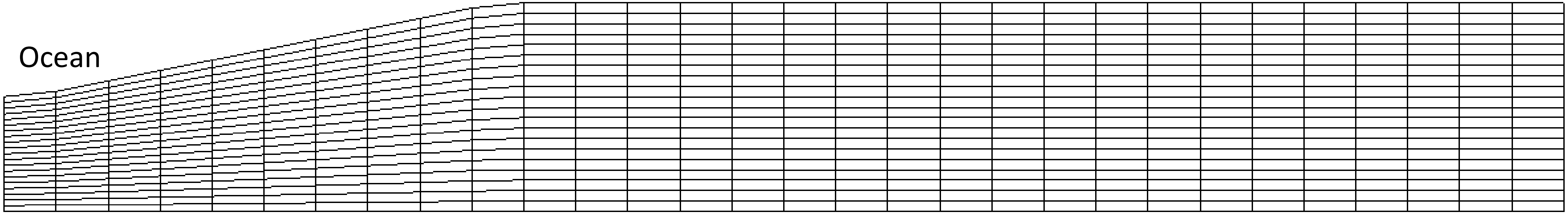
- The SEAWAT program simulates three-dimensional, variable-density, transient ground-water flow in porous media.
- SEAWAT was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute-transport equations.
- MODFLOW was modified to include the appropriate density terms.
- Fluid density is assumed to be only a function of the concentration of dissolved constituents; the effects of temperature on fluid density are not considered.
- Temporally and spatially varying salt concentrations are simulated in SEAWAT using the MT3DMS program.
- The flow and transport equations are solved multiple times for the same timestep until the maximum difference in fluid density between consecutive iterations is less than a user-specified tolerance.

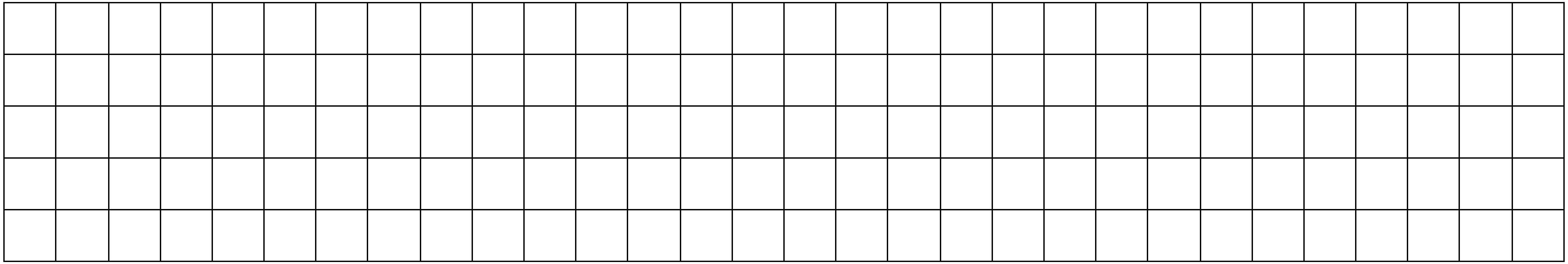
SEAWAT Steps

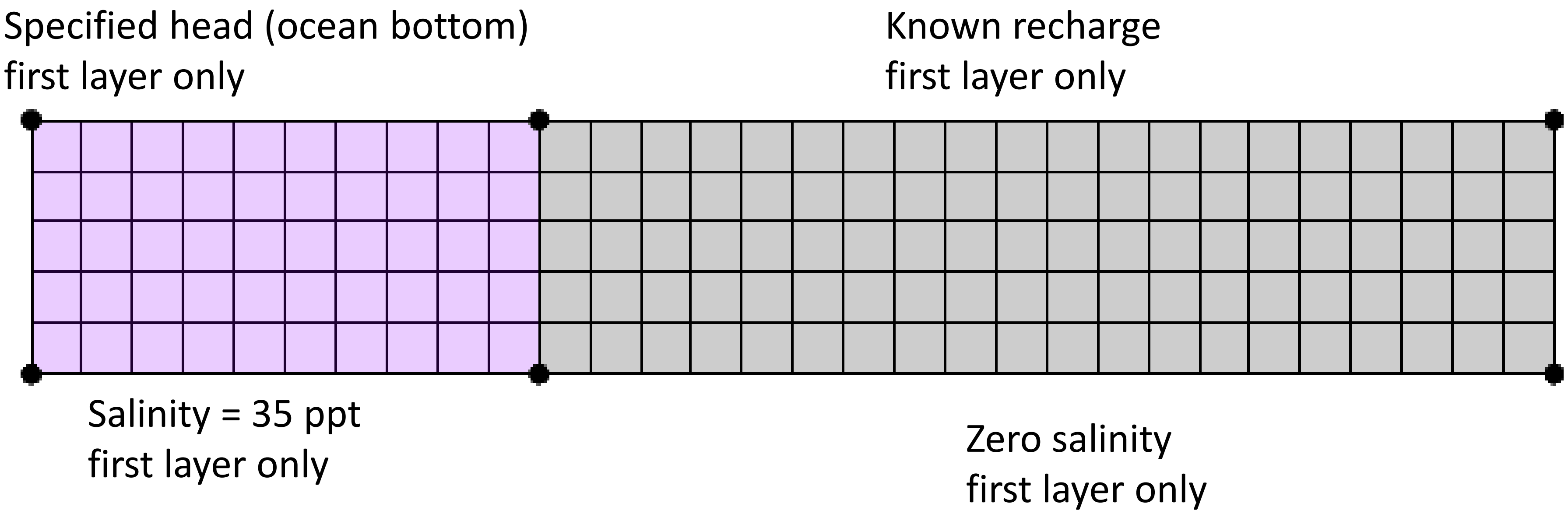
- Setup MODFLOW as usual
- Setup MT3DMS as usual with salinity as the species
- Add other species as needed, e.g., contamination near the ocean
- Setup SEAWAT
- Run SEAWAT (<u>no need to run MODFLOW or MT3DMS</u>)

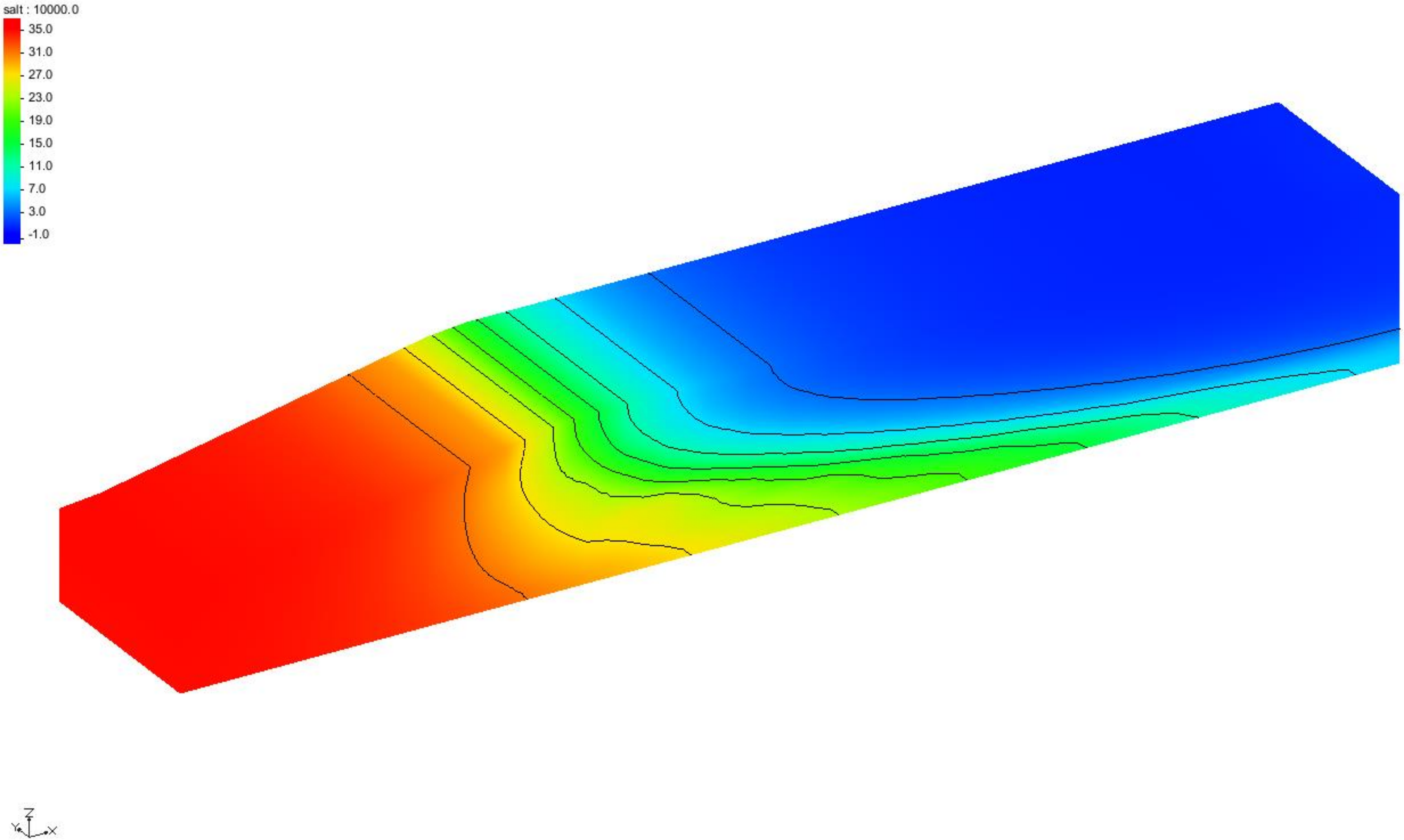
- Important: A fine vertical grid is needed due to non-linearity of the problem; best to use vertically expanding grid moving down.

Example setup






Specified head (ocean bottom)
first layer only
Known recharge
first layer only
Salinity = 35 ppt
first layer only
Zero salinity
first layer only



salt : 10000.0
35.0
31.0
27.0
23.0
19.0
15.0
11.0
7.0
3.0
-1.0
Z
Y
X