

Revisiting the Henry Problem of 'density driven'
groundwater flow:
A review of historic Biscayne aquifer data.

by
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What does "density-driven" mean?

Density-driven movements only exists
in a gravitational field.

Hence density-driven means gravitationally-driven.

Groundwater flow systems are also gravitationally-driven.

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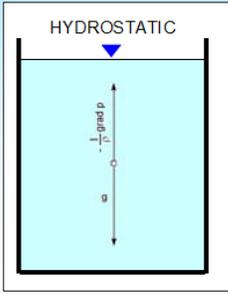
What is then the difference between the two:

“density driven” flow (migration) within a
gravitational force field
and
gravitationally-driven groundwater flow systems?

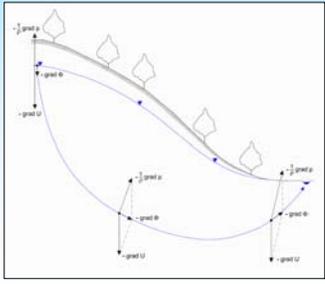
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The difference is in the boundary conditions:
hydrostatic vs hydrodynamic

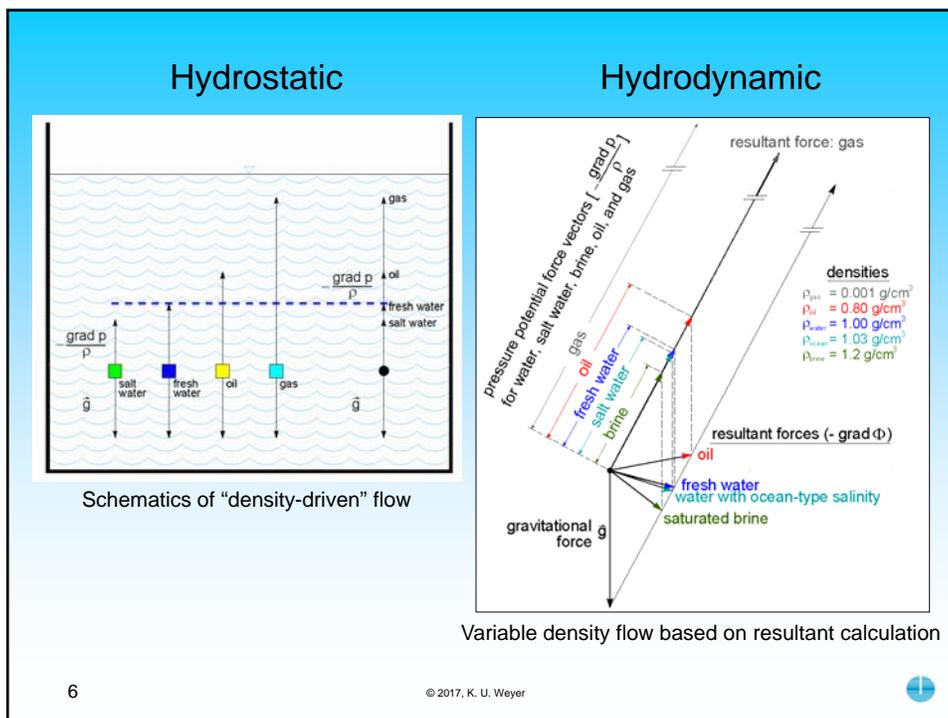
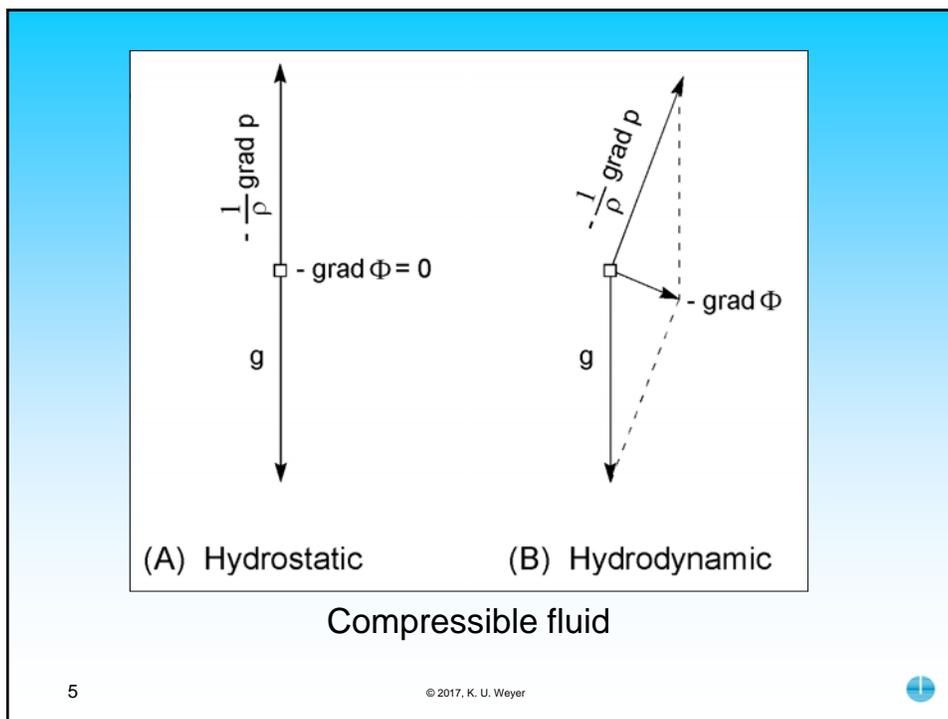
“density-driven” ----- ”groundwater flow systems”



HYDROSTATIC



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After an introductory visit to the basics of the physics of subsurface fluid flow, we will now concentrate on the field investigation which gave rise to the concept of sea water intrusion by density driven flow: the Biscayne aquifer at the Custer site along Biscayne Bay in Florida

Reference: Cooper, Kohout, Henry, and Glover, 1964, Sea water in Coastal aquifers.. USGS water supply paper 1613-C

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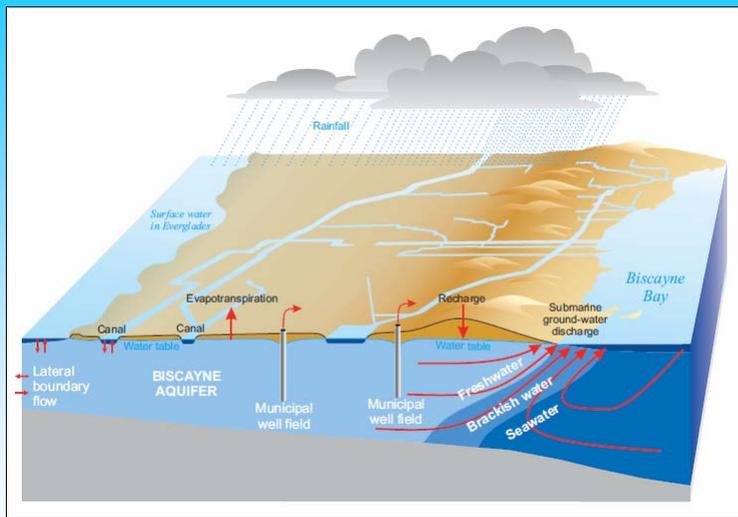


Map source: <http://ontheworldmap.com/usa/state/florida/florida-physical-map.html>
 Inset: <http://tides.mobilegeographics.com/locations/1456.html>

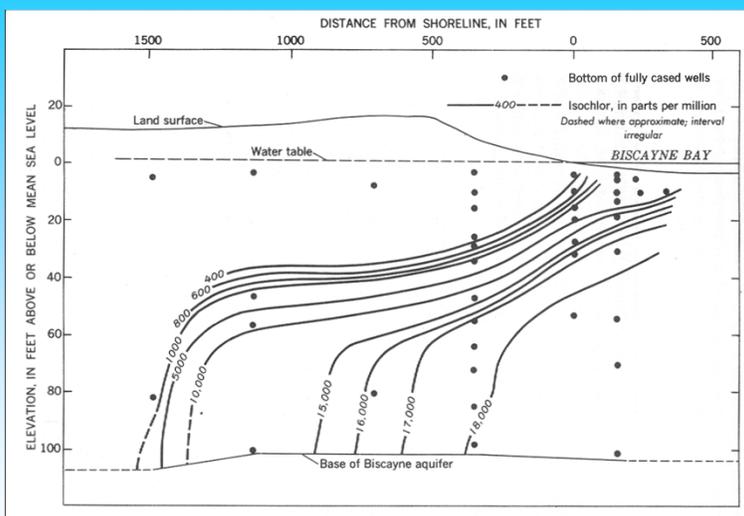
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Langevin, 2001, Fig. 15



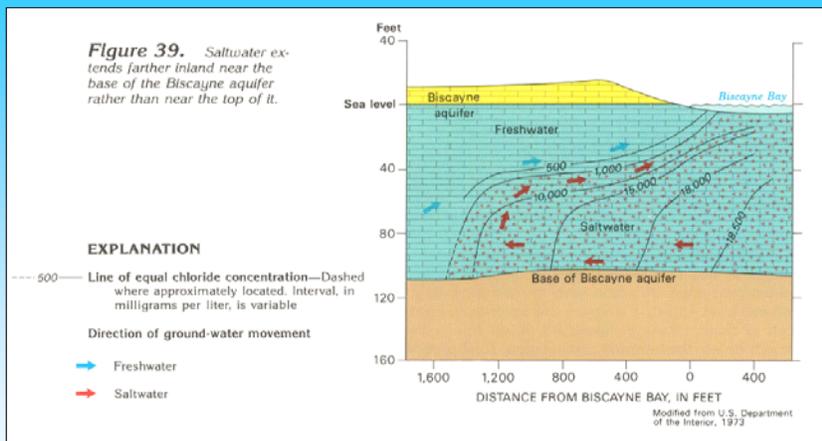
Cooper et al., 1964, Fig. 5

Biscayne aquifer: lines of equal chloride concentration (in ppm)



Interpretations of the chemical data:

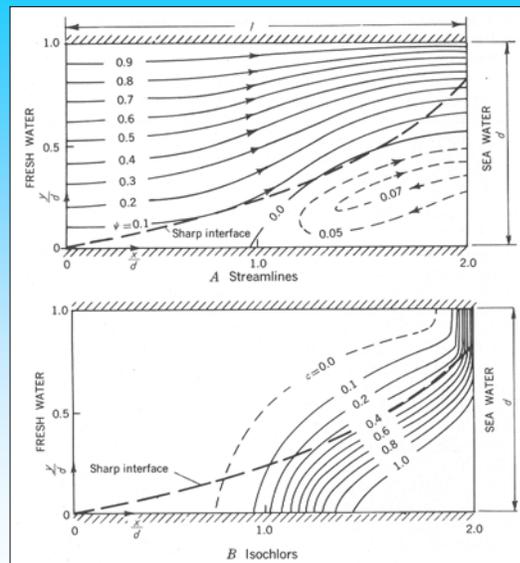
It is a seawater wedge!
 It is a case of density-driven flow!
 It is an example of a convection cell!



Miller, 1990, Fig. 39

Presumed convective flow





Cooper et al., 1964, Fig. 34

The Henry Problem

A mathematical concept of the Biscayne aquifer system: boundary conditions, streamlines, and isochlors

Note

The unconfined field conditions have been replaced by confined conditions to accommodate the mathematics involved.

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Why continue? Everything seems to be quite clear. The chemical data seem to loosely support the flow interpretation by Henry in Cooper et al., 1964.

Nevertheless, let's have a look at Cooper et al.'s, head data and other data from USGS field studies in the region.

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How can the relatively flat Florida topography cause deep groundwater flow systems to bring saline water up to the distant beach areas in south Florida?

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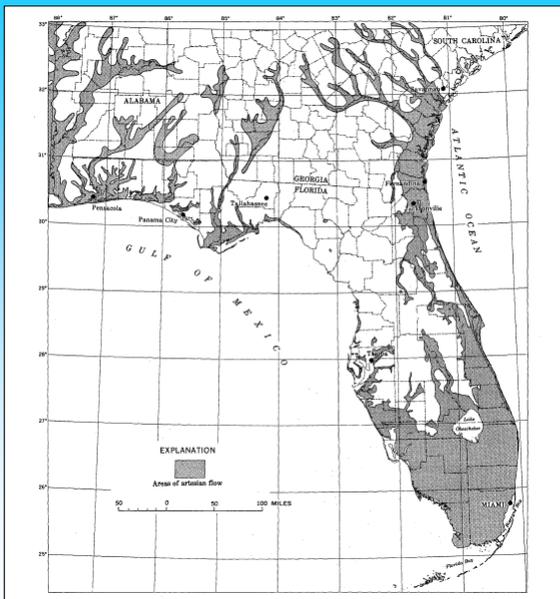
Artesian (flowing) wells are an infallible indicator for groundwater discharge



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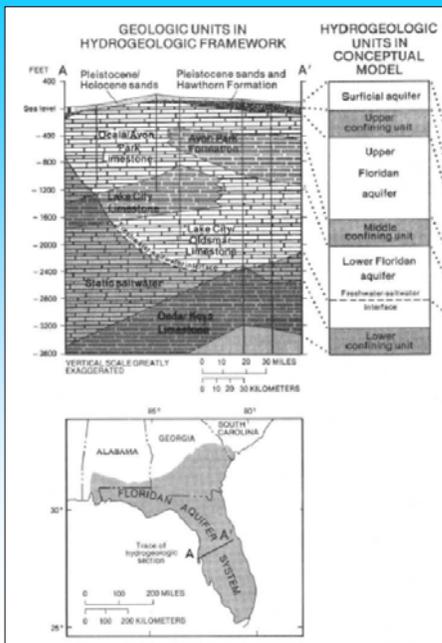


Hatched areas indicate regional discharge areas with the occurrence of artesian (flowing) wells

Springfield, 1966, Fig. 28

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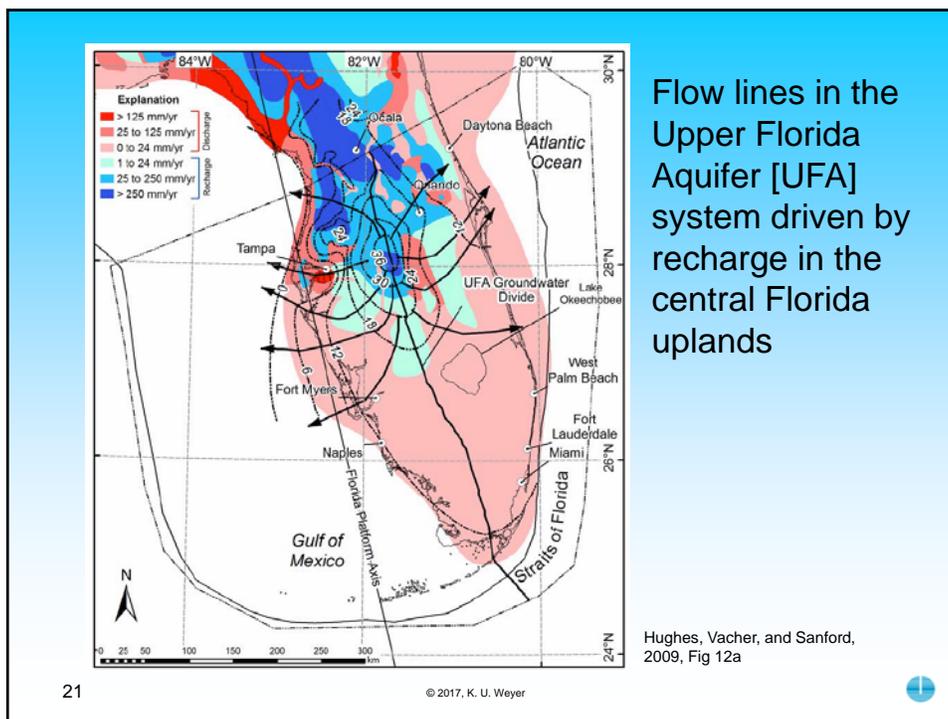
Indications of deep groundwater flow systems in central Florida from chemical data with freshwater-saltwater interface

Bush and Johnson, 1986, Fig. 9

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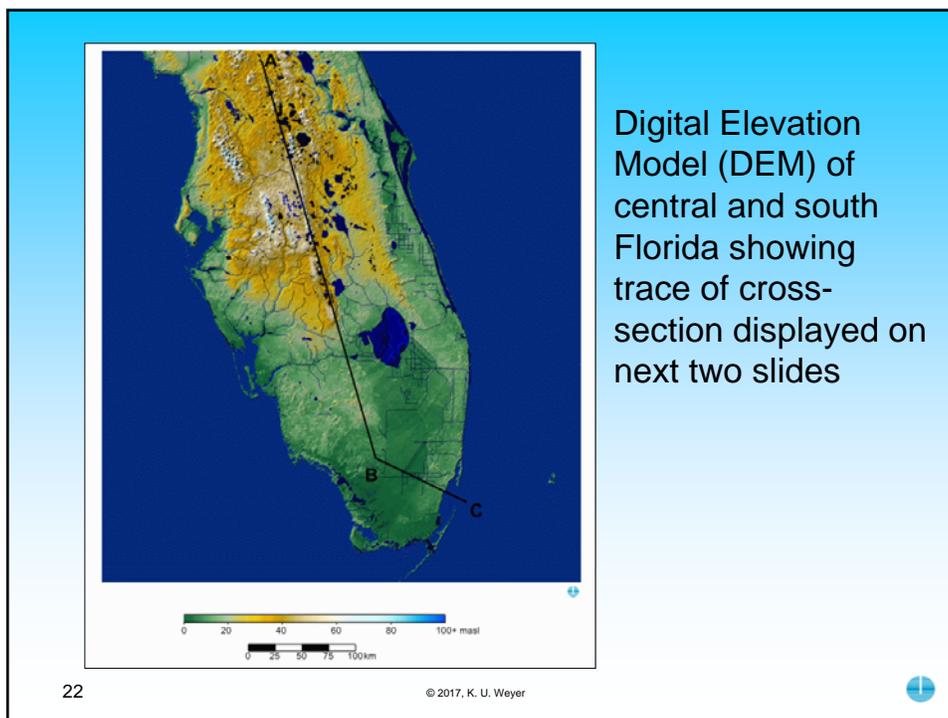




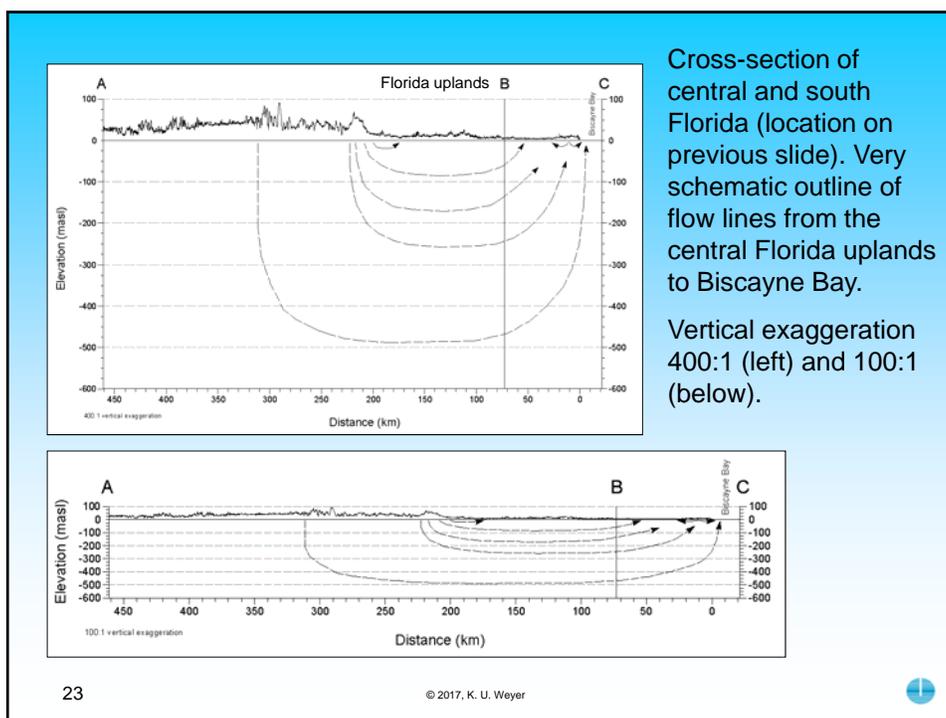
Flow lines in the Upper Florida Aquifer [UFA] system driven by recharge in the central Florida uplands

Hughes, Vacher, and Sanford, 2009, Fig 12a

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Cross-section of central and south Florida (location on previous slide). Very schematic outline of flow lines from the central Florida uplands to Biscayne Bay.

Vertical exaggeration 400:1 (left) and 100:1 (below).

Three independent methods have shown that at the classic site of the 'Henry Problem' for density-driven sea water intrusion there exists no seawater wedge, and, accordingly, no density-driven flow.

The saline zone has been created and is maintained by gravitational discharge of deep saline groundwater.

QED

Quod erat demonstrandum