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Hydrological role of Central European forests in changing climate –review

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Abstract— Climate change exerts one of the most relevant impacts on hydrological processes by altering precipitation patterns and evapotranspiration processes. Forests, the terrestrial ecosystems with the highest water demand, will likely be the most influenced by the changing water regime. The study aims to outline the vital role forests play in the global water cycle, a role that increases as climate change intensifies. The deforestation that has occurred in recent years is a main trigger of global climate change, one that negatively affects climate-sensitive areas. The study focuses on the importance of crown and litter interception as well as the manner in which climate change alters these. We also present some results for forest and groundwater relations in Hungary and the impact of forests on runoff during extreme weather conditions.

Key-words: forest hydrology, climate change, interception, groundwater, runoff

1. Introduction

Forest vegetation currently covers 37% of global land surface and is known for its high carbon-absorbing capacity. Nevertheless, recent practices – primarily changes in land use – have accelerated deforestation considerably with forest cover loss reaching 29.7 million hectares (73.4 million acres) globally in 2016 (*Weisse* and *Goldman*, 2017). Agricultural land expansion causes about 80% of forest cover loss, while industrial activity accounts for the remainder 20% (*UNFCCC*, 2007). This forest loss is one of the driving factors behind climate change, contributing as much as 10 to 30% to global greenhouse gas emissions each year (*Johnson*, 2009; *RA*, 2017; *Schrope*, 2009). The changing climate causes a feedback loop and negatively impacts climate-sensitive areas, especially forests (*Szép*, 2010).

In addition, forests possess many additional features that intensively affect the climate and the water cycle. The characteristics of precipitation transformed by forest vegetation greatly influence the amount of water available for runoff and recharge, but also influence concentration time, as in the case of flood wave formation processes. Forests generally reduce the negative impacts of floods as water drainage in undisturbed forest-covered areas tends to be of high quality (*Baird* and *Wilby*, 1999).

Researching hydrological behavior in an ecosystem with such a significant influence on water circulation is also important in assessing climate change effects, because the quantity and quality of available water resources will become a bottleneck in the future.

The main objective of this paper is to summarize relevant research results in forest hydrology and climate change, focusing specifically on water-related problems in Hungary. Special emphasis is put on the analysis of interception and groundwater relations of the forests.

2. Forest hydrology

A portion of the rain that falls onto a forested area simply moistens the vegetation and then evaporates back into the atmosphere. This is called interception (crown interception), which is usually divided into two parts: storage capacity and evaporation during the precipitation event. Some precipitation makes its through the crown or flows down stem and reaches the forest litter surface on the ground, where it remains, filling the storage capacity of the forest floor. This is known as litter interception. The remaining water infiltrates into the forest soil and contributes to subsurface water reservoirs. Precipitation that does not completely infiltrate the soil creates surface runoff; see *Fig. 1.*

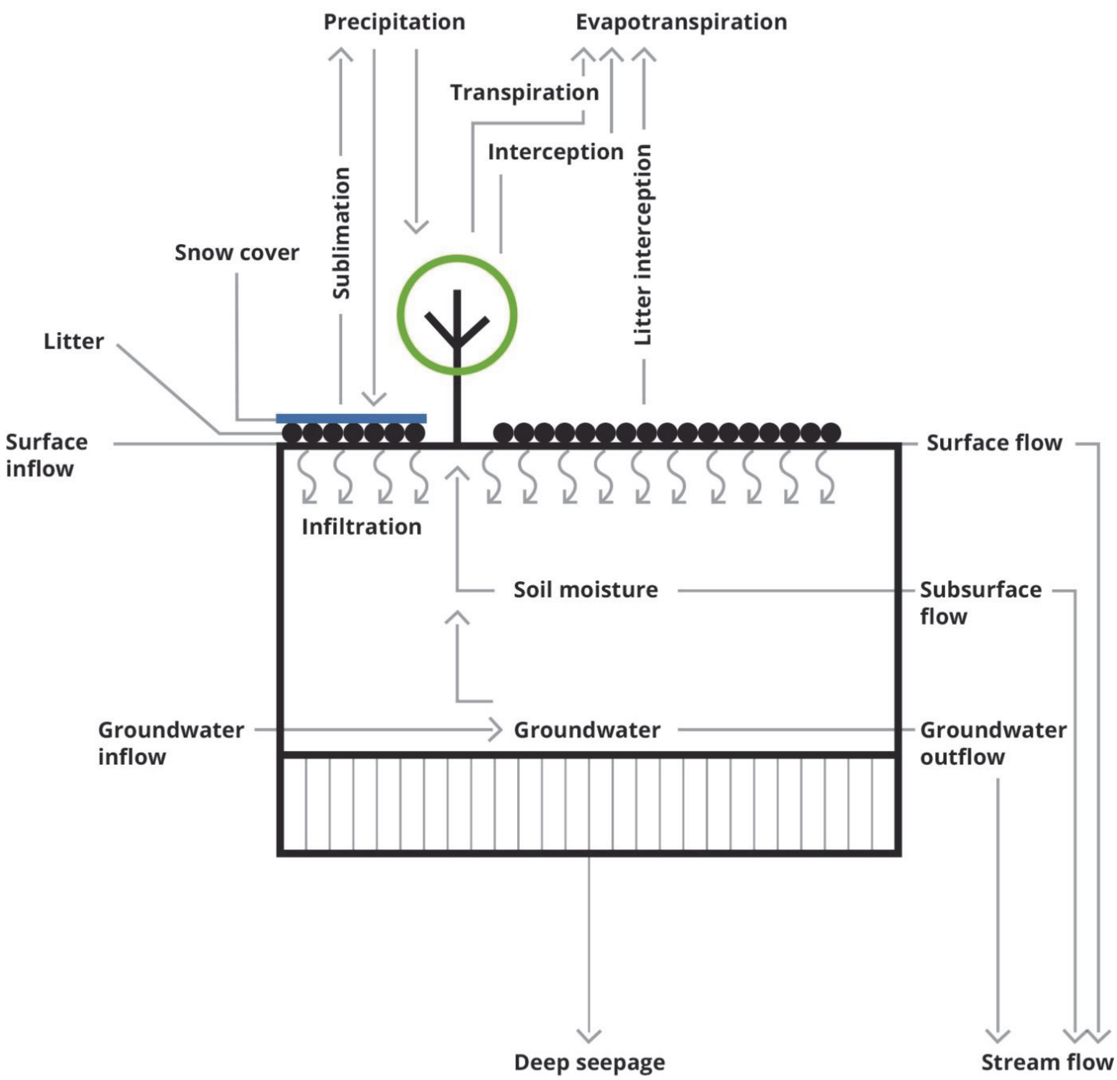

Fig. 1. Water balance of the forest.

The water balance of the forest can be characterized by considering the quantities of incoming, used, temporarily stored, and exiting water:

$$P + p + Rin_{s,gw} - I - T - Rout_{s,gw} = dS, \tag{1}$$

where P is the liquid and the solid macro precipitation (measurable by normal Helman-type ombrometer like rain and snow); p is the liquid and the solid micro precipitation (like dew, frost, rime, and mist precipitation [fog drip]); $Rin_{s,gw}$ is the inflow (surface and subsurface); dS is the storage change of water in the area; I is the interception (crown and ground litter); T is the transpiration from the vadose zone and groundwater; and $R_{s,gw}$ is the outflow (surface and subsurface).

2.1. *Effects of forests on the amount of macro and micro precipitation*

Forests receive the largest amount of water intake from macro precipitation. Its varying volume and distribution due to climate change significantly impacts the biological production and structure of typical forest types. The modifying effect of forests on macro precipitation is quite disputed (*Rácz*, 1981).

The micro-precipitating effect of the forest can be significant, especially in mountainous terrains, where mist precipitation (fog drip) and rime can lead to horizontal precipitation. This effect translates into about 30% of the macro precipitation depending on forest stand characteristics. This value can be 1–3 times higher in mountainous areas than it is in lowland areas. This effect happens in the Hungarian Great Plain during the winter and reduces interception loss (*Szőnyi*, 1966, 1967; *Hazslinszky*, 1976).

2.2. *Kinds of interception and their relation to climate change*

As stated earlier, one part of the precipitation remains in the crown and evaporates, while another, perhaps seemingly insignificant part, is absorbed by leaves. This temporarily stored and quickly evaporating precipitation amount is called interception (*Delfs*, 1955). The interception loss usually varies between 10% and 40% depending on the forest ecosystem (*Dingman*, 2001); it is a vital factor and the first stage in the hydrological cycle of forests (*Savenije*, 2004).

Normally, interception means crown interception. However, total interception loss (I) is the sum loss of crown interception (E_{su}) and litter interception (E_s):

$$I = E_{su} + E_s. \quad (2)$$

Whether interception loss plays an additional or substitutional role or not is an open question currently. In the dormant period, interception is an incoming factor of evaporation. In the vegetation period, interception evaporation has an advantage over transpiration because stomatal resistance does not regulate interception evaporation; thus, transpiration continues at a lower level. According to the latest research, interceptive evaporation is many times higher than the rate of transpiration, but replaces transpiration only for short periods (*Dingman*, 2001). Interceptive evaporation is around three times higher (*Stewart*, 1977) than the transpiration rate under the same conditions.

Negative interception is possible under certain, specific circumstances. In these cases, forests can adsorb humidity from the air. This process is known as condensed horizontal precipitation, which may reach 30% of precipitation depending on tree stand characteristics. This phenomenon mainly occurs at forest edges, and its importance decreases further into the internal areas of the forest. In some places, the condensed horizontal precipitation significantly reduces the interception loss (*Rácz*, 1981; *Ward* and *Robinson*, 1975).

Snow interception loss is one of the least known factors in the water balance equation of forests. Research in coniferous forests has estimated that interception loss may reach 20–50% of precipitation. The storage of snow (both the mass and the duration of the storage) is ten times higher than it is for rain. However, most hydrological models treat snow interception in a rather simplified form (*Lundberg* and *Halldin*, 2001).

2.2.1. Crown interception

The difference between crown interceptions of different forest stands in Hungary can be summarized as follows (*Járó*, 1980):

- The average interception of coniferous forests is 5% higher than the interception of deciduous forests.
- Crown precipitation retention amounts to 1/3 of the precipitation on average, usually along the dry forest edge, in typical climatic conditions in Hungary.
- The precipitation retention level of forest stands with a multi-layered canopy is higher than those of with one-layer canopy.

Considering the different crown interception losses (*Table 1*) the changes in interception show a growing tendency depending on the age of the stands (*Járó*, 1980). Subsequently, higher interception losses must be considered by the same canopy closure in the older stands because of the growing evaporation surface.

Precipitation distribution also influences the amount of interception. Years involving the same annual precipitation amounts may have fewer large precipitation events; this reduction of rainy days decreases the sum of annual interception. Using a daily time-step interception model, *Kalicz et al.* (2017) compared the present and future interception totals of a beech forest in the Sopron Hills and projected, that the current 30% crown interception level would decline to 27–28% by the end of the twenty-first century.

Table 1. Results of interception studies on Hungarian forests (interception expressed as a percentage of the annual precipitation)

Forest type	**Interception [%]**	**Source**
Turkey oak – Sessile oak	22.3	*Szabó* (1979)
Sessile oak	25	*Führer* (1984)
Hybrid poplar clones	25	*Járó* (1980)
Hornbeam –Turkey oak	27	
Turkey oak	27.5	
Linden	28	
Hybrid poplar clones	29	
Black locust (young)	30	
Beech (young)	30.9	*Kucsara* (1998)
Black locust (old)	31	*Járó* (1980)
Northern red oak	33	
Beech (unmanaged)	39.7	*Koloszár* (1981)
Larch	34	*Járó* (1980)
Scots pine (young)	35	
Balck pine (young)	36	
Scots pine (old)	37	
Spruce (old)	37	*Führer* (1984)
Eastern white pine	36	*Járó* (1980)
Hornbeam-Scots pine	37	
Douglas fir	38	
Black pine (old)	39	
Spruce (young)	41.6	*Kucsara* (1998)
Spruce (middle age)	40.5	*Kucsara* (1998)
Beech (managed)	47 28 29.7	*Járó* (1980) *Führer* (1984) *Koloszár* (1981)

2.2.2. Litter interception

Litter cover significantly influences the root zone water balance by retaining precipitation, thereby preventing it from entering the root zone and potentially reducing the amount of absorbable water. At the same time, litter also prevents the drying of the soil.

Litter positively influences the root zone water balance during decomposition. *Table 2* contains some representative data for the amount of litter interception collected from different climate regimes and forest stands.

Table 2. Litter interception in different forest stands as a percentage of the annual precipitation

Forest type	Litter interception [%]	Region	Source
	1–5%	Eastern United States	*Helvey* and *Patric* (1965)
Deciduous	2-5% in the summer time and 3.5% in the winter time	Eastern United States	*Helvey* and *Patric* (1965)
Sessile oak	5–7%	Sopron, Hungary	*Zagyvainé et al.* (2014)
Sessile oak	8% in the summer time and 16% in the winter time	Hungary	*Führer* (1994)
Mixed oak	8–12%	Himalayas	*Pathak et al.* (1985)
Beech	34%	Western Europe	*Gerrits et al.* (2006)

Litter interception of 1–5% of annual rainfall has been detected in the United States. In the eastern part of United States, this loss generally does not exceed the limit of 50 mm/year. For deciduous species, litter interception is 2–5% of the precipitation in summer and 3.5% in winter (*Helvey* and *Patric*, 1965). For coniferous species, litter interception losses increase from 2% to 4% in aging stands that are between 10 and 60 years old (*Helvey*, 1967).

Studies in other climatic conditions show a higher value of litter interception than previously mentioned. The litter interception of sessile oak forest stands is 5–7% of the annual precipitation in the western part of Hungary (*Zagyvainé et al.*, 2014). In the Himalaya region, 8–12% of the throughfall precipitation was detected in mixed oak forest (*Pathak et al.*, 1985). One of the greatest litter interception values (34%) was measured as a western European beech forest (*Gerrits et al.*, 2006). Litter interception of a sessile oak forest in Hungary was 8% of the precipitation in summer and 16% in winter (*Führer*, 1994).

Litter storage capacity, which is a key factor for litter interception size, is proportional to the mass of litter per unit area (*Putuhena* and *Cordery*, 1996; *Rowe*, 1955). This fact was confirmed in *Zagyvainé et al.* (2013), which considered spruce, beech, and oak stands. The maximum water holding capacity of the litter per unit weight was independent from the tree species and could be characterized as 2.1–2.2 l/kg. Naturally, forests with larger litter masses can retain more water due to the differences in dry weight. The calculated storage capacities for 1 m^2 forest area are the following: 2.3 l/m^2 for beech, 4.1 l/m^2 for spruce, and 1.8 l/m^2 for sessile oak (*Zagyvainé et al.*, 2013).

2.3. Transpiration and transpiration factors

Active water release, i.e., transpiration, is essential for maintaining plant production. Plants lose significantly more water than that is required for them to build biomass and transport nutrients from the soil to the leaves (*Madas*, 1980). Transpiration is actually an evaporation process controlled by similar factors. Evaporation can only occur when water is available and can be defined as the process where liquid water is transformed into a gaseous state. Meadows and forests have differing transpiration and evaporation surfaces. The evaporation and transpiration surface of a forest is usually larger, and the surface resistance plays a more important role in the process (*Lee*, 1980). Forests possess a higher roughness and leaf area index, both of which determine transpiration constraints when compared to other land cover forms. Both roughness and leaf area index increase the transpiration when adequate water is available. On the other hand, the forest root depth is higher, and deeper soil possesses a higher capacity for water storage. Thus, forests are less vulnerable to water stress caused during longer dry periods than other vegetation covers generally are. However, longer dry periods can significantly endanger forests as well and decrease their survival and regeneration potential.

The transpiration water use amount for the forest biomass production per year can be calculated using the following equation:

$$AT = ABP \cdot TC \, , \tag{3}$$

where AT is the annual transpirational water use of the forest, ABP is the annual biomass production, and TC is the transpiration coefficient, which is the amount of transpirational water required per unit of produced biomass.

As a result, the weight of the annual increment, the weight of the annual crown, and the weight of the annual root biomass are proportional to the annual transpirational water used. In the equation, the multiplication factor is the amount of water required for unit biomass formation. This is called the transpiration coefficient (TC), the inverse of which is generally referred to as water use efficiency (WUE):

$$TC \; (1/WUE) = \frac{T}{BP} \, . \tag{4}$$

According to Eq. (4), the amount of transpirational water (T) required to form one gram of biomass (BP) of different tree species can be seen in *Table 3*.

Table 3. Transpirational water use of various forest stands (based on *Polsters*' results; *Járó*, 1981)

Species	Amount of required transpirational water to form 1 g biomass (g)	Annual maximum transpirational water consumption of main tree species (mm/year)
Beech	169	188
Hornbeam		163
Sessile oak		267
Pedunculate oak	344	441
Turkey oak		317
Black Locust		279
Birch	317	
White Willow		646
Hybrid poplar	520	680
Domestic poplar	585	800
Scots pine	300	205
Black pine		185
Spruce	231	148
Larch	257	

Table 3 shows that light demanding wood species require larger water amounts to produce one unit of biomass, while shade-tolerant wood species require a smaller water amounts, because they utilize water far more efficiently (*Madas*, 1980).

According to Eq. (3), the transpiration coefficients of different stands multiplied by the sum of the dry weight of the annual growth, leaf, and root, presents the annual transpirational water consumption of forest stands. Based on the water consumption equation, the maximum water consumption per year for stands of main tree species can be calculated, for example, as a unit per hectare in mm (*Table 3*).

In terms of forest water use in Hungary, forests in semi-humid areas containing species such as beech and spruce show less transpirational water demand than forests in semi-arid environments containing common oak and native poplars (*Járó*, 1981). Consequently, the forests at the xeric limit in the Hungarian Great Plain generally have a higher transpirational water demand. However, some species with low transpirational water demands – such as Scotch pine, black pine, and black locust – also occur in the dry climate conditions that characterize the Great Plain region.

2.3.1. Forest groundwater relations

The most studied topic of the past twenty years has been the interaction of forests and groundwater at the Hungarian Great Plain.

Forest evapotranspiration (both transpiration and interception) is generally higher than the evapotranspiration of the neighboring grasslands because of the enhanced LAI (leaf area index) and the greater root depth that woody vegetation within forests possess. These differences are characteristic for the relatively dry climate of the Hungarian Great Plain where precipitation is generally inadequate to support woody vegetation; consequently, trees only survive arid periods if they can access groundwater resources (*Ijjász*, 1939).

The groundwater level can be detected throughout the year under forests (if the trees are able to reach it). It is deeper under forests than under grasslands, but the difference between these two vegetation covers is bigger during the growing season in the Hungarian Great Plain (*Ijjász*, 1939).

The groundwater level was on average 0.8–1.1 m deeper under a middle-aged pine forest in the Danube-Tisza sand plateau region than it was in the surrounding, non-forested areas (*Major*, 2002). The actively growing black pine forest had a mean annual evapotranspiration (ET) rate of 712 mm $year^{-1}$. On average, this forest used 130 mm more water than it received as annual precipitation.

Gribovszki et al. (2012) compared the groundwater balance of two neighboring plots, an oak forest and a pasture. The study found the water level to be 0.44 m lower in the oak forest than it was under the pasture, whereas the groundwater uptake for the oak forest was more than twice as much as it was for the pasture during the extremely dry summer of 2012. Both results point to a significantly deeper groundwater level under forest vegetation. The larger amount of forest groundwater use does not work in a parallel fashion for salt uptake; therefore, salts accumulate in the soil and also in the groundwater. The salt content of the groundwater is slightly greater under the forest than it is under a pasture. The measured differences pose no problem for forest vegetation productivity and vitality, but the climate change induced salt accumulation can be a long-term effect. Afforestation can also contribute to salt accumulation in soils; see *Fig. 2.*

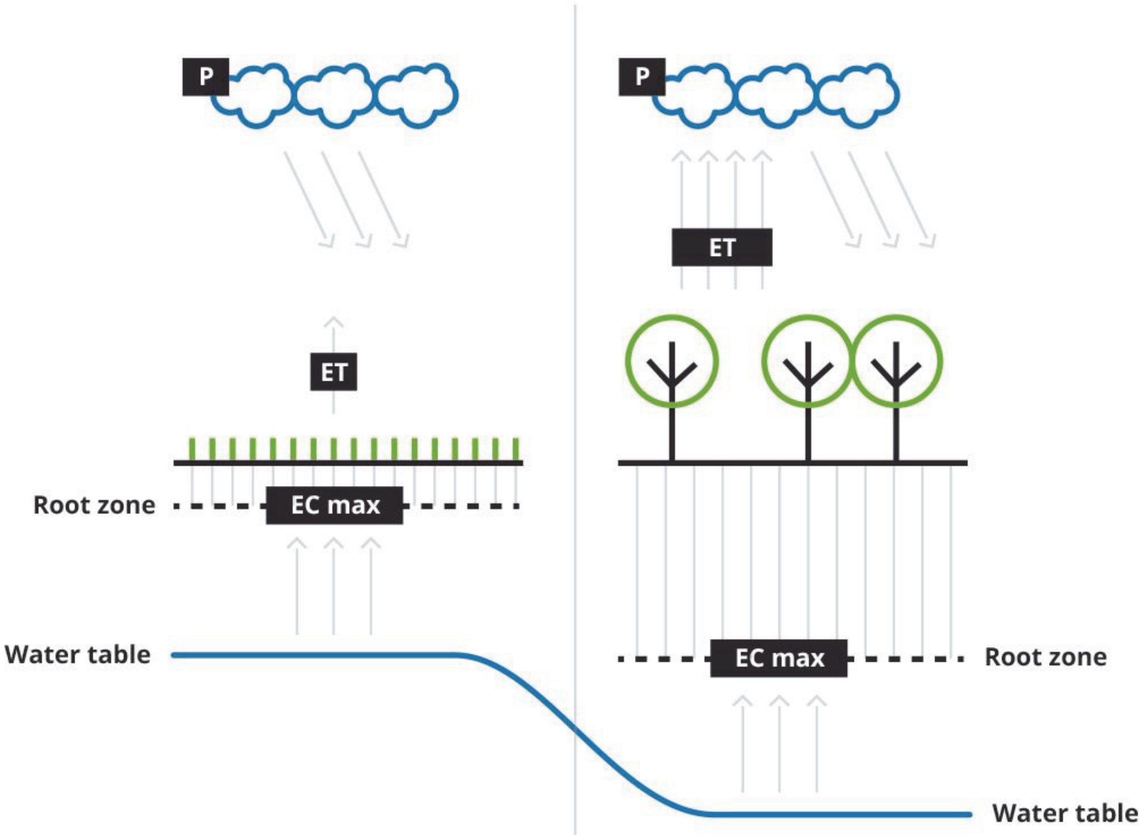

Fig. 2. Impact of forest vegetation on the water and salt balance by a shallow groundwater site (hypothetical model) (after *Szabó et al*., 2012). ET is the evapotranspiration, P is the precipitation.

In addition to vegetation type, soil type and layering also affect the groundwater uptake. Unfortunately, research is related to forest and groundwater relations focused mostly on sandy areas; therefore, the effect of soil parameters cannot be discussed in this paper.

Complex hydrological studies on forest water balance components in Hungary are rare.

The water balance of different land using forms in the northeastern part of the Hungarian Great Plain (Nyírség) was analyzed by *Móricz et al.* (2012). The study considered a dry (2007) and a wet growing season (2008). The lowland common oak forest showed approximately 30% higher evapotranspiration (758 mm) than the neighboring fallow (623 mm) on the yearly scale. The difference was more significant (threefold) for the groundwater use of different vegetation types (oak: 243 mm, fallow: 85 mm). Groundwater consumption was close to 60% of the total transpiration of the oak forest and approximately 30% of the fallow plot. Groundwater consumption was approximately 40% less during the wetter growing season than during the drier growing season despite the deeper groundwater level during the dry period. Consequently, vegetation in both the oak and fallow forests use available groundwater resources.

Remote sensing broadens our possibilities to map and analyze the spatial heterogeneity of landscape unit hydrology, including forests, which are important landscape elements from hydrological point of view.

Evapotranspiration (determined by linear transformation of the MODIS: Moderate Resolution Imaging Spectroradiometer daytime land surface temperature) in the Danube-Tisza sand plateau region of the Hungarian Great Plain was analyzed by *Szilágyi et al.* (2012). The largest ET – 505 mm year^{-1} – according to land cover occurred over deciduous forests. The regional annual precipitation was 550 mm, which shows that in some locations ET amounts are estimated to be larger than precipitation amounts.

These groundwater discharge areas are overlapped by forest areas in many regions. Often the dense and deep root system of forests can tap the shallow groundwater level, which leads to a high evapotranspiration rate that frequently exceeds the precipitation rate. The average annual evapotranspiration for forests is 620 mm year^{-1} in groundwater discharge areas, which is about 70–80 mm more than the mean annual regional precipitation rate. This negative water balance can be maintained if forests create a local depression in the water table and induce a groundwater flow that is directed toward to the forest itself.

2.4. Surface runoff and flood peak reduction

Hydrological studies focusing on streamflow differences between forested and non-forested areas influenced by climate change are scarce in Hungary.

As an example, *Gribovszki et al,* (2006) analyzed rainfall and runoff time series of two neighboring small mixed forested catchments (100% forest cover) in western Hungary in the dry year of 2001 and found, that only 7–10% of the annual precipitation (606 mm) was streamflow, while evapotranspiration remained a dominant part (90–93%) of the annual simple water balance.The average annual evapotranspiration in this forested region was 615 mm (85%), while the yearly average precipitation was 726 mm from 2000 to 2008 (*Kovács,* 2011).

Kalicz et al. (2012) evaluated the runoff data sets of three different subcatchments (forested [HAZ], countryside [BAN], and urban [TESCO]) around Sopron, Hungary. They concluded that specific peak discharges of floods in urban areas induced by major rainfall events exceed those in a forested drainage basin by as much as two magnitudes.

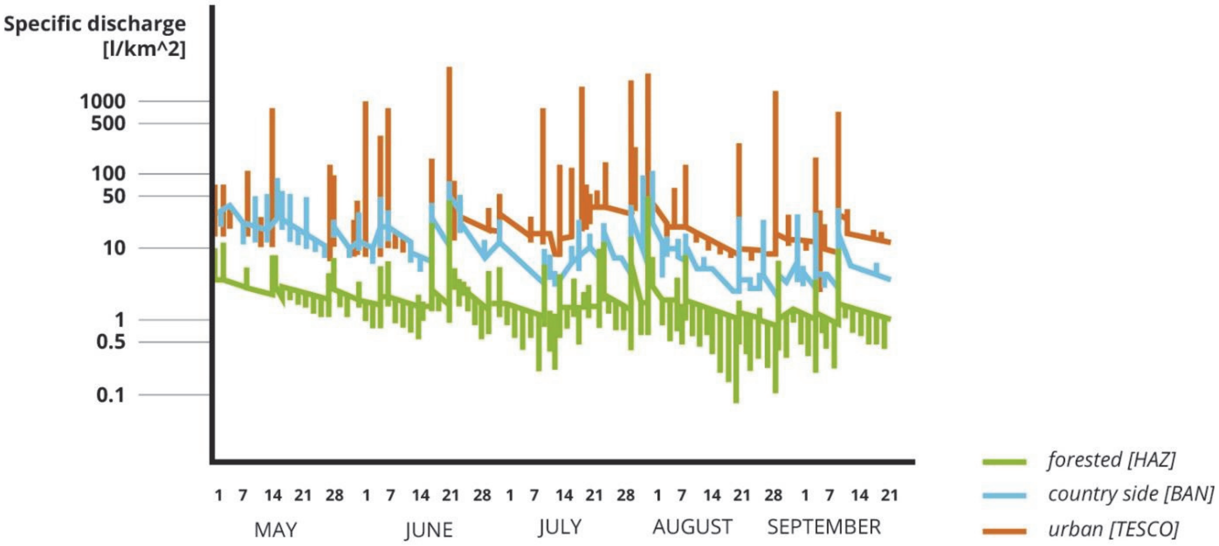

Fig. 3. Comparison of streamflow (specific discharges) for some characteristic subcatchments in Sopron neighborhoods.

3. Concluding remarks

Since forests ecosystems have the most complex hydrological cycle, they will likely be the most influenced by the changing water regime. In the following we summarize the possible changes in the forest water balance elements regarding climate change.

The evapotranspiration of forests (both transpiration and interception) is generally higher than that of other non-woody vegetation due to higher LAI and root depth.

Changes in precipitation distribution due to climate change, such as the increasing frequency of heavy precipitation events, reduces interception loss. This effect increases the amount of water available for transpiration and runoff. Otherwise, the rising temperature coupled with a larger leaf area index induces a higher transpiration if adequate water is present. This increases storage capacity and interception loss.

The greater water demand of forests is most obvious in areas where rainfall alone is insufficient to maintain woody vegetation, but where trees are able to reach groundwater sources through roots. Utilization of this possibility allows forests to survive dry periods. Nonetheless, dry periods that last several years can significantly endanger the survival and regeneration of forests.

Impacts on the water absorption of forests will become increasingly prevalent in a drier climate as long as forest root systems can reach water resources (the soil moisture content of the deeper soil layers or the groundwater). However, forests in these areas will be at great risk once these resources are exhausted. The possible disappearance of these forests is especially problematic in river basins, where forests play a key hydrological role in reducing the amount of surface runoff and the extension of time of concentration in case of floods.

Extreme weather conditions such as large storms will likely be more frequent and more intense due to human-induced climate change. Forests could significantly mitigate the adverse effects of heavy rainfall-related greater surface runoff.

Driven by rising temperatures, increasing transpiration demand in the future will likely induce an enhanced groundwater uptake by plant communities. Eventually, this could lead to the lowering of the groundwater table and significant salt accumulation. If this occurs, the existence of groundwater-dependent forest communities in these areas is questionable, since the root structures of younger forests probably will not be able to reach the additional water source. One possible option to satisfy the demand of groundwater dependent forests is to supply them with water through other means such as river flood waves.

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References

Baird, A.J. and *Wilby, R.L.* (eds), 1999: Eco-hydrology, Plants and water in terrestrial and aquatic environments. Taylor & Frances, London, New York. https://doi.org/10.1046/j.1365-2745.2000.00526-2.x

Delfs, I., 1955: Die Niederschlagzurückhaltung im Walde /Interzeption/. Mitteilungen des Arbeitskreises "Wald und Wasser". Koblenz 2. (In German)

Dingman, S.L., 2001: Physical Hydrology (2nd edition). Prentice Hall.

Führer, E., 1994: Csapadékmérések bükkös, kocsánytalan tölgyes és lucfenyves ökoszisztémában. *Erdészeti Kutatások 8*4, 11−35. (In Hungarian)

Gerrits, A. M. J., Savenije, H. H. G., Hoffmann, L., and *Pfister, L.*, 2006: Measuring forest floor interception in a beech forest in Luxembourg. *Hydrol. Earth Sys. Sci. Discus. 3*, 2323–2341. https://doi.org/10.5194/hessd-3-2323-2006

Gribovszki, Z., Balog, K., Fodor, N., Szabó, A., and *Tóth, T.*, 2012: Impact of lowland forests on water table in shallow groundwater areas of the Hungarian Great Plain. Hydrocarparth International Conference, Catchment processes in regional hydrology: from experiment to modelling in Carpathian drainage basins, Sopron, Hungary, 28-30 October 2012, Conference CD, p. 7. ISBN 978-963-334-069-1.

Gribovszki, Z., Kalicz, P., and *Kucsara, M.*, 2006: Streamflow Characteristics of Two Forested Catchments in Sopron Hills. Acta Silv. Lign. Hung. 2, 81-92.

Hazslinszky, T., 1976: Az erdő szerepe a hidrológiai körfolyamatban. *Vízügyi Közlemények 2*, 295–301. (in Hungarian)

Helvey, J.D. and *Patric, J.H.*, 1965: Canopy and litter interception of rainfall by hardwoods of eastern United States. *Water Resour. Res. 1,* 193-206.https://doi.org/10.1029/wr001i002p00193

Helvey, J.D., 1967: Interception by eastern white pine. *Water Resour. Res.* 1, 723–729. https://doi.org/10.1029/wr003i003p00723

Ijjász E., 1939: A fatenyészet és az altalajvíz, különös tekintettel a nagyalföldi viszonyokra. *Erdészeti Kísérletek 42*, 1–107. (In Hungarian)

Járó, Z., 1980: Intercepció a gödöllöi kultúrerdei ökoszisztémában. *Erdészeti kutatások 73*, 7–17. (In Hungarian)

Járó, Z., 1981: A hazai erdők vízfogyasztása. *Agrártudományi közlemények 40*, 353–356. (In Hungarian)

Johnson, T., 2009: Deforestation and Greenhouse-Gas Emissions. Council on Foreign Relation [online]. in<https://www.cfr.org/backgrounder/deforestation-and-greenhouse-gas-emissions>[quoted on February 12, 2018]

Kajtár, L. and *Vörös, Sz.*, 2004: Risk-Based Modelling of Air Conditioning Systems in Hungary. ROOMVENT 2004: 9th Internaitonal Conference on Air Distribution in Rooms. 2004.09.05-2004.09.08., Coimbra, Portugália, 236–237.

Kalicz, P., Erős, M., Gribovszki, Z., Markó, G., and *Primusz, P.,* 2012: A soproni Rák-patak egy városi szakaszának hidrológiai és hidrodinamikai vizsgálata. In (Eds. A*lbert L., Bidló A., Jancsó T., Gribovszki Z.*) Városok öko-környezetének komplex vizsgálata a nyugat-dunántúli régióban. Nyugat-magyarországi Egyetem Kiadó, Sopron. (In Hungarian)

Kalicz, P., Herceg, A., Kisfaludi, B., Csáki, P., and *Gribovszki, Z.,* 2017: Canopy interception variability in changing climate. *Geophys. Res. Abs. 19*: Paper EGU2017-14894. EGU General Assembly 2017. 2017.04.23 -2017.04.28. Bécs, Ausztria.

Koloszár, J., 1981: Természetes erdei ökoszisztémák és a csapadék. Erdő és víz, VEAB, 75–88. (In Hungarian)

Kovács, Á.D., 2011: Tó- és területi párolgás becslésének pontosítása és magyarországi alkalmazásai. PhD Thesis. TUB, Budapest. (In Hungarian)

Kucsara, M., 1998: Az erdő csapadékviszonyainak vizsgálata. *Vízügyi Közlemények 3*, 456–475. (In Hungarian)

Madas, A., 1980: Az erdőgazdálkodás hatása és jelentősége az árvizek kialakulására. Erdő és víz. Workshop Sopron. Veszprém, 12–22. (In Hungarian)

Major, P., 2002: Síkvidéki erdők hatása a vízháztartásra. *Hidrológiai Közlöny 82*, 319–324. (In Hungarian) https://doi.org/10.1136/bmj.324.7333.319

Móricz N., Mátyás C., Berki I., Rasztovits E., Vekerdy Z., and *Gribovszki Z.*, 2012: Comparative water balance study of forest and fallow plots. *Forest-Biogeosci. Forestry 5(4),* 188-196. [online] in<http://www.sisef.it/iforest/contents?id=ifor0624-005>[quoted on August 2, 2012] https://doi.org/10.3832/ifor0624-005

Lee, R., 1980: Forest Hydrology. Columbia University Press, New York.

Lundberg, A. and *Halldin, S.*, 2001: Snow interception evaporation. Review of measurement techniques, processes, and models. *Theor. Appl. Climatol. 70*, 117–133. https://doi.org/10.1007/s007040170010

Pathak, P.C., Pandey, A.N. and Singh, J.S., 1985: Apportion of rainfall in central Himalayan forests (India). *J. Hydrol. 76*, 319–332. https://doi.org/10.1016/0022-1694(85)90140-4

Putuhena, W. and *Cordery, I.,* 1996: Estimation of interception capacity of the forest floor. *J. Hydrol. 180*, 283–299. https://doi.org/10.1016/0022-1694(95)02883-8

RA, 2017: Rainforest Alliance. What is the Relationship Between Deforestation and Greenhouse Gas Emissions? [online].in<https://www.rainforest-alliance.org/articles/relationship-between-deforestation-greenhouse-gas-emissions>[quoted on February 12, 2018]

Rácz, J., 1981: Az erdő szerepe a vízgyűjtő területek vízháztartásában. Erdő és víz, VEAB, 23–29. (In Hungarian)

Rowe, P.B. 1955: Effects of forest floor on disposition of rainfall in pine stands. *J. For. 53*, 342–355.
Savenije, H.G. 2004: The importance of interception and why we should delete the term evapotranspiration from our vocabulary. *Hydrol. Proc. 18*, 1507-1511. https://doi.org/10.1002/hyp.5563
Schrope, M., 2009: When money grows on trees. Nature Reports *Climate Change 3*, 101–103. https://doi.org/10.1038/climate.2009.78
Szabó, M., 1979: Egy cseres-tölgyes erdő („Síkfőkút projekt") víz és ásványanyag forgalma. Candidate dissertation. Budapest, Hungary. (In Hungarian)
Szabó, A, Kiss, K., Gribovszki, Z., and Tóth, T., 2012: Erdők hatása a talaj és altalaj sóforgalmára, valamint a talajvíz szintjére. *Agrokémia és Talajtan. 61*, 195-209. (In Hungarian) https://doi.org/10.1556/Agrokem.60.2012.1.14.
Szép, T., 2010: A klímaváltozás erdészeti ökonómiai vonatkozásai. *Doktori (PhD) értekezés.* Nyugat-magyarországi Egyetem. 175.
Szilágyi J., Kovács Á., and *Józsa J*., 2012: Remote sensing based groundwater recharge estimates in the Danube-Tisza Sand Plateau region of Hungary. *J. Hydrol. Hydromech. 60*, 64–72. https://doi.org/10.2478/v10098-012-0006-3
Szőnyi, L., 1966: Erdészeti hidrológiai megfigyelések a mátrafüredi kisérleti vízgyűjtőben. *Erdészeti Kutatások 62*, 202–213. (In Hungarian)
Szőnyi, L., 1967: Az erdő hatása a víz levonulására. *Az Erdő 9,* 411–414. (In Hungarian)
Stewart, J.B., 1977: Evaporation from the wet canopy of a pine forest. *Water Resour. Res*. *13*, 915–921. https://doi.org/10.1029/wr013i006p00915
Weisse, M. and *Goldman, E. D.,* 2017: Global Tree Cover Loss Rose 51 Percent in 2016. World Resource Institute. in<http://www.wri.org/blog/2017/10/global-tree-cover-loss-rose-51-percent-2016>[quoted onApril 12, 2018]
Zagyvainé Kiss, K.A., Kalicz, P., and *Gribovszki, Z.*, 2013: Az erdei avar tömege és víztartó képessége közötti összefüggés. *Erdészettudományi közlemények 3*, 79−88. (In Hungarian)
Zagyvainé Kiss, K. A., Kalicz, P., Csáfordi, P., and *Gribovszki, Z.*, 2014: Forest Litter Interception Model for a Sessile Oak Forest. *Acta Silv. Lign. Hung. 10*, 91–101. https://doi.org/10.2478/aslh-2014-0007
Ward, R.C. and *Robinson, M.*, 1975: Principles of hydrology, third edition. McGraw-Hill Book Company Europe 3, 54–70.