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Extending Class A pan evaporation for a shallow lake to simulate the impact of littoral sediment and submerged macrophytes: a case study for Keszthely Bay (Lake Balaton, Hungary)

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ABSTRACT

Class A pan evaporation rate, E_p with sediment cover (S) and submerged aquatic macrophytes (P_s) was analysed in a temperate freshwater shallow lake at Keszthely (Hungary), over three growing seasons between 2014 and 2016. The aim was to identify the importance of this water body's natural components (S and P_s) on E_p. Measured E_p together with reference E of Shuttleworth (E_0) and the FAO-56 equation ET were also derived. Pan coefficient, K_a for filled in pans with S and P_s were computed as the ratio of E_p of the planted pan (P_s/S) and E_p. K_a values determined on-site were tested in the estimation of E for an open water body, namely Keszthely Bay of Lake Balaton. Overall seasonal mean evaporation rate was lower for E_p (3.2 ± 1.05 mm day^{-1}) than the seasonal daily average E_p of S (3.7 ± 1.16 mm day^{-1}) and the E_p of P_s (4.0 ± 1.28 mm day^{-1}). Interannual variation of E_p was controlled by variations in seasonal air temperature, T_a. Data of the wet 2014 season showed a significant suppression of E_p, and this was related to humid and cooler weather conditions causing late emergence and early senescence of the submerged macrophytes (*Potamogeton perfoliatus* L., *Myriophyllum spicatum* L. and *Najas marina* L.) at Keszthely Bay. Overall seasonal mean K_a was greater than 1.0 as determined for the three-season time period in pans with S and P_s (K_{as}: 1.14 ± 0.04; K_{ap}: 1.20 ± 0.05). Except for a previous study from our group (Anda et al., 2016, J Hydrol 542: 615–626) over a two-season period, no such ratio or coefficients have been published, until now. The dominant component of the energy balance was latent heat flux, which accounted for more than 60% of net radiation in Keszthely Bay, depending on Class A pan filling (S and P_s). Diurnal variation in heat storage of the pan also changed due to the occurrence of sediment cover and macrophytes inside the evaporimeters. The most important daily meteorological variables were used to develop the E_p model and to validate S and P_s. Our results show that linear models, even with more input variables, performed better than tree-based models with respect to mean absolute errors (MAE), root mean square errors (RMSE) and determination coefficient (R^2) in predicting daily E_p of S and P_s. The use of pan coefficients K_{as} and K_{ap} increased seasonal E of Keszthely Bay by 4.2, 14.4 and 17.1% during the 2014–2016 seasons, respectively. Total seasonal increments for Keszthely Bay (surface area is about 39 km^2) accounted for 0.97, 4.31 and 3.91 million m^3 throughout 2014–2016, respectively. In the warmer seasons, an increasing trend in the growth of Keszthely Bay's E was detected. These results indicate that Class A pan E_p rates need to be modified to take into account sediment cover and submerged macrophytes to derive open water E. This approximation may lend additional credit to the estimation of E in lakes. Given that appropriate estimation of E can effectively impact the management of an ecologically functional lake's water, maintaining the proper water level and quality can contribute to the sustainability of lakes in the long run.

1. Introduction

Lake Balaton is the largest shallow freshwater lake in Central Europe with a surface area of about 600 km^2 and a mean depth of 3.3 m. The catchment area is about twice as large as the lake's surface area. The most important tributary is River Zala, which enters the lake at Keszthely Bay (Fig. 1). Due to its shallowness (high water surface area compared to mean water depth), Lake Balaton is sensitive to any

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Fig. 1. Location map of the Lake Balaton including Keszthely Bay with Agrometeorological Research Station.

changes in the climatic environment. As evaporation (E) and rainfall (P) are the main factors controlling the lake's water budget, the water level of Lake Balaton is sensitive to actual weather conditions. Tourism around the lake is strongly dependent on stability of the water level, thus information on the lake's E is of primary importance. Four basins can be distinguished based on water circulation patterns. Keszthely Bay,