Analytical modeling of freshwater lenses in different settings: from coastal embryo dunes in the Netherlands to inland mega dunes in Abu Dhabi

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ABSTRACT

Freshwater lenses are generally formed by rainfall and infiltration on land with saline water in the underground. They are extremely important for fresh water supply to man, wildlife and vegetation. Their extreme vulnerability to marine inundations, coastal erosion, groundwater extraction and climate change calls for a profound understanding of their genesis, growth, decay, shape and size under natural and stressed conditions.

Closed-form analytical models that simulate observations well, are good proof of understanding. The existing analytical models perform well, however, only under ideal situations which are rarely met. In this study, we demonstrate that they in fact perform badly, if no due consideration is given to (i) the presence of intercalated aquitards within the freshwater lens, (ii) salinity of the salt groundwater below the lens, (iii) recharge rate, and (iv) periodical inundations by the sea.

We show field observations on 21 coastal locations in the Netherlands, in the early 1900s when the (medium) large lenses were still little disturbed by among others groundwater pumping. On these locations, the observed Ghyben-Herzberg ratio was not 40 (as mentioned in many textbooks) but 18.6 on average, while ranging between 6 and 46. This deviation triggered the development of the here proposed, empirical correction factor for the height of the watertable, the depth to the fresh/salt interface and the lens formation time, as calculated with well known, closed-form analytical solutions from the literature.

The salinity of coastal seawater and of the salt water below the freshwater lens is another issue often overlooked, which contributes to significant deviations from Ghyben-Herzberg's ratio of 40. In the Netherlands, coastal North Sea water is shown to have an average salt water density of 1.020 kg/l, with variations mainly depending on the distance to the coast, the distance to the main outlet of the Rhine River, its discharge, wind direction and wind velocity. Measurements of the saline groundwater below the coastal lenses are more or less identical to this coastal North Sea water, with few but interesting exceptions. Very large, inland dune areas, such as the Veluwe in the central Netherlands (~circular with 19 km radius) and the Liwa – Al Qafa dunes (~elongate 100x50 km) in Abu Dhabi, have totally different salinities below their fresh water lenses, ranging from brackish to hypersaline. This has a strong impact on their size.

The recharge rate of dune or sandy recharge areas is difficult to assess, even though surface water discharge (often <5%) can (nearly) be ignored. It has a strong impact on the outcome of analytical modeling, justifying efforts to provide accurate estimates. Observations on the water balance of 4 megalysimeters in coastal dunes near Castricum (Netherlands) are presented, which may help to estimate the annual recharge rate as function of vegetation and

annual rainfall in temperate climates. Another option is to use the chloride mass balance, with due consideration of several pitfalls.

Inundations of the sea have a strong impact on small lenses below coastal embryo dunes on the higher parts of beaches. The smaller or lower dunes are easily eroded or inundated during once in 1-10 years flooding, but they will dilute the infiltrating seawater and may give rise to a broad beach zone with brackish groundwater in the phreatic aquifer, as noted on the Dutch islands of Texel and Schiermonnikoog.
In this contribution, observations ànd analytical modeling results are presented, with examples from small embryo dunes on the beach, (medium) large coastal dunes and (very) large inland dune systems, in the Netherlands and Abu Dhabi.

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