University of West Hungary
Faculty of Forestry

Thesis of doctoral (PhD) dissertation

Comparative Water Balance Study of Forest and Fallow Plots

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Background and objectives

Forests have significant effect on the elements of the hydrological cycle (e.g. interception loss, evapotranspiration, runoff, groundwater recharge) thereby forest cover bears a great importance in water management.

Effect of lowland forests on the water balance components (groundwater resources) have been debated quite intensively in the past among foresters and water managers. Several studies concluded the negative effect of forests on groundwater resources in the Hungarian Lowland, based on past afforestation data. At the same time, some studies have demonstrated little differences in groundwater consumption between various vegetation cover types.

Climate model projections predict that summer temperatures may increase by up to four degrees by the end of this century in Hungary, while precipitation is likely to increase in winter and decrease in summer. Consequently, groundwater consumption of vegetation can be expected greater due to increased evapotranspiration especially in the groundwater-dependent lowlands where further afforestation is expected in the future.

Regional climate models, studying the feedback of forests on climate do not consider the available groundwater resources for evapotranspiration up to now. Thus, the higher evapotranspiration of the shallow groundwater regions is neglected that presumably influences the feedback of land cover on climate variables.

The main objective of the dissertation is to contribute to the classification of the contradiction regarding the groundwater consumption of lowland forests. The dissertation estimates and compares water balance components (groundwater consumption) of an oak and a fallow plot, exposed to similar weather and soil conditions, by calibration of a Hydrus 1-D model.

After comparing of the water balance components of the plots, the applicability of the evapotranspiration results in regional climate models as well as the question of simulating the effect of climate change on groundwater-dependent forests is discussed.

Research questions of the dissertation are the following:

- Was the greater evapotranspiration (groundwater consumption) of the forest detectable?
- Was the difference in evapotranspiration (groundwater consumption) at the study plots between a dry (2007) and wet (2008) growing season significant?
- Was the background groundwater supply significant during the vegetation period? Was it also observable beyond the growing seasons?
- How much was the deviation between the results of various evapotranspiration assessment methods?

Data and methods

The author compared the water balance components of an oak and fallow plot by applying the Hydrus 1-D model, calibrated on measured soil moisture and groundwater level in a shallow groundwater environment. The research was carried out in Nyírség, in an undisturbed environment during a two-year period (2007.04-2009.03).

The input variables of the model were determined by field measurement, such as the root profile, the leaf area index, the soil water storage capacity and meteorological variables. The seasonal cycle of leaf area index and albedo were estimated, based on the MODIS remote sensing database. Soil moisture and groundwater level were measured with high frequency to calibrate the Hydrus 1-D model.

The interception loss was estimated in the oak stand by considering also the evaporation from the canopy during rainfall events, whilst at the fallow site a simple water storage method was applied. Potential transpiration and evaporation were computed by the Penman-Monteith method.

The author compared the water balance components of the sites and determined the seasonal change of the groundwater consumption using the simulated soil moisture profiles for two differing growing seasons. The groundwater consumption was also estimated by an empirical approach through the water table fluctuation method, applying groundwater data, measured with high frequency.

The computed evapotranspiration was compared with results of the surface temperature based MODIS calculation.

Theses of the dissertation

1. According to the model results, the evapotranspiration of the groundwater-dependent oak stand was 30% higher than that of the fallow plot during the study period.

- The interception loss of fallow plot was barely the half of the oak stand, which can be attributed to the higher evaporation rate of intercepted water in the forest.
- The transpiration of the fallow was only two third of the oak stand.
- The soil surface evaporation in the oak stand was approximately one fifth of fallow plot.

2. The groundwater consumption of the oak stand was almost three times higher than that of the fallow site using the Hydrus 1-D model.

- The groundwater consumption was close to 60% of the total transpiration at the oak site and approximately 30% at the fallow site.

3. The groundwater supply from background was significant at both sites during the growing seasons. In the dormant season, the precipitation was the primary source of groundwater recharge, which was obvious at the fallow site. The effect of rainfalls during autumn and winter appeared only gradually at the oak site due to the relatively deeper groundwater level.

- The abrupt rise of groundwater level at the end of the evapotranspiration periods (especially in 2007) can be explained by the groundwater supply replenishing the groundwater depression. Groundwater levels rose initially rather quickly then slowed down until the equilibrium groundwater level was reached.

4. The proportion of groundwater consumption from the total transpiration was greater in the dry growing season of 2007 than in the wet one of 2008, despite of the fact that groundwater level was much higher in 2007. The sum of evapotranspiration changed only slightly between the growing seasons.

- Groundwater consumption decreased by about 40% in the wetter year 2008 at both sites.

5. The estimated groundwater consumption of the water table fluctuation method deviated by 9% from the Hydrus model results, originated from the uncertainty concerning the measurements and modeling techniques of the different approaches.

- The evapotranspiration of the Hydrus model differed by 5% from ET results of similar sites (leaf area index, groundwater level), based on remote sensing data.

Application of the results

The possibility of spatial extension of the model results is rather limited. The main difficulty is the great spatial heterogeneity of environmental parameters (vegetation, soil, groundwater level). The estimated evapotranspiration results, confirmed by measurements, are primarily suitable for comparison with other ET results, based on different spatial scale and approach.

The MODIS remote-sensed ET results have shown good accordance not only with ET values of water loosing sites, but also with results of groundwater-dependent areas. The estimation of spatial evapotranspiration by remote sensing is a promising area with minimum data requirement.

The evapotranspiration of shallow groundwater areas may substantially influence the temperature prediction of regional climate models and the extent of feedback by the vegetation. Presently the spatial resolution of regional models makes it possible to integrate exact vegetation, soil and hydrology data into the model, but so far, groundwater resources were not taken into consideration. Simulation of the groundwater system would be necessary to improve the prediction of regional models. It would be advantageous to compare ET results of regional climate models with remote sensed values.

By further developing the water balance model, it is possible to simulate the effects of climate change on groundwater resources. Beyond the climatic changes, also the local and regional groundwater supply has to be estimated. Based on the predicted groundwater changes, conclusions can be drawn about the future of groundwater-dependent forests.

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