Expected changes in water resources availability and water quality with respect to climate change in the Elbe River basin (Germany)*

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Abstract Reliable modelling of climate–water interactions at the river basin and regional scale requires development of advanced modelling approaches at scales relevant for assessing the potential effects of climate change on the hydrological cycle. These approaches should represent the atmospheric, surface and subsurface hydrological processes and take into account their characteristic temporal and spatial scales of occurrence. The paper presents a climate change impact assessment performed for the Elbe River basin in Germany (about 100 000 km²). The method used for the study combines:

(a) a statistical downscaling method driven by GCM-predicted temperature trend for producing climate scenarios, and

(b) a simulation technique based on an ecohydrological semi-distributed river basin model, which was thoroughly validated in advance.

The overall result of the climate impact study for the basin is that the mean water discharge and the mean groundwater recharge in the Elbe basin will be most likely decreased under the expected climate change and diffuse source pollution will be diminished. Our study confirms that the uncertainty in hydrological and water quality responses to changing climate is generally higher than the uncertainty in climate input. The method is transferable to other basins in the temperate zone.

Keywords Climate change; ecohydrological model; river basin modelling; water availability; water quality; the Elbe river

Introduction There have been numerous studies of the potential impact of climate change on water resources and agriculture at the regional scale over the last decade. They are reported and reviewed by the Intergovernmental Panel on Climate Change (IPCC) (Watson et al. 1998; McCarthy et al. 2001) and elsewhere (Arnell 1998, 1999; Reilly and Schimmelpfennig 1999; Krysanova et al. 1999; Krysanova and Wechsung 2002). However, in most studies climate change impact was investigated for the hydrological regime and agriculture separately, using different tools, whereas the water quality aspect got much less consideration.

Nutrient wash-off to surface waters and leaching to groundwater in rural agrolandscapes is usually classified as one of the most important diffuse source pollution types. Moreover, it represents one of the most significant sources of water pollution in Europe in general. Therefore, understanding the factors influencing losses of nutrients from soils, their transport to the river network and their transformation in streamflow is very important. However, evaluation of climate change impacts on water quality in river basins is much more difficult
than on water quantity, because it requires more input information and more comprehensive tools. Probably this is why publications on this subject are very scarce.

Only a small chapter, giving an overview of recent publications related to climate change and water quality, is included in the IPCC report in 1998 (Watson et al. 1998). This overview is focused mostly on lake and river temperatures and the corresponding effects. The latest IPCC report about this topic is very concise as well (McCarthy et al. 2001).

Several studies indicated that changes in stream water quality in terms of nutrient transport and nutrient loads are very dependent on changes in streamflow: increased streamflow would lead to increased nutrient loading from diffuse sources (Alexander et al. 1996; Frisk et al. 1997; Kallio et al. 1997; Hanratty and Stefan 1998).

A more extended study of the expected changes in water quality in Britain under changing climatic conditions was done by Arnell (1998), who outlined five major factors affecting streamwater quality under a changing climate: (1) higher water temperature, (2) changed flow volumes (altering residence time and dilution), (3) changed rate of CO₂ dissolution in water, (4) change in soil properties, and (5) changes in the input of chemicals to the catchment. The last two factors can be hardly related to climate change, at least in the shortest time perspective. The first three factors are focused mainly on processes in streams, whereas the direct effect of changing climate and changing water flux intensity on the generation of diffuse pollution in catchments was not considered, though it certainly deserves attention.

Murdoch et al. (2000) reviewed the impact of climate change on water quality in North America, considering the effects of an increase in temperature and a decrease in water inflow (additional evapotranspiration exceeds increase in precipitation). The potential impacts relevant for the Great Lakes are summarised in the Report of the Great Lakes Water Quality Board to the International Joint Commission (Climate Change and Water Quality in the Great Lakes Basin 2003).

One of the major challenges for current research in the framework of the IPCC is the adequate description and modelling of the complex interactions between climate, hydrological and ecological processes at different scales. The ecohydrological model SWIM (Krysanova et al. 1998, 2000) has been developed as a tool to serve this purpose in mesoscale and large river basins and at the regional scale. This paper aims to demonstrate the ability of SWIM to investigate the potential effects due to climate change in major components of the hydrological cycle and the generation of diffuse pollution at the regional scale.

**Materials and methods**

**Modelling tool**

The modelling system SWIM (Soil and Water Integrated Model) is a continuous-time spatially semi-distributed model, integrating hydrological processes, vegetation growth (agricultural crops and natural vegetation), nutrient cycling (carbon, C, nitrogen, N and phosphorus, P) and sediment transport at the river basin scale (see a full description of the model in Krysanova et al. (2000)). SWIM is based on two previously developed tools – SWAT (Arnold et al. 1993), and MATSALU (Krysanova et al. 1989), and serves mainly for climate and land use change impact studies in mesoscale and large river basins and at the regional scale.

In addition, the modelling system SWIM includes the interface to the Geographic Information System GRASS (Geographic Resources Analysis Support System, GRASS4.1, 1993), which allows us to extract spatially distributed parameters of elevation, land use, soil and vegetation, and to create automatically the hydrotope structure and the routing structure for the basin under study. A three-level scheme of spatial disaggregation “basin–subbasins–hydrotopes” or “region–climate zones–hydrotopes” and a vertical subdivision of the soil...
root zone into a maximum of 10 soil layers in accordance with the soil database are used in SWIM. A hydrotope is a set of elementary units in a subbasin or climate zone, which have the same land use and soil.

The simulated hydrological system (Figure 1) consists of four control volumes: the soil surface, the root zone of the soil, the shallow aquifer and the deep aquifer. The soil root zone is subdivided into several layers in accordance with the soil database. The water balance for the soil surface and soil column includes precipitation, surface runoff, evapotranspiration, subsurface runoff and percolation. The water balance for the shallow aquifer includes groundwater recharge, capillary rise to the soil profile, groundwater contribution to the river flow and percolation to the deep aquifer.

Surface runoff is estimated as a non-linear function of precipitation and a retention coefficient, which depends on soil water content, land use and soil type (modification of the Soil Conservation Service (SCS) curve number method (Arnold et al. 1990)). The method was adapted to German conditions by validation in seven mesoscale river basins of different sizes (all in the Elbe drainage area) and with different climatic conditions, land use and soils. Lateral subsurface flow (or interflow) is calculated simultaneously with percolation to groundwater. Interflow appears when the water storage in a soil layer exceeds the field capacity after percolation and is especially important for soils having impermeable or less permeable layers below several permeable ones. The approach is based on the mass continuity equation in the finite difference form with the entire soil profile as the control volume.

Potential evapotranspiration is estimated using the method of Priestley–Taylor (Priestley and Taylor 1972), though the method of Penman–Monteith (Monteith 1965) can also be used. Actual evaporation from soil and actual transpiration by plants are calculated separately.
The percolation from the soil profile is assumed to recharge the shallow aquifer. Return flow from the shallow aquifer contributes directly to the streamflow. The equation for return flow was derived from Smedema and Rycroft (1983), assuming that the variation in return flow is linearly related to the rate of change of the watertable height.

Three lateral flows from hydroteope to the subbasin outlet – surface runoff, subsurface runoff and groundwater flow – are considered. The Muskingum flow routing method (Maidment 1993) derived from the finite difference form of the continuity equation and the variable discharge storage equation is used to route water flows from subbasin to subbasin and to the basin outlet.

The module representing crops and natural vegetation is an important interface between hydrology and nutrients. A simplified EPIC approach (Williams et al. 1984) is included in SWIM for simulating arable crops (like wheat, barley, rye, maize and potatoes) and aggregated vegetation types (like ‘pasture’, ‘evergreen forest’ or ‘mixed forest’), using specific parameter values for each crop/vegetation type. A number of plant-related parameters are specified for 74 crop/vegetation types in the database attached to the model. Vegetation in the model affects the hydrological cycle by the cover-specific retention coefficient, impacting surface runoff and indirectly influencing the amount of transpiration, which is simulated as a function of potential evapotranspiration and leaf area index (LAI).

Interception of photosynthetic active radiation (PAR) is estimated as a function of solar radiation and leaf area index. The potential increase in biomass is the product of absorbed PAR and a specific plant parameter for converting energy into biomass. The potential biomass is adjusted daily if one of the four plant stress factors (water, temperature, nitrogen and phosphorus) is less than 1.0, using the product of a minimum stress factor and the potential biomass. The water stress factor is defined as the ratio of actual to potential plant transpiration. The temperature stress factor is computed as a function of daily average temperature, optimal and base temperatures for plant growth. The N and P stress factors are based on the ratio of accumulated N and P to their optimal values. The leaf area index is simulated as a function of a heat unit index (ranging from 0 at planting to 1 at physiological maturity) and biomass.

Sediment yield is calculated for each subbasin with the Modified Universal Soil Loss Equation (MUSLE, Williams and Berndt 1977) using the surface runoff, the peak runoff rate, the soil erodibility factor, the crop management factor, the erosion control practice factor, and the slope length and steepness factor for every hydroteope inside the subbasin. The sediment routing model consists of two components operating simultaneously – deposition and degradation in the streams. Deposition in the stream channel is based on the stream velocity in the channel, which is estimated as a function of the peak flow rate, the flow depth and the average channel width. The sediment delivery ratio through the reach is defined as a nonlinear function of the stream velocity. If the delivery ratio is less than 1, sediment deposition occurs and degradation is zero. Otherwise, the deposition is zero, and the degradation is estimated from the delivery ratio, taking into account the channel erodibility factor.

The nitrogen and phosphorus modules include the following pools in the soil layers: nitrate nitrogen, active and stable organic nitrogen, organic nitrogen in the plant residue, labile phosphorus, active and stable mineral phosphorus, organic phosphorus and phosphorus in the plant residue, and the fluxes (inflows to the soil, exchanges between the pools and outflows from the soil): fertilization, input with precipitation, mineralisation, denitrification, plant uptake, leaching to groundwater, losses with surface runoff, interflow and erosion. The amount of nitrate N and soluble P in surface runoff is estimated considering the top soil layer only. The amounts of nitrate N and soluble P in the subsurface flow and percolation are estimated as the products of the volume of water and their concentrations in the corresponding soil layers. Besides, nutrients associated with the sediment phase can be washed-off with erosion. The interaction between vegetation and nutrient supply is modelled...
by the plant uptake of nutrients, release of residuals entering the mineralisation process and by using nitrogen and phosphorus stress factors, which affect plant growth.

Case study basin

The region under study is the German part of the Elbe River basin (about 100,000 km²). This river basin can be characterized as vulnerable to water stress in dry periods. The region is located around the boundary between the relatively wet maritime climate in western Europe and the more continental climate in eastern Europe with longer dry periods, and the annual long-term average precipitation is relatively small. The long-term mean annual precipitation in the German part of the basin is 659 mm. The long-term mean discharge of the Elbe River is 716 m³ s⁻¹ at the mouth, and the specific discharge is 6.21 s⁻¹ km⁻², which corresponds to the mean annual runoff of 10.06 × 10⁹ m³, or 29.7% of the annual precipitation. Therefore the Elbe river basin is classified as the driest among the five largest river basins in Germany (Rhine, Danube, Elbe, Weser and Ems) with all the resulting potential problems and conflicts.

The region is representative of semi-humid landscapes in Europe, where water availability during the summer season is the limiting factor for plant growth and crop yield. The drainage basin is densely populated and includes two large metropolitan areas: Berlin and Hamburg. Within Europe the Elbe River basin has the second lowest water availability per capita. Due to possible changes in circulation patterns and local orographical conditions the amount of precipitation will most likely decrease in the Elbe region (Werner and Gerstengarbe 1997).

Model validation

In advance, the model was extensively validated in the Elbe River basin using the multi-scale, multi-criteria and multi-site validation method. The model validation included four major steps:

1. sensitivity analysis to define a set of the most important parameters;
2. uncertainty analysis to evaluate the model uncertainty related to input data and the most important model parameters defined in Step 1;
3. multi-scale and multi-site hydrological validation: simulated and measured water discharges are compared in the outlet and intermediate gauges in different subregions and scales;
4. multi-criterial model validation, including other model outputs, like groundwater table, evapotranspiration, crop yield, nutrient concentration and load, and erosion.

The model has proven to be able to reproduce sufficiently well the observed hydrological characteristics (river discharge, groundwater table, evapotranspiration) in meso- and large subbasins of the Elbe and in the total Elbe basin (Krysanova et al. 1998; Hattermann et al. 2002, 2004), water quality characteristics (concentrations and loads) in four mesoscale subbasins and crop yield for six major crops in the state of Brandenburg (largely overlaps with the Elbe basin) and the Elbe basin (Krysanova et al. 1999, 2004). As water quality is an important aspect of this paper, an example of model validation for nitrogen dynamics – a comparison of the simulated and observed NO₃⁻N concentrations in the Nuthe River, gauge Babelsberg – is shown in Figure 2.

Climate change scenario

Currently the resolution of General Circulation Models (GCMs) is too rough for the correct representation of hydrological cycle variations within river basins. The 10 km climate model resolution, which is not yet achieved, is a critical threshold, since at this scale the climate model outputs become comparable with the scale of hydrological cycle variations within catchments, and climate variables could be predicted without the need for downscaling.
The problem can be partly solved by applying downscaling methods to transform the GCM outputs onto the regional or river basin scale. Two main types of downscaling methods are in use: the deterministic dynamical downscaling method and the statistical downscaling method. The deterministic downscaling models are applied by nesting their grid structure into the grid structure of GCMs, whereas the outputs of GCMs are taken as boundary conditions to calculate climate input data for regional applications. This type of model is still under development.

The statistical downscaling method makes use of the correlation between the large-scale climate patterns (where the results of GCMs are relatively reliable) and their regional representation, considering the consistency in frequency distribution, annual and interannual variability and persistence of the main climate characteristics. The advantage of this method is that its results are relatively robust as long as the basic climate correlations in the observed and scenario periods do not differ. The method takes the results of GCMs as boundary and initial conditions and therefore the inherent GCM uncertainty is transferred to the regional scale as well.

The applied climate scenario was produced using the statistical downscaling method by F.-W. Gerstengarbe and P. Werner (Climate Department of the Potsdam Institute for Climate Impact Research, personal communication) from the ECHAM4-OPYC3 GCM, which was driven by the IPCC emission scenario A1. The climate change scenario is characterized by an increase in temperature by 1.4°C until 2050 and a moderate decrease in mean annual precipitation in the basin, corresponding to the observed regional climate trend with notable subregional differences. On average, a -17% decrease in average annual precipitation is expected according to this scenario for the total German part of the Elbe basin in 2046–2055 compared to the reference period 1991–2000. In accordance with this scenario, lower precipitation will be especially noticeable in the central and southern parts of the basin, whereas some increase in precipitation will be detectable in the northern part of the basin area.

A conditioned Monte Carlo simulation was implemented in the downscaling procedure, so that 100 realizations of the scenario were produced to investigate the uncertainty of the method. It allowed us to evaluate the uncertainty of climate impacts. In other words, the modelling with SWIM was used to transform the uncertainties in climate input represented by 100 realizations into hydrological responses like evapotranspiration, surface and subsurface runoff, river discharge and groundwater recharge.

Figure 2 Comparison of the simulated and observed NO₃–N concentrations in the Nuthe River, gauge Babelsberg in 1990–2001
Results and discussion

Climate change impact: water quantity

Climate change impacts were evaluated for the basins as a whole, and for major subregions of the Elbe. Expected changes in temperature and precipitation would result in respective changes in water storages and fluxes.

A comparison of typical seasonal dynamics of evapotranspiration (AET), runoff (surface runoff and interflow) + percolation (RUN), and groundwater recharge (GWQ) in the reference and scenario periods in the studied basin is depicted in Figure 3. Here, two years with annual precipitation closest to the average annual precipitation in the periods 1960–1990 and 2046–2055 were chosen as representative: 1965 and 2055. As one can see, summer evapotranspiration is lower, though the values above 2 mm d$^{-1}$ appear earlier; the sum of runoff and percolation is also lower, and it is even becoming negative due to capillary rise in summer during the scenario period. Groundwater recharge becomes smoother under a drier and warmer climate.

Evapotranspiration of water into the atmosphere is a function of energy and water availability. With the temperature rise more energy is available for evaporation, but lower precipitation and soil moisture would restrict the amount of actually transpired and evaporated water. According to the simulation results, actual evapotranspiration is expected to decrease on average by 4% in the Elbe basin, with significant subregional differences corresponding to the change in precipitation. Namely, a moderate increase up to $\approx 100$ mm yr$^{-1}$ is expected in the north-western part of the basin, and a decrease down to $\approx 120$ mm yr$^{-1}$ was simulated for the loess subregion located in the central part of the basin (Saxony–Anhalt). In this case we did not account for other possible effects, like decreased water use of plants when they are exposed to higher carbon dioxide levels (see such a study in Krysanova et al. (1999); Krysanova and Wechsung (2002)).

Runoff and groundwater recharge show a decreasing trend, whereas groundwater recharge responded most sensitively to the anticipated climate change ($\approx 37\%$ on average) (see Figure 4). Groundwater recharge decreased practically everywhere, whereas lower absolute changes were simulated in the loess area, where it is very low anyway due to soil properties.

River flow is an integral characteristic for the basin, and therefore it is particularly important as an indicator of climate change. Figure 5 demonstrates a comparison of the average river flows in the reference period 1960–1990 and in the scenario period 1946–1955 with uncertainty intervals evaluated as the standard deviation over the period. The river flow is becoming significantly lower under the climate change scenario: a maximum of about $410$ m$^3$ s$^{-1}$ compared to more than $550$ m$^3$ s$^{-1}$, and a minimum of about $50$ m$^3$ s$^{-1}$ compared to about $180$ m$^3$ s$^{-1}$, and the seasonal dynamics is much smoother.

Climate change impact: water quality

Our study was focused on climate change impact on the generation of diffuse pollution in catchments. In this case, only total losses of nitrate-nitrogen (NO$_3$–N) with water from agricultural soils were considered: NO$_3$–N wash-off with surface runoff and interflow and leaching to groundwater, not taking into account the following transport processes (lateral fluxes to the river network and streamflow processes) and resulting changes in river water quality. We restricted the study by one major nutrient and considered agricultural soils only, because they are known to represent the major source of diffuse pollution in Europe. In order to reveal the ‘pure’ effect of changing climate and changing water flux intensity on the generation of diffuse pollution, no changes in land management were considered (like, for example, changes in the input of fertilizers) and point sources of pollution were ignored.
Figure 3 Comparison of typical seasonal dynamics of evapotranspiration (AET), surface runoff + interflow + percolation (RUN) and groundwater recharge (GWQ) in the reference and scenario periods in the studied basin. The year 1965 was chosen as representative for the period 1960–1990 and the year 2055 as representative for 2046–2055.

Figure 4 Average annual groundwater recharge in the Elbe basin in the reference (1991–2000) and scenario (2046–2055) periods and the difference map.
In advance, a series of simulation experiments aimed at quantification of the effects of natural conditions (soil, climate and topography) and human impacts (land management practices: fertilisation rates and crop rotations) was performed with SWIM for a restricted set of natural and land management conditions representative for the tributary of the Elbe, the Saale River basin (drainage area 23 687 km²). These simulation experiments are described in details in Krysanova and Haberlandt (2002). Here only some selected results related to climate effects on diffuse pollution are reported.

Agricultural land occupies about 70% of the Saale River basin. The natural conditions considered in the simulation experiments included five climate zones (represented by climate stations), nine different soil classes (from sandy to loamy and clay soils according to soil map BÜK-1000 (Hartwich et al. 1995)) and five elevation classes (represented by slope steepness). The land management conditions included three crop rotations and three fertilisation schemes.

The choice of climate stations in the region was based on a graphical cluster analysis of the long-term average annual precipitation and average temperature. The five selected climate stations – Artern, Erfurt, Gera-Leumnitz, Hof-Hohensaas and Bad Sachsa – have average annual precipitations ranging from 460 to 940 mm and average temperatures ranging from 8.4 to 6.5°C. The altitudes of the stations range from 164 m a.m.s.l. in Artern to 567 m a.m.s.l. in Hof-Hohensaas. The higher altitudes in the basin (up to 1100 m) were ignored, because most of the agricultural land is at lower altitudes. Namely, about 40% of agricultural land is located in areas lower than 200 m, 79% lower than 400 m and 96.4% lower than 600 m. Five elevation classes represented by topographic slopes ranging from 0.2% to 10% were considered.

The arable land in the basin includes 34 soil types (BÜK-1000, Hartwich et al. 1995), whereas 23 of them occupy 96.7% of the total cropland area. Loess soils or soils from loess mixed with weathering products are the dominant types, rocky soils occur mainly in the highland and mountain areas, where arable land is infrequent. The 23 soils were subsequently classified into nine soil classes, primarily in accordance with their field capacity, saturated hydraulic conductivity and occurrence in arable land. The nine soil classes represent a wide range of field capacities (32.3–49.8 vol. %) and two orders of magnitude of saturated hydraulic conductivity (0.4–41.1 mm h⁻¹).

![Figure 5](https://iwaponline.com/hr/article-pdf/36/4-5/321/364656/321.pdf)  
**Figure 5** Comparison of the average river flows in the reference period 1960–1990 and in the scenario period 1946–1955 with uncertainty intervals evaluated as standard deviation over the period
Simulation runs were performed over a 30 year period (1961–1990) for all possible combinations of climate zones, soil classes, rotation schemes, fertilisation schemes and elevation zones, which produced $4 \times 9 \times 3 \times 3 \times 5 = 1620$ time series with daily time steps. The simulated 1620 time series of daily water fluxes (direct runoff, interflow, groundwater recharge and evapotranspiration) and daily N fluxes (N wash-off with direct runoff and interflow, N leaching to groundwater, N uptake by plants, denitrification and mineralisation) were aggregated to monthly, annual and average annual values and then analysed with respect to the different natural conditions and management practices.

The combined effects of climate, soil and elevation on N losses with water, considering direct runoff, interflow and leaching to groundwater, are depicted in Figure 6. Three graphs include long-term average annual N losses for three slopes: the minimum slope of 0.2% (upper graph), the average slope of 5% (middle) and the maximum slope of 10% (lower graph). In this example, only the basic rotation and fertilisation schemes were considered. As one can see, total N losses with water fluxes are practically independent of elevation; however, the elevation affects the redistribution of fluxes, N losses in interflow increase at higher elevation and leaching to groundwater decreases, while the total amount remains practically the same. Under the minimum slope assumption (0.2%) the groundwater recharge and N leaching to groundwater for sandy soils increase only slightly, and more significantly for loess soils in comparison with the average slope conditions, while the total N losses with water remain practically the same.

Nitrogen losses with water for all soils distinctly increase with increasing precipitation from climate zone 1 to climate zone 5. This is due to more intensive washing of the soil column with incorporated nutrients in a wetter climate. Soil classes with high field capacity and high loam share (1–4) have relatively low N leaching, which increases only slightly under wetter conditions (climate zone 5). The N wash-off with direct runoff is rather small: it is notable only for the less permeable soil classes 3 and 4 under wetter conditions.

The analysis of factors influencing N losses from arable soils was done in advance and only for the large subbasin of the Elbe. However, it provides a good basis for climate change impact assessment on water quality. In this case, only total N losses with water from agricultural soils, nitrogen wash-off with surface runoff and interflow and leaching to groundwater were considered, without evaluation of point sources, land management and without simulation of lateral fluxes in the basin.

The results are mapped in Figure 7. As one can see, total NO$_3$–N losses with water in the reference period are mostly below 80 kg N ha$^{-1}$ yr$^{-1}$. Significantly higher values of 300–400 kg N ha$^{-1}$ yr$^{-1}$ were obtained only for organic soils Nidermoor and Hochmoor, which contain about 20% of organic carbon in the upper 100 cm layer (Hartwich et al. 1995). The high values simulated for organic soils are in agreement (within an order of magnitude) with reported values of nitrogen release from peat soils in Germany (Renger et al. 2002): from 400 to 1200 kg N ha$^{-1}$ yr$^{-1}$, assuming a decrease of the peat layer thickness by 1 cm.

Under climate change N losses with water are lower in all soils except the organic ones. On average, N leaching and wash-off in the scenario period is 9.4 kg N ha$^{-1}$ yr$^{-1}$ lower compared to the reference period. The organic soils show higher values, which could be explained by higher mineralisation under warmer climate conditions, and thus higher leaching. A notable decrease is visible in the northern and south-eastern parts of the basin, whereas they are less pronounced in the central part. These subregional differences correlate well with changes in groundwater recharge under changing climate. The results are in agreement with our previous assessment (Figure 6 and Krysanova and Haberlandt (2002)) and other similar studies (Jansons and Butina 1998).

So, we can conclude that the impact of a warmer and drier climate on diffuse pollution from agriculture is expected to be positive, because this type of pollution is highly correlated
with hydrological process intensity. The effects of changes in land use and land management practices should be evaluated in additional.

The uncertainty in hydrological and water quality responses was evaluated. The overall result of the study is that the mean water discharge and the mean groundwater recharge in the Elbe basin will be most likely decreased, but the uncertainty in hydrological response to changing climate is generally higher than the uncertainty in climate input. It was shown that the uncertainty in hydrological predictions in lowland is in general higher than that in mountainous areas.

Conclusions

The method combining a statistical downscaling method driven by a GCM-predicted temperature trend for producing climate scenarios and the ecohydrological spatially semi-distributed river basin model SWIM has proven to be appropriate for climate impact assessment on water resources, including water quantity and water quality.

The overall result of the study is that the mean water discharge and the mean groundwater recharge in the Elbe basin will be most likely decreased, and diffuse source pollution will be
diminished, but the uncertainty in hydrological response to changing climate is generally higher than the uncertainty in climate input. The hydrological and water quality responses and the propagation of uncertainty differ in three Elbe sub-regions – the mountainous area, the loess sub-region and the lowland area – due to differences in geomorphological and climate conditions. Development of climate models with 10 km resolution would allow us to verify the regional climate scenario as well as its hydrological consequences.

References


