The hydrological effects of changes in forest area and species composition in the federal state of Brandenburg, Germany

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Abstract

This thesis aims to quantify the human impact on the natural resource water at the landscape scale. The drivers in the federal state of Brandenburg (Germany), the area under investigation, are land-use changes induced by policy decisions at European and federal state level. The water resources of the federal state are particularly sensitive to changes in land-use due to low precipitation rates in the summer combined with sandy soils and high evapotranspiration rates. Key elements in landscape hydrology are forests because of their unique capacity to transport water from the soil to the atmosphere. Given these circumstances, decisions made at any level of administration that may have effects on the forest sector in the state are critical in relation to the water cycle. It is therefore essential to evaluate any decision that may change forest area and structure in such a sensitive region. Thus, as a first step, it was necessary to develop and implement a model able to simulate possible interactions and feedbacks between forested surfaces and the hydrological cycle at the landscape scale.

The result is a model for simulating the hydrological properties of forest stands based on a robust computation of the temporal and spatial LAI (leaf area index) dynamics. The approach allows the simulation of all relevant hydrological processes with a low parameter demand. It includes the interception of precipitation and transpiration of forest stands with and without groundwater in the rooting zone. The model also considers phenology, biomass allocation, as well as mortality and simple management practices. It has been implemented as a module in the eco-hydrological model SWIM (Soil and Water Integrated Model). This model has been tested in two pre-studies to verify the applicability of its hydrological process description for the hydrological conditions typical for the state.

The newly implemented forest module has been tested for Scots Pine (*Pinus sylvestris*) and in parts for Common Oak (*Quercus robur* and *Q. petraea*) in Brandenburg. For Scots Pine the results demonstrate a good simulation of annual biomass increase and LAI in addition to the satisfactory simulation of litter production. A comparison of the simulated and measured data of the May sprout for Scots pine and leaf unfolding for Oak, as well as the evaluation against daily transpiration measurements for Scots Pine, does support the applicability of the approach. The interception of precipitation has also been simulated and compared with weekly observed data for a Scots Pine stand which displays satisfactory results in both the vegetation periods and annual sums.

After the development and testing phase, the model is used to analyse the effects of two scenarios. The first scenario is an increase in forest area on abandoned agricultural land that is triggered by a decrease in European agricultural production support. The second one is a shift in species composition from predominant Scots Pine to Common Oak that is based on decisions of the regional forestry authority to support a more natural species composition.

The scenario effects are modelled for the federal state of Brandenburg on a 50m grid utilising spatially explicit land-use patterns.

The results, for the first scenario, suggest a negative impact of an increase in forest area (9.4% total state area) on the regional water balance, causing an increase in mean long-term annual evapotranspiration of 3.7% at 100% afforestation when compared to no afforestation. The relatively small annual change conceals a much more pronounced seasonal effect of a mean long-term evapotranspiration increase by 25.1% in the spring causing a pronounced reduction in groundwater recharge and runoff. The reduction causes a lag effect that aggravates the scarcity of water resources in the summer. In contrast, in the second scenario, a change in species composition in existing forests (29.2% total state area) from predominantly Scots Pine to Common Oak decreases the long-term annual mean evapotranspiration by 3.4%, accompanied by a much weaker, but apparent, seasonal pattern. Both scenarios exhibit a high spatial heterogeneity because of the distinct natural conditions in the different regions of the state. Areas with groundwater levels near the surface are particularly sensitive to changes in forest area and regions with relatively high proportion of forest respond strongly to the change in species composition. In both cases this regional response is masked by a smaller linear mean effect for the total state area.

Two critical sources of uncertainty in the model results have been investigated. The first one originates from the model calibration parameters estimated in the pre-study for lowland regions, such as the federal state. The combined effect of the parameters, when changed within their physical meaningful limits, unveils an overestimation of the mean water balance by 1.6%. However, the distribution has a wide spread with 14.7% for the 90th percentile and -9.9% for the 10th percentile. The second source of uncertainty emerges from the parameterisation of the forest module. The analysis exhibits a standard deviation of 0.6% over a ten year period in the mean of the simulated evapotranspiration as a result of variance in the key forest parameters. The analysis suggests that the combined uncertainty in the model results is dominated by the uncertainties of calibration parameters. Therefore, the effect of the first scenario might be underestimated because the calculated increase in evapotranspiration is too small. This may lead to an overestimation of the water balance towards runoff and groundwater recharge. The opposite can be assumed for the second scenario in which the decrease in evapotranspiration might be overestimated.

The relative small area of the transition from agriculture to forest in the first scenario analysis leads to a profound change in groundwater recharge indicating a high sensitivity of the state towards such changes. On the other hand, in the second scenario, the transition from evergreen pine forest to deciduous oak forest, concerns a much larger area with a much less pronounced impact on groundwater recharge. In addition, the areas of the strongest response to the two scenarios do not necessarily overlap. Consequently, the chances for a neutralisation of the negative effects for the water balance from the increase in forest area by the change in species composition for some regions might be low. As a result, changes in species composition initialised by local forest authorities to adapt to decreasing groundwater levels and climate change can only be effective if it takes possible interaction with forest area changes at the landscape scale into account.

In general, it can be concluded that the situation in Brandenburg is comparable to other regions with a low climatic water balance. In these regions, most of the water is lost to the atmosphere by evapotranspiration and only a small amount contributes to runoff and groundwater recharge. Based on this environmental precondition, any land-use change that increases the forested area will increase evapotranspiration and over proportionally decrease in groundwater recharge and runoff. On the other hand, changes from evergreen species towards deciduous species can improve groundwater recharge. This analysis demonstrates the general interaction of policy-induced land-use change with other environmental issues such as the landscape water balance. This clearly indicates the need for environmental assessment procedures to evaluate the impact of decisions that influence land management and that such an evaluation should take account of the interactions of different levels of decision making.