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ECOHYDROLOGICAL PROCESSES IN ALMOST FLAT WETLANDS

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Abstract

In spite of their modest relief almost flat wetlands are able to maintain definite topographically driven groundwater flow systems. Large seepage areas create ecohydrological gradients which determine a flat wetland's vegetational variety, ranging from acid oligotrophic to base-rich mesotrophic. The authors give a theoretical explanation, underpinned by field evidence. Seepage faces are vulnerable to human interventions like groundwater withdrawal and land development. They show good prospects, however, of restoration.

Introduction

The vast area of wetlands, once predominating the landscape of the Netherlands, has gradually been reduced to a handful of natural preserves. Nowadays, the existence of most non-acid mesotrophic plant communities is seriously threatened by land development, dewatering works and groundwater abstraction. Current licensing policy with regard to groundwater wells rightly stresses the importance of conservation of the remaining natural values. Shut down or reallocation of groundwater plants are advocated as means to improve natural potencies. Optimal allocation, however, requires knowledge of determinative ecohydrological processes, that are still poorly understood. This paper features some results of an investigation of a small wetland sanctuary (Punthuizen) in a Plistocene landscape, which may be exemplary for *almost flat wetlands*. The investigation is part of an ongoing research program of the Netherlands Waterworks Associ-

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ation, aiming at a quantitative description of adverse ecohydrological effects of groundwater development.

Ecohydrological processes in almost flat wetlands

Introduction

Most wetlands of The Netherlands show only a minimum of topographic relief, with altitude variations in the order of a meter (yard). Nevertheless, their vegetations exhibit characteristic patterns that can be related to topographically driven groundwater flow systems. Typically, almost flat wetlands have relatively large areas of so called *seepage faces*, where groundwater exfiltrates to the soil surface, and it is on these faces that the most threatened non-acid mesotrophic plant communities are still found. Conservation of seepage faces seems to be essential. It is necessary to understand their functioning, in order to take appropriate water managerial measures. This section indicates the hydrological processes that we believe are of major importance.

Hydrological conditions along a seepage face

Fig.1a shows a schematic section along a gentle slope, whose gradient has been grossly exaggerated for clarity. Actual slopes are in the order of 1:100, although there may be local variation. This aspect has been incorporated in the figure, by the dent at C. Points A and E indicate water divides. Other noticeable points are B, at the edge of a pool, and the upper boundary D of a seepage face. Groundwater flow in natural terrains is usually very unsteady, but we will start our consideration from a steady state. Rain is supposed to fall at rate P, which can only infiltrate the unsaturated part of the slope. Rain on the seepage face runs off superficially to the pool. The 'actual' steady two-dimensional flow pattern is given by fig.1b. It shows that *exfiltration of groundwater does not occur evenly along the saturated part of the slope*: the seepage flow focusses on spots of preference, related to topography. We will depend on a simple Dupuit-Forcheimer approach to highlight the most prominent hydrological features of the seepage face. (The Dupuit-Forcheimer approach assumes the water pressure to be hydrostatic along any vertical). Along section DE we have phreatic flow with precipitation, giving rise to a parabolic groundwater mound. Flow in section CD is governed by the hydraulic gradient along the soil surface, where the pressure is atmospher-ic. By Darcy's law, the groundwater flux through this section is proportional to the slope tan(β) of the soil surface. Continuity of flow forces the free water table to be tangent to the soil surface at D. We note that this requirement *completely* determines the position of the upper

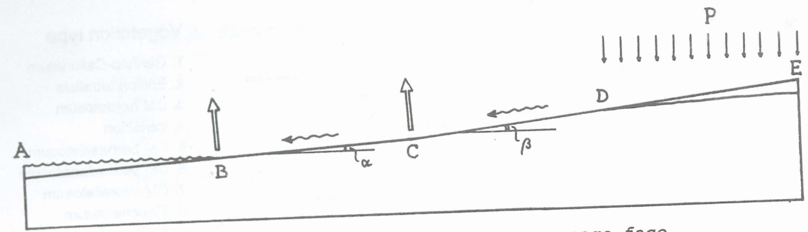

Fig.1a: idealized section along a seepage face

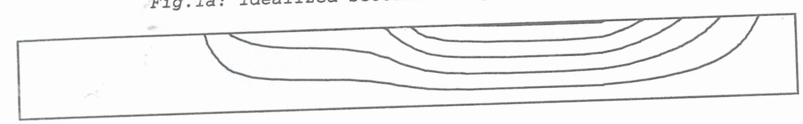

Fig.1b: actual flow pattern

boundary D of the seepage face: what may happen downstream of D cannot possibly influence the head between D and E, as long as the seepage face is intact. *Seepage faces, therefore, act as buffers that help protect an area from external influences.* Quoting Darcy again, section BC carries an amount of groundwater proportional to tan(α), the slope along BC. α being smaller than β, section BC conveys less groundwater than section CD does. The difference must of necessity leave the soil at C, creating a concentrated outflow of groundwater there (compare fig.1b). A comparable, though usually more dramatic phenomenon occurs at the edge B of the pool, as section AB can transmit no water at all, because of the zero gradient of the pool's water table. There is some outflow of groundwater along the straight slopes BC and CD, due to the aquifer loosing thickness in the direction of flow, but the slopes being minimal, this amount is almost negligible. Groundwater flows practically parallel to straight seepage faces.

Seepage faces may be absent during most of the growing season, while taking up considerable space during the winter half year. As rain comes in showers, the position of the upper boundary D is actually very dynamic. It may vary from the edge of the pool to well up the slope. The edge of the pool is itself dynamic, as pools wax and shrink with the seasons. Consequently, the concentrated flux at B moves up and down the lower slope. The flux at C, on the contrary, has a steady position, but is effective during a shorter period of time.

Finally, the groundwater quality shows a gradient from atmocline at the infiltration faces to lithocline at B, the amount of carried minerals depending on the soil matrix composition. If the pool is drained, leaching minerals will ultimately leave the system. On the other hand, undrained pools can trap and accumulate minerals.

Vegetation gradients

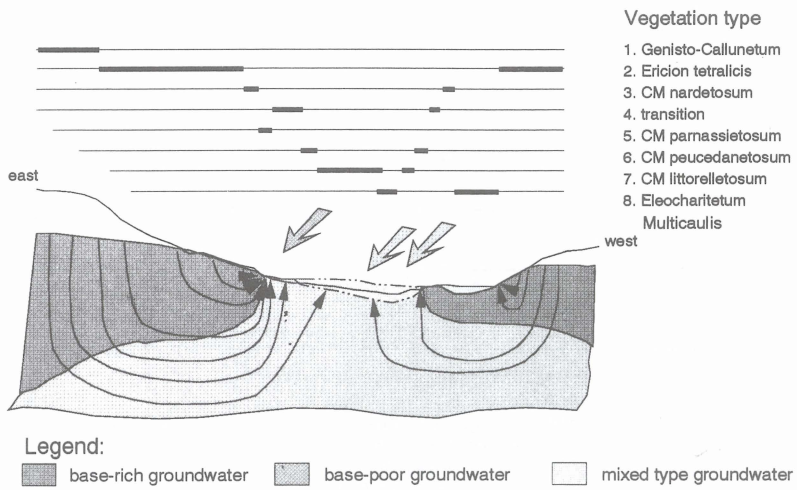

Fig.2: vegetation gradient at Punthuizen

The small wetland sanctuary Punthuizen, situated in a Plistocene landscape near the German border, shows a vegetational gradient related to its modest topography (fig.2). Going from the higher to the lower parts one meets with the following plant communities: Genisto-Callunetum typicum, Ericetum tetralicis typicum, Cirsio-Molinietum nardosum, Cirsio-Molinietum parnassietosum, Cirsio-Molinetum agostietosum and littorelletosum and Eleocharitetum multicaulis. The various communities claim specific conditions from their habitats, that can be related to the hydrological scheme of fig.1. Genisto-Callunetum typicum and Ericetum tetralicis typicum seek out the acid and oligotrophic positions caused by infiltrating or stagnant rain water, respectively. These conditions prevail hydrologically around point E, and along the slope DE, fig.1. The Cirsio-Molnietum communities depend on groundwater, with levels that are high during the winter and not deeper than 1,30 m (4 ft) in the summer. Cirsio-Molinietum nardosum and parnassietosum are never inundated, in contrast to Cirsio-Molinietum littorelletosum. The former two prefer hydrological positions as exist near point B, fig.1, while the latter prevails along slopes like BA. Eleocharitetum multicaulis knows lengthy periods of inundation, as near point A.

The richness of bases and the acidity of the upper groundwater also show a distinct variation between the various plant communities. EC and pH were measured from 12-12-91 through 5-14-92 in water tubes at depths of 40, 80 and 120 cm (16, 32 and 47 inch, resp.) for several

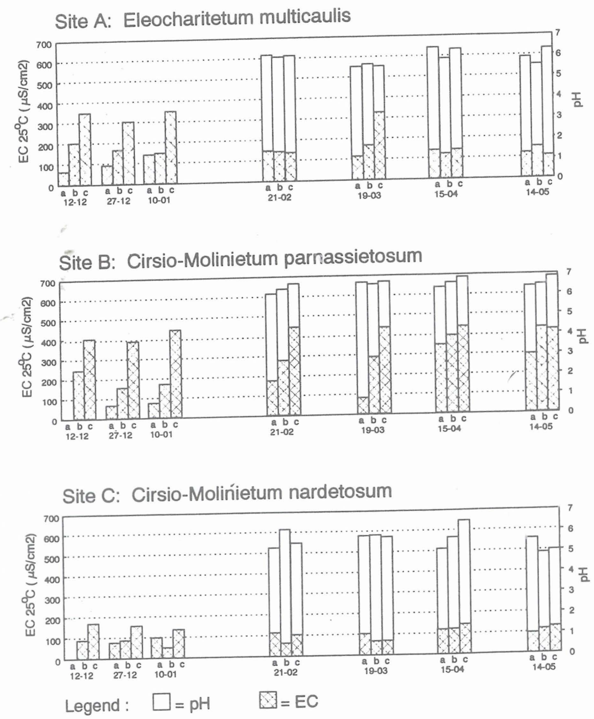

Fig 3a: Site conditions of three plant communities

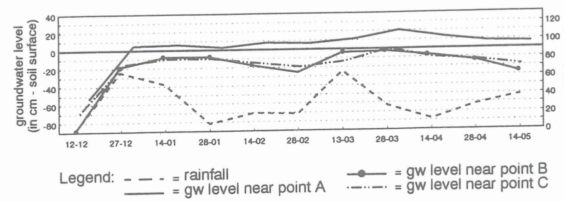

Fig.3b: Groundwater levels and precipitation at the above three sites

vegetational types. Some typical examples are shown by fig.3, labeled site A, site B and site C, resp. (The labels correspond to the hydrological positions A, B and C indicated in fig.1). The upper three diagrams show measured EC and pH values. The lower diagram gives corresponding groundwater levels with respect to the soil surface and bi-weekly sums of rainfall. It appears, for instance, that site A was inundated during most of the observation period. The diagram also shows two wet intervals, followed by dryer periods.

In natural (i.e. non-polluted) water electrical conductivity is a measure of base-richness. The samples at 40 cm are thought to be representative of the root zone. We classify a sample as base-poor if the EC-value at 25°C (77°F) is lower than 100 $\mu S/cm^2$. Samples with EC-values from 100 to 200 $\mu S/cm^2$ are moderately base-rich and higher EC-values indicate base-richness. Base-rich groundwater never reaches the root zones of Eleocharitetum multicaulis (A) and Cirsio-Molinietum nardetosum (C). In the former case, base-rich groundwater does show in the tubes at 120 cm during wet periods, due to the moderate upward flux. Cirsio-Molinietum parnassietosum, at position B, always has base-rich groundwater at 120 cm. It reaches the root zone intermittently, thanks to the concentrated groundwater flux. EC-values decline during periods of heavy rainfall. Base-rich conditions are generally believed to be a necessity for conservation of this community. It is apparently sufficient if they exist periodically. Variations in base richness of the groundwater correlate with acidity. pH-values of Cirsio-Molinietum nardetosum, Eleocharitetum multicaulis and Cirsio-Molinietum parnassietosum increase in the order of enumeration.

The site conditions EC, pH and inundation period determine the existance of these plant communities, and their rank along the ecohydrological gradient.

Vulnerability and prospects of restoration

The length of the period, during which seepage conditions exist at the soil surface, is quite sensitive to human interventions like land development, civil-technical works and groundwater withdrawal outside of but adjacent to endangered wetland areas. Their adverse effects usually show themselves in a lowering of the groundwater head of deeper aquifers. Being more or less confined, deeper aquifers are effective conveyers of pressure disturbances, often propagating them well under wetland areas. The secondary result is a downward loss of water from the wetland, causing a lowering of the groundwater table and a decrease of seepage faces. Consequently, the mechanism that brings base-rich groundwater to the root zone becomes less effective and more confined to smaller areas. On the other hand, groundwater heads of deeper aquifers are apt to hydraulic manipulation by suitable water managerial measures in the direct vicinity of a wetland. Actions may range from creating buffer zones with high water levels, to artificial infiltration by means of wells, the goal being *to restore seepage faces to their former extents.*