Batelaan, O. and J.P.M. Witte, 2008, Ecohydrology and groundwater dependent terrestrial ecosystems, Proceedings of the 28th Annual Conference of the International Association of Hydrogeologists (Irish Group), Tullamore, Ireland, 22-23 April, p. 01-08.

ECOHYDROLOGY & GROUNDWATER DEPENDENT TERRESTRIAL ECOSYSTEMS

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ABSTRACT

Throughout the world ecohydrology has lately been discovered, and tightly embraced, as a new scientific discipline. Several authors have stressed its importance to the progress of hydrology and ecology but there appears to be a wide range of ideas on the topics ecohydrology is supposed to include. Elements of the history of ecohydrology are described here and different ecohydrologic schools are distinguished. One of the roots of ecohydrology is based on the dependence of phreatophytic plant species on groundwater. In the first half of the 20th century plants were regularly used as indicators in groundwater investigations by hydrologists. More recent the interest in phreatophytes in general revived again, following the interest in groundwater dependent ecosystems. A case study is used to show the benefit of use of phreatophytes in hydrological studies. It is argued that a well balanced use of 'soft' phreatophytic information can be complementary to 'hard' groundwater data and analysis techniques and help to understand more profoundly groundwater dependent ecosystems.

INTRODUCTION

Throughout the world ecohydrology has lately been discovered, and tightly embraced, as a new scientific discipline. Several authors have stressed its importance to the progress of hydrology and ecology but there appears to be a wide range of ideas on the topics ecohydrology is supposed to include. Here elements of the history of ecohydrology are described and different ecohydrological schools are distinguished.

In arid regions there is a relatively simple relationship between plants and the occurrence of groundwater. In more humid areas the situation is much more complex: The vegetation, has especially in discharge areas lavish available water for its growth and transpiration, it specialises in a wide range of species adapted to different environmental site or local conditions. This results in highly valued groundwater dependent wetlands with a high biodiversity, which is the main reason for their protection. However, mankind is changing the hydrological system and consequently the site conditions and hence plant occurrences. Hence, the scientific challenge is what role can plants play in the study of groundwater?

ECOHYDROLOGY DEFINED

In the last 10 years several definitions have been published of what ecohydrology is supposed to mean.

- Wassen and Grootjans (1996): 'An application driven discipline aiming at a better understanding of hydrological factors determining the natural development of wet ecosystems, especially in regard of their functional value for natural protection and restoration'.
- Baird and Wilby (1999): 'Eco-hydrology is the study of plant-water interactions and the hydrological processes related to plant growth'.
- Rodriguez-Iturbe (2000): 'Eco-hydrology seeks to describe the hydrological mechanisms that underlie ecological pattern and processes'.

- Nuttle (2002): 'Eco-hydrology is … concerned with the effects of hydrological processes on the distribution, structure and function of ecosystems, and on the effect of biological processes on the elements of the water cycle'.

Since 2000 ecohydrology in hydrological literature tends to be dominated by dryland hydrology, that means soil moisture limited evapotranspiration processes. Eagleson and Rodriguez-Iturbe are the main authorities in this version of ecohydrology (Rodriguez-Iturbe and Porporato, 2004; Eagleson, 2002).
Did ecohydrology as it appears from these recent references pop out of the sky? To investigate the roots of ecohydrology or its 'founding father' it is very useful to look back in time, following the geological principle of the past is the key to the future.

Pre-historic man must have had some ecohydrological consciousness, since he was able to recognise plants to warn him against dangerous places where he could drown, or to find food. However, he did not publish his observations and hence he was not a scientist and therefore he cannot be regarded as the founding father of ecohydrology. Ross (2007) interprets and translates the Hebrew bible text of Isaiah 44 in modern language as: 'I will pour out My spirit as suddenly and overwhelmingly as a rainstorm in the desert. After such a storm, the willow does not fade like grass, but is kept green for many years by groundwater that recharges in the storm'. Obviously, the prophet made accurate observations relating rainfall-recharge-groundwater and plant species occurrence. Vitrivius, roman architect and engineer in the 1st century published following remark concerning exploration of drinking water: 'One of the indications where groundwater can be found is the occurrence of small rushes, willows, alder, vitex, reeds and ivy'.
It is significant to notice that he remarks: 'one must not rely on these plants if they occur in marshes, which receive and collect rain water'. Hence, he was well aware of the relativity of the plants as indicators for good quality groundwater.

In the famous work of Darcy (1856) is besides the well known column tests in the appendix also described the search for drinking water by spring seeker Father Paramel. It is written that he infers from the nature and strength of the plants, the probable presence of water, and even the approximate depth of the water below the ground surface. Schimper (1898) made a difference between wet, hygrophyte and dry, xerophyte plant species. The important difference lies in the physiology: if a soil contains too much salt the plants cannot absorb the water and hence it is physiologically dry. All soils which are physically dry are also physiologically dry; and hence only the physiological dryness or wetness of soils need be considered in ecology. Schimper used the term xerophytes to include plants, which live in soils which are physiologically dry, and the term hygrophytes those which live in soils which are physiologically wet or damp.

Oscar Edward Meinzer (1923), the father of modern groundwater hydrology, was the first to define the term phreatophyte as a plant that habitually obtains its water supply from the zone of saturation. In 1927 he wrote a whole book about these phreatophytes. He describes the principle phreatophytic species, like common salt grass (Distilchlis spicata) and their occurrence in the arid and semi-arid regions of the US (Meinzer, 1927). In these days plants were for groundwater hydrologists clearly indicators for locations of groundwater resources. After the first half of the 20th century it seems that hydrogeologists lost their interest in the use of phreatophytes in groundwater studies, however ecologists continued the study of their habitat requirements (Londo, 1988; Ellenberg et al., 1992). Phytosociologists started in the 1950's the research on the relationship between vegetation types and groundwater dynamics. Ellenberg (1948, 1950, 1952, 1953, 1974) and Tüxen (1954) were the first to systematically study the relationship between groundwater level and the occurrence of vegetation types.

The first publication in which the word 'ecohydrology' is mentioned is from the Dutch author van Wirdum in 1982 (van Wirdum, 1982). It is an annual report of the activities in 1981 of the Ecohydrology section of the Dutch national institute for nature research. Frequently used in ecohydrology is his simple and elegant diagram of electrical conductivity versus ionic ratio in which a groundwater sample can be plotted to directly infer its position in the hydrological cycle between rainwater (atmotrophic water), groundwater (lithotrophic water) and seawater (thalossotrophic water). More recent the interest in phreatophytes in general revived again, following the interest in groundwater dependent ecosystems (Batelaan et al., 2003a; Witte and von Asmuth, 2003, Loheide II et al., 2005).

This very short overview did not give tribute to many important contributions like the pioneering work of Russians and other scientists on bogs and fens. However, what this tells us is that ecohydrology and especially the groundwater versus plant species relationship is not new. Its scientific content has grown over the ages, while the recognition of its scientific importance in the wider hydrological community is only now realized. It also tells us that potentially a lot of interesting and useful information for groundwater studies is contained in the ecological knowledge. Ecologists build more and more complex vegetation prediction models based on groundwater level and chemistry dynamics: for understanding the differences in groundwater chemistry and levels urgently more hydrogeological support is needed.

APPLICATION: LINKING VEGETATION, GROUNDWATER FLOW AND GEOCHEMISTRY

The relationships between soil, water characteristics and nature quality (i.e. diversity of vegetation) of three Flemish groundwater dependent wetlands were examined (Huybrechts et al., 2000). These wetlands are 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 (Fig. 1). Large parts of these wetlands are groundwater saturated for most of the year, therefore they are mainly occupied by phreatophytic vegetation types such as reed lands, brook forests, sedges, etc. It is observed that there is a large diversity in vegetation types between the areas (Fig. 2). While the Doode Bemde is mainly dominated by reed and grasslands, it appears that Vorsdonkbos has a lot of brook forests and large sedges and Zwarte Beek is dominated by smaller sedges. Since regional land use, soil and climate is not significantly different, it is hypothesized that these vegetation differences are due to differences in groundwater fluxes and qualities. A groundwater modelling exercise was performed to investigate the differences between the areas with respect to the connected groundwater system.

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. Batelaan et al. (2003b) describe the groundwater model for the area in detail. The recharge for the model was simulated on basis of distributed land use, soil, topography and hydrometeorology with the spatially distributed WetSpass modelling procedure (Batelaan and De Smedt, 2007). The used discretization for the groundwater modelling was 20 m. 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 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. The USGS modular three-dimensional finite difference groundwater model, MODFLOW (Harbaugh and McDonald, 1996) has been used to simulate the groundwater flow extended with a SEEPAGE package (Batelaan and De Smedt, 2004) to accurately delineate the groundwater discharge areas. A MODPATH (Pollock, 1994) simulation was performed to determine by particle tracking the recharge area and flow times.

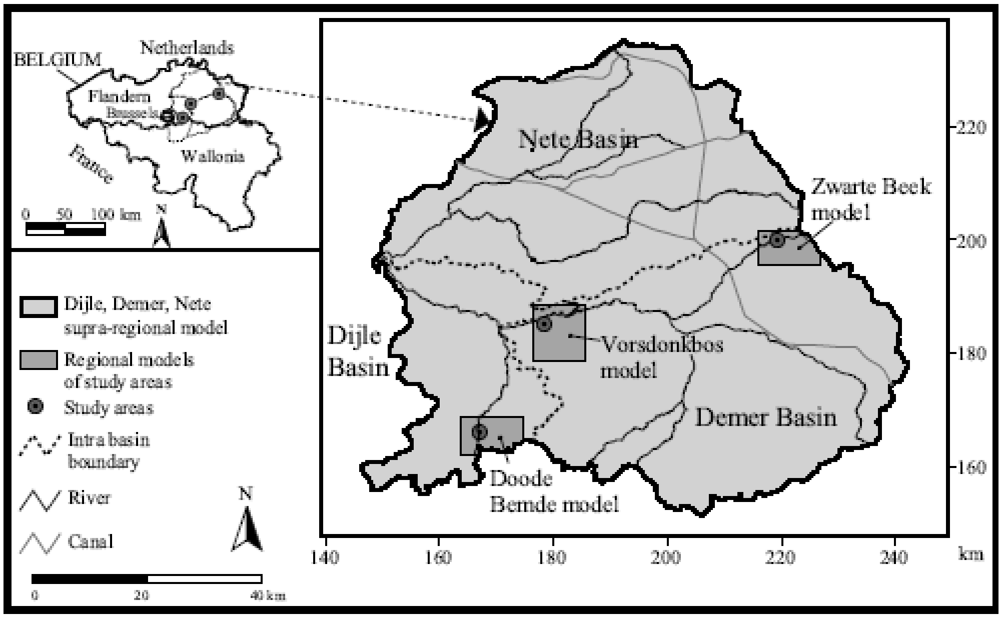

Fig. 1: Location of the three study areas and their regional groundwater models within the supra-regional model for the Dijle, Demer and Nete Basin.

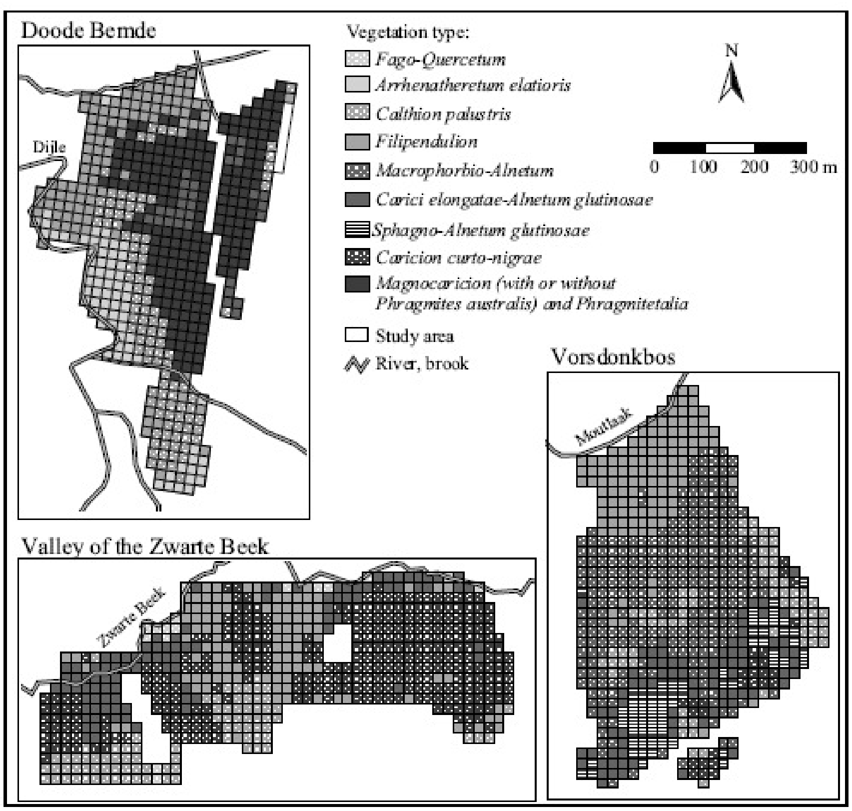

Fig. 2: Vegetation types, derived from cluster analysis of species mapping, for the study areas Doode Bemde, Vorsdonkbos and Valley of the Zwarte Beek.

RESULTS AND DISCUSSION

Figure 3 shows for the three study areas, the calculated groundwater discharge areas, while Fig. 4 shows the simulated recharge areas and flow times of the discharge areas. The sizes of the study areas and the discharge zones in each area are very similar. The average discharge flux however varies much more due to the strongly varying size of the recharge areas and the average flow times from recharge to discharge area. If the discharge map (Fig. 3) is compared to the vegetation map (Fig. 2) it is clearly observed that the patterns of the discharge correlate well with the patterns of phreatophyte occurrence. However, it does not explain the diversity of the vegetation.

The shallow groundwater quality (Fig. 5) on the other hand clearly shows that the three groundwater dependent wetlands receive groundwater with quite different qualities. The acidic groundwater type 1a occurs only along the hill side of the wetlands, the comparable (but less acidic) type 1b also more inside the valleys. Both types are dominant in the Vorsdonkbos, calcium is the major cation. It is counteracted equally by chloride, bicarbonate and sulphate. In groundwater types 2, 3 and 4 calcium and bicarbonate dominate, but these types differ in total ionic concentration, acidity (pH), and the significant sulphate concentration in groundwater type 4. Groundwater type 2 has the lowest ionic concentration of all, type 4 the highest. The acidic groundwater type 2 dominates in the Zwarte Beek Valley, the more neutral, calcareous groundwater type 3 in the Doode Bemde. Groundwater type 4 is found in the Doode Bemde, but also in the Vorsdonkbos.

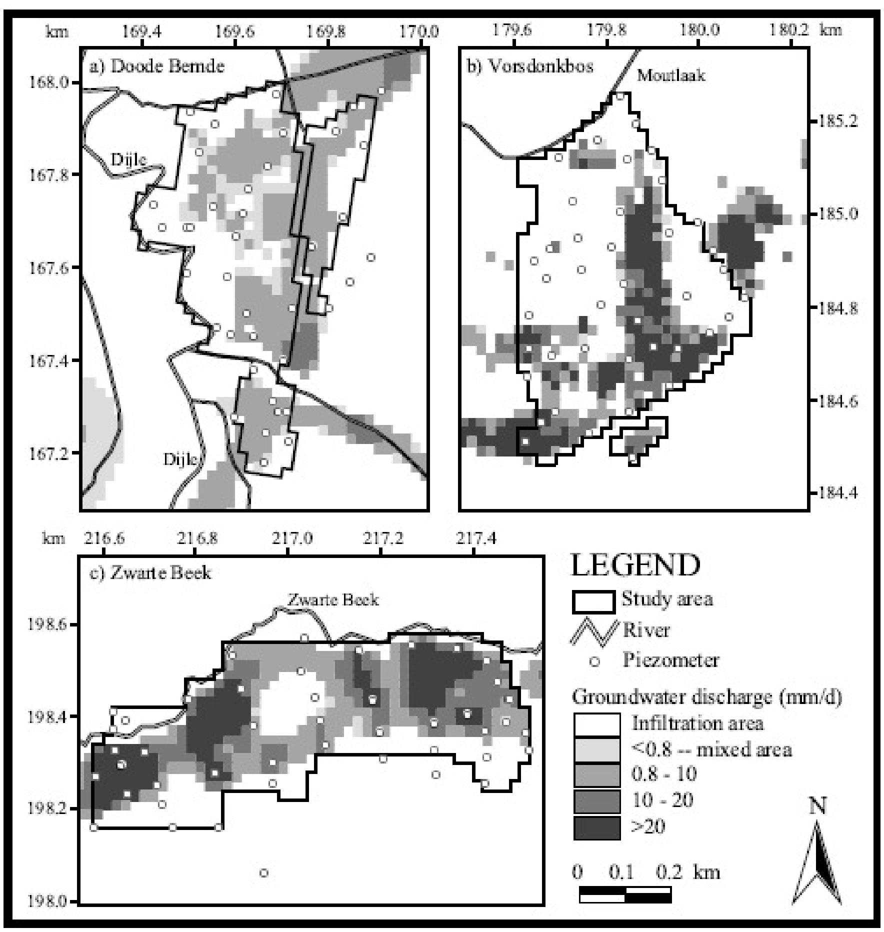

Fig. 3: Simulated discharge areas and fluxes in a) Doode Bemde, b) Vorsdonkbos and c) Zwarte Beek.

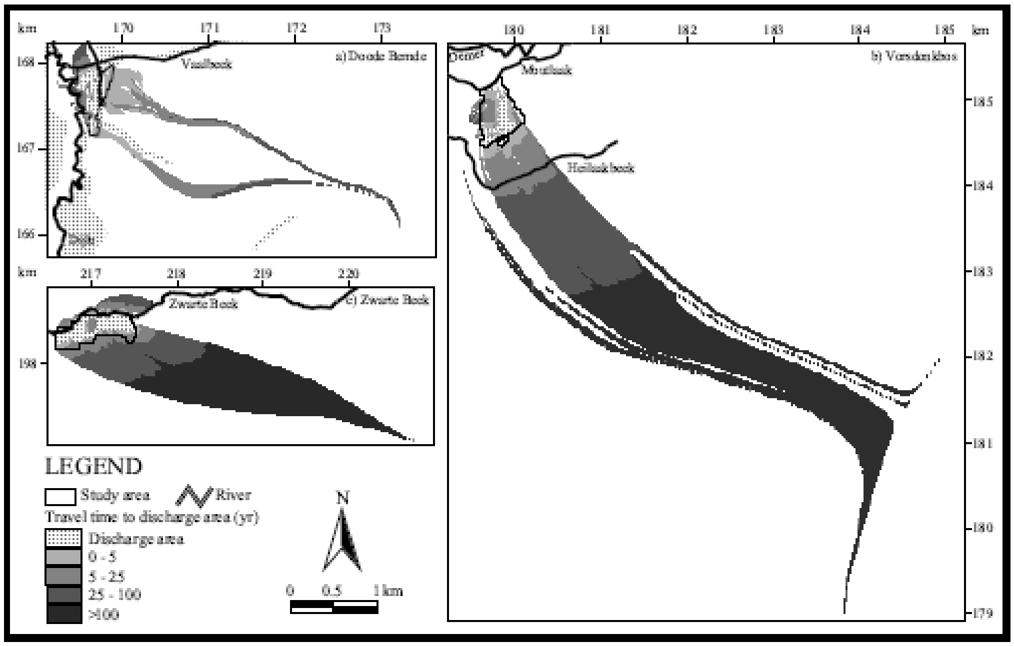

Fig. 4: Simulated groundwater flow systems and travel times from recharge to discharge location for: a) Doode Bemde, b) Vorsdonkbos, and c) Zwarte Beek study area.

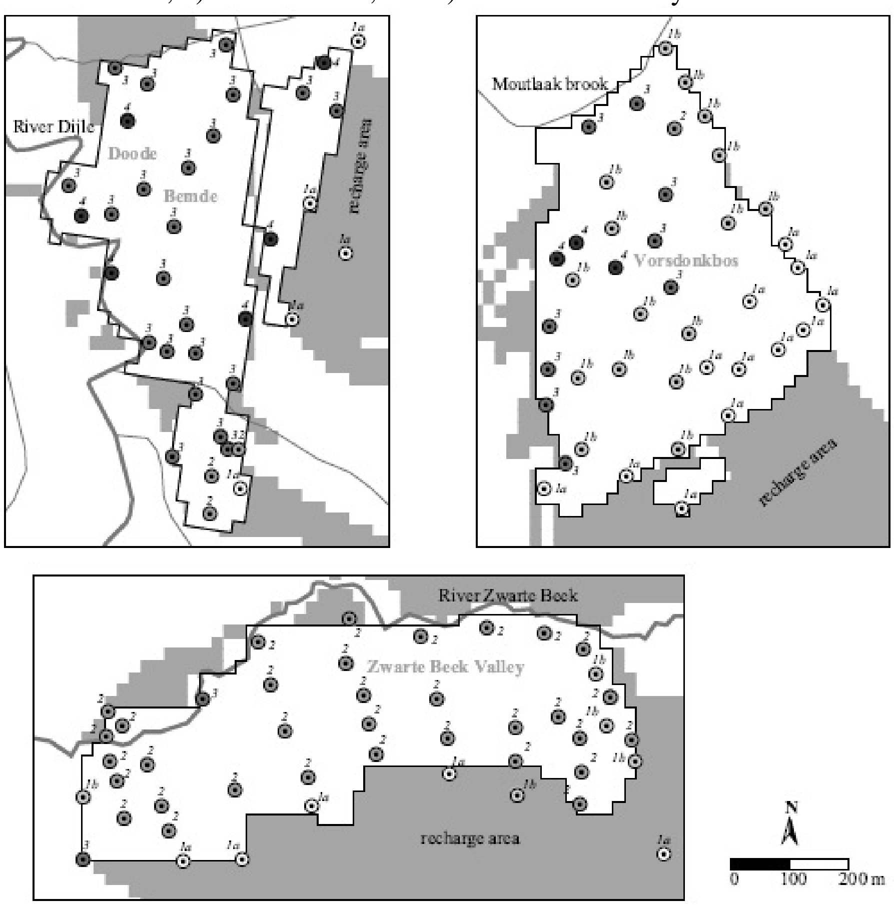

Fig. 5: Distribution of the four groundwater types (indicated by 1a, 1b, 2, 3 and 4) in piezometers of the Doode Bemde, the Vorsdonkbos, and the Zwarte Beek Valley.

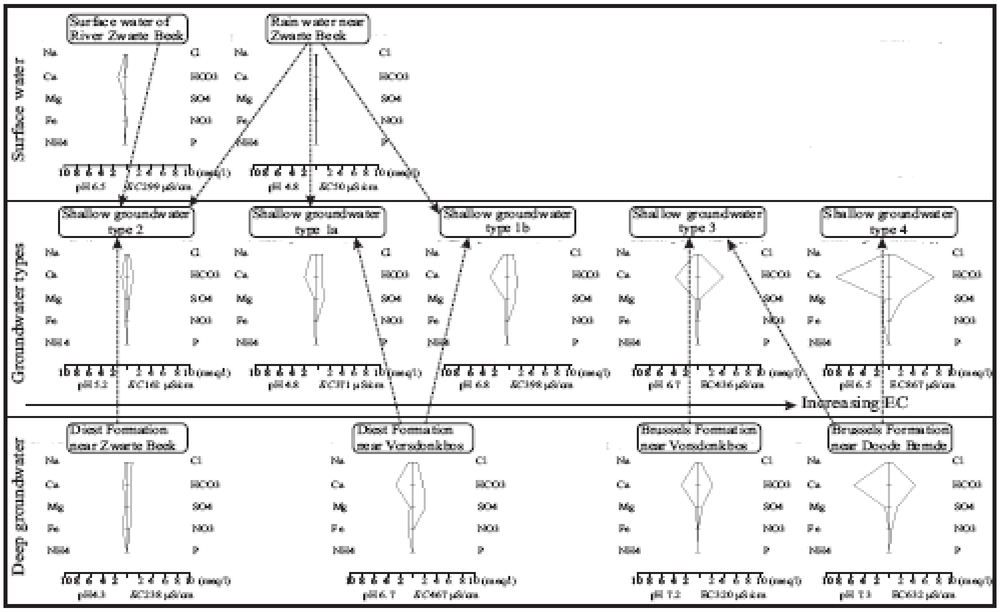

Fig. 6: Stiff diagrams for the groundwater types in the wetlands, the deeper groundwater in the aquifers, the surface water in the River Zwarte Beek, and the local rain water near the Zwarte Beek Valley (Huybrechts et al., 2000).

Figure 6 shows that the cause of the varying shallow groundwater quality lies in the geochemical composition of the feeding aquifers. Interaction between the flowing water and the porous medium of the Diest or Brussels Formations appear to have a major impact on the resulting shallow water quality. Van Rossum et al. (2000) shows that the mineral reactivity determines the possibility for dissolution of minerals in the groundwater and that flow time and distance is of secondary importance. The Brussels Formation contains more soluble minerals than the Diest Formation and is the main aquifer for the Doode Bemde area, while for Vorsdonkbos it is one of the two feeding aquifers. The Diest Formation feeds also Vorsdonkbos, it is as well the main contributor to the Valley of the Zwarte Beek. Together with groundwater, which is very little mineralized, atmotrophic qualities, due to very short flow paths and times, the vegetation in these different wetlands are highly determined by the groundwater discharge from these qualitative different sources.

CONCLUSIONS

The investigated vegetation diversities are mainly determined by regional factors such as topography, hydrology (recharge areas and groundwater-flow times) and hydrogeochemistry (mineral reactivity in the aquifers). Soil moisture dynamics is for the groundwater dependent wetlands of much less important.
Important is that it is shown that by synthesizing data and methods from different fields of sciences (i.e. ecology and hydrology) new insights in the functioning of ecosystems can be obtained. It is therefore, in line with Harte (2002), advocated that more integration of ecological and hydrological sciences will benefit problems in earth system sciences.

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