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A comprehensive study of nutrient losses, soil properties and groundwater concentrations in a degraded peatland used as an intensive meadow — Implications for re-wetting

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Summary Most of the once ecologically valuable and widespread peatlands in Western Europe as well as in Mecklenburg-Vorpommern (North-Eastern Germany) have been drained in the course of the intensification of agricultural land use. Peat degradation and mineralisation frequently caused high nitrate–nitrogen (NO_3^-–N) losses, while re-wetting may lead to elevated phosphorus concentrations in the porewater. High concentrations of NO_3^-–N and other solutes in a ditch draining a catchment (85 ha) dominated by degraded peatland under intensive grassland use gave reason to investigate the relationship between the spatial and temporal variability of the shallow groundwater quality on the one hand and soil properties, topography and hydrological dynamics on the other hand. Therefore, in addition to the ditch, three transects of dipwells were sampled and soil samples were taken along the transects at a high spatial resolution. Soil organic carbon C_{org} and total nitrogen N_t contents varied considerably from 0.8% to 40.9% and 0.08% to 2.87%, respectively. A trend surface analysis (TSA) of these soil properties showed a strong trend depending on the ground elevation and the distance to the adjacent drainage ditch, reflecting both a transition from mineral to organic soils and differences in peat formation and degradation connected to the topography and, consequently, to the depth to the groundwater table. Semivariogram analysis was performed using the normally distributed residuals of the TSA and showed for each transect a strong spatial dependence and short (5–26 m) ranges. If possible, soil sampling in peatlands should be conducted at short distance sampling intervals. The patterns of groundwater solute concentrations were

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complex. They were spatially and temporally very variable between as well as within the transects, thus proving that a few groundwater samples are insufficient for a representative characterisation of the peatland status and for an evaluation of possible environmental impacts or potential consequences of re-wetting. Groundwater concentrations ranged from 0 to 65.4 mg l^{-1} NO_3^-–N and 0–1.95 mg l^{-1} P_t, while during the same period, ditch water concentrations of 0–15.9 mg l^{-1} NO_3^-–N and 0.05 to 0.44 mg l^{-1} P_t, respectively, were measured. Factor analysis of groundwater concentrations, topographical data, hydrological conditions and soil properties led to the identification of five factors explaining up to 80% of the observed variance of the data: (i) topography and soil chemical properties, (ii) biogeochemical processes, (iii) drainage effects, (iv) climatic effects and (v) dilution effects.

Introduction

Worldwide, peatlands are not only a major store of carbon (C) and nitrogen (N), but also frequently a resource of high ecological, historical, recreational and/or agricultural value (Mitch and Gosselink, 2000). Covering around 13% of its area, peatlands are typical of the federal state of Mecklenburg-Vorpommern in North-Eastern Germany (Lenschow and Thiel, 2000). However, these extensive peatlands have been drained and 'improved' like most of the fenlands and bogs throughout Europe, causing soil degradation (Schwärzel et al., 2002; Zeitz and Velty, 2002), loss of vegetation (Wheeler et al., 1995), greenhouse gas emission (Flessa et al., 1998; Nykänen et al., 1995; Renger et al., 2002) and the release of nitrate (Hacin et al., 2001; Martin et al., 1997) and other solutes (Sallantaus, 1993).

High nitrate (NO_3^-) concentrations in the porewater of drained peatlands are caused by aeration of the peat and subsequent mineralisation and nitrification of organic nitrogen (Holden et al., 2004; Olde Venterink et al., 2002; Willison et al., 1998). These processes will be particularly intensive in the case of low groundwater levels (Martin et al., 1997) and of high amplitudes of the groundwater level fluctuations, which is typical of degraded peatlands due to the altered hydraulic properties of the peat (Price et al., 2003; Tiemeyer et al., 2006a). Nitrogen supply by fertilisation or atmospheric deposition further aggravates mineralisation (Verhoeven et al., 1996; Willison et al., 1998). In heavily drained peatlands under intensive grassland use, net N mineralisation rates of 360 kg N ha^{-1} a^{-1} have been measured (Okruszko, 1989), leading to N losses of up to 135 kg NO_3^-–N ha^{-1} a^{-1} (Behrendt et al., 1996). In the case of phosphorus (P), in contrast, aeration causes the mineralisation of organic P compounds, which are then frequently sorbed to Fe(III)-hydroxides and thus become temporarily immobilised (Zak et al., 2004). However, many of these studies have not been conducted on the field or catchment scale, but on the scale of lysimeters (Behrendt et al., 1996) or soil cores (Martin et al., 1997; Olde Venterink et al., 2002; Willison et al., 1998).

During the last decade, there have been several projects aimed at reinstating and saving at least parts of the peatland ecosystems (Lenschow and Thiel, 2000; Pfadenhauer and Grootjans, 1999; Wheeler et al., 1995). The effects of re-wetting on the nutrient status are twofold: Firstly, depending on the groundwater level and the availability of NO_3^- and easily decomposable organic carbon, high denitrification rates may be achieved (e.g. Davidsson et al., 2002; Gensior and Zeitz, 1999; Koops et al., 1996). However, although the re-wetting of dried soil cores strongly stimulated denitrification, Olde Venterink et al. (2002) and Van Dijk et al. (2004) reported that N mineralisation was sometimes not significantly decreased. Secondly, at the same time, the anaerobic soil conditions and low redox potentials may cause a reduction of Fe(III)-compounds and therefore an enhancement of the mobilisation of P from peat soils (Olde Venterink et al., 2002). Furthermore, the release of Fe-bound P is accelerated by increased sulphate (SO_4^{2-}) reduction rates, while NO_3^-, which is an energetically more favourable electron acceptor than SO_4^{2-}, may function as a redox buffer and therefore reduce the P mobilisation (Lucassen et al., 2004). Depending on the redox status and the solute composition, elevated P concentrations may thus be found in the porewater of re-wetted peatlands (Gelbrecht and Lengsfeld, 1998; Kalbitz et al., 1999; Rupp et al., 2004). In any case, artificially drained or re-wetted, the risk of surface water pollution by elevated solute concentrations in the porewater depends on the hydrological conditions of the area, since the hydrology of wetlands is not only recognised as the key feature for the assessment of methods and success of re-wetting, but also as the basis for studies on solute movement (Balla and Gensior, 2000; Price et al., 2003).

Although the overall effect of artificial peatland drainage on nitrate losses is well known, the spatial-temporal development of the NO_3^- (and other solute) concentrations within the porewater or the shallow groundwater of a peatland has rarely been studied in combination with the measurement of actual losses (Holden et al., 2004). To assess how representative point measurements (e.g. by suction cups or dipwells) can be, how they relate to the water quality of adjacent water bodies and whether they may be useful for predicting possible environmental impacts downstream, the spatial variability needs to be determined. For example, the microtopography is well known to affect the vegetation development in peatlands (e.g. Meade, 1992; Roy et al., 2000). However, the influence of the topography, the soil properties or the groundwater level on the water quality have usually not been investigated in their spatial distribution. Furthermore, if re-wetting might be a future option, knowing the relationship between water quality and variability of e.g. the groundwater level or the soil physical