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Field measurements of groundwater discharge to a lagoon under variable density water conditions (Ringkøbing Fjord, Denmark)

Carlos Duque (1), Kinza Haider (1), Peter Engesgaard (1), Eva Sebok (1), and Torben O. Sonnenborg (2)

(1) University of Copenhagen, Department of Geosciences and Natural Resource Management, Denmark (cad@geo.ku.dk), (2) GEUS. Geological Survey of Denmark and Greenland

Ringkøbing Fjord is a lagoon located near the west coast of Denmark. It has an extension of 300 km2 and receives water from the Skjern River (plus other smaller streams), direct rainfall, sea water through a controlled connection with the sea (sluice), and, finally, from groundwater. While most of these fluxes are relatively well known, groundwater inputs to the lagoon have never been quantified. The salinity of the lagoon changes from 4 g/L (winter) to 12 g/L (summer) due to the seasonal changes in discharge (mainly Skjern River) and the operation of the sluice. Four field surveys (March, May, August and October) were accomplished in 2012 to determine, for the first time, the groundwater discharge to the lagoon at four locations/transects on the eastern shore line. The main objective was to understand the groundwater-fjord exchange processes that take place in the near-shore lagoon environment where, according to the theory, most groundwater discharge to the lagoon is to be expected. The investigative methods were similar to those utilized in lake and stream studies. More than 350 seepage meter measurements and around 150 vertical groundwater temperature logs of the first 50 cm under the lagoon bed were collected providing direct and indirect quantification of fluxes, respectively. Nevertheless, a significant difference remains compared with e.g. lakes, because of the salinity changes of the fjord water and, subsequently also the groundwater directly beneath the fjord. The seasonal contrasts in the density of groundwater and lagoon water made it necessary to take into account the salinity distribution in the shallow groundwater, because it can affect the pattern and amount of groundwater discharge to the lagoon. Thus, the salinity of the groundwater was measured every 25 cm in vertical profiles until 3 m depth along each transect. In total, more than 1300 points were sampled to obtain the spatio-temporal salinity distribution at the four locations. These discharge and salinity data were used to; i) Study the groundwater Electrical Conductivity (EC) changes due to both salinity changes in the fjord and groundwater discharge variations, (ii) Compare the freshwater discharge flux rates obtained by different methods and, finally, iii) Correlate the groundwater salinity distribution and the estimated flux patterns at the fjord bed. The changes in the salinity of groundwater combined with analysis of the saline wedge location indicate that the system is dynamic with slow seasonal changes and characterized by high heterogeneity along the lagoon shore. The measured average flux rates ranges from 0.5 to 2 cm/d. The discharge from the aquifer to the fjord tends to decrease with distance to the shoreline, but affected by the presence of the saline wedge.