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Groundwater flow modelling of three wetland ecosystems in river valleys in Flanders, Belgium

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ABSTRACT

Research in the ecology of wetlands is quite established. However, research in the hydrology of wetlands is much less developed. In Flanders, Belgium, a research project was initiated to investigate ecohydrological differences in wetlands. Three wetlands (Doode Bemde, Vorsdonkbos, and Zwarte Beek Valley) have been examined in detail. As these wetlands are predominantly fed by discharging groundwater, the groundwater flow to the wetlands is here investigated by way of modelling and the results discussed. A supra-regional groundwater model was developed, as well as three regional groundwater models. Together with particle tracking models, these models reveal the flow system characteristics of the wetlands. The results indicate the dependence and vulnerability of the wetlands with respect to their recharge area. The results also form the basis for further hydrochemical analysis of the wetland groundwater system.

1. INTRODUCTION

In Flanders, Belgium, restoration of wetland ecosystems in river valleys is receiving an increasing amount of attention. The study of evaluation tools for restoration scenarios has therefore become a point of priority within the framework of the Flemish governmental impulse program for nature conservation and development (VLINA). In one of the research projects, conducted within this program, the relationships between soil, water characteristics and nature quality (i.e. vegetational diversity) of three Flemish river basin wetlands were examined (Huybrechts *et al.*, 2000). These wetlands were the Doode Bemde in the valley of the Dijle River, Vorsdonkbos in the valley of the Demer River, and Zwarte Beek Valley along the Zwarte Beek River, a tributary of the Demer River (Figure 1).

This paper presents the part of the project concerning the modelling of the groundwater flow to the wetlands under investigation, as these wetlands are predominantly fed by seepage groundwater. The characteristics of the groundwater system, together with the groundwater chemistry, are therefore the major controlling factors for the vegetation. Van Rossum *et al.* (2000) discuss the different groundwater quality characteristics, origins and hydrogeochemical evolutions of the groundwater within and around the wetlands.

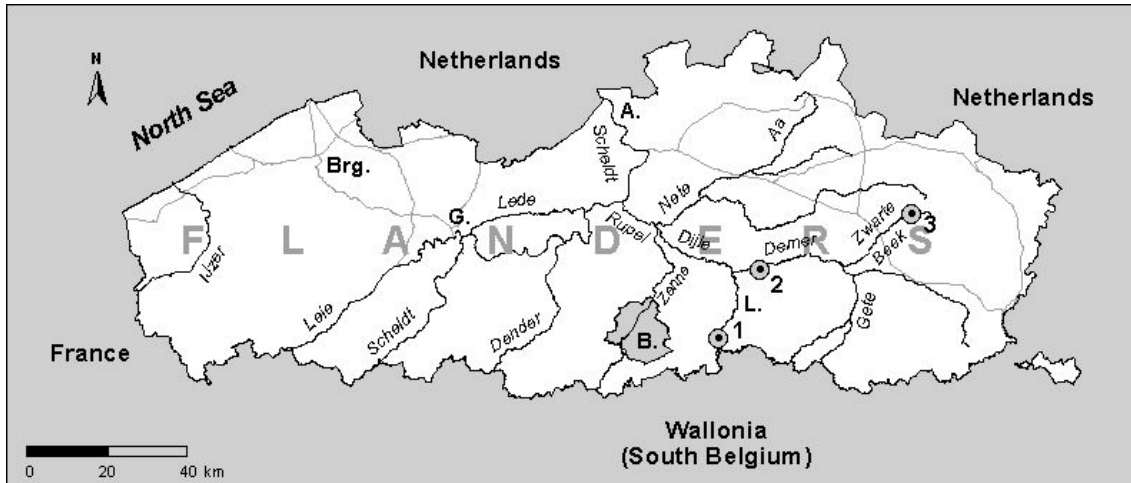


Figure 1: Location map of the three examined river basin wetland ecosystems. 1 = Doode Bemde, 2 = Vorsdonkbos, and 3 = Valley of the Zwarte Beek. B. = Brussels, A. = Antwerp, G. = Ghent, Brg. = Bruges, and L. = Louvain.

2. MODEL SETUP

The groundwater seepage in all three wetlands is sourced from recharge in the surrounding hills. Subsequently, it moves through sandy aquifers towards the wetlands. In the Doode Bemde these aquifers belong to the Brussels Formation (Eocene). In the Valley of the Zwarte Beek they belong to the Diest Formation (Miocene) and in the Vorsdonkbos to both.

Since the groundwater discharge to the study areas occurs with a fairly constant flux, the model is best setup as a steady state model. For the modelling of the three study areas it was necessary to set up realistic boundary conditions, heads or fluxes. There were insufficient measured piezometric heads in the surroundings of the study area available, nor were there any natural boundaries, such as rivers or water divides, to define boundary conditions. Therefore, 'telescopic refinement' has been used instead to obtain realistic boundary conditions. In the first instance a supra-regional model was applied, and on the basis of the calculated groundwater heads from this model the boundary conditions for the regional model were extracted.

For this study, the supra-regional model for the Nete, Demer and Dijle basins could be used (Batelaan *et al.*, 1996) (Figure 2). This existing model was improved by calculating the actual spatially distributed recharge using the WetSpass modelling procedure (Batelaan & De Smedt, 2001). Since groundwater level is an input for the recharge estimation model, and recharge is an input to the groundwater model, the two models are coupled. Five iterations of the model couple (supra-regional model and WetSpass) were necessary to obtain a stable, steady-state solution. At every simulation of the groundwater model the most recently calculated recharge is used, and consequently the recharge is recalculated with an updated groundwater level. The calculated groundwater level in the supra-regional model had a spatial resolution of 50 m and was interpolated for the boundary conditions to 20 m for the regional model.

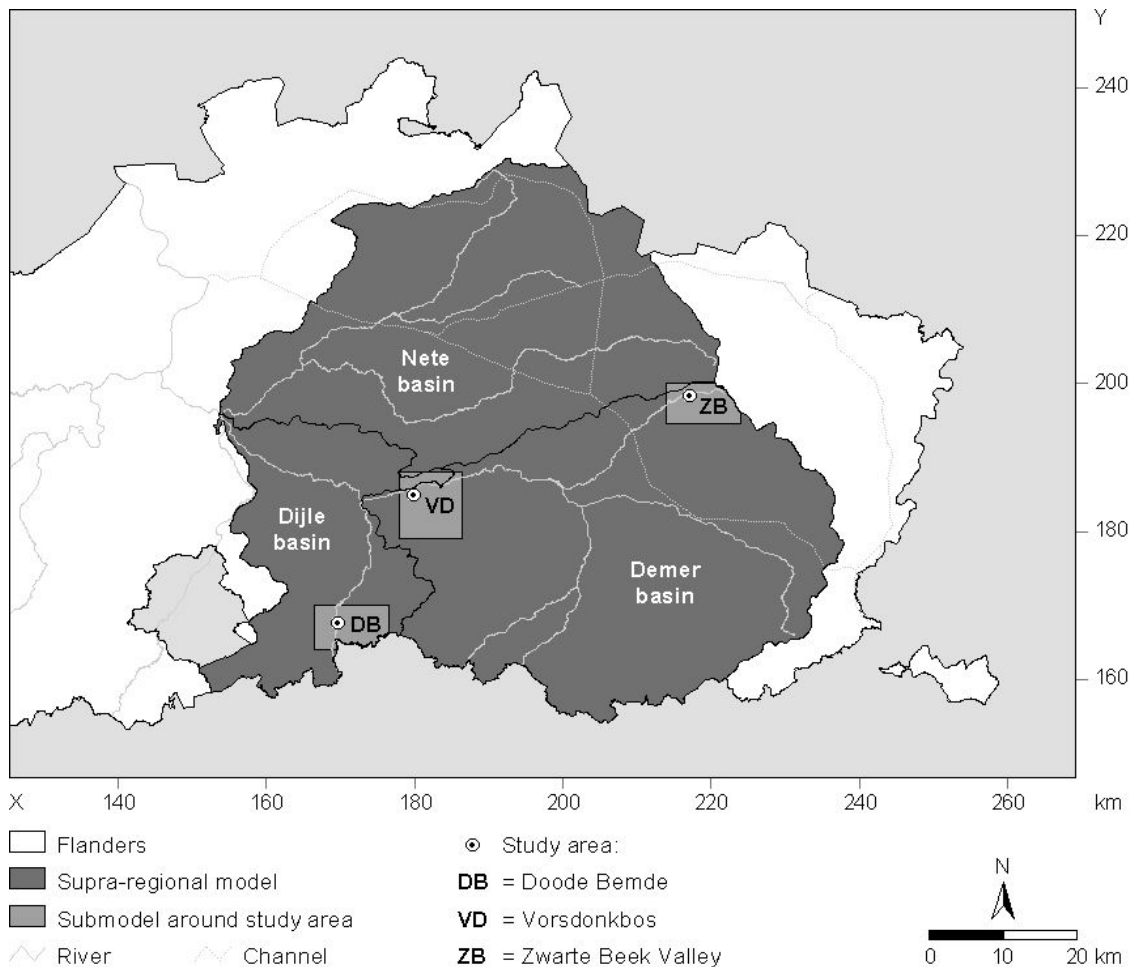


Figure 2: Nete, Demer and Dijle supra-regional model, with the three submodels.

In the Vorsdonkbos model a constant head is defined by the Demer River, just north of the study area. This head is calculated on the basis of the average measured river stage (1991-1997) of 9.8 m (TAW) in nearby Aarschot and an estimated water slope of 0.5 m km^{-1} . In addition, constant heads for the main river for the Dijle (Doo de Bemde) and Zwarte Beek have been defined for use in the regional models.

The level at which the groundwater will seep at the land surface, in drainage ditches or wetlands is defined as the maximum seepage level. This level has been determined by way of an Arc/Info Topogridtool interpolation of the contour lines of 1:10 000 scale topographic maps. Locally, in the study area, measured topographic levels were also included in this interpolation, as well as a high resolution topographic database of the Demer valley obtained from aerial laser altimetry.

Average groundwater pumping rates have been determined for the three areas on the basis of pumping data for 1993-1995. Within the model areas of Doo de Bemde, Vorsdonkbos and Zwarte Beek extractions of respectively 532 , 7501 and $212 \text{ m}^3 \text{ d}^{-1}$ were estimated.

3. MODELLING TOOLS

The USGS modular three-dimensional finite difference groundwater model, MODFLOW (Harbaugh & McDonald, 1996) has been used to simulate the groundwater flow.

MODFLOW's DRAIN package has been used to simulate the groundwater discharge areas. The seepage surface has initially been set to topography minus 0.5 m. This value is assumed to represent the average field ditch depth, which drains the groundwater discharge. This value has been optimized for each regional model during calibration based on the extensive piezometer network within the study areas. The calibration resulted in a seepage level of 0.31, 0.25 and 0.50 m for Doode Bemde, Vorsdonkbos and Zwarte Beek respectively. These differences in seepage levels can be attributed to a different density of drainage ditches in each area. The mean absolute errors finally obtained for the calibration of the groundwater level in Doode Bemde, Vorsdonkbos and Zwarte Beek were respectively 0.33, 0.10 and 0.23 m.

MODPATH (Pollock, 1994) has been used to determine by particle tracking the recharge area and flow times. In order to determine the recharge areas as accurately as possible forward tracking was used from all potential recharge areas linked to the discharge areas of concern. Subsequently, by analyzing all the flow paths obtained, those ending in the groundwater seepage areas could be selected.

Table 1: Characteristic values for discharge, recharge area and flow times for the three study areas.

Study area	Vorsdonkbos	Doode Bemde	Zwarte Beek
Area [km ²]	0.25	0.21	0.26
Discharge area [km ²]	0.10 (40 %)	0.11 (52 %)	0.17 (64 %)
Average discharge [mm d ⁻¹]	21.2	2.6	16.4
Recharge area ¹ [km ²]	4.32	0.57	2.06
Ratio rech./dis. area	43.2	5.2	12.4
Average flow time [yr]	162	16	192
Maximum flow time [yr]	848	193	1634
% dis. younger 5 year	3.8	37.5	3.0
Average age discharge ² [yr]	170	17	194

¹ Exclusive groundwater discharge area

² Average flow time weighted by recharge flux

4. RESULTS

Table 1 gives typical calculated values related to the groundwater system for the three study areas. The sizes of the study areas and the discharges occurring therein are very similar for the three areas. The average discharge however varies much more due to the strongly varying size of the recharge areas and the average flow times from recharge to discharge area. Compared to the other two areas, the size of the recharge area is very low for the Doode Bemde, resulting in a low groundwater discharge.

In Figure 3 (lower right), as an example for the three study areas, the calculated groundwater discharge area for Vorsdonkbos is given. This discharge map is compared in the figure to estimates of the groundwater discharge as indicated by phreatophytic vegetation (Figure 3, upper left), the zone with a measured maximum yearly groundwater level fluctuation of less than 0.6 m (Figure 3, upper right) and measured upward groundwater pressures. It can be observed from this figure that the groundwater discharge occurs mainly along the southern rim of the study area and in a north-south band, east of the centre of the study area.

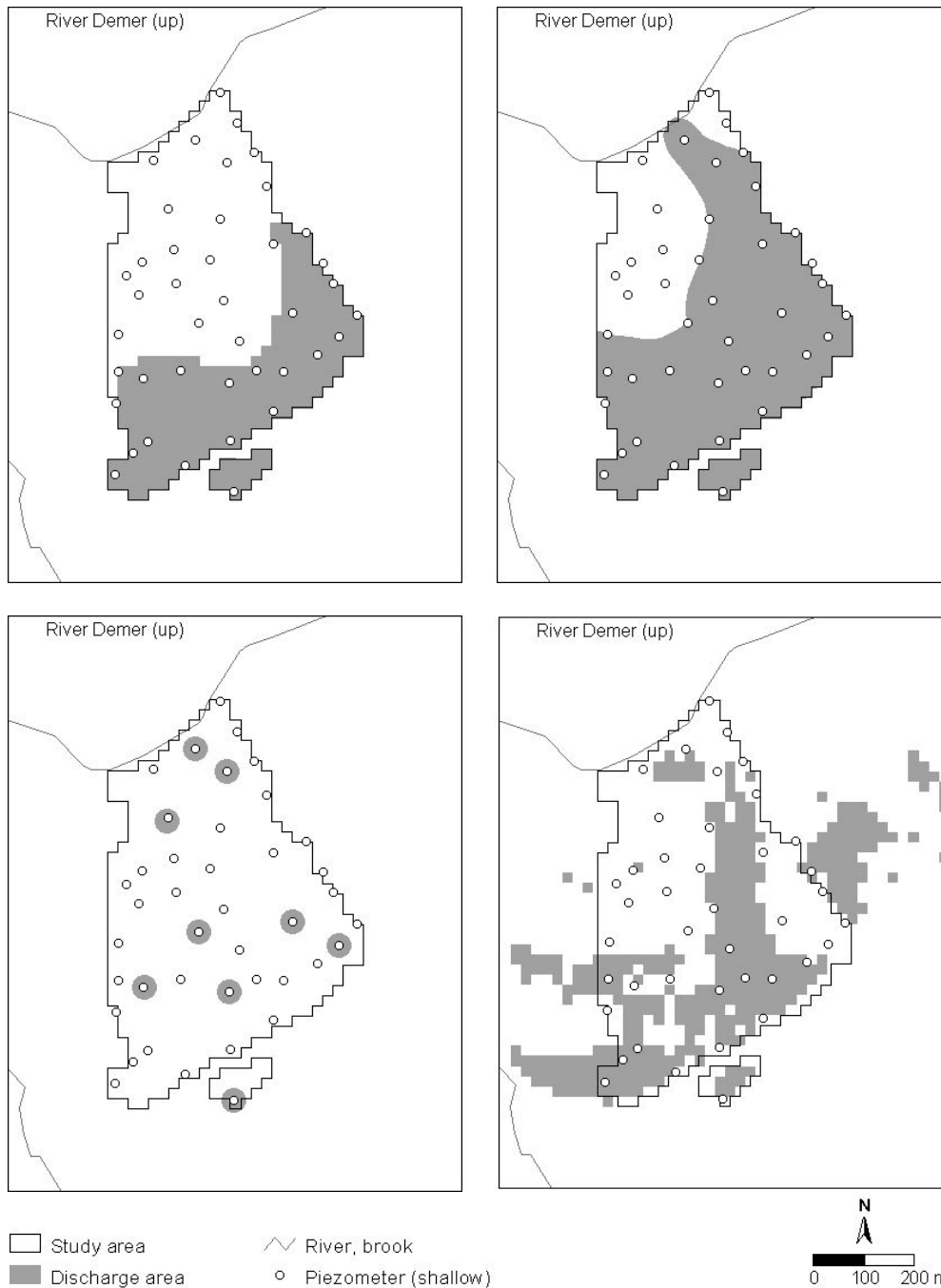


Figure 3: Modelled and measured groundwater discharge area for Vorsdonkbos, upper left: mapped phreatophytes indicating groundwater discharge, upper right: measured yearly groundwater level fluctuation less than 0.6 m, lower left: installed piezometer nest with piezometers measuring at two depths, indicating upward groundwater flow, lower right: groundwater model calculated groundwater discharge.

The total surface of groundwater discharge within the study area is 0.10 km², which means that 40 % of the study area receives permanent discharge. The discharge has an average flux of 21.1 mm d⁻¹. This flux is much greater than the flux in the Doode Bemde and slightly greater than in the valley of the Zwarte Beek.

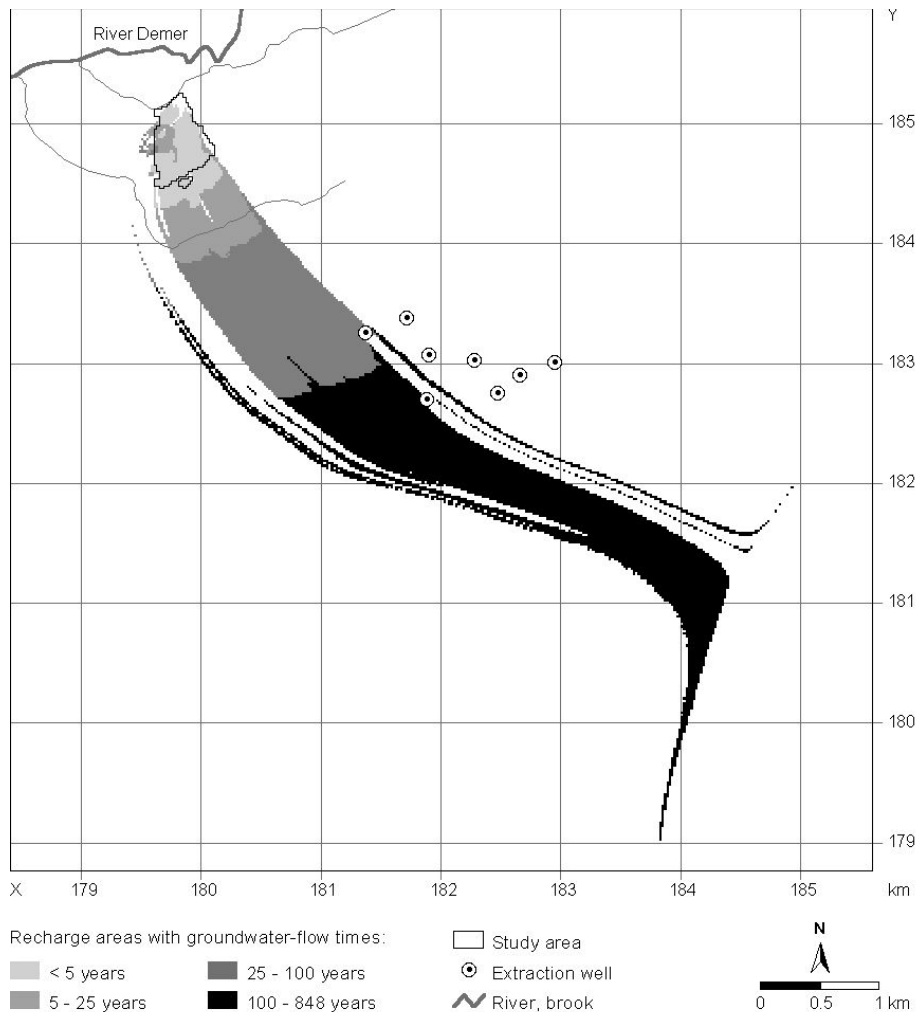


Figure 4: Simulated recharge areas and flow times to groundwater discharge areas of Vorsdonkbos.

Figure 4 gives the simulated recharge areas and flow times of the discharge areas within the study area of Vorsdonkbos. The recharge area extends up to 6 km in a south-easterly direction from the study area. The recharge area, excluding the discharge area itself, is 4.32 km², 43.2 times the area of discharge. This ratio of recharge to discharge area is much greater than in the other two study areas. At the north-eastern part of the recharge area the effect of some pumping wells can clearly be observed.

The average and maximum flow times to the discharge area in Vorsdonkbos are respectively 162 and 848 yr (Table 1). The average flow time is slightly shorter than in the valley of the Zwarte Beek, but much longer than in the Doode Bemde. The average age of the seeping groundwater in Vorsdonkbos, i.e. the average flow times weighted according to their recharge, is 170 yr. The spatial distribution of the recharge seems therefore to be quite uniform. The percentage of young groundwater (younger than 5 years) that is discharging in the study area is 3.8 %. This percentage is relatively low, which means that the area has a relatively low vulnerability with respect to water quality deterioration.

5. CONCLUSIONS

A groundwater flow modelling procedure for wetlands was introduced and applied to three wetland ecosystems in river valleys in Flanders. The size of the wetlands and the discharge zones within it are similar. However, the discharge intensity is quite different, as well as the recharge area and the flow times. The results indicate the vulnerability of the wetlands with respect to their hydrological system and the importance of groundwater systems analysis for the protection and re-development of wetlands.

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