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Hydrological modelling of small scale processes in a wetland habitat

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Abstract Numerical modelling of the hydrology in a Danish rich fen area has been conducted. By collecting various data in the field the model has been successfully calibrated and the flow paths as well as the groundwater discharge distribution have been simulated in details. The results of this work have shown that distributed numerical models can be applied to local scale problems and that natural springs, ditches, the geological conditions as well as the local topographic variations have a significant influence on the flow paths in the examined rich fen area.

Key words distributed numerical modelling; data collection; fens; wetlands; small scale; water level; discharge

INTRODUCTION AND BACKGROUND

The interaction between groundwater and surface water in riparian areas is of great significance for the whole aquatic environment and for the groundwater dependent terrestrial ecosystems. Meeting the standards of the EU Water Framework Directive requires an improved knowledge on site specific hydrological processes which affect the preservation status of the ecosystem.

Groundwater modelling is widely used as a tool for evaluating the groundwater resources on a regional scale and thus a great effort has been put into collecting a sufficient amount of data at this scale for model construction, calibration and validation. However, when it comes to describing the hydrological processes, which occur on field and point scale, the data resolution is often insufficient (Beven, 2008). Water level, water discharge, water chemistry, and nutrients availability are all significant elements affecting plant communities in wetland habitats (Van Diggelen *et al.*, 2006). A key to predicting each of these elements lies in an improvement of the methods for modelling the detailed flow processes.

MATERIALS AND METHODS

Study site

The site is located in the northern part of Denmark in the Lindenberg River valley and the adjacent aquifer consists of fractured high yield limestone formations. In the river valley a peat layer of approximately 1-2 m and below that an organic silt layer of 1-7 m where found. The area that was intensively studied is illustrated in Fig. 1.

Data collection and numerical hydrological model

Continuous water level measurements were conducted in 9 wells in the river valley (6 piezometres 5-7 metres below the surface and 3 short water level wells) and in a deep monitoring well in the plantation. The water level was stored every 2 hours from March 2007 to present by use of pressure loggers (mini-diver from Schlumberger Water Services).

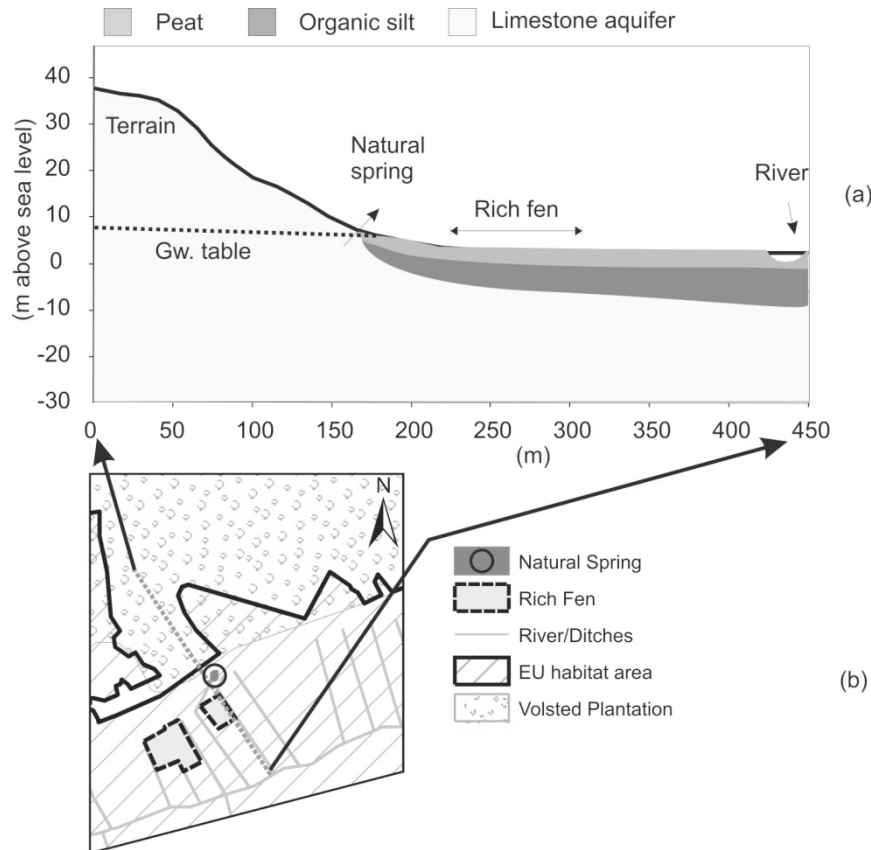


Fig. 1 Illustration of the study site. (a) Profile view of the river valley showing the location of the spring and the rich fen. (b) Map of the study site and the location of the profile in (a).

Discharge was measured in springs and ditches in the valley using a 50 mm propeller. In the ditches the flow rates were small ($<2 \text{ L s}^{-1}$) and it was necessary to use a plate to cut off the ditches and only allow the water to run through an 80 mm hole. Such device was constructed and calibrated in a laboratory before taken into the field.

A 3D numerical model that covers an area of 0.5 km^2 corresponding to Fig. 1b has been constructed using the Mike She code (Abbott *et al.*, 1986). The boundary conditions used were extracted from a regional model, which was validated against both water level and discharge measurements in the catchment area. In order to describe the small scale hydrological processes in the springs and ditches surrounding the rich fen area a horizontal resolution of 5×5 metres was chosen.

RESULTS

Figure 2 presents water level data from the plantation and from the rich fen, and at each location two filter depths are monitored.

From the water level measurements it is clear that there is an upward pressure gradient in the area and that this gradient is fairly constant the entire period from May 2007 until November 2008. This applies to both the plantation and the rich fen area. The amount of water discharged to the fen area is proportional to the magnitude of this pressure gradient. In the plantation, the maximum water level in the spring of 2007 was approximately 1 m higher than in the spring of 2008. In the fen area the same tendency is seen to some extent in the deep filter, but not in the surface water level, which is controlled by the ditches and the terrain level.

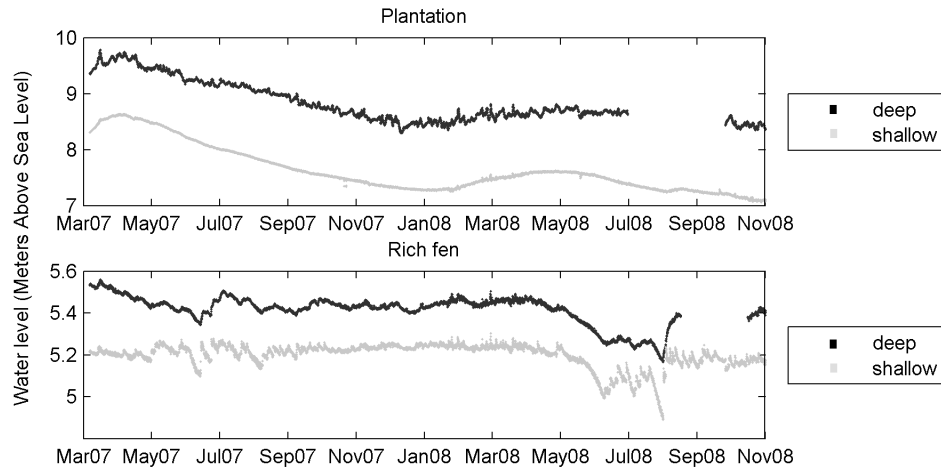


Fig. 2 Water levels measured in the plantation and in the rich fen. The horizontal distance between the plantation and the rich fen is 1 km. The deep filters are in both cases positioned below a semi-confining layer and the upper filters measure the water table.

The discharge of groundwater to the surface was measured in ditches and natural springs in the study area (Fig. 1b). The results are compared to simulated discharge rates in Table 1. The springs account for more than 90% of the discharge to the surface. The measured discharge through the rich fen is estimated by the measuring discharge in the surrounding ditches.

Table 1 Discharge rates measured in natural springs and ditches compared to model results. The simulated discharge rates do not include evapotranspiration.

	Measured discharge	Simulated discharge
Natural springs	25 (L s ⁻¹)	23 (L s ⁻¹)
Ditches (sum of 10)	3 (L s ⁻¹)	3.2 (L s ⁻¹)
Rich fen area (sum of 2)	< 0.2 (L s ⁻¹)	0.07 (L s ⁻¹) = 1.2 (mm/day)

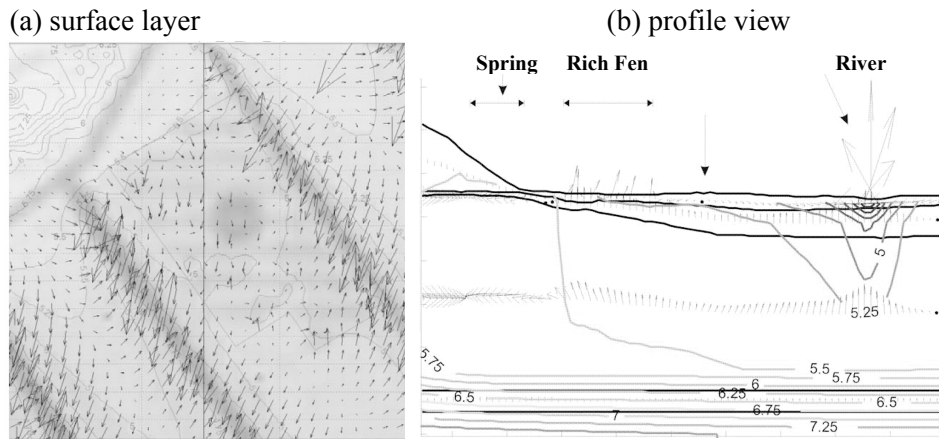


Fig. 3 Simulated flow vectors in the rich fen area. (a) Flow vectors in the surface layer (peat). (b) A profile view through all layers of the model. The position of the profile is similar to the profile in Fig. 1.

Fig. 3 illustrates the simulated flow patterns. In the left (a) flow vectors in the surface layer (peat) of the rich fen indicate the effect of the ditches. The profile view (b) illustrates how conditions on the surface affect flow paths in the underlying aquifer.

DISCUSSION AND CONCLUSION

The water level measurements provide valuable information in relation to calibration of the model as well as knowledge on the hydrological system in general. Monitoring the vertical pressure gradient gives an indirect measure of the discharge variations and improves knowledge on the dynamics of areas fed by groundwater significantly. Quantifying the discharge rate in springs and ditches by direct measurements is possible for flow rates $>0.2 \text{ L s}^{-1}$ with the applied method.

By using a regional hydrological model to provide the boundary conditions and local measurements of water levels and discharge rates to provide the primary calibration and validation data it was possible to simulate small scale hydrology in a Danish rich fen. The average groundwater flow through the rich fen was found by simulation to be 1.2 mm/day.

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