Impact of climate change on the water balance of fen wetlands in the Elbe Lowland

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Summary

The purpose was to determine the impact of climate change on the water balance of fen wetlands in the Elbe Lowland in Germany. Climate models forecast decreasing summer precipitation and increasing potential evapotranspiration for this region. The results of a water balance model show increasing water use conflicts in the Elbe Lowland in future with the consequence of lower ground water levels in the wetlands. This risk will increase especially in dry years. Water management options, such as improvement of the water storage capacity within the wetlands, can help to reduce the impact but not wholly compensate it.

Key index words: climate change, fen wetlands, water balance model, water balance

Introduction

Most of the German Elbe Lowland is situated in a climatic region with a mean annual precipitation between 500 and 600 mm. Nevertheless, the lowland is rich in fens which are often associated with groundwater-influenced sandy soils (denoted in this paper by 'wetlands'). Today, these areas are mainly used as extensive grassland. A precondition for the agricultural use of wetland sites in times with water surplus is artificial drainage. This has been practised for more than two hundred years. Because of low precipitation, the fens are strained by a climatic water balance deficit during summer months. They depend on recharge from their basins to meet the high water demand over the vegetation period. Often the water supply is insufficient to compensate the climatic water deficit or the supply does not reach all parts of a wetland. One consequence is that ground water levels fall deep below the surface. For this reason, complex sub-irrigation systems were developed to regulate the water budget of wetlands, often also including the water resources management of the entire basin. So the water balance of fen wetlands is not a natural one today, especially that of large sites in the Elbe basin; it is strongly influenced by water resources management systems and strategies.

The last decade, with dry summers and hot temperatures, showed an increasing risk of droughts in parts of the Elbe basin. Results of climate scenarios suggest an additional threat from increasing temperatures and decreasing precipitation in summer months over the next decades in north-east Germany (Gerstengarbe and Werner, 2005). The example of the Spreewald wetland, situated between Berlin and Cottbus, showed that, on the one hand, wetland areas will increasingly demand for water, but on the other hand, water supply to the Spreewald wetland from its basin will decrease in future (Dietrich *et al.*, 2007a, 2007c). With reference to the impact of climate change on the wetlands water balance in the Elbe Lowland, a lot of questions are interesting, for example:

- Are water balance results of the Spreewald wetland typical for wetlands in the whole Elbe basin?
- Are there regional differences within the basin in dependence on the special situation of each wetland and sub-basin?
- To what extent are wetlands in the Elbe Lowland vulnerable to climate change?
- Are there appropriate water management options to reduce negative impacts?

Within the GLOWA-Elbe research project (www.glowa-elbe.de), scenario investigations based on a water balance model were used to answer these questions. By means of the model, the impact of climate change on the water balance of wetlands in the Elbe Lowland was investigated, and the potential of water resources management options to reduce the vulnerability of wetland sites against drought was evaluated.

Material and methods

In the German Elbe Lowland, many areas are influenced by ground water, but not all were integrated into the GLOWA-Elbe research project. The model-based investigations carried out in the project cover the water balance of the Elbe basin as a whole (148,000 km²). Only wetlands with a size above 1,000 ha and with active water management systems were considered. In a first step the relevant sites were identified. Digital soil, land use and elevation maps, made available by the federal states, provided the basis for this identification. Eventually, 35 wetlands comprising an area of 3,840 km² were integrated into the water balance model (Fig. 1). Examination of soil maps showed around 50 % of the wetland sites to be dominated by groundwater-influenced sandy soils and 35 % by deep and shallow peat.

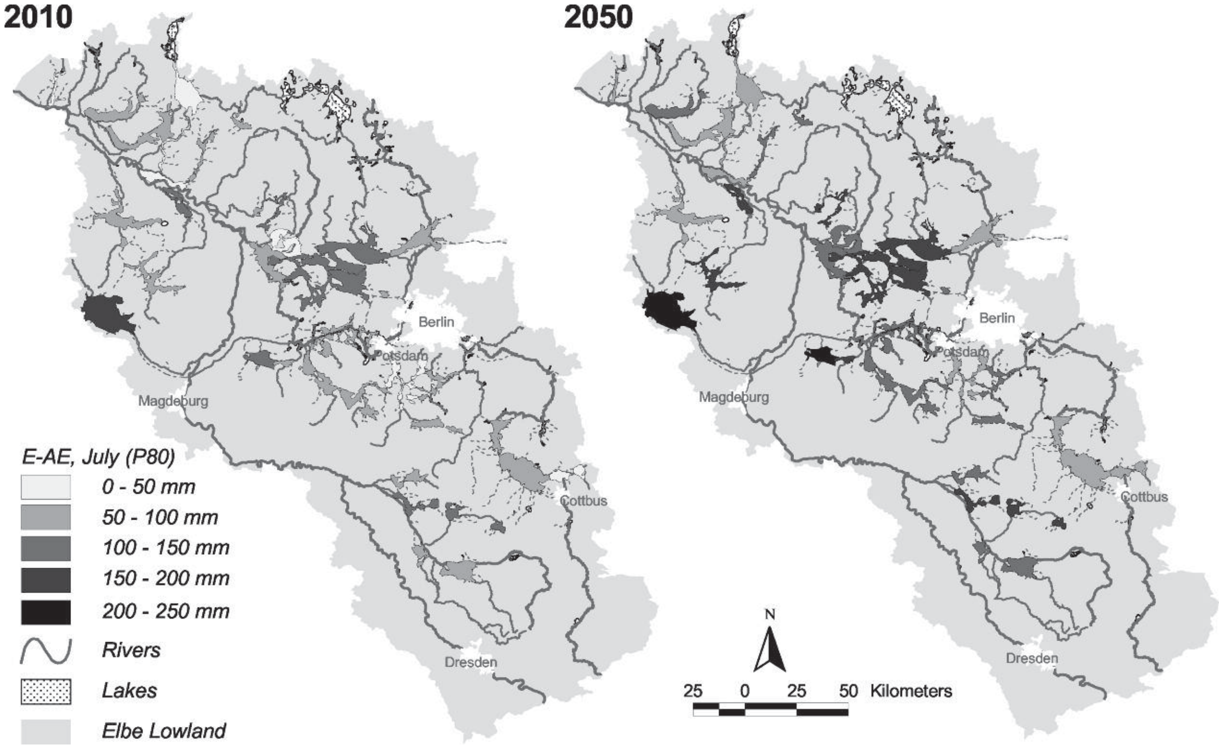

Figure 1. Location of the considered wetlands within the Elbe Lowland and progress of the water deficit indicator in dry years 2010 and 2050 (P80 - 80th percentile)

The main land use is grassland farming (54 %). Fields (34 %) are primarily found on sandy soils.

The WBalMo® model system (WASY, 2006) served as the basis for the Elbe basin water balance investigation. This system simulates both hydrological processes and the water management in a river basin. River basins are represented by simulation sub-basins, running waters, balance profiles, water users and reservoirs. Input variables are time series either calculated by precipitation runoff models or stochastically generated. Water utilization processes are reproduced deterministically. The time step is one month. An especially programmed module was integrated into WBalMo: WABI for calculation of the water balance of groundwater-influenced areas with drainage and sub-irrigation systems. To use this module, each wetland was divided into sub-areas, the smallest where the ground water level can be regulated separately. One important assumption of the WABI module is a horizontal groundwater surface in each sub-area. The module requires a target water level for each sub-area, and information about the distributions of elevation values, land use and soil types, as well as a storativity function extended for open water conditions. A detailed description of the basic models, the WABI module integration into the WBalMo system and the model tests on the example of the Spreewald wetland is given in Dietrich *et al.* (2007b). In this paper, the model for the Elbe River basin is denoted by WBalMo GLOWA Elbe.

In the GLOWA-Elbe research project scenarios were defined as combinations of boundary conditions and water resources management options. Project partners prepared the climatic input data by using the regional climate model STAR (Werner and Gerstengarbe, 1997) based on results of the GCM ECHAM5 (Roeckner *et al.*, 2003) for the SRES scenarios A1 and B2, and the discharge of the sub-basins by using the precipitation runoff model SWIM (Krysanova *et al.*, 1998). Input series were made available for each month from 2003 to 2052 with 100 realizations of every year (Monte Carlo Simulation). The water resources management assumed in WBalMo GLOWA Elbe represents the current practice in the sub-basins and wetlands. We will discuss only results of the B2 scenario, because the difference between both scenarios (A1 and B2) is negligible in terms of the wetland water balance in the Elbe Lowland. Scenario B2 is named *basis scenario*. There are different water management options within the wetland or in its basin to reduce the impact of climate change on the wetlands water balance (Dietrich *et al.*, 2007a). One possibility is to increase the water storage capacity of a wetland by increasing the target water levels. We analysed a scenario with less intensive grassland use on all fen sites of our wetlands. The target water levels will be raised, especially in winter months, and the drop down of the target water levels due to activated drainage will start later in spring. This is the *extensive scenario*.

Results and discussion

Model results were statistically evaluated for each 5-year period of the 50 years between 2003 and 2052. In the following we will discuss and compare results of the period 2008-12 (named 2010) with the latest period 2048-52 (named 2050). The change in the wetland water balance will be demonstrated using large-scale comparisons of selected water balance parameters for July. July is a typical dry month associated with big water use conflicts in the sub-basins of the Elbe Lowland. There are manifold indicators for the analysis of changes in the wetlands' water balance, such as evapotranspiration, water demand, water withdrawal, water deficit, and occurrence of water-use conflicts or the development of ground water levels. In this paper we want to demonstrate increasing problems associated with the water deficit and the development of the ground water levels below surface.

The water deficit (E-AE) is the difference between water demand and actual water withdrawal of all sub-areas of a wetland within a time step (here for July). The water demand depends on the precipitation, the actual evapotranspiration in the current month, and in circumstances on a deficit in water storage inherited from the preceding time step or from raising the target water level in the current month. Water withdrawal in the calculation depends on the water demand, as well as the useable water inflow into the wetland.

Fig. 1 displays the water deficit for each modelled wetland in comparison of dry years of 2010 and 2050 (80th percentile) in the *basis scenario*. In all wetlands water deficits occur already in the dry years of 2010. In 2010, the largest water deficits develop in wetlands with small basin areas in relation to their own area. The wetlands in the Havel River basin north-west of Berlin are typical examples. Conflicts will increase in all those wetlands up to 2050 even though with regional differences. For the Lower Havel region the climate model calculated the most distinct decrease in summer precipitation (-40 mm) and increase in summer potential evapotranspiration (+70 mm). This region, already characterised by water scarcity problems during summer months today, will expect even larger water deficits in 2050. Another example is the Drömling fen region north-west of Magdeburg. It experiences the biggest water deficit (150-200 mm) already in 2010 and will also in 2050. The reasons are the small basin area in relation to the wetland area (relation of nearly 1:1) and an exceptionally large water withdrawal for irrigation in the basin upstream the wetland.

The increasing water deficits will result in an increasing undershooting of the targets by water levels in the sub-areas. This is clearly shown by the undershooting frequency curves for all modelled wetland areas of the *basis scenario* in July 2010 and 2050 (Fig. 2). Even in mean climatic years in 2010 (50th percentile), the target levels are met by the ground water levels only for 30 % of the whole area. For 90 % the difference between both is smaller than 2 dm. In dry years 2010 (80th percentile) for less than 10 % of the area the target water levels would be met. This is nearly the same in mean years in 2050. The situation proves especially critical in dry years under changed climatic conditions (2050, 80th percentile). The target water levels will be undershot at 95 % of the wetland areas, at 40 % by more than 6 dm. This result underlines the increasing problems anticipated on wetland sites especially in dry years of the next decades.

Improving water storage in periods of water surplus can help to reduce the impact of changing climate conditions in the future (*extensive scenario*). Fig. 3 shows increasing the target water levels and its impact on ground water levels for July of 2050. But we see also that the increase of ground water levels is smaller than the increase of target water levels. Especially in dry years, ground water levels fall deep below the target water levels, despite improved water storage in the wetlands. Some of the modelled areas have targets and water levels in July (> 15 dm below ground surface) which are not typical for wetlands. Reasons are the model assumption of a horizontal ground water surface, parts within the wetland areas with higher elevation that are not excluded, and furthermore, imprecision of the DEMs used. However, the impact of these latter factors on the principal model results can be ignored.

Conclusion

New large-scale modelling results underline the former results of the Spreewald wetland (Dietrich *et al.*, 2007a). The water balance problems of north-east German wetlands will increase over the next decades provided the climate will develop as forecasted by climate models. But the results also indicate differences in the impact of climate change within the Elbe Lowland. There are some regions clearly more

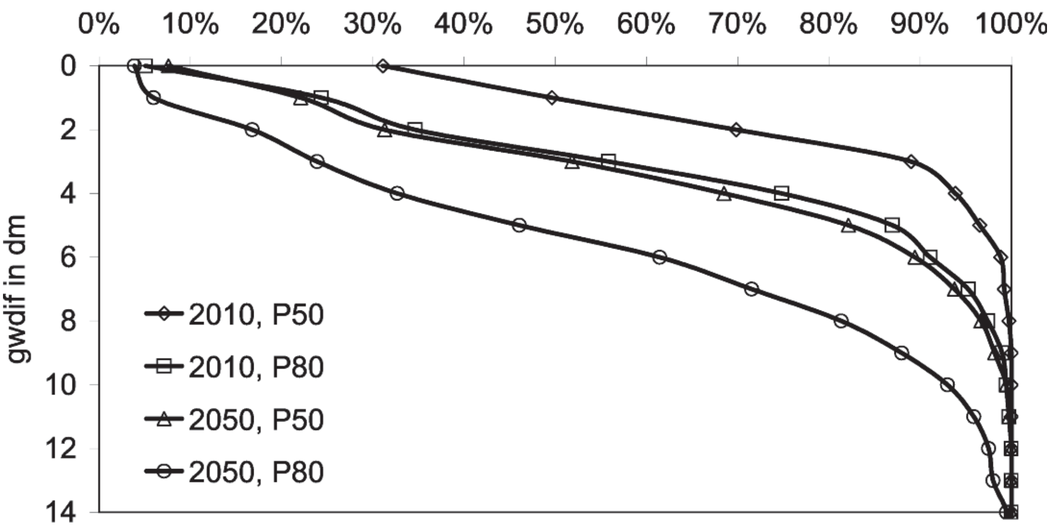

Figure 2. Frequency curve of the difference between target water levels and ground water levels (gwdif) for all modelled wetland areas in 2010 and 2050 (*basis scenario*, P50 - 50th percentile, P80 - 80th percentile)

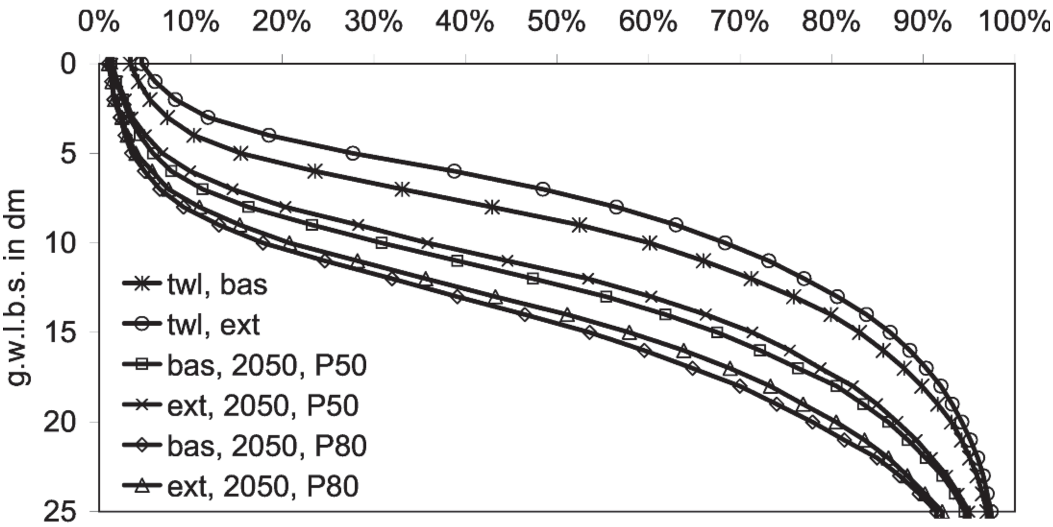

Figure 3. Impact of improved water storage on the ground water levels below surface (g.w.l.b.s) of the fen sites in mean and dry years in 2050 (twl – target water level, bas - *basis scenario*, ext - *extensive scenario*, P50 - 50th percentile, P80 - 80th percentile)

affected. These are mostly the regions where we face a lot of problems already today. The investigated water management option can help to reduce the impact, but especially in dry summers it is not sufficient to compensate the climatic water balance deficit. More effective measures will be necessary to preserve the fen wetlands in the Elbe Lowland for the future.

Acknowledgements

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