SYNTHESIZING HYDROLOGY AND ECOLOGY: SUGGESTIONS AND SOME EXAMPLES

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Abstract: Ecological research of wetlands is quite established. However, hydrological research of wetlands is much less developed. Harte (2002) noticed differences in intellectual tradition between ecologists and physicists as the reason why both groups of scientists have so opposing worldviews. He argues that synthesizing these different worldviews have large advantages in solving important issues in earth system science. Difficulties, different possible solutions and ingredients for synthesis are suggested by Harte (2002). Two examples from Flanders, Belgium in which ecological and hydrological aspects have been integrated are presented. The examples show that the synthesis give new additional insight in the functioning of the ecosystems not recognized before by the individual science fields alone.

NEWTON VS DARWIN

The environmental physicist Harte (2002) published a paper titled 'Toward a synthesis of the Newtonian and Darwinian worldviews'. In this paper he argues that physicists and ecologists have a different intellectual tradition. Physicists and I classify hydrologists in this paper under the physicists, are determined from their education and the historical development of their field of science by a Newtonian approach. However, ecologists and ecology as a science is filled with ideas stemming from a Darwinian approach. Table 1 simplifies the Darwinian and Newtonian worldviews in opposing concepts (Harte, 2002). It is then argued that if one could come to a synthesis of these opposing worldviews this would maybe offer opportunities in making progress towards attacking big research issues of the earth system science as: How will climate warming alter life? How important is biodiversity? and What is needed for a sustainable future?

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Table 1: Comparison of Newtonian and Darwinian worldviews (after Harte, 2002).

PHYSICS	ECOLOGY
The more you look the simpler it gets	The more you look, the more complex it gets
Primacy of initial conditions	Primacy of complex historical factors
Universal patterns; search for laws	Weak trends; reluctance to seek laws
Predictive	Mostly descriptive, explanatory
Central role for ideal systems	Disdain for caricatures of nature

However, several difficulties can be expected in trying to solve these issues. For example is due to human activities the past not a reliable indicator for predicting the effects of actions. Further make mechanisms as feedback, non-linearity, thresholds and irreversibility complex and hard to predict functioning systems. Finally, there is an impossibility of performing large-scale experiments, which could give insight to the problem, since the Newtonian approach demands inaccessible or impossible detailed data on initial conditions.

Harte (2002) suggests consequently three possible confronting ‘solutions’:

1. Give up the goal of prediction, start doing scenario building, pattern identification and historical analysis.
2. Force a complete Newtonian framework, i.e. build detailed predictive models and measure all necessary model parameters.
3. Stop improving knowledge: we know enough, so go straight to implementation of policies.

As usual there is not a simple one sentence solution and therefore only the following ingredients of synthesis, contributing to the solution, can be suggested (Harte, 2002). Firstly, aim initially for simple falsifiable models, which are mechanistic with lumped system variables. Secondly, search for patterns and laws e.g. spatial scaling and finally, embrace the science of a place, i.e. try to understand very specific environments, then it is possible to go from pattern to process and then to generalizations.

As examples of synthesis two case studies from Flanders, Belgium in which ecological and hydrological aspects have been integrated are presented.

EXAMPLE 1: LINKING VEGETATION, GROUNDWATER FLOW AND GEOCHEMISTRY

Within the Flemish governmental impulse program for nature conservation and development (VLINA) the relationships between soil, water characteristics and nature quality (i.e. diversity of vegetation) 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

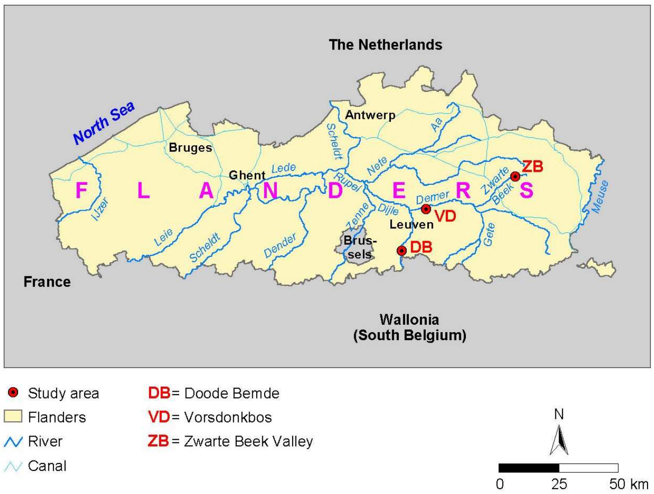

Figure 1: Location map of the three examined river basin wetland ecosystems.

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 therefore performed to investigate the differences between the areas with respect to the connected groundwater system.

GROUNDWATER MODELLING

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. (2003a) 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 & De Smedt, 2001). 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 where 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 & McDonald, 1996) has been used to simulate the

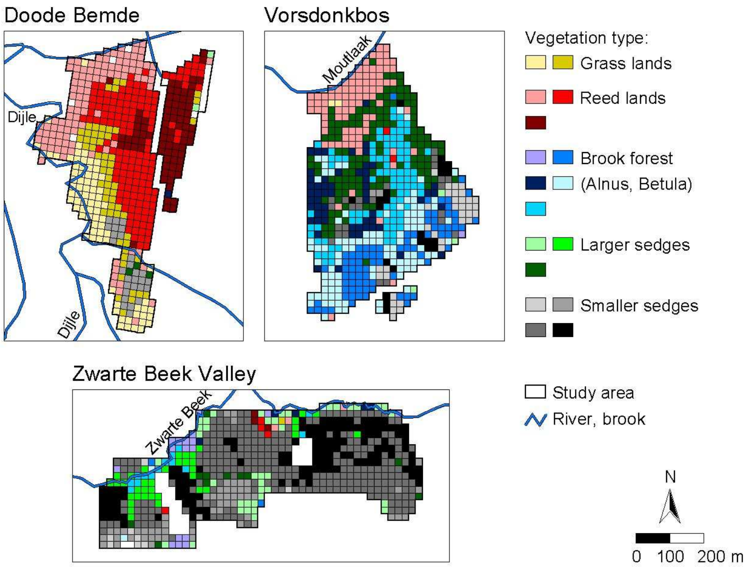

Figure 2: Vegetation types in three wetland areas (Huybrechts et al, 2000).

groundwater flow, while a MODPATH (Pollock, 1994) simulation was performed to determine by particle tracking the recharge area and flow times.

RESULTS AND DISCUSSION

Fig. 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.

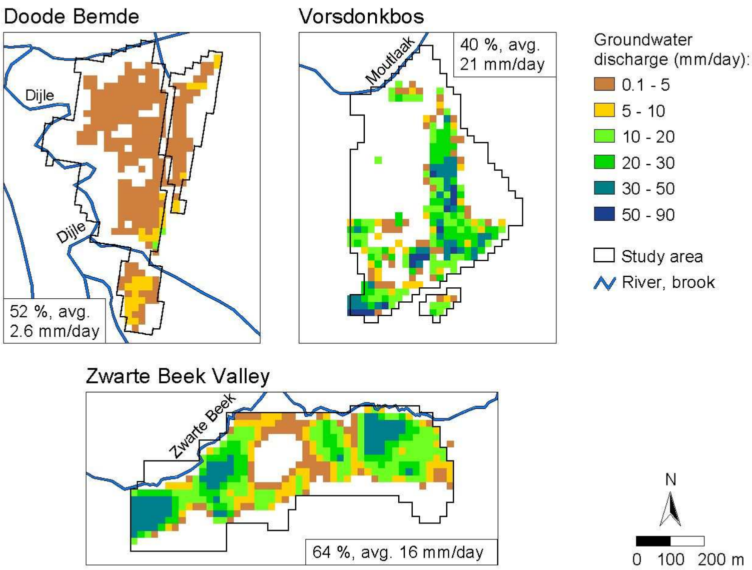

Figure 3: Simulated groundwater discharge areas and fluxes.

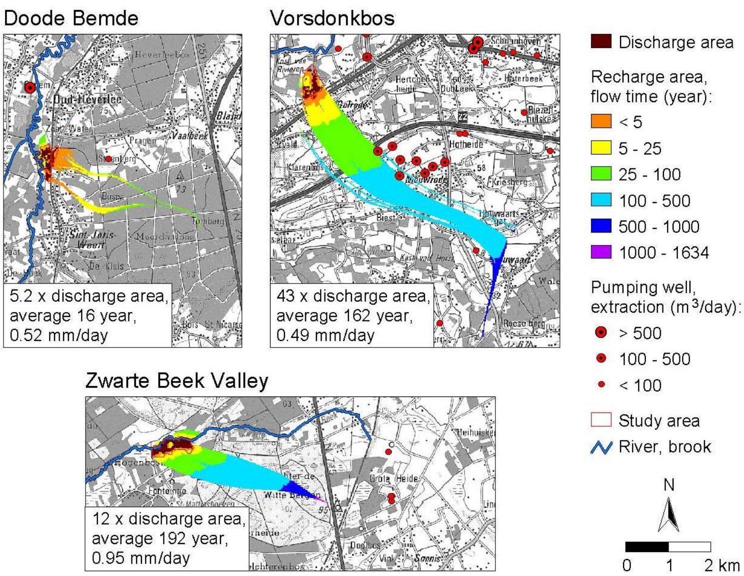

Figure 4: Simulated recharge areas and flow times to groundwater discharge areas.

Fig. 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)

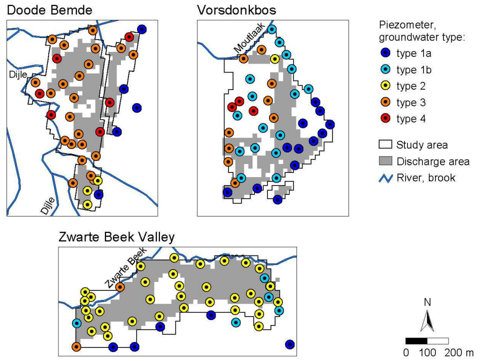

Figure 5: Distribution of shallow groundwater qualities.

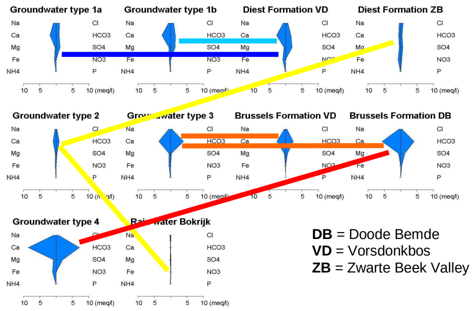

Figure 6: Correspondence between water quality from aquifers and shallow groundwater types.

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 different wetlands are highly determined by the groundwater discharge from these qualitative different sources.

EXAMPLE 2: LINKING REGIONAL GROUNDWATER SYSTEMS TO ECOSYSTEM CHARACTERISTICS

Batelaan et al. (2003b) describe a study for a part of the Grote Nete catchment (Fig. 1) in which groundwater flow modelling results are linked to a characterization of ecosystems in valleys on basis of a phreatophyte mapping and a biological evaluation map.

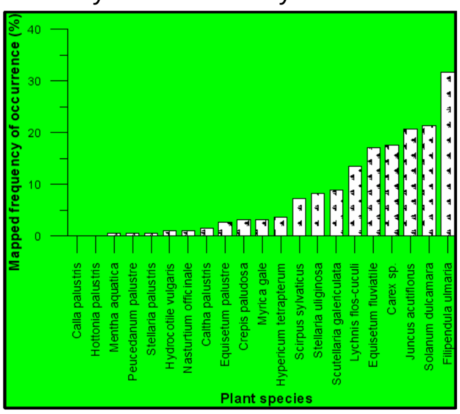

Figure 7: Occurrence of mapped phreatophytes

DATA

Fig. 7 shows the occurrence of the mapped phreatophytes at from 193 locations. It was shown that the mapped locations corresponded well to groundwater simulated seepage zones (Fig. 8). It is therefore suggested that the phreatophytes could be used as additional calibration information for the groundwater model. For simulating the seepage zones MODFLOW in combination with the

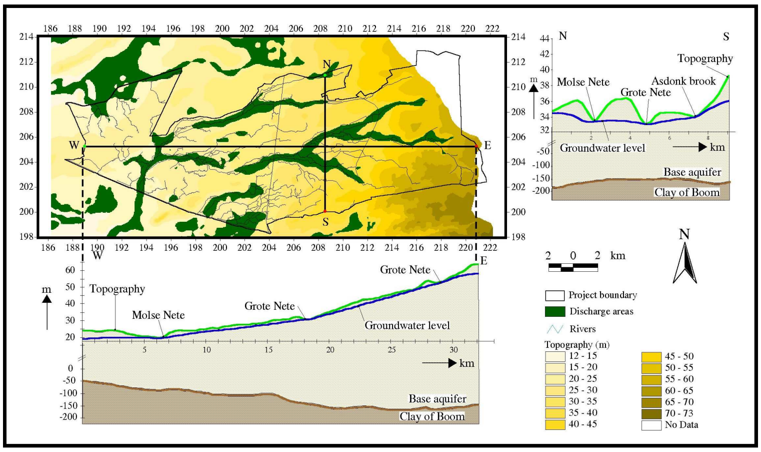

Figure 8: Simulated groundwater discharge areas in the Grote Nete area

SEEPAGE package (Batelaan & De Smedt, 2004) was used.

Ellenberg (1991) defined indicator values for more than 1750 vascular plants species with respect to their habitat for Middle European locations. He defined two groups of three indicators. The first group refers to the tolerance with respect to climatic conditions: light exposure (L-value), temperature (T-value) and continentality (K-value), the second group refers to soil factors: wetness (F-value), acidity (R-value) and nitrogen (N-value). The wetness and acidity indicators are regarded to be the most useful indicators for characterization of groundwater discharge areas with phreatophytes. The R-value ranges from 1, highly acidic, to 9, highly alkaline conditions. The F-value ranges from 1, dry, to 12, very wet habitat conditions. In addition, the Biological Evaluation Map (BEM) (Berten et al., 2000) was also used. This digital map gives an evaluation of every ecotope on the basis of four criteria: rareness, biological quality, vulnerability and replaceability. The map is based on a phytosociological vegetation mapping on parcel level, scale 1:10,000, using a system of hierarchical vegetation units. On basis of these vegetation units environmental indicators as the alkalinity and trophic status are defined.

RESULTS AND DISCUSSION

16 discharge regions with 'similar' characteristics are delineated (Fig. 9) on basis of the contiguity of the groundwater model based discharge areas, topographical and landscape ecological position of the discharge area and the similarity of the vegetation types, as given by the Ellenberg indicator values. For understanding of the spatial variation in ecological conditions in the study area it is necessary to link each discharge region to a recharge region by way of particle tracking (MODPATH model). The size and location of the recharge area, and the flow time from the recharge area to the discharge area can be used as indicators for the mineralisation level, and the buffer, adsorption and decay capacity of the

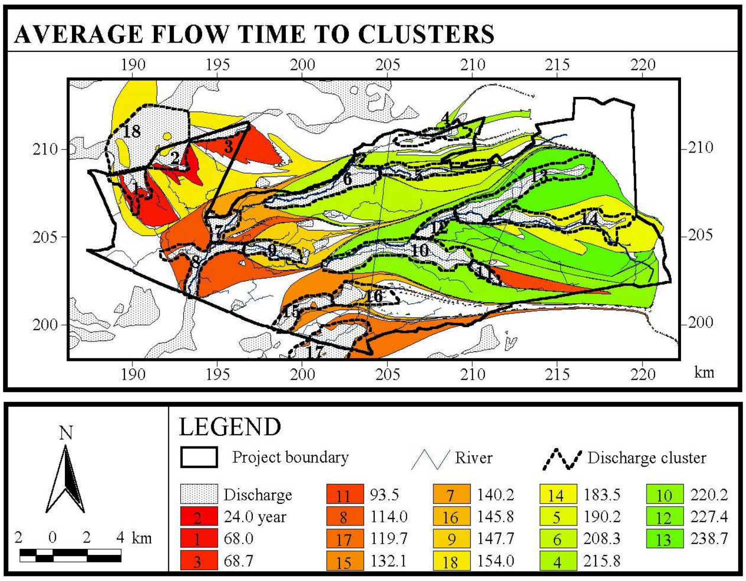

Figure 9: Simulated groundwater systems (recharge-discharge areas) and flow times of delineated groundwater discharge zones.

groundwater. The delineated different groundwater systems are given in Fig. 9, as well as their flow times. A relative comparison of these systems is required in order to increase our knowledge about the relationship between regional groundwater and phreatophytes. By way of a cluster analysis on basis of the parameters groundwater discharge flux, average flow time and ratio recharge over discharge area, which describe the groundwater flow between the recharge and discharge areas, as well as the alkalinity and trophic indicator, which describe the ecological status of the groundwater discharge areas aggregation is achieved of the different recharge-discharge systems into four significantly different types of ecohydrological systems.

The cluster dendrogram (Fig. 10) shows the four clusters of groundwater systems. Clusters I and II consist of discharge areas that all are located in headwaters in the geomorphologically highest locations of the study area. The groundwater flow times are very similar and characteristic for relatively local but deep groundwater systems, with infiltration areas extending to the regional groundwater divide. The alkalinity is also similar, and clearly lower than for the other clusters, indicating atmotrophic seepage water. The difference between cluster I and II is that cluster I has a higher recharge/discharge area ratio and discharge flux and a slightly lower trophic level than cluster II. This difference can be explained as an expression of the geomorphological position of the two clusters. Clusters III and IV are situated respectively in the centre and most downstream part of the study area. All average parameter values for clusters III and IV are higher than for clusters I and II (except for flow time and flux of cluster IV). This indicates their more regional, lithotrophic character. Cluster III has the most regional flow system of all clusters,

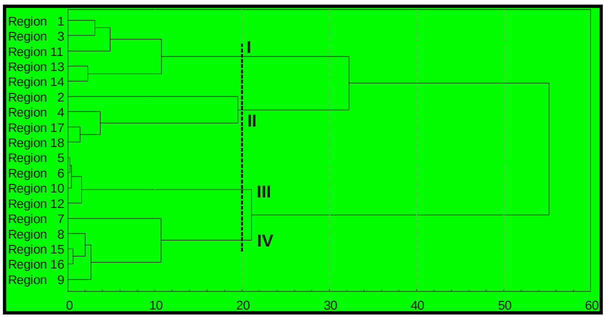

Figure 10: Dendogram of cluster analysis for 16 regions, three groundwater and two ecological indicators.

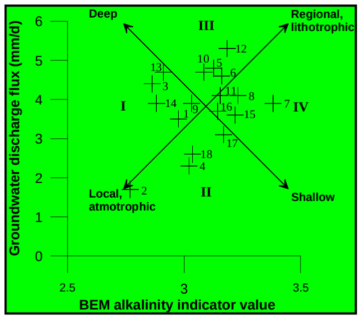

Figure 11: Graphing of ecohydrological regions on basis of groundwater discharge flux and alkalinity.

characterized by long flow times, high recharge/discharge area ratios, and high seepage fluxes. This is mainly due to the central location, enabling it to receive deep and regional groundwater flow with a relatively lithotrophic quality. Cluster IV also consists of regional systems with large recharge areas, resulting in high recharge/discharge area ratio, fluxes, alkalinity and trophic levels. However, it differs from cluster III due to its more downstream location, such that the groundwater flow occurs in a much shallower part of the aquifer, which explains the shorter flow times.

The qualitative differences between the groundwater systems in relation to their ecological and hydrological characteristics can more simply be discerned by plotting the most important hydrological parameter, the groundwater discharge flux versus the most important ecological parameter, the BEM alkalinity indicator (Fig. 11). The delineation of the clusters in the graph is rather striking. It follows that on the basis of these two parameters, significant ecohydrological characteristics of groundwater systems are revealed. It is suggested that this graph can help in identifying major ecohydrological zoning in a catchment, which are due to differences in groundwater flow on a regional scale.

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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