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Temperature profiles to measure groundwater discharge to Ringkøbing Fjord

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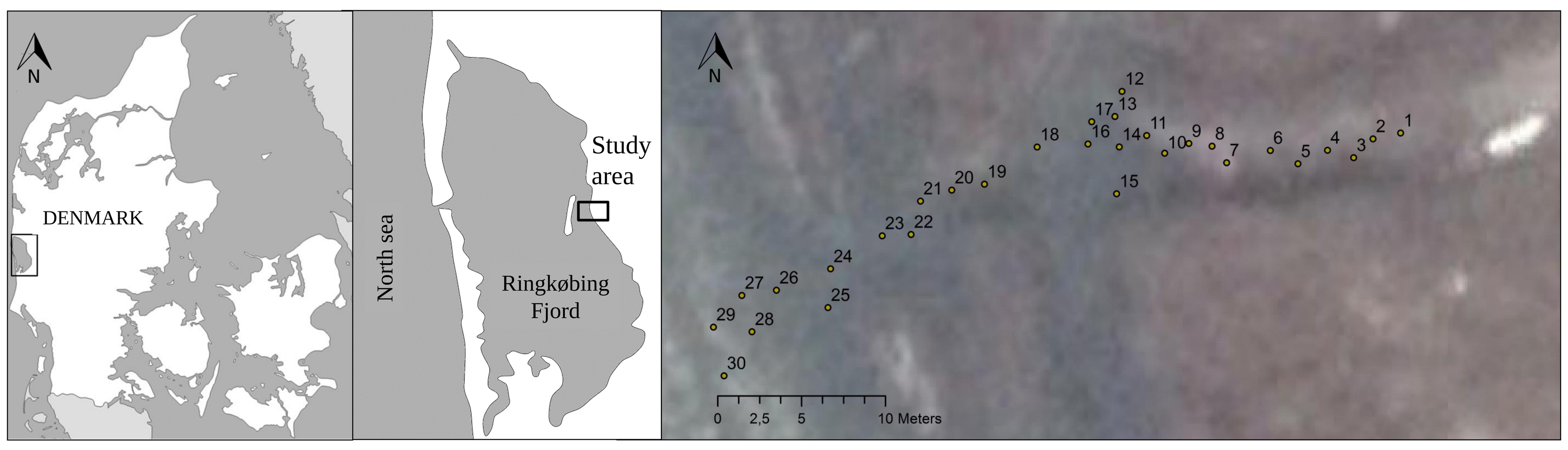
Introduction

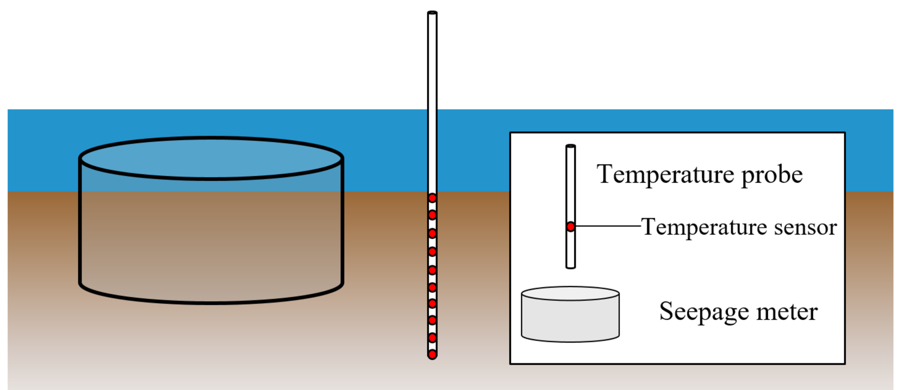
Groundwater discharge or upwelling is spatio-temporal dependant, and its quantification implies a considerable effort in terms of field work for the data acquisition.
The use of heat as a tracer to locate and quantify surface water – groundwater interactions has proven to be a useful technique in different scenarios [1].
We apply this methodology to study whether it is a feasible and faster alternative to direct measurement using seepage meters.

Objectives

- Measure groundwater discharge to Ringkøbing Fjord by the use of seepage meters.
- Calculate the groundwater discharge to Ringkøbing Fjord by the use of near surface temperature profiles data.
- Compare seepage meter measurements with discharge estimated from 1D heat transport modeling.

Location & Setup





- 30 temperature probes.
  - 50 cm below the fjord bed.
  - 10 measurements each profile.
  - 10 min equilibration period.

- 30 seepage meters.
  - Direct groundwater discharge ⟶ increase in weight.
  - 6 measurements at each seepage meter.

Methodology

- Direct measurement

$$q = \frac{W_e - W_s}{t \rho A}$$

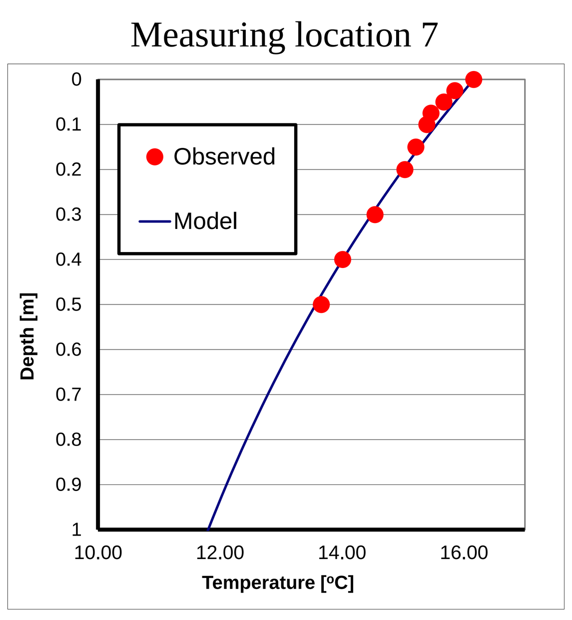
q: flux (m/s)
t: time of the experiment (s)
ρ: density of water (kg/m³)
A: seepage meter area (m²)
W_s: seepage meter bag weight at the start of the experiment (kg)
W_e: seepage meter bag weight at the end of the experiment (kg)

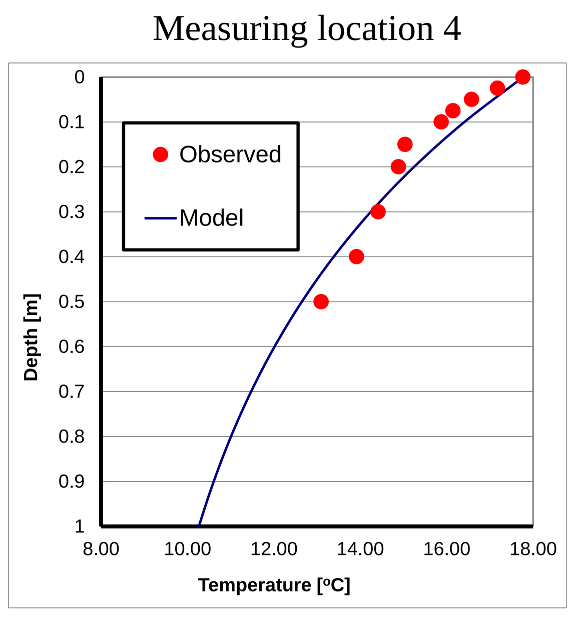
- Temperature profile (Bredehoeft and Papadopulos [2])

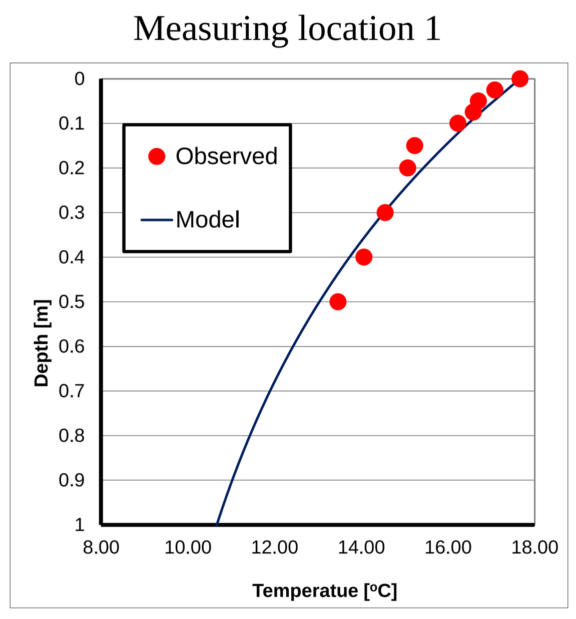
$$T(z) = T_s + (T_g + T_s)\frac{\exp[N_{pe}(z/L)] - 1}{\exp[N_{pe}] - 1}$$

$$N_{pe} = \frac{q \rho c L}{K_e}$$

z: depth of the temperature sensor (m)
L: depth at which the groundwater temperature is constant (m)
T(z): temperature at depth z (°C)
T_s: surface water temperature (°C)
T_L: temperature of groundwater at depth L (°C)
c: specific heat capacity of the fluid (J/kg °C)
K_e: bulk thermal conductivity (J/m s °C)
N_{pe}: Peclet number (-)

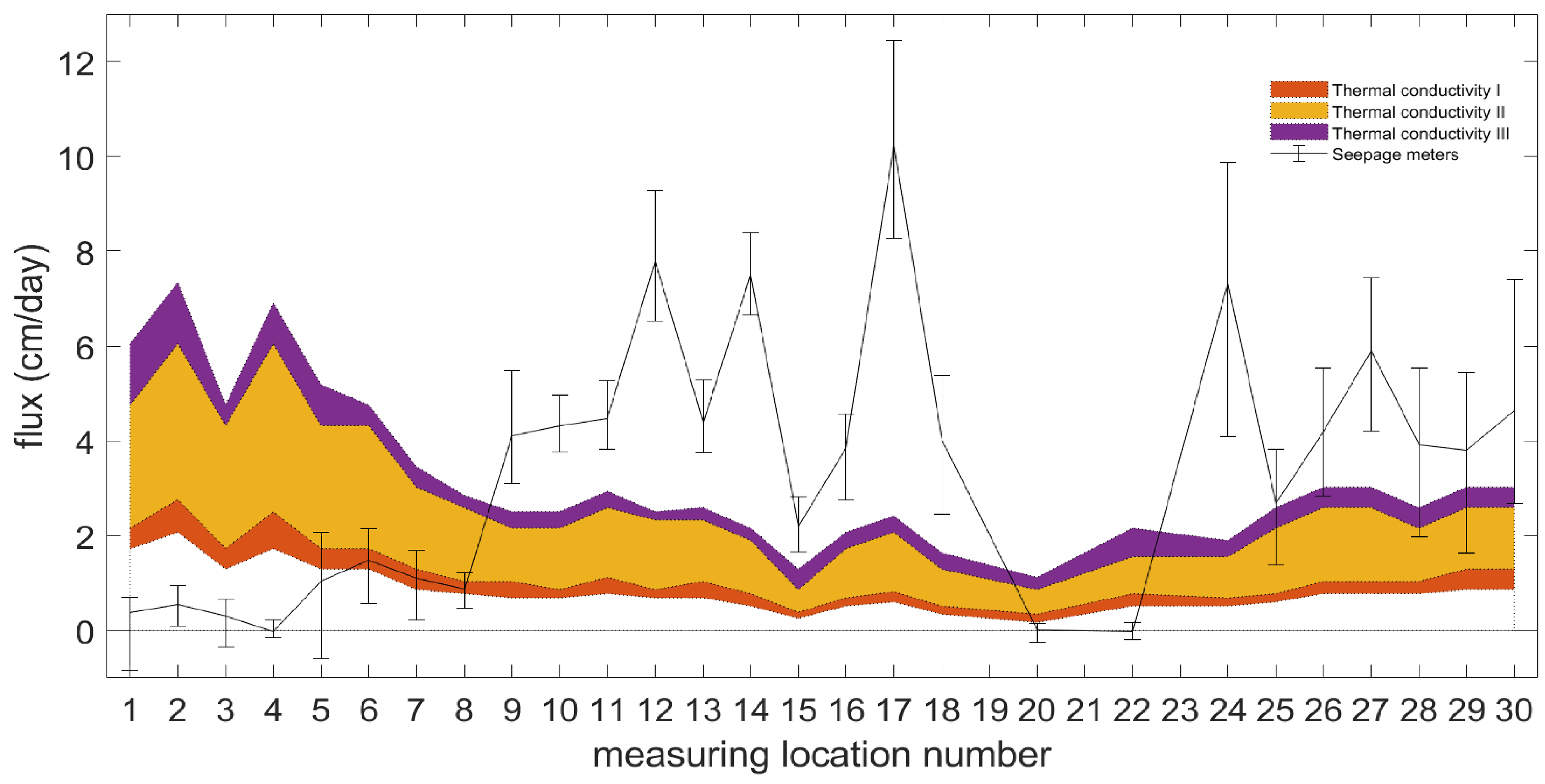






- Trial-and-error manual fitting of Bredehoeft and Papadopulos equation to temperature data.
- Top boundary condition: temperature at depth 0 m.
- Bottom boundary condition: groundwater temperature (from deep boreholes temperature data).
- Application of 3 different thermal conductivity ranges based on previous studies at the site [3].
  - Thermal conductivity I: 0,62-0,83 $Wm^{-1}{}^{o}C^{-1}$
  - Thermal conductivity II: 0,83-1,86 $Wm^{-1}{}^{o}C^{-1}$
  - Thermal conductivity III:1,86-2,19 $Wm^{-1}{}^{o}C^{-1}$

Results



- Same order of magnitude in flux results using both methods.
- Opposite relative magnitudes:
  - Temperature ⟶ higher fluxes near the shore.
  - Seepage meters ⟶ higher fluxes offshore.
- Seepage meter measurements:
  - Mostly groundwater discharge to fjord.
  - Fluxes ranging from -1 to 12 cm/day.
  - High variability within same location.
- Temperature calculations:
  - Fluxes ranging from 0,5 to 7 cm/day.

Conclusions & Future work

- Groundwater discharge to Ringkøbing Fjord was sucessfully measured by the use of two different techniques: direct flux measurement using seepage meeters and flux calculation applying a 1D steady heat transport equation using temperature profile data.
- The use of different ranges of thermal conductivity does not provide a perfect match between direct measurements and calculations. This could imply that the range in thermal conductivity may be bigger than expected or that the model assumptions (e.g. 1D vertical flow) do not apply for the study area.
- While obtaining temperature profile data is faster than measuring fluxes with seepage meters, the uncertainty in the parameterization increases the modeling uncertainty.
- The developement of an Integrated Surface and Subsurface Hydrologic Model with special focus on the heat transport processes will shed some light on the interaction between the groundwater and the surface water at the fjord.

References

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[3] C. Duque, S. Müller, E. Sebok, K. Haider, P. Engesgaard. Estimating groundwater discharge to surface waters using heat as a tracer in low flux environments: the role of thermal conductivity. *Hydrological Processes*, **30**, 383-395, (2016).