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Long-term behavior of groundwater chemistry in a periodically rewetted fen area covered with macrophytes

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ABSTRACT

We studied the long-term changes in groundwater composition in the context of peat restoration at a degraded water-table managed peatland site typical for many agriculturally used fen areas in the northern hemisphere. At the study site, peatland rewetting with groundwater control and pumped canal water was carried out in two periods: from 1997 to 2002 and from 2011 to 2013. The site was not managed between 2002 and 2011, which led to an unstable groundwater table that had declined in part. The aim of this study was to investigate the consequences of rewetting and desiccation on groundwater chemistry. We pursued a multivariate approach using nonlinear principal component analysis (Isomap) to identify the prevailing processes that control the groundwater quality in this system.

Sixteen years after peatland restoration, the groundwater quality had significantly improved. Principal component analysis revealed that hydrological processes had a major impact on groundwater quality, i.e. fluctuations between upwelling of local, salt-influenced groundwater and downwelling of surface and rainwater (first principal component) as well as upwelling of regional groundwater from deeper layers (second principal component) which originated from the catchment. In particular, the upwelling of regional deep groundwater had a strong positive impact on the groundwater quality of upper layers at the Biesenbrow site. Another major impact on groundwater quality was nutrient withdrawal by macrophytes and incorporation into organic matter. In the upper groundwater layer, peat mineralization processes resulted in substantially increased SO_4 concentrations.

We concluded that potential matter release after rewetting is buffered by hydrological barriers, and seems to be marginal with little impact on adjacent environments in the long term. The ecosystem is sustainably stabilized, and therefore has no negative impact on groundwater quality during periods of water shortage. Due to the strong influence of regional groundwater, management measures in the catchment are very important for maintaining and improving groundwater quality in peatlands.

1. Introduction

Over the last century, the period of intensive peat land use led to a major loss of growing peat area. In Europe, from Iceland to the European part of Russia, more than 60% of intact peatland has disappeared; in Western Europe, including Germany, about 99% has been lost (Joosten and Couwenberg, 2001; Joosten and Clarke, 2003). Approximately 80% of the peat soils in the United States are highly decomposed (Malterer, 1997).

A wide range of peatland rewetting projects have been established following the initiation of a broad discussion concerning the nature conservation of peatlands in Europe (Lamers et al., 2002), and especially in Germany (Pfadenhauer and Klötzli, 1996), rewetting for peat accumulation and peat-building production (Succow, 1996), followed by the global debate on the effects of climate change and the role peatlands play in carbon sequestering and greenhouse gas production (Dunn and Freeman, 2011). Hydrological conditions permitting, rewetting seems to be the best way of achieving maximum environmental, societal, and economic

Abbreviations: An-N, inorganic nitrogen; c, concentration; CWB, climatic water balance; DGW, depth to groundwater; DIC, dissolved inorganic carbon; DOC, dissolved organic carbon; EC, electric conductivity; ET_p, grass reference evapotranspiration; ET_a, actual evapotranspiration; PC, principal component; P_{corr}, corrected precipitation; SAC, spectral absorption coefficient; SRP, soluble reactive phosphorus.

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benefit for peatlands (Verhagen et al., 2009; Wichtmann and Wichmann, 2011).

One main research focus of German rewetting projects, most of which were introduced post-1991, is water availability for rewetting depending on the climatic gradient. In western regions of Germany, precipitation exceeding evapotranspiration combined with a blocking of artificial peatland drainage devices usually produces higher groundwater tables. In contrast, the same management measures in northeast Germany lead to a continued water deficit of 100–150 mm in the summer months. As a consequence, peatland rewetting is dependent on additional water supplies from the catchment, especially during the dry summer months (Dietrich et al., 2001). This requirement has made it more expensive to maintain and manage water via groundwater control, e.g. using weirs for sub-irrigation or pipelines for water distribution above the peat surface. Another main research topic is the investigation of matter accumulation in rewetted, newly growing peat areas and their related sink function (e.g. for organic carbon). Studies in fens (Maassen and Balla, 2010; Maassen et al., 2012) and bogs (Glatzel et al., 2006) have shown that maintaining a water-table close to the surface is the key prerequisite for safeguarding the successful development of restored peatlands.

This study focuses on assessing the long-term changes of groundwater composition in the context of peat restoration. The study was carried out at an 8-hectare rewetted pilot site close to the village of Biesenbrow in Germany, which reflects typical conditions for decomposed water-table controlled peatlands for temperate climate conditions. The pilot site was established in 1996 and is mainly covered by the macrophyte *Phragmites australis*. Controlled peatland rewetting with high water-tables in summer was carried out until 2002. No surplus water from the catchment was added to the site between 2002 and 2011, which led to unstable groundwater tables, some of which had declined depending on the climatic water balance. Groundwater control and water surplus with an elevated groundwater table in summer was reactivated between 2011 and 2013.

We used this study site to fill a knowledge gap in the long-term dynamics of the groundwater chemistry of an unused reed field, enabling us to determine the consequences for the sink function if water control in a rewetted peatland is partly disturbed and the water-table fluctuates.

2. Material and methods

2.1. Study site description

The pilot site is situated in the northern part of the Federal State of Brandenburg/Germany. It is located in the Randow–Welse valley (53°06′N, 14°01′E) which covers 2800 ha of fen peatland (Fig. 1a and b). The elevation of the valley ranges from 22 to 11 m a.s.l. declining to northeast. The whole fen peatland is highly degraded (Gensior and Zeitz, 1999). The river valley has a continental climatic influence – an excess of the mean annual evapotranspiration (657 mm) over the annual precipitation (547 mm, 1951–1980, DVWK, 1996).

Before rewetting started in 1997, the area was intensively used for corn production until 1977 and then for 18 years as grassland (two harvests per year) until 1995. As a consequence, despite the installation of sub-irrigation/controlled drainage facilities, water levels fell to 120 cm below the surface in summer due to evapotranspiration and artificial subsurface drainage involving drain pipes and collectors. Desiccation and intensive land use led to significant degradation of the upper peat layer. The 8-hectare pilot site is situated in the center of the valley, surrounded by areas of land now used for suckler cow husbandry and grassland.

The fen peat cover has a mean thickness of 60 cm and a maximum thickness of up to 120 cm. Land use and drainage caused peat consolidation, subsidence, shrinkage, and the mineralization of organic matter, leading to the formation of several organic soil horizons. This was mainly caused by the fluctuation of groundwater due to past water management for agricultural land use.

2.2. Hydrological conditions and rewetting history

Reed (*Phragmites australis*) and sedges (*Carex gracilis*) were planted in 1996 and early 1997 in order to regenerate peat-forming vegetation. To achieve rewetting, the water levels of surrounding ditches were permanently raised by weirs, and water from the main canal was pumped into surface water storage reservoirs (Fig. 1b). The site was rewetted for peat accumulation, carbon sequestration, and water quality improvement from 1997 to 2002 (period A). Surface water flowed via several pipelines across the pilot site during the vegetation period from April to October (Fig. 1b). Thus,

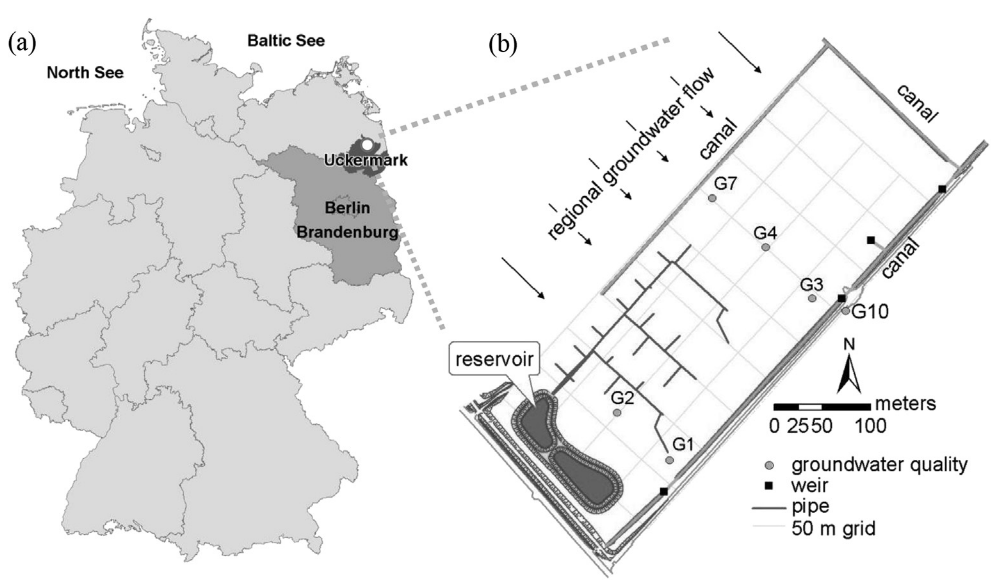

Fig. 1. (a) Location of Biesenbrow pilot site; (b) water distribution system with monitoring/sampling design and grids with different clones of *Phragmites australis*.