

VERTICAL SALINIZATION BY FREE CONVECTION; A SIMPLE BENCHMARK PROBLEM BASED ON PHYSICAL THEORY.

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ABSTRACT.

Salinization of groundwater by free convection from an overlying salt source is a fundamental hydrogeological process that occurs in many natural and man-made settings (salt lakes, inundations by the sea, saline disposal ponds). Over the years, this process has been studied by many researchers. Due to the complexity of the observed fingering behaviour two benchmark problems have been proposed that serve for intercomparison of numerical codes: 1) the 'short-heater Elder problem' and (2) the 'salt lake problem'. A limitation of these benchmarks is that, although they are suitable to bring to light differences among codes, there is no independent verification of the predicted behaviours through analytical solutions or physical theory. This is primarily due to the restricted width over which a salt source is imposed at the top boundary, which induces edge effects, and the nonuniform regional flow in the salt lake problem. A comprehensive theory that accounts for these complicating factors does not seem to exist. I therefore propose a third, more simple benchmark problem which retains the basic elements of both previous benchmarks, but which also allows a more direct comparison with physical theory. It is referred to as the 'long-heater Elder problem with uniform upward seepage': a rectangular domain is initially filled with fresh pore water; the left and right side are closed to both fluid and solute transport; at the lower boundary a fresh water salt mass fraction is imposed together with a specified upward flow rate; at the top boundary a finite salt mass fraction is specified in conjunction with zero fluid pressure. Homogeneous and isotropic dispersion (diffusion) is used. The key element in the behaviour of this problem resides in the accurately defined transition from stable to unstable conditions when the rate of upward flow is progressively reduced. For sufficiently strong upward flow, the saline boundary layer that develops just beneath the top boundary attains a steady state characterized by exponentially decreasing salinity with depth. The boundary layer remains stable indefinitely. If upward flow is below a threshold value, the boundary layer becomes too thick, unstable and fingering ensues. Numerical experiments with the variable-density groundwater code Metropol-3 shows that the theoretical threshold seepage rate (or critical boundary layer Rayleigh number) that follows from linear perturbation analysis of the corresponding differential equations is accurately reproduced by this code. Also the characteristic horizontal wavelength of the initial instabilities that define the characteristic dimensions of salt fingers was found to be in concert with physical theory.

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