DOI: 10.31577/ahs-2020-0021.01.0010

ACTA HYDROLOGICA SLOVACA

Volume 21, No. 1, 2020, 82 – 88

METHOD OF WETLANDS WATER REGIMEN DIAGNOSIS

Štefan Rehák*, Peter Stradiot, Karol Kňava, Ľubica Kopčová, Viliam Novák

Wetlands are territories, permanently or temporary waterlogged; temporary waterlogging must cover majority of the season. Wetlands are ecosystems typical by maximum (potential) evapotranspiration with high solar energy consumption; therefore, they are important as local climate stabilizers. In this paper, method of wetland water regimen diagnosis is described, applicable to wetlands with so called autonomous water regimen. It means, that wetland water regimen is formed mostly by precipitation and (potential) evapotranspiration; such wetlands are hydrodynamically isolated from its neighbourhood. This is typical for majority of wetlands in Slovakia. Method of diagnosis is based on evaluation of water fluxes to and out of the wetland and is illustrated on three typical wetlands.

KEY WORDS: waterlogging, precipitation, potential evapotranspiration, wetland management

Introduction

Wetland is permanently or temporary inundated (wet) territory, with characteristic ecosystem. Another define-tion is „wetland is a territory in which water is basic factor influencing living organisms of the territory". They occurred where water table is on the surface, close to the soil surface or soil surface is covered by thin water layer (The Ramsar Convention Manual, 1994). In the past, wetlands were taken as unusable water bodies and were frequently drained.

It was shown that wetlands are home of specific plants and animals; this knowledge led to their conservation. The principles of wetlands conservation as well as the list of the most important wetlands was accepted at Ramsar – a city in Iran; therefore this list is often notified as „Ramsars list of wetlands ". It was shown that wetlands are not important for their biotopes only; but their area on the Earth is so huge, that it can basically influence Earth's climate.

Results of measurements (from the satellites mostly) have shown that the area of wetlands covers about 5 percent of the Earth's surface, i.e. at about 7.5 million of square kilometre (7.5×10^6 km^2). Natural freshwater wetlands area is 5.7×10^6 km^2; even rice fields are wetlands with area 1.3×10^6 km^2; the rest are saline wetlands. As it follows from this analysis, wetlands (7.5×10^6 km^2) together with tropical rainforests (12×10^6 km^2) are the basic ecosystems influencing not microclimate only, but even macroclimate of the Earth. This strong effect on climate is based on the fact, that majority of rainforests and wetlands are in tropical areas, where observed precipitation totals are in the range 3000–6000 mm per year. High incoming fluxes of solar energy allows to evaporate in average about 2500 mm of water layer annually, thus consuming the huge quantity of energy as latent heat of evaporation at about 6.5×10^9 J m^{-2} year^{-1}. Corresponding ratio of biomass production (2.2 kg m^{-2} year^{-1}), represents about four times of boreal forests production. From point of climate change, important is high portion of energy consumption by evaporation and only relatively small part of it (about 10 percent) is heating environment. High rate of photo-synthesis absorbs high quantity of carbon dioxide and thus decreases its concentration in an atmosphere and weakens so called „greenhouse effect".

In Slovakia, the effect of wetlands on water regimen and climate is not so profound as it can be expected in tropical or subtropical areas. The total area of wetlands in Slovakia is 45 km^2, which represents about one thousand of its territory. From 1049 wetlands registered over Slovakia, 21 wetlands are listed in so called „Ramsars list", among them wetland Devínske Jazero which will be analysed.

In this contribution the method of wetlands water regimen diagnosis is presented. Water deficits are quan-tified and needed compensating water fluxes to wetlands can be estimated to optimize their water regimen.

Material and methods

The water regimen of wetlands is characterized by typical pattern of water fluxes to and from wetland as a part of their water balance during the season. To evaluate the type of wetland water regimen, it is necessary to quantify water fluxes between wetland and its environment and to estimate the most important ones which are determining retention of water in wetland. Therefore, to perform wetland water regimen diagnosis, the basic meteorological, hydrological and soil characteristics are needed, the basic ones should be measured at site. Methods of measurement description as well as results of measurement can be found in publications by Holubová et al., (2014 M3; M4).

Three typical wetlands were studied: wetland at Devínske Jazero, (site Šrek), another called Čiližska wetland at Žitný ostrov (Rye Island) nearby village Čiližska Radvaň and wetland at inundation Stará Nitra river (Martovce). All the three wetlands are typical for Slovakia. The method of wetlands water regimen identification will be demonstrated in detail on wetland Devínske Jazero (site Šrek) but results of water regimen analysis of all three wetlands will be presented. Devínske Jazero wetland is so called "Ramsar wetland", i.e. it is listed in the Ramsar list of important wetlands (Fig. 1).

The most important source of water in wetland Devínske Jazero is precipitation (precipitation was measured at site), the most important outflow component is evapotranspiration. The wetlands surface is usually water table with wetlands vegetation, or vegetation grown in wet environment, evapotranspiration of such surfaces can be indicated as potential evapotranspiration, i.e. evapotranspiration is not limited by lack of water, the limiting factors are parameters of atmosphere only. Then, biomass production in such conditions is maximum too. Because evapotranspiration of wetland is technically difficult to measure, its quantification was done by mathematical simulation model HYDRUS-1D (Šimůnek et al., 1997; 2008; Radcliffe and Šimůnek, 2010).

Results and discussion

The basic measured meteorological, hydrological and soil characteristics at wetland Devínske Jazero, site Šrek were measured to be used as input data to the simulation model model to perform diagnosis of wetland water regimen.

Results of water tables measurement of wetland Devínske Jazero and river Morava are in Fig. 2. Water table courses of wetland (1), and river Morava (2), during the wet year 2014 are shown. As it can be seen, inundation surface (3) is usually above the wetlands water table. Precipitation daily totals expressed in mm are also shown.

As it follows from Fig. 2, water table in the river Morava (with exception of short high-water table periods), is below the water table monitored in nearby wetland. Exceptions are periods of high precipitation, and corresponding high-water table level in which Morava river flooded inundation. During the wet year 2014 it was observed in May/June, in August and October. During the dry seasons such inundation is rare. Except of those short periods of inundating, there were not observed interactions between river and wetland. Due to extremely low hydraulic conductivity of soils at the bottom of the wetlands (estimated by measurements) it is assumed low wetland interaction with surrounding water bodies and therefore, analysed wetlands water regimen type can be indicated as autonomous. It means, that wetlands water regimen is formed preferentially by precipitation and evapotranspiration. Particularly, wetland Šrek can be influenced by short time inundation during the wet periods.

Results of analysis have shown:

Significant relationship between water table in the river Morava and water table in wetland (Blato Morava), was not identified during dry periods, because water table in wetland was higher, than water table in the river Morava. Wetland was inundated during the periods of high precipitation totals in catchment of river Morava, which can improve function of wetland.

Because water table in wetland nearby river Morava is not significantly influenced by the river Morava during dry (precipitation free) period, water delivery to the wetland to keep their expected function is necessary. Because Morava river water table is usually below the wetlands water table, it is necessary to manage water pumping from the river to wetland. The necessary fluxes to preserve this wetland function will be evaluated by wetland water regimen modelling.

Quantitative diagnosis of wetland Devínske Jazero water regimen

Quantitative diagnosis of wetland water regimen is evaluation of wetland water fluxes, which significantly influence its water balance and retention. As it was shown previously, the most important water fluxes to and from wetland (Devínske Jazero) are precipitation and evapotranspiration. Infiltration of water from river Morava to wetland is not expected, because water table in the river is below the water level in wetland, (with exception of short intervals of extreme water levels due to high precipitation) as it is demonstrated in Fig. 2, for wet year 2014.

Water fluxes from wetland to river Morava during the vegetation period are negligible, because hydraulic conductivity of wetland bead is extremely low. Hydraulic conductivity of bottom sediments is about K=1x10^{-7} m s^{-1}, (0.1 cm d^{-1}), it is about three orders lower than hydraulic conductivities of neighbouring soils. Low values of hydraulic conductivities of fine particle sediments of wetlands beads is primary reason of wetlands occurrence. Using other words, wetlands were formed in depressions secondary colmated by fine washload transported by nearby river. The natural depression and nearby river occasional flooding its inundation is the condition of such type wetland occurrence. Wetlands at Záhorska lowland (like Zelienka nearby Šaštín) in similar soil conditions (sandy soils), but beads (bottom) sediments of extremely low hydraulic conductivity are the reason of low rate of water infiltration from wetland to groundwater and thus wetlands water regimen are autonomous.

To evaluate wetlands water deficit, water flow to the wetland (measured precipitation) and outflows (potential evapotranspiration), calculated by simulation model will be compared.

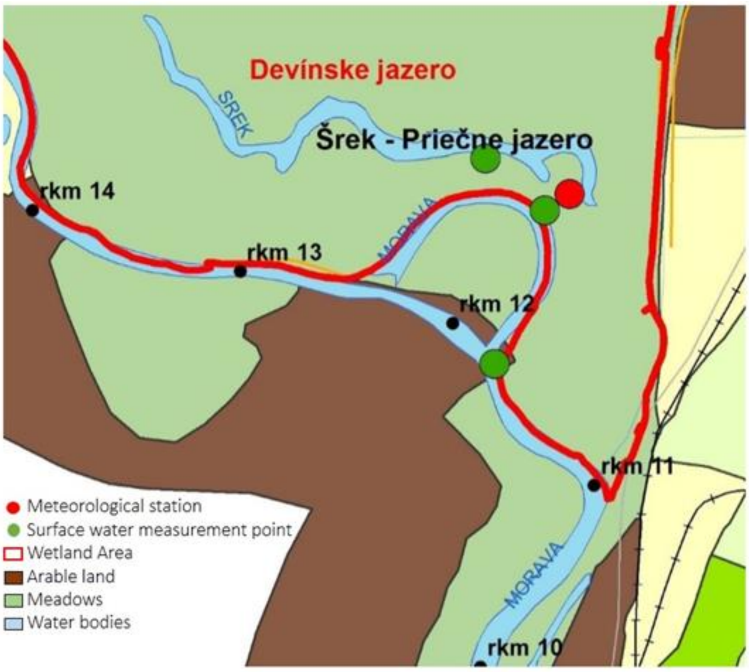

Fig. 1. The wetland Devínske Jazero locality and sites of measurement.

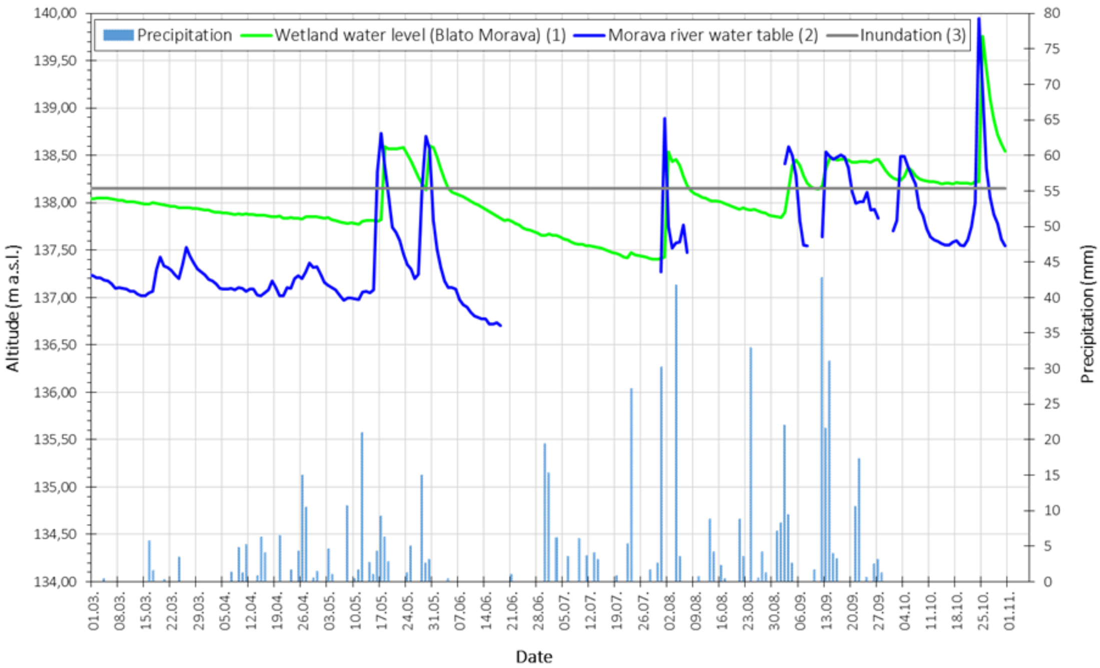

Fig. 2. Measured water table level of wetland Devínske Jazero (1), and water level in river Morava (2). Level of inundation at measurement site is also shown (3). Wet season 2014. Daily precipitation totals are expressed in mm.

Two contrast seasons (wet and dry) were evaluated. The seasonal courses of water deficits (or surplus) of water in wetlands will be estimated and thus water fluxes to wetlands can be managed, to preserve their optimal function.
To calculate water fluxes from a nd to wetlands, mathematical simulation model HYDRUS–1D, was applied to calculate daily totals of potential evapotranspiration of wetlands. Meteorological characteristics as well as soils hydrophysical characteristics measured at site and laboratory (Polák et al., 2014; Holubová et al., 2014, M4) were used as input data.

Simulation model HYDRUS

Model HYDRUS (Šimůnek et al., 1997; Šimůnek et al., 2008; Radcliffe and Šimůnek, 2010; Novák and Hlaváčiková, 2016) is mathematical, deterministic model simulating transport of water, heat and dissolved compounds in porous media (soil). It is used worldwide. Typical for this model is friendly interface, which is continuously improved. Detailed description of the model can be found in the above-mentioned literature.
Richards partial differential equation is the governing equation of the model. Its one dimensional form is used in the model HYDRUS-1D and can be used to simulate transport of water (solute) in one dimension to all directions (vertical, horizontal or in various angle).
To solve Richards equation, initial conditions must be known (initial distribution of soil water content or soil water matric potential) as well as boundary conditions, i.e. conditions at the boundary of the area to be solved. Typical boundary conditions is free drainage at the bottom boundary and precipitation and evapotranspiration at the upper (atmospheric) boundary. Evapotranspiration calculation is a part of the model HYDRUS 1D; in the case of wetlands it is potential evapotranspiration.

Wetland potential evapotranspiration calculation

Modified Penman–Monteith method called FAO method (Allen et al, 2006; Novák, 2012) was used to calculate wetland potential evapotranspiration. Potential evapotranspiration calculated by this method is known as „reference" evapotranspiration. It is potential evapotranspiration of „reference" grass canopy, albedo of which is 0.23. Because wetlands plant canopy grows in wet (and often flooded) environment, its albedo is lower, than albedo of grassland. Albedo *a*=0.13 was used as typical for wetland with appropriate plant canopy, for evaporating surface strongly influenced by water table. Therefore, lower albedo was used accounting for water table as a part of evaporating surface.
FAO Penman–Monteith equation for reference evapotranspiration surface was modified for wetlands, with defined properties of grass and water table. It can be written as (Allen et al., 2006):

$$ET_p = \frac{0.408\,\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_o - e)}{\Delta + \gamma[1 + 0.34\,u_2]} \qquad (1)$$

where
ET_p – is reference evapotranspiration [mm day^{-1}];
R_n – is the net radiation at evapotranspiration surface level [MJ m^{-2} day^{-1}];
G – is the heat flux to or from the wetland [MJ m^{-2} day^{-1}];
T – is the mean daily air temperature at standard height 2 m above evaporating surface [°C];
u_2 – is the wind velocity at standard height 2 m above evaporating surface [m s^{-1}];
e_o, e – is the saturated water vapor pressure at actual air temperature and actually measured water vapor pressure [kPa];
Δ – is the slope of the water vapor pressure curve [kPa K^{-1}];
γ – is the psychrometric constant [kPa K^{-1}].

Results of wetlands water regimen modelling

Daily totals of wetland potential evapotranspiration were calculated by the model. Positive differences between precipitation daily totals (*P*) and daily totals of potential evapotranspiration (E_p) indicate ideal hydric situation covering potential evapotranspiration. Negative differences between them can indicate higher potential evapotranspiration, than can be covered by current precipitation. Then, water table of wetland decreases. It can be noted, that evapotranspiration of wetland can be potential even when the negative difference of precipitation totals and precipitation is observed, it depends on evaporative demand of an atmosphere (Novák, 2012).
Sums of precipitation daily totals (*P*) and calculated potential evapotranspiration (E_p), of wetland Devínske Jazero of wet year 2014 and dry year 2015 expressed in mm are in Figs. 3 and 4.
The difference of precipitation daily totals (*P*) and calculated potential evapotranspiration (E_p), represents the surplus (or deficit) of water in wetland to cover potential evapotranspiration. The water deficit in wetland (negative difference between precipitation daily totals and potential evapotranspiration during the season) means suboptimal function of wetland, because there are not established conditions for potential evapotranspiration and thus for maximum biomass production. The sums of differences between daily precipitation totals (*P*) and daily potential evapotranspiration totals (E_p), expressed in mm of both wet season 2014 and dry season 2015 are presented in Fig. 5. The basic wetlands characteristics were calculated using seasonal courses of differences (P - E_p).
From results of water regimen wetland Devínske Jazero modelling (1308 hectares) it follows necessary water inflow to cover its potential evapotranspiration during time interval of water deficit increase up to 306 l s^{-1} (dry year) and 144 l s^{-1} (wet year). Data for all the three wetlands are in Table 1.

Conclusions

In this contribution the method of wetlands water regimen diagnosis is presented, quantified and quantities of water needed to manage their favourable water regimen are evaluated.
Water regimen of three typical wetlands of Slovakia (Devínske Jazero, Čiližska Radvaň and Martovce) were analysed, based on long – term measurements of their environmental characteristics. As it follows from analysis, their water regimen can be characterized as „autonomous" which means, that precipitation and evapotranspiration are dominant processes of wetland water regiment formation; water fluxes between wetlands and their nearby water bodies (rivers, groundwater) are not significant. This „isolation" is due to extremely low hydraulic conductivities of wetlands beads, located in terrain depressions. Specific situation can be observed at

site Devínske Jazero, where at high water level of Morava river water can inundate wetland.
Quantification of wetlands water regimen was conducted assuming autonomous water regimen, i.e. their water regimen is formed by precipitation and evapotranspiration only. The water balance of wetland was performed for two types of seasons (Table 1): for wet season (2014) and dry season (2015). For the wet season

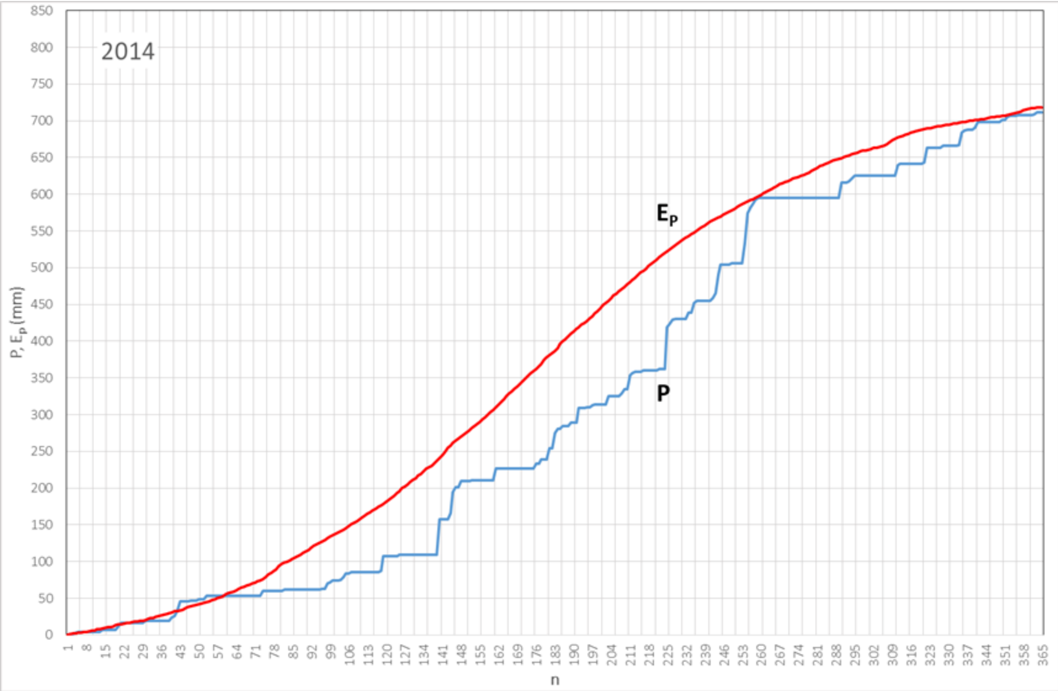

Fig. 3. Sums of precipitation daily totals (P) as well as sums potential evapotranspiration daily totals (Ep), expressed in mm, n is number of the day during the current year. Wetland Devínske Jazero, wet season 2014.

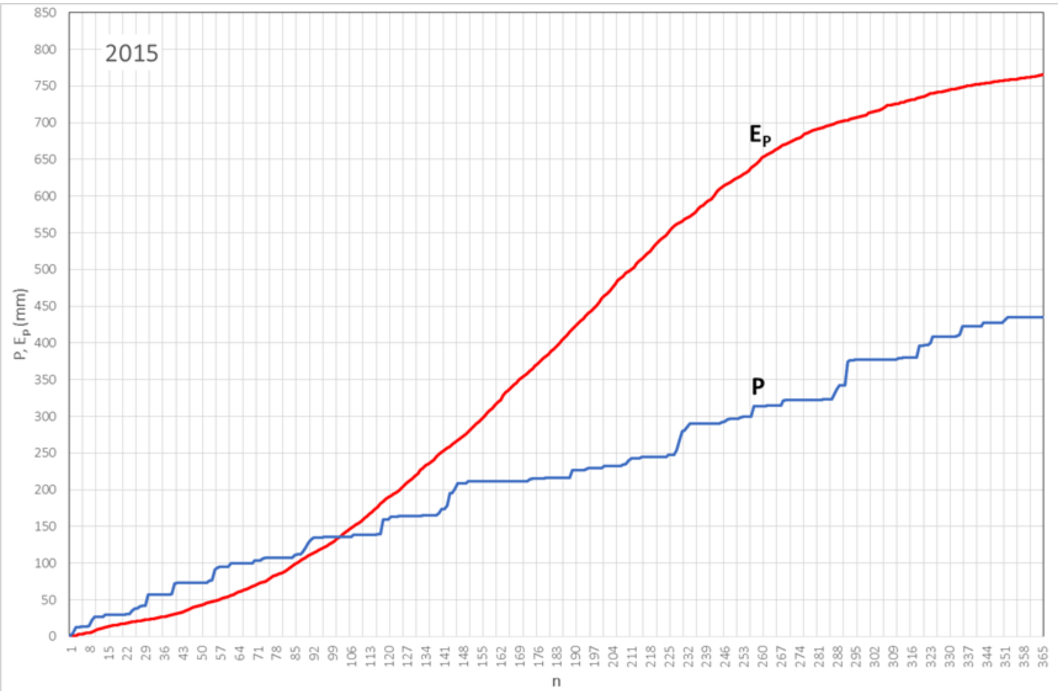

Fig. 4. Sums of precipitation daily totals (P) as well as sums potential evapotranspiration daily totals (Ep), expressed in mm, n is number of the day during the current year. Wetland Devínske Jazero, dry season 2015.

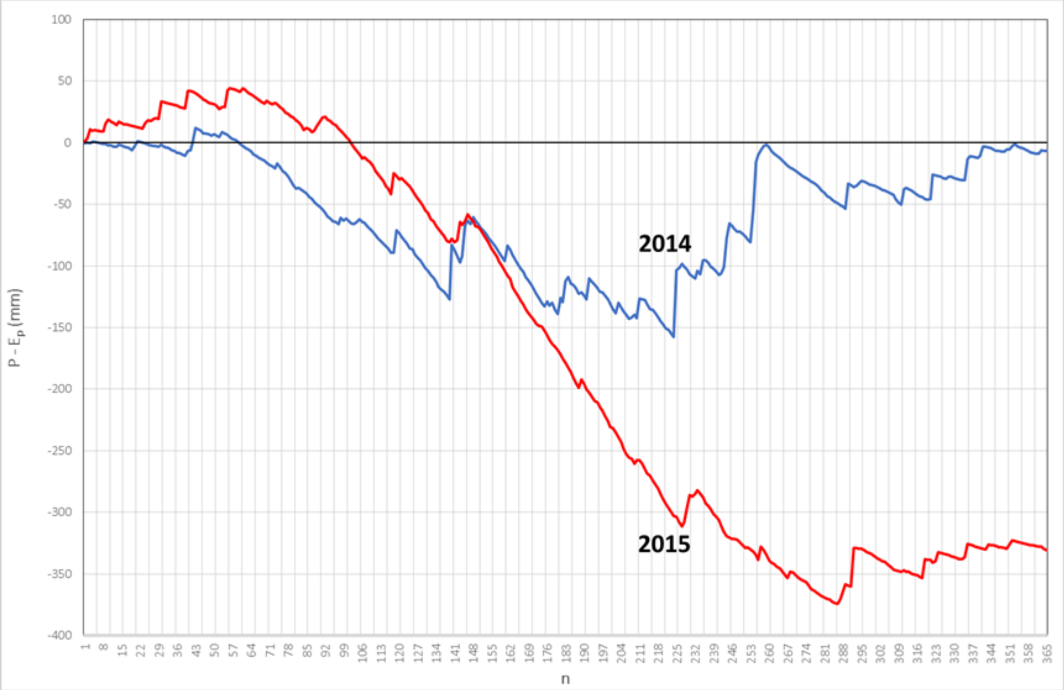

Fig. 5. Sums of differences between precipitation daily totals (P) and potential evapotranspiration daily totals (E_p), expressed in mm, n is number of the day during the current year. Wetland Devínske Jazero, wet season 2014 and dry season 2015.

Table 1. Wetlands water regimen characteristics (Devínske Jazero, Čiližska Radvaň, Martovce) calculated by the model HYDRUS-1D

	D. Jazero	Č. Radvaň	Martovce	Dimensions
n_w	201	174	185	-
n_d	264	275	218	-
D_w	-158	-145	-138	mm
D_d	-374	-282	-244	mm
n_{wd}	166	120	142	-
n_{dd}	185	141	80	-
Q_w	144	2.1	44	l s^{-1}
Q_d	306	3.8	141	l s^{-1}
A	1308	15.6	400	ha
P_w	711	800	787	mm
P_d	435	500	548	mm
E_{pw}	719	720	720	mm
E_{pd}	763	750	750	mm
P_w/E_{pw}	0.98	1.11	1.09	-
P_d/E_{pd}	0.57	0.66	0.73	-

Where: n_w, n_d number of days in wetlands with water deficit during wet (w) and dry year (d); D_w, D_d are total (integral) wetlands water deficits expressed in mm water layer; n_{wd}, n_{dd} are number of days with increasing water deficit during wet (w) and dry year (d); Q_w, Q_d are calculated water inflow needed to cover water deficits during wet (w) and dry year (d) expressed in litres per second; A is the area of wetland in hectares, P_w, P_d are annual precipitation totals during wet (m) and dry year (d); E_{pw}, E_{pd} are annual potential evapotranspiration totals during wet (w) and dry year (d); P_w/E_{pw} and P_d/E_{pd} are relative values of annual precipitation totals and annual potential evapotranspiration during wet (w) and dry year (d).

was not found critical water deficit, (Devínske Jazero, 157, Čiližska Radvaň, 145 and Martovce, 138 mm layer of water) and delivery of water to wetlands is not needed. During the dry season deficits of water are significant (Devínske Jazero, 375, Čiližska Radvaň, 282 and Martovce, 244 mm layer of water) and delivery of water is needed, when some „critical" water deficit (which must be evaluated on site) will be reached.

This approach to the wetlands water regimen type identification and quantification can be applied for wide variety of wetlands with autonomous water regimen. It can be used to manage their water regimen by water delivery to wetlands according to the estimated fluxes and volumes of needed water.

Acknowledgement

Authors are grateful to the Slovak grant agency APVV for financial support of the Project APVV-14-0735 and APVV-16-0278.

References

Allen, R. G. et al. (2006): A recommendation on standardized surface resistance for hourly calculation of reference ET_0 by the FAO56 Penman-Monteith method. Agric. Water Manag. 82, 1–22.

Holubová, K. et al. (2014, M3): Revitalizačné postupy – možnosti obnovy narušenej dynamiky vody v mokradiach. Záverečná správa, VÚVH Bratislava

Holubová, K., et al. (2014, M4): Syntéza najdôležitejších výsledkov a poznatkov. Záverečná správa, VÚVH Bratislava.

Novák, V. (2012): Evapotranspiration in the Soil Plant Atmosphere System. Springer Science + Business Media, Doordrecht, pp. 253.

Novák,V., Hlaváčikova, H. (2016): Hydrológia pôdy. VEDA, Vydavateľstvo SAV, Bratislava, s. 347.

Polák, et al. (2014) (M1). Abioticko – fyzikálne procesy: Komplexná analýzy vodného režimu mokradí. Záverečná správa, VÚVH Bratislava

Radcliffe, D.E., Šimůnek, J. (2010): Soil Physics with HYDRUS. Modeling and Applications, CRC Press, Taylor and Francis Group, LLC, USA

Rejmers, N. F. (1985): Mikroenciklopedija biosfery, Znanie, Moskva.

Šimůnek, J., Huang, K., Šejna, M., van Genuchten, M. Th., Majerčák, J., Novák, V., Šutor, J. (1997): The HYDRUS-ET software package for simulating one dimensional movement of water, heat and multiple solutes in variably saturated media. Institute of Hydrology, SAS, Bratislava, pp. 184.

Šimůnek, J., Saito, H., Sakai, M., van Genuchten, M. Th. (2008): The HYDRUS-1D software package for simulating one dimensional movement of water, heat and multiple solutes in variably saturated media. Version 4., Hydrus Series 3. Dept. of Environmental Sciences, Univ. of California Riverside. Riverside, CA, USA.

The Ramsar Convention Manual (1994): The Ramsar Convention Secretariat, Mauverny.

doc. RNDr. Štefan Rehák, PhD. (*corresponding author, e-mail: rehak@vuvh.sk)
RNDr. Peter Stradiot, PhD.
Ing. Karol Kňava, PhD.
Ing. Ľubica Kopčová, PhD.
Institute of Water Resources Research
Nábrežie arm. gen. L. Svobodu 5
812 49 Bratislava 1
Slovak Republic

Ing. Viliam Novák, DrSc.
Institute of Hydrology SAS
Dúbravská cesta 9
84104 Bratislava
Slovak Republic