Modelling Water and Nitrogen Exchange in Peatlands with the web-based Decision Support System WETTRANS

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Abstract: WETTRANS is a web-based decision support system for quantification of nitrogen retention in peatlands where groundwater and surface water hydrology are connected with a flow-path, mass budget approach. This approach allows a calculation of nitrogen retention in a peatland based on peatland stratigraphy, hydrological position, water management and land use inside the peatland. The model results give a detailed, site-specific picture of the water and nitrogen exchange pattern and its reaction on land use and water management changes. These data are urgently needed for an informed selection of sites and water management measures for the implementation of the Schleswig-Holstein peatland rehabilitation programme aiming to restore the high nitrogen transformation potential of peatlands to reduce diffuse nitrogen input into surface water bodies.

Introduction

Peatlands contribute to the human well-being with several functions (De Groot 1992; Maltby et al. 1994; Joosten & Clarke 2002). Presently, the discussion of future land use concepts on peat soils is still dominated by the use of peatlands for agriculture, forestry and peat excavation. Other functions such as the contribution of peatlands to the regulation of the global climate, their potential for water quality improvement, their ability to damp flood waves, or their offer of aesthetic and

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spiritual inspiration are underrepresented, because these uses result not directly in an income for the land owner. Only, the society as a whole profits from these ecological services or indirect uses. While ecological services receive increasing attention within the scientific community (De Groot 1992; Maltby et al. 1994; Joosten & Clarke 2002) and in international environmental policy, e.g. by the adoption of the Guidelines for global action on peatlands by the contracting parties of the RAMSAR-Convention, their consideration in the preparation of future management concepts for single peatlands is still in the beginning. This imbalance has several reasons: (I) Quantification of non direct uses is often uncertain (Roulet 2000; Rosenberger et al. 2003). (II) The effect of a single peatland to global climate regulation or regional water quality improvement appears to be quantitatively not relevant for local decision makers. (III) The political and social pressure for the implementation of national peatland action plans is in most European countries minimal. All three reasons are related to quantification of ecosystem services. In an informed society, environmental administration and policy come to decisions on knowledge and numbers. Thus, an influence of the decision making process towards the implementation of multifunctional land use concepts on peat soils requires understanding of the involved processes and quantification of the effect of a changed land use or water management on aspects of the regulation and information function. Mathematical models and decision support systems are tools for this purpose (Bunnell & Boyland 2003; Trepel et al. 2000).

This paper presents a flow-path oriented decision support system (DSS) for the quantification of nitrogen retention in peatlands. The DSS was developed in the frame of the Schleswig-Holstein peatland rehabilitation programme, which was adopted by the Environmental Ministry in July 2002. The goal of the programme is to use the high nutrient transformation potential of peatlands for the reduction of diffuse nitrogen input into surface water bodies in order to achieve the agreements of the Baltic and North Sea Conventions and the European Water Framework Directive. The rehabilitation programme offers funding for land purchase and planning on 30.000 ha, nearly one third of the states peatland area. The DSS system will be used by local environmental agencies (I) for the selection of most effective peatlands sites and (II) for the selection of the most effective water management measure for nutrient load reduction.

RATIONALE FOR THE DSS: EFFECT OF PEATLANDS ON WATER QUALITY IMPROVEMENT

Minerotrophic peatlands are transitional zones between aquatic and terrestrial ecosystems. Their abiotic (e.g. water table near the surface, high carbon availability, anoxic soil water) and biotic (e.g. high productivity) conditions support several physical, biological and biogeochemical transformation processes leading to a reduction of the nutrient concentration in the outflowing water when compared to the inflowing water (Howard-Williams 1985; Verhoeven & Meuleman 1999). The effect of peatlands on water and nutrient outflow depends on positional and manageable factors (Figure 1). The positional factors determine the potential effect of a single peatland. Important positional factors are the profile stratigraphy of the peatland (determining the hydrogenetic peatland type), the hydrogeological conditions in the surrounding of the peatland and the position of the peatland in the drainage basin.

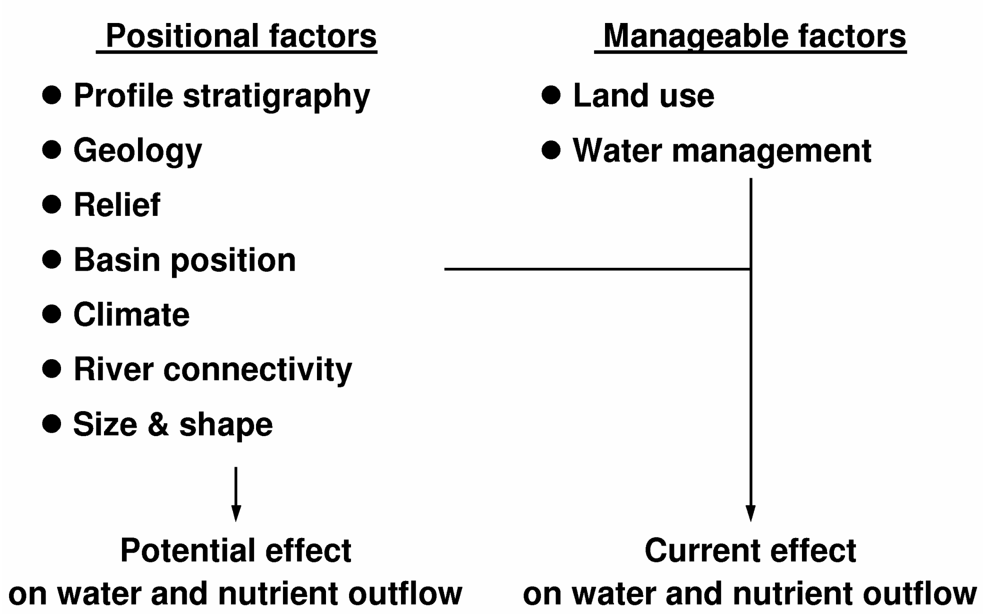

Figure 1: Overview of factors controlling the hydrological and hydrochemical effect of peatlands on their water and nutrient outflow. If there is a large difference between current effect and potential effect of a peatland on its water and nutrient outflow, then there is a high priority for restoration planning.

Positional factors change slowly caused by landscape evolution, climate change, or geomorphological processes. For water management decisions concerning midterm water quality improvement, positional factors can be considered as static. The current effect of a peatland on water and nutrient outflow is determined by the positional factors and the personal manageable factors land use and water management.

WETTRANS: A FLOW-PATH-ORIENTED WEB-BASED DECISION SUPPORT SYSTEM

Developing tools for application in environmental agencies is a tightrope walk between scientific accuracy and end-user requirements. A good DSS represents the scientific understanding of the problem structure and takes from the beginning data availability and accuracy into account. To meet these requirements, the DSS WETTRANS was developed in close co-operation with potential end-user as a web-based, user-friendly programme. All equations are documented and explained in an online help functions.

The DSS WETTRANS follows a steady-state, flow-path oriented, mass budget approach and assumes homogenic stratigraphical condition in the peatland under question. A detailed model description is given by Trepel & Kluge (2004). According to a flow-path-oriented approach, peatlands receive water and nutrient input via several hydrological inflow pathways. The inflow pathways differ in their age and due to different transient times and origin in their nutrient concentrations (Table 1). Especially, younger, lateral inflow pathways show a high variability of nutrient concentrations due to differences in soil texture and land use. The lateral water entering a peatland is a mixture of these different lateral inflow pathways (Table 1). In the WETTRANS model, the peatland is considered as a system which distributes the inflow from different inflow pathways to outflow pathways. The outflow pathways are characterized by different hydrological detention times, oxygen status and carbon availability (Trepel & Kluge 2004). Thus, they can be connected with different nitrogen transformation potentials (Table 1). In the current model version, each outflow pathway has a potential nitrogen transformation coefficient which is modified by the outflow path specific flow length and a site specific land use intensity index.

Input data

The input data for the WETTRANS DSS are grouped in five categories. The first category contains basic information about peatland size, mean peatland width, peatland length, precipitation and evapotranspiration, and the size of the upstream basin and lateral basin. In the second category, the user has to choose a substrate type (peat type) and a depth for three layers. From this information, a peatland type is calculated based on transmissivity differences between (I) layer 1 and layer 2 and (II) layer 2 and layer 3 (for details compare Kluge & Trepel 2004). The third category includes information about the hydrological conditions in the lateral drainage basin adjacent to the peatland. The user is asked for data about e.g. the proportion of adjacent slopes in the lateral basin, proportion of drained slopes, building area of young oxic groundwater, building area of anoxic ground water, and additional inflow of deep groundwater from a second aquifer. The data from these first three categories are used to calculate the water and nitrogen inflow for 8 inflow pathways. For the calculation of the nitrogen inflow, the programme suggests for each inflow pathways a mean nitrogen concentration which is based on a statistical analysis of available water quality data from the area (Trepel & Kluge 2004).

In the fourth category, the user has to provide information about the water management inside the peatland. Data include proportion of drains on peatland perimeter, proportion of ditch drainage and tile drainage in the peatland, mean ditch depth, mean tile depth, mean annually flooded area and mean annual flood duration. These data are used to calculate together with information about the peatland stratigraphy the water exchange from the surrounding through the peatland to a receiving surface water body. Finally in a fifths category, a user has to provide data about the proportion of different land use types on the peatland. Each land use type is assigned with (changeable) fertilizer amount. Land use data are needed for the calculation of total nitrogen input and output by harvest.

Table 1: Definition and characteristics of inflow and outflow pathways to and from a peatland; °NTP: Nitrogen transformation potential.

	Inflow pathways	Age	N (mg L^{-1})
A	Precipitation	< hours to days	1.0 - 2.0
B	Surface runoff	< hours to day	2.0 - 15.0
C	Interflow	< 30 days	5.0 - 30.0
D	Tile drainage	< 30 days	5.0 - 30.0
E	Young oxic groundwater	< 20 years	1.5 - 20.0
F	Young anoxic groundwater	> 20 years	0.0 - 10.0
G	Old anoxic groundwater	> 100 years	0.0 - 1.0
H	River inflow	Mixed water of different age	2.0 - 7.0

	Outflow pathways	Hydraulic detention time	NTP°
1	Evapotranspiration	-	-
2	Ditch outflow	< 10 days	Medium
3	Drain outflow	< days	Low
4	Overland flow	< hours to days	Medium
5	Subsurface flow	< 30 days to years	High
6	River throughflow	< 10 days	Low
7	Groundwater bypass	< 1 year	High

Model results

For each simulation a water partitioning matrix is calculated, which distributes the inflowing water and nutrients from the inflow pathways to the outflow pathways. Figure 2 visualizes the numbers in the water partitioning matrix for a percolation peatland (slightly humified peat layer above a thick, impermeable layer) with increasing drainage intensity. When this peatland is not drained, the inflowing water leaves the peatland via overland and subsurface flow. Under poorly drained conditions, both the proportions of overland and subsurface flow decrease while the proportion of ditch outflow increases. An excessively drained peatland is dominated by ditch and tube drainage outflow. Lowering of the river sole has resulted also in a reduced water exchange between the river inflow and the peatland.

Figure 2 shows clearly the idea of the model approach. The water partitioning matrix presents the structure of the system and contains information of the peatland stratigraphy and water management.

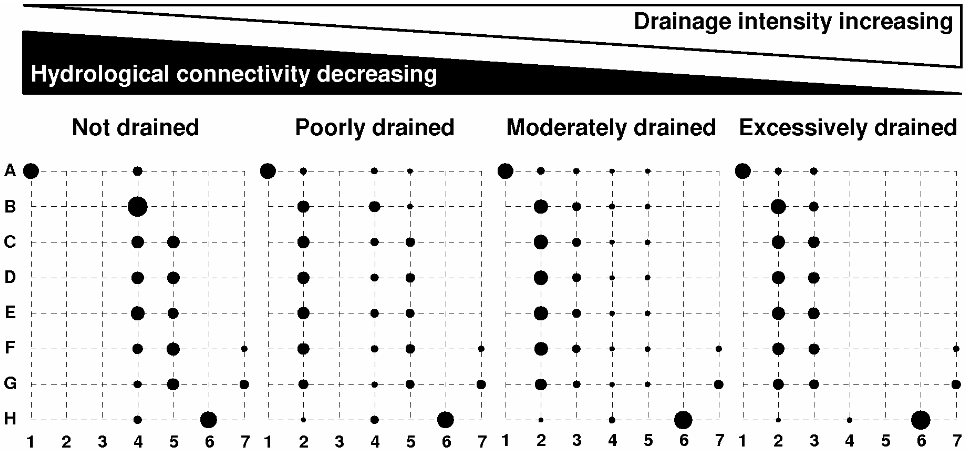

Figure 2: Changes of the water exchange pattern of a percolation peatland with increasing drainage intensity. For explanation of inflow pathways (letters) and outflow pathways (numbers) see Table 1.

Parallel to the water partitioning matrix a nitrogen transformation matrix is calculated (Trepel & Kluge 2004). The final model results are values for nitrogen input to the system, nitrogen output from the system, nitrogen retention in the system and nitrogen retention efficiency of the system. Additionally, nitrogen retention and retention efficiency is calculated for three subsystems: The vertical subsystem represents effects of water management, land use and mineralization on nitrogen outflow and harvest, the lateral subsystems represents effects of water management on nitrogen retention from lateral inflow pathways, and the longitudinal subsystem represents nitrogen retention via flooding.

Table 2: Changes of nitrogen input and nitrogen outflow of a percolation peatland with increasing drainage intensity. The water exchange pattern for the modelled situations is displayed in Figure 2.

Indicator		not drained	poorly drained	moderately drained	excessively drained
Flooding index	-	0.25	0.25	0.12	0.04
Vertical N input	t N yr^{-1}	4.6	13.8	51.9	70.4
Total N outflow	t N yr^{-1}	240.8	260.4	328.0	346.7
Total N retention	t N yr^{-1}	61.9	51.5	22.0	21.7
Lateral N retention	t N yr^{-1}	27.6	20.2	8.6	6.1
Longitudinal N retention	t N yr^{-1}	31.5	25.3	7.4	7.4

EFFECT OF WATER MANAGEMENT AND LAND USE ON NITROGEN OUTFLOW

Figure 3 summarizes the effect of water management and land use on nitrogen outflow from a percolation peatland. Increasing drainage intensity is often combined with increased land use intensity. Both aspects affect the nitrogen outflow from the whole system as well as nitrogen outflow from the three subsystems. The difference between the four system states can be best visualized with an amoeba diagram, where all values of the potential natural status are transformed to 1 and changes of the parameters from the other scenarios are calculated against this value. The untransformed values are given in Table 2.

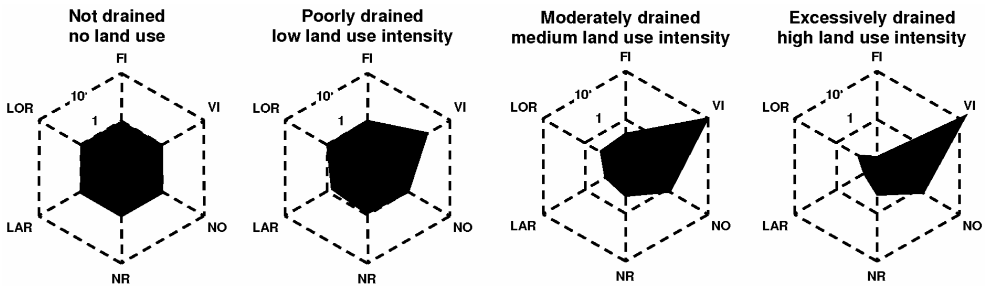

Figure 3: Changes of nitrogen outflow from a percolation peatland with increasing drainage intensity. Note the scale of the amoeba diagram is logarithmic. Changes are calculated against the most natural state (not drained and no land use). FI = Flooding index; VI = vertical nitrogen input (mineralization, fertilizer and deposition); NO = total nitrogen output from the system; NR = total nitrogen retention in the system; LAR = lateral nitrogen retention; LOR = longitudinal (flooding) nitrogen retention. The untransformed values for the diagram are given in Table 2.

Flooding index (FI) and vertical nitrogen input (VI) are indicators for the system itself. Under natural conditions, the system has a flooding index of 0.25 and receives a vertical input of 4.6 t N yr^{-1} (mineralization and atmospheric deposition). Flooding decreases first when the system is moderately drained, the vertical input increases immediately when the system is drained and fertilized. Nitrogen outflow (NO) and nitrogen retention are indicators for the reaction of the system as a whole. Nitrogen outflow increases slower as nitrogen retention decreases. This reaction is caused by the basin position of the peatland. In this example, a major nitrogen inflow is coming from the upstream basin of the peatland. Nitrogen retention of the system decreases considerably with increasing drainage intensity and land use intensity. Lateral retention (LAR) and longitudinal retention (LOR) are indicators for the reaction of these subsystems on water management and land use changes. The amount of lateral nitrogen retention decreases when the system is drained by ditches and drains. These outflow pathways have lower nitrogen transformation potentials as the natural outflow pathways overland flow and subsurface flow (compare Table 1 and Figure 2).

The amoeba diagrams indicate how far the drained systems have mowed away from the not drained status.

DISCUSSION

Selection of sites and measures are crucial for an effective implementation of any environmental programme aiming to improve the environmental conditions. In practice, both aspects are often limited by the amount of knowledge within the implementation body about the complex interactions between water, nutrients and biota on different spatio-temporal scales. Decision support systems transform the available knowledge required for a solution of a problem into a user-friendly frame with reduced data input (Bunnell & Boyland 2003). The development of such tools is an important scientific contribution to make the increasing detailed scientific knowledge about environmental processes applicable for the solution of current environmental problems. The WETTRANS DSS is an example for a decision support system for quantification of nitrogen retention in peatlands. In the WETTRANS model, groundwater and surface water hydrology of peatlands are connected with a flow-path, mass budget approach. This approach allows a calculation of nitrogen retention in a peatland based on peatland stratigraphy, hydrological position, water management and land use inside the peatland. The model results give a detailed, site-specific picture of the water and nitrogen exchange pattern and its reaction on land use and water management changes. These data are urgently needed for an informed selection of sites and measures during the implementation of wise use on peatlands.

Acknowledgements

The development of the DSS was funded by the State Agency for the Environment of Schleswig-Holstein, Dep. Water Management. The web version of the DSS is programmed by Frank Bartels.

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