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Published in:
Hydro Eco2009 : Proceedings

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Hoffmann, C. C., Pedersen, M. L., & Rasmussen, K. R. (2009). How a regional aquifer, a local aquifer and an oxbow lake impact on hydrological and biogeochemical processes in ariparian fen-meadow ecosystem. In J. Bruthans, K. Kovar, & P. Nachtnebel (Eds.), *Hydro Eco2009 : Proceedings: 2nd International Multidisciplinary Conference on Hydrology and Ecology : Ecosystems Interfacing with Groundwater and Surface Water, 20-23 April 2009, Vienna, Austria* (pp. 59-62). University of Natural Resources and Applied Life Sciences Vienna (BOKU).

How a regional aquifer, a local aquifer and an oxbow lake impact on hydrological and biogeochemical processes in a riparian fen-meadow ecosystem

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Abstract The groundwater flow pattern through a riparian fen-meadow was investigated by use of piezometer transects, soil survey, measurements of piezometric heads and measurements of hydraulic conductivity. Groundwater was sampled from piezometers and analysed for nitrate-N. Water balances and nitrate-N mass balances were calculated.

Key words hydraulic head; hydraulic conductivity; riparian; modelling; groundwater discharge; nitrate removal

INTRODUCTION AND BACKGROUND INFORMATION

A riparian fen-meadow ecosystem in the River Gjern catchment area (114 km^2) was studied intensively during a four year period. Land use in the catchment is mainly agriculture, 77.4%, while forests occupy 13.9%, towns and paved areas 4.6%, and meadows and wetlands 4.4%. Soil types are sandy loams, 61.2%, loam, 34.8% and loamy sand 4.0%.

The River Gjern valley is located in a hilly moraine landscape from the Weichsel Ice age with underlying older Tertiary deposits. The Tertiary deposits form an impermeable lower boundary throughout the valley, whereas the younger Quaternary glacial deposits make up the groundwater aquifer and low-permeable deposits (Christensen *et al*., 1998). The regional groundwater is influenced by these Tertiary and Quaternary sediments.

The studied wetland is situated along the middle reach of Gjern River at Søbyvad (UTM: 32-6233665N, 548651E), and the groundwater aquifer consists of permeable glacio-fluvial deposits of Quaternary origin. The river valley is approximately 250 m wide, with steep eastern and western slopes. The study site is located at the eastern slope and the distance from the valley slope to the river varies between 30 m and 75 m. The minerotrophic wetland is a groundwater discharge area receiving large amounts of nitrate-rich groundwater from the upland aquifers.

Three transects were laid out extending from the spring fed valley slope to the riverbank. Piezometer nests were established along the groundwater flow paths - transect 1: stations 1-5; transect 2: stations: 1-7; transect 3: stations 1-7. Each station was equipped with 1-5 polyethylene piezometers with a slotted well point of 10 cm (Fig. 1). Hydraulic heads were measured weekly from 1992-1995, but less frequently during the years 1996-1997, i.e. 2-week intervals to 2-month intervals. Groundwater was analyzed for nitrate-N fortnightly.

The spring fed valley slope is covered with European ash and alder while the valley bottom is covered with herbaceous vegetation characteristic for a fen-meadow system (e.g. Dechámpsia flexúsa, Alopecurus praténsis, Urtica dioéca, Epilobium sp, Filipendia ulmaria, Glyceria sp, Phalaris arundinácea and others).

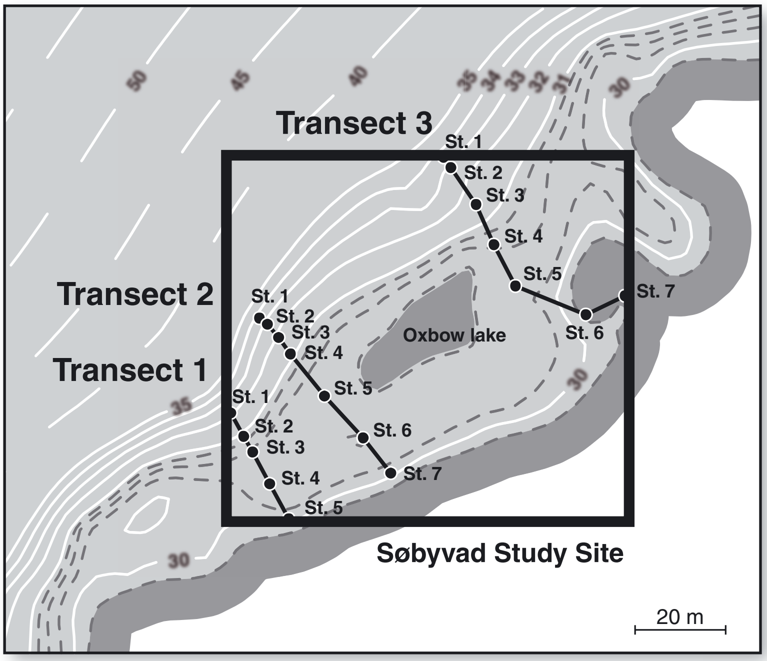

Fig. 1 Topographical survey of the study site showing the three transects extending from the hill slope (piezometric nests 1) to the river (piezometric nests 5 & 7). Contour lines in meters above sea level.

Hydraulic conductivities were measured *in situ* using Kirkham's method (Kirkham 1946) and the conductivity was calculated using the formula (1) introduced by Luthin & Kirkham (1949) and modified by Päivänen (1973):

$$K=\frac{2.30\cdot\pi\cdot r^2}{A\cdot(t_2-t_1)}\cdot\log\frac{h_1}{h_2} \qquad (1)$$

Where: K = the hydraulic conductivity, r = inside radius of the piezometer cavity, h_1 and h_2 = distance from groundwater table to water level in the piezometer at time t_1 and t_2, respectively, $(t_1 - t_2)$ = the period over which the water level rise is measured, A = a function of the geometry of the flow and the cavity. The daily groundwater flow from hillslope to river in each transect was calculated using a model based on the Darcy equation (see Hoffman *et al.*, 2007).

The physical environment in the model was set up using the geological data retrieved from the soil survey in the area. The groundwater flow is divided into two separate aquifers on the hillslope by an impermeable gyttja layer, and the modelling was therefore carried out on both the upper and the deeper aquifer separately. Daily groundwater flows were aggregated and a total groundwater balance for each transect as the difference between the influx at hillslope and the flow in the upper and lower aquifers to the river.

RESULTS AND DISCUSSION

The typical soil profile consists of a top layer of sapric peat underlain by fine to medium sized sand. Below an additional fine grained sand layer of Tertiary origin is found. At a depth of 2 meter are small silt-gyttja layers, which are impermeable, thus restricting upward groundwater flow to the meadow. Several silt layers are embedded in the sand layers. These impermeable layers create a mosaic of lenses that divide the groundwater into an upper and lower flow system. The aquifers are interconnected and exchange of water between the upper and lower layer are thus possible. Hydraulic conductivity varies considerably being 0.004 m day^{-1} in sapric peat layers and 3.24 m day^{-1} in fibric peat layers, while fine sand varies between 0.04 - 9.27, medium sand between 0.01 - 2.43 and coarse sand between 3.39 - 4.06 m day^{-1}.

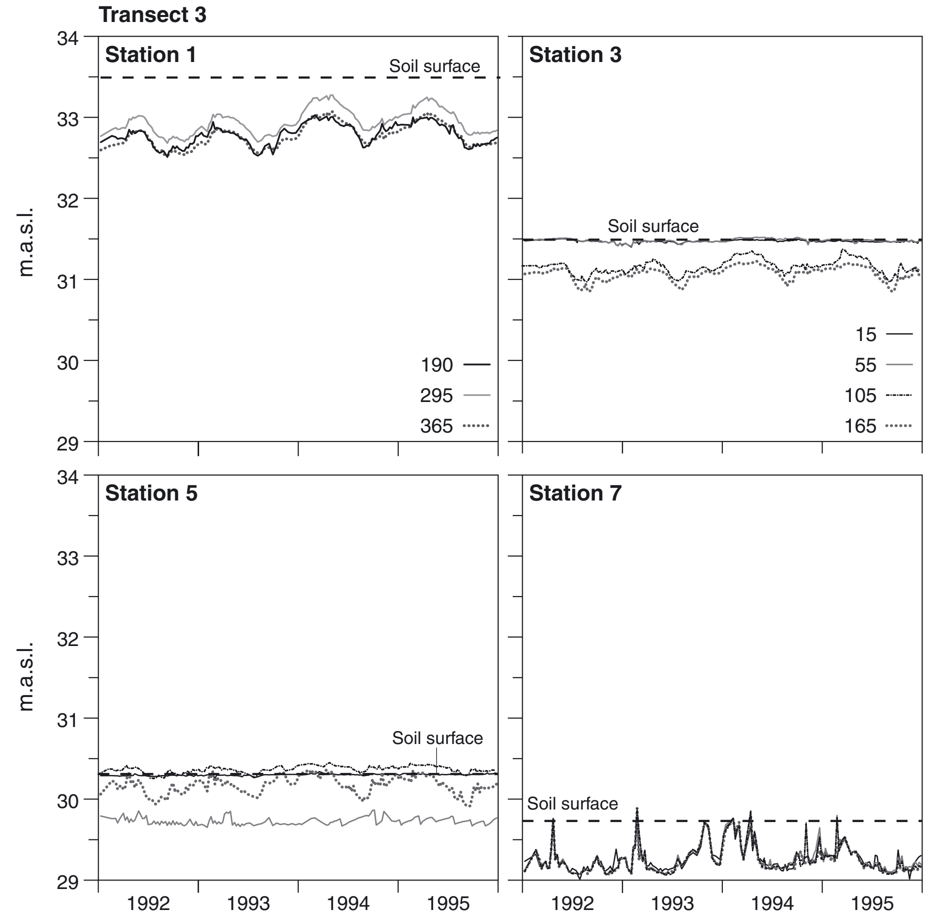

Fig. 2 Hydraulic heads measured at different depths at selected piezometer nests (i..e. stations 1 – 7) along transect 3. Unit: meter above sea level, m.a.s.l.

The hydraulic heads reveal two sets of heads with different temporal sequences. One group, located in the upper part of the soil profile, displays an almost constant water table in both summer and winter. The other group shows a distinct annual fluctuation, i.e. with the lowest head in summer and the highest head in winter (Fig. 2). In general, the groundwater flow takes place along the transects, but at transect 2 the flow lines divert at station 5 indicating groundwater flow towards transect 3.

Table 1 Groundwater flow through the wetland from hillslope to river. The calculations are made for each transect and for both the upper and lower aquifer.

$\text{Transect}_{\text{station}}$	$Q_{\text{upper, mean}}$	$Q_{\text{deeper, mean}}$	$Q_{\text{tot, mean}}$
$1_{\text{1-river}}$ (l m^{-1} day^{-1})	28	214	242
$2_{\text{1-5}}$ (l m^{-1} day^{-1})	67	260	327
$2_{\text{5-river}}$ (l m^{-1} day^{-1})	-	252	252
2_5 - 3_5 (l m^{-1} day^{-1})	33	-	33
$3_{\text{1-4}}$ (l m^{-1} day^{-1})	86	357	443
$3_{\text{5-river}}$ (l m^{-1} day^{-1})	113	361	474

The water balance revealed that most water is transported in the lower aquifer at all transects (Table 1). The relative proportion of the flow taking place in the upper layer varies considerably among the three transects (Table 1).

Mean nitrate-N concentrations measured at the recharging hill slope and at the discharging stream site are shown for the both the upper and lower aquifer in Table 2. There is a significant decrease in nitrate-N concentration as groundwater flows through the fen-meadow system indicating a high removal of nitrate through denitrification.

Table 2 Mean concentration of nitrate-N (mg N l^{-1}) measured in the upper aquifer and lower aquifer at the recharging hill slope and discharging stream site for transect 1 and 3. Shown with 95 % confidence limits and with number, n, of measurements shown in parenthesis.

	Transect 1		Transect 2		Transect 3	
	Hill slope	Stream site	Hill slope	Stream site	Hill slope	Stream site
Upper aquifer	18.19 ± 1.49 (n=45)	0.68 ± 0.56 (n=63)	18.19 – 20.24	.	20.24 ± 1.26 (n=120)	1.86 ± 0.86 (n=80)
Lower aquifer	0.11 ± 0.04 (n=125)	0.06 ± 0.02 (n=127)	0.11 – 4.37	0.06 – 0.25	4.37 ± 0.86 (n=122)	0.25 ± 0.19 (n=124)

The resulting nitrate-N mass balance shows that the nitrate removal along this reach of River Gjern varies between 500 and 3000 mg N m stream bank^{-1} day^{-1} and with highest removal in the upper aquifer (Table 3).

Table 3 Mass balance calculation for nitrate-N for the upper and lower aquifer showing the amount of nitrate-N entering the meadow with recharging groundwater at the hill slope and the amount of nitrate-N being discharged to the stream per running meter stream bank per day (mg Nitrate-N m^{-1} day^{-1}).

	Transect 1		Transect 2		Transect 3	
	Hill slope	Stream site	Hill slope	Stream site	Hill slope	Stream site
Upper aquifer	509	19	1219 – 1356	.	1741	210
Lower aquifer	24	13	29 – 1136	15 – 19	1560	90

CONCLUSION

The groundwater flow in the wetland takes place through two more or less distinct pathways, due to the geological conditions with an impermeable layer separating the groundwater flow in an upper and a lower aquifer. The flow pattern and the hydraulic heads vary over short distances due to the geological conditions. Calculation of wetland recharge and discharge by use of piezometer data showed that the lower aquifer transported 214 – 361 l m stream bank^{-1} day^{-1}, while the transport in the upper aquifer only was 28 – 113 l m stream bank^{-1} day^{-1}, but with highest nitrate removal.

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