Monitoring and modelling of springflow in the Noor catchment (the Netherlands)

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1. Introduction

The Noor catchment is located in the border area between Belgium and the Netherlands near Maastricht and Liège. The catchment consists of permeable Cretaceous deposits overlying impervious Upper-Carboniferous shales and sandstones. The lower part of the Cretaceous deposits comprises fine sandy silts with thin-bedded fractured sandstone layers (Vaals Formation) and the upper part chalk (Gulpen Formation). The conductivity of the Vaals Formation is limited (k = 0.4 m·day^{-1}), with the exception of the sandstone layers which have a high conductivity (k = 20-50 m·day^{-1}). The lower part of the chalk has a conductivity of 2.5 m·day^{-1}, whereas in the upper parts the conductivity is supposed to increase significantly (k = 30 m·day^{-1}; Downing et al., 1993). The Cretaceous deposits form a multiple-aquifer system with a thickness of 40-50 m and a decreasing conductivity with depth. The Pleistocene overburden in the Noor catchment consists of unsaturated loess and river gravels at the plateaus and clay with flints at the slopes. The overburden allows a readily infiltration of rainfall. Surface runoff is negligible. In the valley, an about 5 m thick layer of low permeable, saturated valley filling (a mixture of predominantly loess, gravels and clay with flints) occurs. The Noor brook is deeply incised in the plateaus, which implies that the chalk is eroded in the central part of the valley. The difference in elevation between the plateaus and the valley bottom is about 50-60 m. Deep water tables (30-40 m) occur under the plateaus. Rainfall surplus (about 250-300 mm·yr^{-1}) infiltrated at the plateaus, flows through the thick unsaturated zone and the multiple aquifer system towards the valley. Numerous springs and an extended seepage area (nature reserve) discharge the groundwater system. Springflow accounts for most of the groundwater discharge (about 60%). The majority of the springs in the Belgian-Dutch chalk are small (< 2 l·s^{-1}). However, some exceptions are the major chalk spring in Sint Pietersvoeren (80 l·s^{-1}) in the Voer valley (Nota and van de Weerd, 1980) and the Sint Brigida Spring in the Noor catchment (0-30 l·s^{-1}). Since 1991 an intensive groundwater monitoring and modelling program has been carried out in the Noor catchment to investigate the hydrogeological system (Dijksma et al., 1997; Van Lanen and Dijksma, 1998). In the context of this program the behaviour of the Sint Brigida spring was studied. The springflow strongly fluctuates: the spring even dries up. Furthermore, the nitrate concentration of the spring is above EU drinking water standard of 50 mg·l^{-1}. The objective of this paper is (a) to compare the discharge of the Sint Brigida spring with a typical chalk spring in the Noor catchment and to investigate the reasons for its response, and (b) to analyse the nitrate concentration, which is expected to be positively correlated to the discharge (Van Lanen et al., 1993). Knowledge about the springflow and the nitrate concentration is needed for the management of the nature reserve in the wet central part of the valley.

2. Results and discussion

2.1 Observed springflow

Since 1991 precipitation, groundwater levels under the plateau and in the wet valley, discharges of the springs and the brook, and the chemical composition have been monitored. Rainfall surplus was calculated, using precipitation, Penman evapotranspiration, land use and soil data. Calculated rainfall surplus varies strongly in the monitoring period. Dry years, such as 1991 and 1995 were alternated by wet years

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(1993, 1994). Table 1 shows the calculated annual rainfall surplus in the period 1991-1996, representing hydrological years (starts on April 1).

Table 1: Annual rainfall surplus in the Noor catchment ($mm \cdot yr^{-1}$).

Year	1991	1992	1993	1994	1995	1996	Average 1991-1996
Rainfall surplus (mm)	185	230	410	405	130	240	270

Eventually, the rainfall surplus feeds the Sint Brigida spring, numerous smaller springs and a seepage area. The Sint Brigida spring collects its water from the north and the east.

The discharge of this spring was compared with a typical chalk spring (Br7). Discharge measurements of spring Br7 started in 1994. Its catchment is small, compared to the Sint Brigida spring. Fig 1 shows the discharge of both springs.

Both springs react on the wet years (1993 and 1994) by a significant increase of the discharge. A remarkable difference between both springs is that the Sint Brigida spring dries up during dry years (e.g. 1996), despite of the large catchment area, while the small spring doesn't dry up. Also the recession of the spring flow of Br7 is more flat. The difference in reaction on variation in rainfall surplus is triggered by the area of the catchment and the position of the spring (level, related to the position of the geological formations).

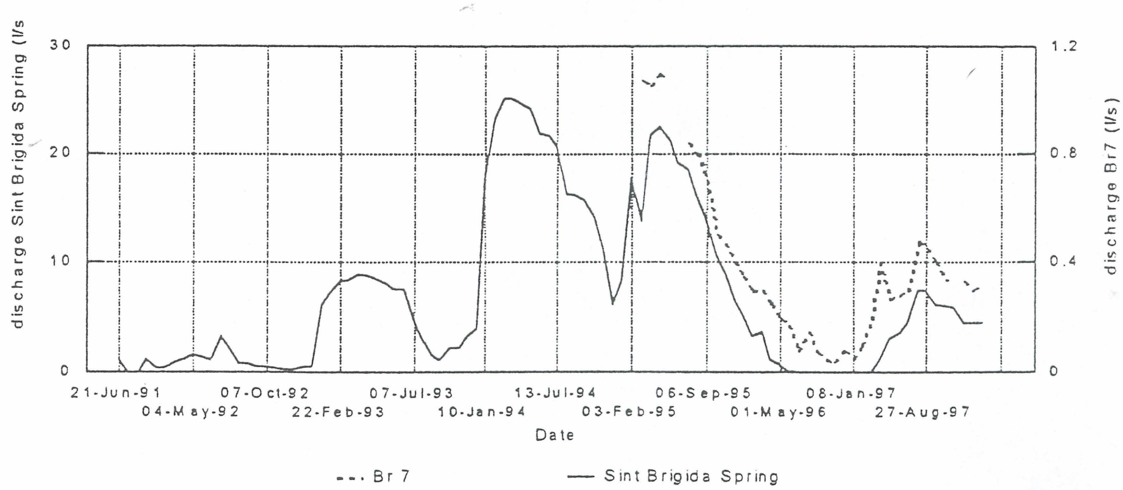

Fig. 1: Discharge of the Sint Brigida spring and the typical chalk spring (Br7).

2.2 Observed nitrate concentrations of the springs

The chemical composition of springs was measured once a month. It was expected that the nitrate concentration would be positively correlated with the discharge. Fig. 2 shows the measured nitrate concentrations of both springs. No correlation between the discharge and the nitrate concentration can be found. Obviously a linear increase in the nitrate concentration in the Sint Brigida spring occurs, without any correlation with the discharge. Br7 shows a somewhat different behaviour. The nitrate concentration appears to be positively correlated with the discharge. On top of that, also an overall increase of nitrate occurs.

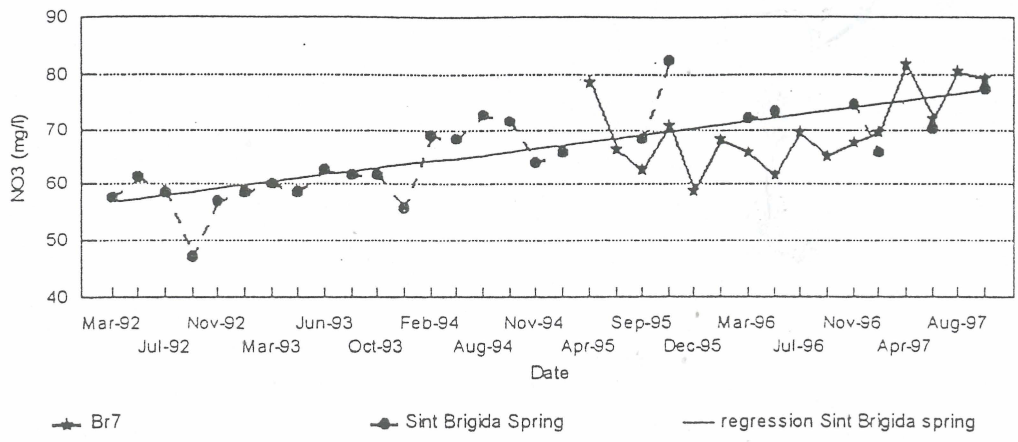

Fig. 2: Nitrate concentration of the Sint Brigida spring and the typical chalk spring (Br7).

2.3 Modelling

Several groundwater flow models have been developed (e.g. MODFLOW, FLONET/TRANS) to investigate the hydrogeological system of the Noor catchment and the impact of human interferences. The behaviour of a specific spring, such as the Sint Brigida spring or Br7 is hard to simulate. Exploration with the models shows a relationship between the discharge of the Sint Brigida spring and the groundwater head under the plateaus as presented in Fig. 3.

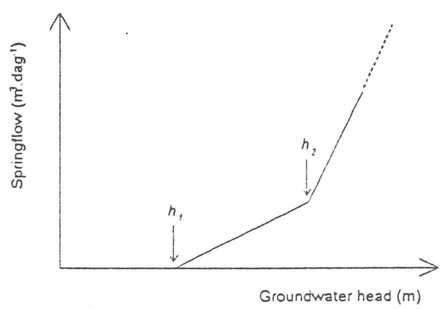

Fig. 3: Schematised relation between the discharge of the Sint Brigida spring and the groundwater head under the plateau.

The Sint Brigida spring predominantly drains groundwater from the chalk. Under prolonged dry conditions the groundwater head in the chalk under the plateaus drops below h_1, which implies that the springs dries up (e.g. 1991, 1992 and 1996). The relatively high position of this spring (headwater) compared to the other more downstream springs is the main reason for this phenomenon. Then groundwater flows below the spring through the lower chalk and Vaals Formation towards other springs. When the groundwater heads under the plateaus are between h_1 and h_2 the Sint Brigida spring receives groundwater, which mainly flows through the lower, less permeable chalk. An increase of the heads causes not more than a restricted increase of springflow. However, under extensive wet conditions the groundwater head may exceed h_2, which results in a substantial increase of springflow (January 1994 and 1995). Under these circumstances remarkable amounts of groundwater can flow through the more permeable upper chalk and feed the spring (Van Lanen et al., 1993). Contrary to the other more typical chalk springs, such as Br7, the Sint Brigida spring has direct contact with the more permeable chalk due to the relatively high elevation. Therefore the spring Br7 does not show the sharp decrease in discharge (expressed in $l \cdot sec^{-1}$). Moreover Br7 never dries up because of the lower position in the groundwater system, which means that the relationship between springflow and the groundwater heads is characterised by a line similar as between h_1 and h_2 in Fig. 3.

In reality the relationship between springflow and groundwater heads in Fig. 3 is more complex. Several loops around the lines occur dependent on the spatial and temporal distribution of the groundwater heads in the catchment area of the Sint Brigida spring. Furthermore the relationship is not exactly linear and does not show the pronounced inflection points h_1 and h_2 due to a more gradual increase of the conductivity of the chalk.

Under wet conditions the Sint Brigida spring receives young groundwater through the upper chalk which passes the older water in the lower chalk. Usually the younger water is more polluted with nitrate than the older water resulting in a positive correlation between the springflow and the nitrate concentration (Van Lanen et al., 1993). Surprisingly this does not apply to the Sint Brigida spring, where hardly any relationship can be recognised between springflow and nitrate concentrations.

3. Conclusions

The discharge of the Sint Brigida spring is higher than of the other typical chalk springs (e.g. Br7) because of the larger catchment area. The higher position in the hydrogeological system causes a drying up of this spring. The steeper recession of the springflow can be explained by conductivity differences of the chalk.

The nitrate concentration of the Sint Brigida spring does not show positive correlation with the discharge. Instead a linear increase occurs. On the other hand, this positive correlation can be recognised in the typical chalk spring Br7.

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