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Development of a Groundwater Model for some Small Sub-Catchments of the Dender Basin

B. Verbeiren, O. Batelaan & F. De Smedt

Vakgroep Hydrologie en Waterbouwkunde, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussel, bverbeir@vub.ac.be

ABSTRACT

To characterise the ecological condition of valleys hydrological variables such as groundwater level, fluctuation, discharge zones, etc. are required. In this study a groundwater modelling approach is used for the estimation of these variables.
Within the framework of the action plan "Development of ecosystem approaches for different valleys in Flanders" a MODFLOW groundwater model was developed, for three sub-catchments of the Dender River. GIS was used to prepare the input, to analyse the output and to present the results of the groundwater modelling. The results of the groundwater model, a set of hydrological variables, was used to analyse the relationship between vegetation and groundwater. Both the present groundwater system as well as a future optimal situation were simulated. The model and its analyses serve, within this ecosystem approach, as a basis for the formulation of policy measures for nature conservation and (potential) nature management in the area.

KEYWORDS

Dender basin, Geographical Information Systems (GIS), Groundwater modelling, MODFLOW, Nature conservation.

Objectives

A groundwater model was developed within the framework of an ecosystem approach. Its purpose is to obtain different hydrological variables and to estimate the hydrological boundary conditions for (potential) future vegetation.

Study area

The study area includes the catchments of Molenbeek-Terkleppebeek, Molenbeek-Ophasseltbeek and Beverbeek. These are small sub-catchments of the Dender River and are situated in the southeastern part of the province of East-Flanders, their surface area is about 132 km² (Fig. 1). The Dender River forms the eastern border of the study area.
The topography of the study varies from more than 100 m at the western hills (Vlaamse Ardennen) to less than 20 m near the Dender River. The tributaries of the Dender River in these sub-catchments run from west to (north-)east.

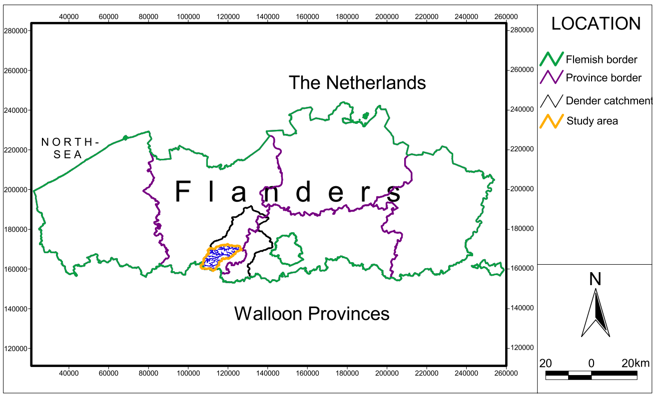

Fig. 1. Location of study area.

The geology of the region is dominated by the Tertiary formations of Kortrijk, Tielt, Ghent, Lede and Maldegem. The Dender valley cuts into the Moen (fine sand) and Saint-Maur (clay) member of the formation of Kortrijk. The western hills consist of the sands and clays of the formations of Tielt, Ghent, Lede and Maldegem. The Quaternary loamy top layer is often very thin on the hills. However in the lower parts of the area it can reach a thickness of minimum 10 to 20 m (Maréchal, 1993; De Geyter, 1999).

Groundwater model

The groundwater modelling was performed with the MODFLOW code (McDonald & Harbaugh, 1988). Since groundwater modelling requires a lot of spatially distributed data, GIS was used to generate and prepare these data. Also, the output of the groundwater model was exported to GIS to be able to perform analysis and to present results in a clear way. An adaptive script environment was built to support the GIS-MODFLOW communication. This environment facilitates considerably the modelling and analysis.

Description

The model area was discretised in cells of 20 by 20 m. The groundwater model consists of two layers, each with 700 rows and 1060 columns, in total about 330.000 active cells a layer.

Hydrogeological concept

Based on the (hydro)geological information of the geological map of Geraardsbergen and on the stratigraphical logs of drillings, the following concept was assumed (Fig. 2):

- The Quaternary top layer forms the first layer of the model, it has a hydraulic conductivity of $5.8\ 10^{-5}$ m/s.
- The second layer includes the formation of Tielt and a part of the formation of Kortrijk (member of Moen). For the hydraulic conductivity a value of $5.8\ 10^{-7}$ m/s was assumed (Loy & De Smedt, 1978).
- The bottom of the model corresponds to the top of the confining layer of Saint-Maur (fine clay).

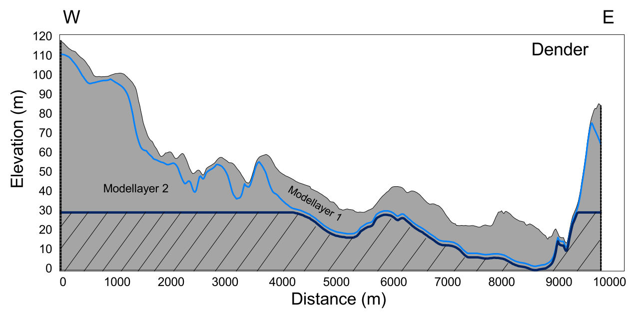

Fig. 2. Hydrogeological profile and model layers.

Boundary conditions

The Dender River in the East was used as a constant head boundary, while the remaining watershed boundaries were assumed as no flow boundaries since the groundwater flow in these areas is mainly determined by topographic differences.

Recharge

Groundwater recharge was calculated with the WetSpass-model (Batelaan & De Smedt, 2001). WetSpass has a flexible structure and is fully integrated within the GIS ArcView. Based upon land-use, soil type, some meteorological parameters, slope, groundwater depth and the runoff-coefficients, WetSpass calculates the spatially distributed groundwater recharge for the model.

Groundwater extraction

Only a few small wells, with negligible pumping rates and very localised effects, are present in the area. Therefore groundwater extractions were not considered in the model.

Drainage depth

During the past decades a considerable part of Flanders was drained, using drainpipes and ditches, in order to extend the agricultural area. However, this often resulted in harmful effects for nature and vegetation, due to the lowering of groundwater levels.

The drainage network in the area (present situation), was investigated by measuring the drainage depth, or water level below the land surface, at 49 locations. Based on these measurements the drainage depths along the drainage network were interpolated, the depths varied from 0.15 to 2.22 m below the land surface. At locations without measurements the average drainage depth value of one meter was assumed.

A groundwater scenario was simulated in which the drainage depth was reduced to the more 'optimal' depth of 0.5 m. Purpose of this scenario was to investigate the effect of an 'optimal' drainage depth on the hydrological variables, which condition nature values.

Calibration

Calibration of the model was performed using available piezometric data. The data of 16 piezometers, over a period of one and a half year (July 2000-Sept. 2001) were used. During the calibration the differences between measured and calculated piezometric heads were minimized by trial and error adjustment of the hydraulic conductivities.

Simulations

Table 1 gives an overview of the different runs of the model that were performed and the obtained hydrological conditions, for the present and optimal scenarios. Steady state modelling was used to calculate the mean groundwater level, groundwater depth, and was used to identify discharge zones (wetlands) and the intensity of the discharge. Transient state modelling was used to calculate for each cell a minimum and a maximum groundwater level. In this way it was possible to model the evolution of groundwater levels during a year, and changes in the recharge and discharge zones and intensities.

A difference in drainage depth is the only prescribed conceptual difference between the present and the optimal scenario.

Table 1. Overview model states and scenarios resulting in different simulated hydrological variables.

Scenario Model state	PRESENT SITUATION	OPTIMAL SITUATION
STEADY STATE	- MEAN groundwater level - MEAN groundwater depth - WETLAND locations	- MEAN groundwater level - MEAN groundwater depth - WETLAND locations
TRANSIENT STATE	For an average year: - MINIMUM gw.level/depth - MAXIMUM gw.level/depth - FLUCTUATION of gw.level	For an average year: - MINIMUM gw.level/depth - MAXIMUM gw.level/depth - FLUCTUATION of gw.level

Results

Piezometric heads

The steady state model resulted in a simulated phreatic groundwater level or depth of the model area. For the present situation, the groundwater depth varies from a few centimetres to several meters. Especially near the rivers the groundwater is rather shallow (< 0.5 meter).

The mean groundwater level at the wetland Moenebroek is shown in Fig. 3 for the present and the optimal situation. Both situations mainly differ in mean groundwater levels near the river.

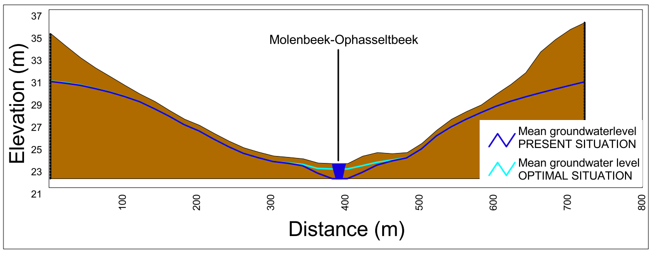

Fig. 3. Mean groundwater levels at Moenebroek.

With the transient state model minimum and maximum groundwater levels were simulated. For the transient state model two stress periods (summer/winter) with each six, monthly time-steps were used. In Fig. 4 the results of the transient state modelling are given for two locations at Moenebroek. This figure shows how the groundwater level changes during the year. The two locations show a similar trend. Both curves reach a maximum in March (at the end of the winter) and a minimum in September (at the end of the summer), however there is an important difference in fluctuation. At location 1 the level varies between 28.78 and 30.09 m, i.e. a yearly fluctuation of 1.31 m, while at location 2 the minimum and maximum groundwater levels are respectively 22.29 and 22.58 m, i.e. a fluctuation of 0.29 m. This difference is due to the fact that location 2 is situated near the river, while location 1 is situated higher up in the valley. In general, the fluctuations near the river are around 0.5 m or less, while higher up in the valley the fluctuations are considerably higher.

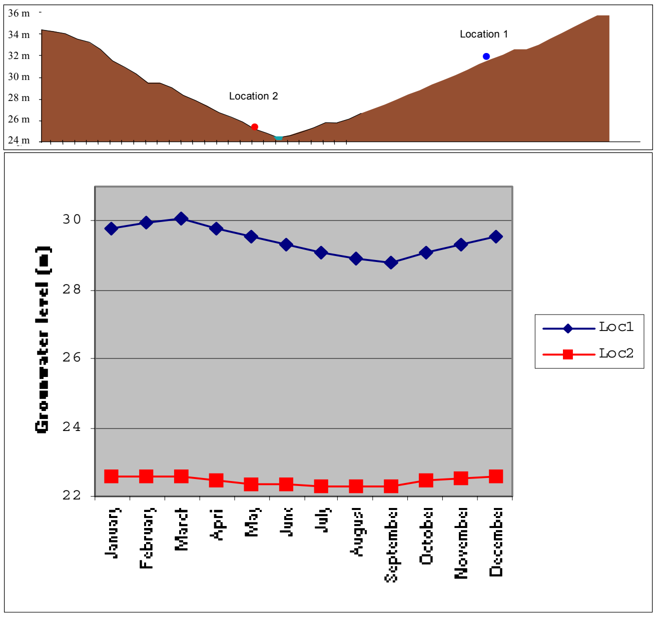

Fig. 4. Evolution of groundwater levels in two locations at Moenebroek.

Wetlands

Discharge zones or wetlands are defined as zones with a groundwater level equal to or near the land surface and with an upward groundwater flow.

The discharge locations and intensities were calculated with the 'steady state' model. For the present situation, 16.1 km² or about 12% of the model area is simulated as groundwater discharge wetlands, for the optimal situation this is 20.3 km² or about 15% of the total surface. This difference results from the change in drainage depth of the rivers between the two situations. However, smaller wetlands do not always imply smaller intensities. This is indicated by the result that about 8% of the wetland area in the present and only 3.5% in the optimal situation have a high discharge intensity (> 15 mm/d). This is due to the larger drainage depth of the rivers in the present situation. The groundwater discharge is therefore more converging to the river itself, which results in higher discharges near the rivers. Fig. 5 shows the wetlands at Moenebroek for the present and optimal situation.

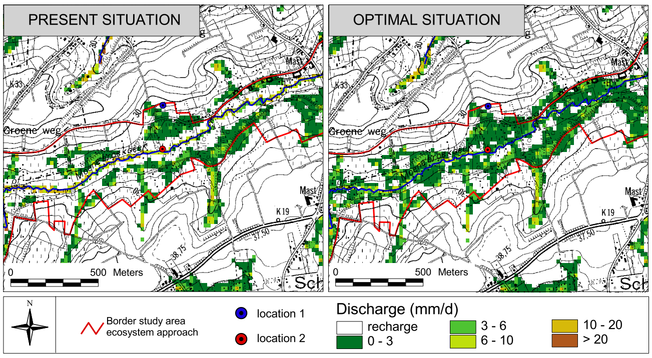

Fig. 5. Wetlands at Moenebroek.

Finally, the modelled locations of wetlands were verified by comparing these locations with the location of phreatophytic vegetation. For 586 parcels a vegetation-inventory was made. In general, there is a good match; only for about 8% of the total surface of the 586 parcels the model predicts no discharge at locations with phreatophytes.

Discussion and conclusions

The presented methodology of using a combination of steady state and transient state modelling, allows to obtain a set of different, eco-hydrological variables; mean, minimum, maximum groundwater levels, yearly fluctuations, locations and intensity of groundwater discharge. These variables were calculated for the present and an 'optimal' situation and were used to characterise the hydrological conditions in the sub-catchments for both scenarios. The, with the model, calculated hydrological conditions show a good correspondence with the occurrence of phreatophytic vegetation. It is therefore believed that the model can be used to predict abiotic boundary conditions for the vegetation.

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