

ANNEX

A freshwater lens on an island

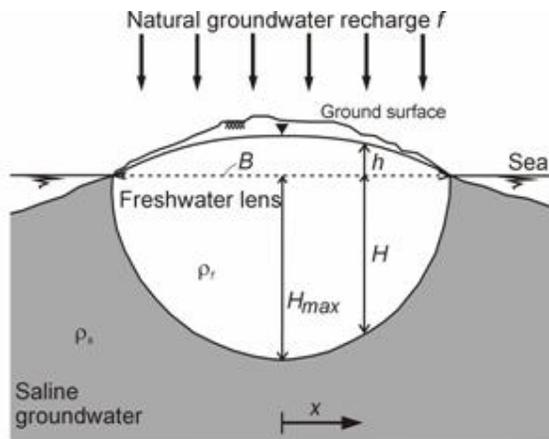


Figure 1: Maldives case: the fresh-salt interface in an elongated island

Based on a quick analysis of the conditions in the Maldives, we have deduced the following values:

- B =width of island=400 m
- f =natural groundwater recharge: we've used the Hanimaadhoo 10 yrs average rainfall figures, and estimated that only 20% would supply the groundwater reservoir. Result for the worst case situation: each year 5 months no recharge and 7 months recharge. In total per year an amount of 303.4 mm (ref: <http://www.meteorology.gov.mv/default.asp?pd=climate&id=3>):
- k =hydraulic conductivity=40 m/day, worst case: it is assumed that the aquifer is good permeable, that the freshwater lens is shallow and the effect of the tsunami is relatively large.
- ρ_s, ρ_f = density of saline and fresh groundwater, 1025 and 1000 kg/m³, respectively.
- $\alpha = (\rho_s - \rho_f) / \rho_f$ =relative density difference=0.025, which is an accurate value for systems in ocean water.

Analytical estimate:

Based on the following analytical formula, the depth of a steady-state freshwater lens H is calculated as:

$$H = \sqrt{\frac{f(0.25B^2 - x^2)}{k(1+\alpha)\alpha}}$$

In addition, the volume of water in the freshwater lens per stretched meter width is equal to:

$$V = \frac{1}{4} \pi (1 + \alpha) H_{\max}^2 B n_e$$

When the natural groundwater recharge is averaged to 303.4 mm over 1 year, viz. $f=0.831$ mm/day, then the deepest position of the interface H_{\max} (in the middle of the lens at $x=0$) is 5.7 m and the highest phreatic groundwater level 0.14 m. With an effective porosity n_e equal to 0.35, the volume $V=641$ m³/m' and the characteristic time to fill the freshwater lens with recharge water is $t=5.3$ year. This means that without pumping, it takes about 16 years (3) before the freshwater lens has 99.5 % of its original shape again: in groundwater terms, this reaction time can be characterized as rather quick.

Computer code

The computer code used, is called MOCDENS3D. This code is based on MODFLOW and MOC3D, both from the USGS and widely used throughout the world. The MOCDENS3D code includes variable density groundwater flow and coupled solute transport (Oude Essink built the density adaptation in 1998). All demonstrated concepts were modeled with the same code.

Some recent reviewed references are:

- Oude Essink, G.H.P. 2001. Salt Water Intrusion in a Three-dimensional Groundwater System in The Netherlands: A Numerical Study, *Transport in Porous Media*, 43 (1): 137-158.
- Bakker, M., Oude Essink, G.H.P. & Langevin, C. 2004. The rotating movement of three immiscible fluids, *J. of Hydrology* 287, 270-278.
- Bouw, L. & Oude Essink, G.H.P. 2003. Development of a freshwater lens in the inverted Broad Fourteens Basin, Netherlands offshore, *Journal of Geochemical Exploration*, Vol. 78-79, 321-325.
- Vandenbohede, A. & Lebbe, L., 2002. Numerical modelling and hydrochemical characterisation of a fresh water lens in the Belgian coastal plain. *Hydrogeology Journal* 10(5), 576-586.
- Oude Essink, G.H.P. 2001. Improving Fresh Groundwater Supply - Problems and Solutions, UNESCO International workshop on cities and coasts, Challenges of growing urbanization of the world's coastal areas, 27-30 September 1999, Hangzhou, China, *Ocean & Coastal Management*, 44 (5/6), 429-449.