Splitting the water balance of drained peatland forests into hydrological components

Harri Koivusalo[1], Hannu Hökkä[2], Ari Laurén[1], Eero Nikinmaa[3], Jukka Laine[4] and Erkki Ahti[5]

[1] Finnish Forest Research Institute, Joensuu Research Unit, PO Box 68, FI-80101 Joensuu, Finland
Phone: +358 50 391 3112, e-mail: harri.koivusalo@metla.fi

[2] Finnish Forest Research Institute, Rovaniemi Research Unit, PO Box 16, FI-96301 Rovaniemi, Finland

[3] University of Helsinki, Department of Forest Ecology, P.O. BOX 27, FIN-00014 University of Helsinki, Finland

[4] Finnish Forest Research Institute, Parkano Research Unit, Kaironiementie 54, FI-39700, Parkano, Finland

[5] Finnish Forest Research Institute, Vantaa Research Unit, PO Box 18, FI-01301 Vantaa, Finland

Summary

Drainage is a prerequisite for a successful forest production in peatlands and ditch network maintenance is performed to sustain the drainage efficiency over the stand rotation. A hydrological model is run over a summer period in a small catchment to quantify hydrological components, such as throughfall, overstorey and understorey interception and transpiration, and runoff in a drained peatland forest. Measured canopy interception, tree sap flow, and runoff were used to assess the model performance. The model was a useful aid in assessing consistency of measurements. Results suggested that either the measured fluxes are not fully consistent, or the model does not consider all relevant processes at the study site.

Key index words: hydrology, drainage, runoff, interception, transpiration

Introduction

About 55% percent of the total peatland area (89 500 km2) in Finland is drained with open ditches to facilitate forest production. About one third of the peatland forests are estimated to require supplementary ditching or ditch cleaning, because the condition of the ditch network in these areas is deteriorated and presumably decreases productivity of the forest stand. In addition to drainage, vegetation cover has an important role in the water balance of peatland forests (e.g. Päivänen and Sarkkola, 2000). Evaporanspiration increases with increasing forest stand volume (Ahti and Hökkä, 2006), and therefore the role of the drainage ditches in the water balance decreases with stand development. It can be hypothesized that at some stage of its development, the vegetation exerts a primary control on the peatland hydrology. In such a situation the condition of the ditch network is no longer decisive for the productivity of the site. Quantitative assessment of the water balance components is essential for understanding the relative roles of vegetation and drainage systems on the hydrology of peatland forests. The objective of this study is to quantify water balance components of a drained peatland forest. We show how hydrological model binds the water balance measurements together and aids in the assessment of the accuracy and conformity of the measurements.

Materials and methods

The study site Sattasuo is located in Northern Finland (66.5 N, 26.7 E), where a forested peatland area of 0.53 ha was artificially isolated from the surrounding forest by using a rectangle-shaped ditch inside another larger rectangle. The distance between the long sides of the ditch-rectangle, i.e. ditch spacing, was 23 m. The inner ditch loop had an outlet through a v-notch weir installed in a well, where the water level was measured to quantify the volume of runoff from the inner ditch loop. Forest stand dominated by Scots pine (*Pinus sylvestris* L.) covered 68% of the artificial catchment area, and the rest of the area was treeless peatland between the ditches and the forest edge (Fig. 1).

For the estimation of transpiration, sap flow was measured every 10 minutes using sensors installed in eight sample trees. The method of Granier (1985) was applied to compute transpiration for eight sample trees based on the sap flow readings, and to scale transpiration from the sample tree level to the forest stand level. Weekly through-fall

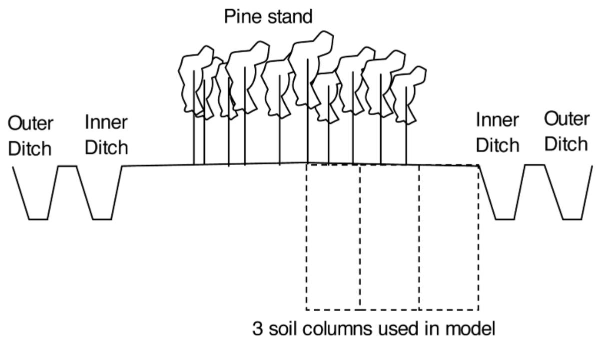

Figure 1. Cross-section of the study area and the modelling columns of FEMMA.

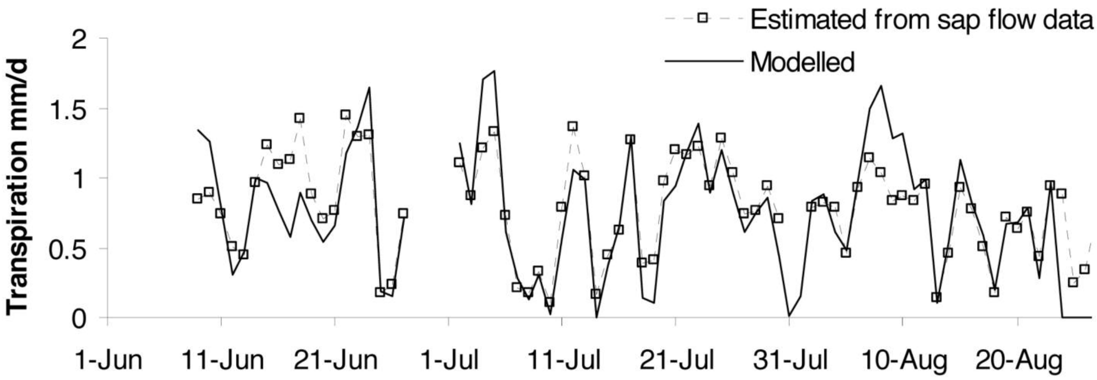

Figure 2. Daily transpiration estimated from the sap flow measurements, and modelled daily transpiration.

estimate was derived based on manual precipitation gauge observations at 20 locations within the forest stand and 5 locations in an adjacent clearcut area.

The volume of the pine forest stand was 93 m^3/ha, the mean diameter at breast height was 14.7 cm, and the stem density was 1252 trees/ha. The ground vegetation consisted of *Sphagnum* mosses, sedges, and dwarf shrubs (*Ledum palustre, Betula nana*). Peat thickness in the area was greater than 1 m, and the soil hydraulic conductivity clearly decreased with depth. The depth of the ditches was 0.95 m down from the soil surface.

Meteorological measurements including precipitation, air temperature, relative humidity, wind speed, and global radiation at a height of 2 m were recorded every 10 minutes in the clearcut. The climate in the area is cold continental with a mean annual temperature of 0.0°C and a mean annual precipitation of 537 mm (Drebs *et al.*, 2002).

The FEMMA hydrological model (Koivusalo *et al.*, 2006; Lauren *et al.*, 2006) was parameterised to describe water balance components in the peatland forest. FEMMA reads hourly meteorological data as input and simulates interception and transpiration of overstorey and understorey vegetation, snow accumulation and melt, soil and ground water movement, and runoff generation. FEMMA is a quasi-two-dimensional model in the sense that vertical water fluxes and lateral water fluxes are computed alternately. Vertical soil water movement in unsaturated zone is based on a numerical solution of the Richards equation and lateral water movement in the saturated part of the soil domain is computed as Darcian flow (Karvonen *et al.*, 1999).

The modelling domain in Sattasuo is a vertical two-dimensional profile between a ditch and the midpoint between two ditches. The midpoint between two parallel ditches acts as a water divide and the water level in the ditch prescribes a boundary condition for the soil water computation. The area is horizontally divided into three computation columns, where the column located next to a ditch is treeless (Fig. 1). The computation period is from 15 May until 24 August 2007. The model is calibrated against transpiration, water table level, and runoff data by adjusting the lateral hydraulic conductivities in soil and the value of the minimum stomatal resistance, which controls the level of transpiration.

Results

Precipitation measured with an automatic gauge and computed throughfall are compared against manually measured accumulations in open and forest, respectively. Manually measured precipitation was 235 mm in open and 190 mm in forest between 28 May and 23 August 2007. The automatic gauge accumulated 205 mm in the open clearcut and the model predicted 176 mm of throughfall for the same time period. Manually measured precipitation is 15 % higher than automatically measured precipitation, which is corrected for gauging error by multiplication with a value of 1.05. The measured overstorey interception is 19 % of precipitation, whereas the modelled interception is 14 %.

Variability in the modelled daily transpiration is higher than the variability in the transpiration estimate based on the sap flow data (Fig. 2), which is explained by the fact that the computed transpiration is more directly related to the net global radiation than the sap flow estimate. The correlation between the computed transpiration and the global radiation is 0.9 in June 2007, whereas the correlation between the radiation and the sap flow estimate is 0.78. The level of the transpiration is calibrated against the transpiration data. The mean measured transpiration during the study period is 0.84 mm/d.

Fig. 3 shows measured hourly runoff, occasional manual runoff measurements, and modelled hourly runoff. A distinct feature of the result is that the highest runoff peak is not reproduced by the model, and the model systematically underestimates runoff during early summer. The runoff simulation during late summer suggests that the model often underestimates the first runoff peak following a dry period.

The total precipitation (automatic gauge) over the period from 9 June to 15 August is 185 mm, the measured runoff is 82 mm, and the modelled runoff is 69 mm. The sum of computed overstorey interception and transpiration is 99 mm, and the measured overstorey evapotranspiration is 78 mm. Measured interception and transpiration include 4 and 6 days of missing data, respectively.

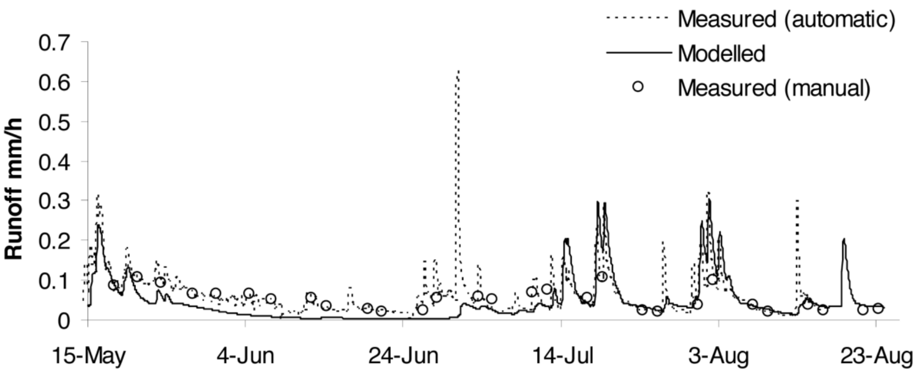

Figure 3. Automatically and manually measured runoff, and modelled runoff.

Conclusions

In an application of a hydrological model, meteorological and hydrological measurements can be bound together and the quality of the data can be assessed from the point of view of the process descriptions embedded in the model. The Sattasuo case study indicated that precipitation measurement easily contains uncertainty, which has the same magnitude as the differences between modelled and measured water balance components. Transpiration estimates from the sap flow measurements and the hydrological model were comparable during most of the time, although the modelled transpiration responded more strongly to solar radiation than the sap flow estimate. Assessment of the runoff results showed that either the measured hydrometeorological fluxes are not fully consistent, or the model is lacking description of important processes that affect the hydrology at Sattasuo. There are three possible processes that need further investigations: 1) freezing of peat surface layers and ditch sidewalls can prolong the recession of the spring flood, which effect is not described in the model, 2) Sattasuo can be affected by a regional groundwater inflow sustaining recession flows in the ditch, and 3) the treeless areas within the catchment (32 % of the area) can generate more runoff than simulated by the model.

References

Ahti, E. and Hökkä, H. (2006). Effects of the growth and volume of Scots pine stands on the level of the water table on peat in Central Finland. In D.M. Amatya and J. Nettles (eds.), *Hydrology and Management of Forested Wetlands. Proceedings of the International Conference, New Bern, North Carolina,* 309-315.

Drebs, A., Nordlund, A., Karlsson, P., Helminen, J. and Rissanen, P. (2002). *Climatological statistics of Finland 1971-2000.* Finnish Meteorological Institute, 99pp.

Granier, A. (1985). Une novelle methode pour la mesure du flux de seve brute dans le tronc des arbres. *Annals of Forest Science* **42**, 193-200.

Karvonen, T., Koivusalo, H., Jauhiainen, M., Palko, J. and Weppling, K. (1999). A hydrological model for predicting runoff from different land use areas, *Journal of Hydrology* **217**, 253-265.

Koivusalo, H., Kokkonen, T., Laurén, A., Ahtiainen, M., Karvonen, T., Mannerkoski, H., Penttinen, S., Seuna, P., Starr, M. and Finér, L. (2006). Parametrisation and application of a hillslope hydrological model to assess impacts of forest clear-cutting on runoff generation. *Environmental Modelling and Software* **21**, 1324-1339.

Laurén, A., Finér, L., Koivusalo, H., Kokkonen, T., Karvonen, T., Kellomäki, S, Mannerkoski, H. and Ahtiainen, M. (2005). Water and nitrogen processes along a typical water flowpath and streamwater exports from a forested catchment and changes after clear-cutting: a modelling study. *Hydrology and Earth System Sciences* **9**, 657-674.

Päivänen, J. and Sarkkola, S. (2000). The effect of thinning and ditch network maintenance on the water table level in a Scots pine stand on peat soil, *Mires and Peat* **51**, 131-138.