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The ‘Henry Problem’ of ‘density-driven’ groundwater flow versus Tothian ‘groundwater flow systems’ with variable density: A review of the influential Biscayne aquifer data

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In subsurface fluid dynamics densities, associated heads, and buoyancy effects are important factors determining the flow behaviour of fresh water, waste water, saline water, brines, hydrocarbons and sequestered CO_2.

In the 1950s and 60s coastal groundwater flow investigations at the Biscayne Bay, south of Miami, Florida, gave rise to the concept of density-driven flow of seawater into coastal aquifers creating a saltwater wedge. Within that wedge, convection-driven return flow of seawater and a dispersion zone were assumed by Cooper et al. (1964) to be the cause of the Biscayne aquifer ‘sea water wedge’. This conclusion was based on the chloride distribution within the aquifer and on an analytical model concept assuming convection flow within a confined aquifer without taking non-chemical field data into consideration. The concept was later labelled the ‘Henry Problem’, which any numerical variable density flow program must be able to simulate to be considered acceptable. All existing variable density flow computer programs are based on the interpretation of the results of field investigations at the Biscayne aquifer test site.

Both, ‘density-driven flow’ and Tothian ‘groundwater flow systems’ (with or without variable density conditions) are driven by gravitation. The difference between the two are the boundary conditions. ’Density-driven flow’ occurs under hydrostatic boundary conditions while Tothian ‘groundwater flow systems’ occur under hydrodynamic boundary conditions.

Revisiting the Cooper et al. (1964) publication with its record of piezometric field data (heads) showed that the so-called sea water wedge has been caused by discharging deep saline groundwater driven by gravitational flow and not by denser sea water. Density-driven flow of seawater into the aquifer was not found reflected in the head measurements for low and high tide conditions which had been taken contemporaneously with the chloride measurements. These head measurements had not been included in the flow interpretation. The very same head measurements indicated a clear dividing line between shallow local fresh groundwater flow and saline deep groundwater flow without the existence of a dispersion zone or a convection cell.

At the Biscayne site density-driven flow of seawater did and does not exist. Instead this site and the Florida coast line in general are the end points of local fresh and regional saline groundwater flow systems driven by gravity forces and not by density differences. These conclusions were corroborated by 5 independent methods