WATER BALANCE OF ZÁHORSKÁ WETLAND ECOSYSTEMS

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Abstract: The hydrology of wetland creates the unique physiochemical conditions that make an ecosystem different from both terrestrial systems and deepwater aquatic systems. Hydrologic pathways such as precipitation, surface runoff, groundwater and flooding rivers transport energy and nutrients to and from wetland. Hydrologic condition are extremely important for the maintenance of a wetland`s structure and function, affect many abiotic factors, including soil anaerobiosis, nutrient availability.

In the following paper can be seen evaluation of the hydrologic condition and quantification of the particular components entering into the water budget in case of the peat bog Zelienka.

INTRODUCTION

The wetlands of the Záhorská Lowland are considered as the rare and relict communities and belong to the most threatened ecosystems of the Slovakia. Although they are not extended in a big area, their value from biodiversity and ecological function point of view exceed their real area. They belong to the most extreme ecosystems with the unique microworld, which we know a very little.

Recent hydrologic conditions of the Záhorská Lowland, while they are not changed by the human activities, are the result of the many factors. There are geologic and tectonic structure, soil and climatic conditions. Development of the hydrologic conditions in the main features affected geology and tectonics of the older sediments. Detailed formation is the result of the several thousand years fight of the climatic and soil factors after glacial period.

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In the era, when the Tatra mountains and the Alps covered the glacier and the glacier of the european glaciate got to the brim of the northern boundary of our country, cold steppe with the smaller lakes and poor vegetation extended on the area of the Záhorská Lowland. In the period of the moderate warming extended birches and pines in the form of the shrubs and later in the form of smaller forest units. The river Morava slowly moved to its present river channel and left behind number of the dead branches. This branches and lakes sprouted by the water vegetation. In this area was strong wind activity. The wind carried away a big amount of the sand and lodged its on the another places. In the localities, where the sand was wetter, were favourable conditions for the forest vegetation overgrowth. There arised forest islands, which pervaded to remaining part of the lowland. It was basis of the forest, while the human planted a big complex of the pines.
Rivers as well as discharge lakes, drained slopes of the Small Carpathians, made a way through the sand dunes to the river Morava. During the ages rivers changed their channel and filled tectonic decreases by the transported materials and formed alluvia cones. Streams in some parts held function of the drainage of the groundwaters, or else supplied their decreases and wet areas, water reservoirs together with precipitation waters. Wet areas arised in dependence of the geologic structure that means on the places, where impermeable subsoil presented by the clay is near the surface. From the reason the exchange of the decreases and elevations came in frequent transition from wet areas to dry areas and conversely. The wind activity decreased during the next warming of the european climate and pine – oaken wood with the hazel undergrowth intensely expanded on the sands. Streams continued in the formation of the terrain morphology. In the period of the high water level they flooded dead branches. There was overgrowth, which allowed formation of fen peat sediments. Growth of alder enlarged on the surface of this peat substance. Grassy communities of psammophytes rooted in the higher sand dunes, where suitable conditions were not for the pine – oaken forests. These conditions endured to beginning of our era.

Exploation of oaken forests began by the soldiers of Roman legions and endured to Middle Ages. During 16 – th century human began with the plantation of the pine monocultures in the big amount. He reforestes all places without agricultural areas.

MATERIAL AND METHODS

In Slovakia the wetlands are among the most seriously threatened natural ecosystems. The first inventories of wetlands in Slovakia have been carried since 1991 (Slobodník & Kadlečík, 2000). The main purpose of these inventories was to collect the relevant information on the wetlands, in accordance with the obligations resulting from the Ramsar Convention, and identify the other wetlands of international importance (in addition to the already designated Ramsar sites).

We evaluated 30 peatlands in the Záhorská Lowland from the current state of their water regime, degree of their degradation by peat extraction or waste disposal (filling), recent and suggested conservation status, their restoration potential and suggested restoration and management measures point of view (Šíbl et al., 2002).

The restoration of the peatbog water regime in the National Nature Reserve Zelienka is the pilot project.

Pilot Project – National Nature Reserve Zelienka

The wetland of National Nature Reserve Zelienka is representative example of the many inter-dune wetlands situated in the Záhorská Lowland.

National Nature Reserve (NNR) Zelienka is situated in central part of the Záhorská Lowland, specifically in the Protected Landscape Area Záhorie. It represents a peat bog community of the relict origin with open water level (Fig. 1.).

Figure 1. The National Nature Reserve Zelienka

The NNR Zelienka occupies area about 82,52 ha, area of only wetland is about 60 ha. In 1980 it was announced as one of the last well – preserved fen bogs in inter - dune area. The wetland belong to the minerotrophic mire. The fen alder grove is dominant there and gradually it converts to the birch plantation, the rest of the area is covered by pine woods.

The formation of the hydrologic condition in the Zelienka National Nature Reserve arose from the geological, tectonic and geomorphological structure of the locality as well as the soil, climatic conditions and impact of human activities.

There are three basic geological indicators, which participated on the peat bog formation in National Nature Reserve Zelienka: the high raised neogene subsoil of the eolian drift sand, slope of the impermeable neogene subsoil in area of sand dune Kobyliarka to the east, the rise of neogene sediments without quarter cover to the eastward from the Šaštínsky brook and also the hydrologic element specifically existence of the Šaštínsky brook. Šaštínsky brook, collecting water from high rised impervious sediments, especially marls, marly loams and loams of the Late Badenian without cover of the quarter sediments, prevented drift sand moving to the east and the north – east through the creation of consistent humidity together with sediments barrier of the Late Badenian situated eastwards from the Šaštínsky brook (Fig. 2.).

This relates to the fact that the peat bog is situated in between the dunes area; the groundwater infiltrated from precipitation to the drift sands in a wide neighborhood of the Kobyliarka sand dune is the main source of the water supply. This water supply of the peat bog by groundwater is dominant and stable with altering intensity of refilling in depending on the total precipitation.

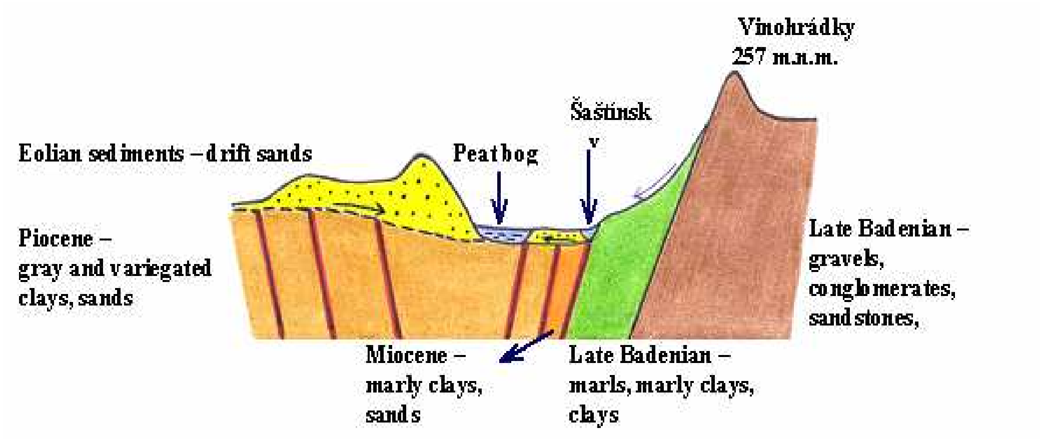


Figure 2. Geological profile through the wetland area

Understanding of hydrological conditions like hydrologic cycle in the area is not doing without quantification of hydrological balance components. The general balance between water storage and inflows and outflows is expressed as (Mitsch & Gosselink, 2000):

$$\Delta V/\Delta t = P_n + S_i + G_i - ET - S_o - G_o \pm T \qquad (1)$$

where:

$\Delta V/\Delta t$ = change in volume of water storage in wetland per unit time t,
P_n = net precipitation,
S_i = surface inflows, including flooding stream,
G_i = groundwater inflows,
ET = evapotranspiration,
S_o = surface outflows,
G_o = groundwater outflows,
T = tidal inflow or outflow.

In the present there are developed numerous methods of the measurement and computation of evapotranspiration. These methods distinguish in dependence of the vaporized surface and time interval, for which is necessary to destimate the evaporation intensity. Quality and number of the available input data decide about method choice. (Novák,1995).

We decided for physical reasoned method according to Budyko a Zubenoková, which is based on the equation solve of the water and energy balance.

Calculation of the Potential Evapotranspiration

The methodology of the potential evapotranspiration computation is developed in the work of Tomlain & Damborská (1999) and it can be determined from equation:

$$E_0 = \rho D(q_s - q) \qquad (2)$$

where:

E_0 = potential evapotranspiration [cm],

ρ = air density (ρ = 1,298 .10^{-3} g.cm^{-3}),

D = integral diffusion coefficient (in winter D= 0,3 cm.s^{-1}, in summer D= 0,63 cm.s^{-1}),

q_s = measuring air humidity saturated by water vapour at the temperature of the vaporized surface[hPa],

q = measuring air humidity in the meteorological box [hPa].

It is important to know the temperature of the vaporized surface T_w in order to q_s. If soil surface temperature data is missing, than T_w is assessed by equation of the surface energy balance:

$$B = \lambda E_0 + H + Q \qquad (3)$$

where:

B = total surface radiation balance [kcal.cm^{-2}.mes^{-1}], (1 kcal.cm^{-2} = 11,63 kWh.m^{-2}),

λ = latent heat of vaporization (λ = 2,5.10^3 kJ.kg^{-1}),

H = turbulently heat flux between surface and atmosphere [kcal.cm^{-2}.mes^{-1}],

Q = soil heat flux [kcal.cm^{-2}.mes^{-1}].

After substitution

$$B = B_0 - 4\varepsilon\sigma T^3 (T_w - T) \quad \text{and} \quad H = \rho C_p D(T_w - T) \qquad (4)$$

Into the equation 2 we get:

$$B' - Q = \lambda \rho D(q_s - q) + (4\varepsilon\sigma T^3 + \rho C_p D)(T_w - T) \qquad (5)$$

where:

B' = radiation balance of the wet surface (lonfwave radiation balance calculated from air temperature) [kWh.m^{-2}],

$4\varepsilon\sigma T^3 (T_w - T)$ = correction at the difference between temperature of the radiated surface and air temperature

T_w = soil surface temperature [K],

T = air temperature [K],

ε = emissivity (for deciduous wood ε = 0,97 a for coniferous les and grass ε = 0,98),

σ = Stefan – Boltzmann constant (σ = 5,67.10^{-11} kWh.m^{-2}.K^{-4}),

C_p = measuring thermal capacity of air at constant pressure [for dry area C_p = 1,004 kJ.kg^{-1}.K^{-1}, for humid area C_p = 1,004(1+0,90q) kJ.kg^{-1}.K^{-1}].

Members T_w a q_s are unknown in the last equation, therefore it is possible to use Magnus equation:

$$q_s = 6{,}1.10^{\frac{7{,}45 t_w}{235 + t_w}} \qquad (6)$$

where:

t_w = soil surface temperature [^oC].

Potential evapotranspiration is evaluated by the physical component series, which is important to take note in framework of its calculation, namely:

- heat, which can be used to the vapour – it is characterized by total radiation balance,
- air potential take in water vapour – it is quantitatively characterized by the vapiur pressure deficit of the air,
- air layers capability contiguous to the soil surface to transfer water vapur from vaporized surface into the atmosphere (turbulently exchange of the water vapour).

Calculation of the Actual Evapotranspiration

Method of the evapotranspiration computation is following (Tomlain & Damborská, 1999):

$$E = E_0 \frac{\overline{W}}{W_0} \qquad (7)$$

where:

E_0 = potential evapotranspiration [cm],

$\overline{W}$ = average soil humidity [cm],

W_0 = critical humidity [cm].

Values of the W_0 are altered during the year and are dependent on the developmental phase of the vegetation as well as yearly run of the air temperature. Average soil humidity $\overline{W}$ can be calculated as follows:

$$\overline{W} = \frac{W_1 + W_2}{2} \qquad (8)$$

where:

W_1 = soil humidity at the time interval beginning [cm],

W_2 = soil humidity at the time interval end [cm].

If $P \geq E_0$, than W_2 is given as:

if $0 < \overline{W} < W_0$

$$W_2 = \frac{P - E_0 + W_1\left[1 - \frac{P}{2W_k}\sqrt{\alpha^2\left[1-\left(1-\frac{E_0}{P}\right)^2\right]+\left(1-\frac{E_0}{P}\right)^2}\right]}{1 + \frac{P}{2W_k}\sqrt{\alpha^2\left[1-\left(1-\frac{E_0}{P}\right)^2\right]+\left(1-\frac{E_0}{P}\right)^2}} \qquad (9)$$

if $\overline{W} \geq W_0$

$$W_2 = \frac{P - W_1\left[\frac{E_0}{2W_0} + \frac{P}{2W_k}\sqrt{\alpha^2\left[1-\left(1-\frac{E_0}{P}\right)^2\right]+\left(1-\frac{E_0}{P}\right)^2} - 1\right]}{\frac{E_0}{2W_0} + \frac{P}{2W_k}\sqrt{\alpha^2\left[1-\left(1-\frac{E_0}{P}\right)^2\right]+\left(1-\frac{E_0}{P}\right)^2} + 1} \qquad (10)$$

If $P < E_0$, than W_2 is given as:

if $0 < \overline{W} < W_0$

$$W_2 = \frac{P - W_1\left(\frac{E_0}{2W_0} + \frac{\alpha P}{2W_k} - 1\right)}{\left(\frac{E_0}{2W_0} + \frac{\alpha P}{2W_k} + 1\right)} \qquad (11)$$

if $\overline{W} \geq W_0$

$$W_2 = \frac{P - E_0 - W_1\left(\frac{\alpha P}{2W_k} - 1\right)}{\frac{\alpha P}{2W_k} + 1} \qquad (12)$$

where:

P = average monthly precipitation total [cm],

W_k = the biggest value W_0 during the year (the biggest water content, which can be kept in the highest soil horizon without groundwater contact) [cm],

α = proportionality coefficient, which depend on the precipitation intensity,

α = 0,2, ak $P \leq 760$ mm,

α = 0,3, ak $760 < P \leq 960$ mm,

α = 0,4, ak $P > 960$ mm.

Value W_1 is assessed by the method of the successive approximation.

RESULT AND DISCUSION

The methods of potential and actual evapotranspiration calculation showed in paper present simplified version, which takes into consideration a fact, that small Zelienka wetland arose in Záhorie as a result of blow away of sand from the dunes to the impermeable rest. Zelienka wetland represents non – runoff depression in the dish shape.

Concerning the determination of the balance formula in a shorter time period, it is very important to take note of water reserves changing in the peat bog ΔV during time interval Δt. This element of hydrological balance is much more important than is the time interval for which the balance formula is constructed. We can retrospectively determine flooding areas and water volumes for the measured water stages which were admitted into the peat bog during the given time interval, namely by graphic construction of the extent and volume lines as the conclusion of the procedure (Fig. 3.).

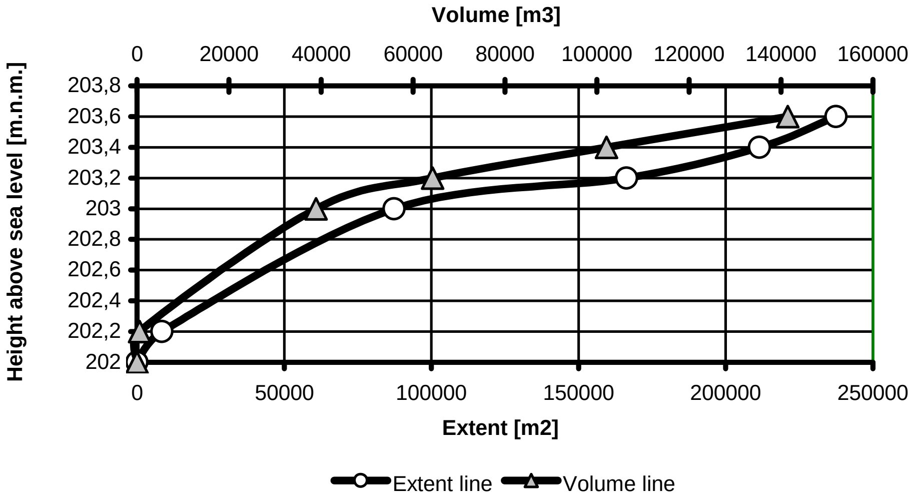


Figure 3. Extent line and Volume line of the peat bog Zelienka

On the right side of the formula balance the net precipitation (P_n) is entered. This is precipitations which actually reaches the water level in the peat bog and is characterized as the difference between the total amount of precipitation and interception. Since the relevant locality is forested, the bulk of the area is covered by boggy alder, which passes into the birch oak grove and the rest of the area is composed of pine woods. For the calculation the points of view of two experts, Dunn and Leopold (1978), were chosen. They indicate that a precipitation percentage which comes under interception is from intervals of 8 – 35%; the average value is 13% from greenwoods and 28% from coniferous woods. In our calculations we chose the amount 20.5%, because the area of interest is covered by greenwoods as well as coniferous woods.

The surface water in the form of runoff is the next important element entered into the balance formula. Since the peat bog is not an integrated component of the stream, we cannot speculate about the stream runoff. It is possible to speculate about the surface inflow into the peat bog. The fact that the peat bog is situated in an inter-dune area makes it possible that rainfalls infiltrate into the surrounding sand drifts. The precipitation passes through the good permeable soil till it reaches impermeable Neogene subsoil. The slope of the Neogene sediments eastwards and northeastwards enables the movement of the precipitation into the peat bog's area. Based on the above-mentioned facts, it is possible to ignore the surface inflow into the peat bog, because is involved in the groundwater inflow on which it is transformed.

Through calculating the monthly evapotranspiration totals we consider the fact that the soil contains sufficient water, whereupon the potential evapotranspiration values are near the actual values. The consequential values of the potential evapotranspiration are displayed graphically (Fig. 4).

It is possible to express balance the equation on the basis of the above-mentioned facts in this form:

$$\Delta V / \Delta t = P - I - ET + G_i - G_o \qquad (13)$$

where:

$\Delta V / \Delta t$	=	change of the water storage in the peat bog per unit time t [m],
P	=	yearly precipitation total [m],
I	=	interception [m],
ET	=	yearly evapotranspiration total [m],
G_i	=	groundwater inflow into the peat bog for year [m],
G_o	=	groundwater outflows from the peat bog for year [m].

We got the following balance formula after the quantification of the individual components during 2001: $0{,}07 = 0{,}529 - 0{,}108 - 0{,}739 + G_i - G_o$

$G_i - G_o = 0{,}388$ m. The change of the water capacity represents 10 000 m^3 on the area 124 500 m^2.

The year 2002: $0{,}08 = 0{,}707 - 0{,}145 - 0{,}471 + G_i - G_o$

$G_i - G_o = 0{,}091$ m The change of the water capacity represents 14 000 m^3 on the area 200 000 m^2.

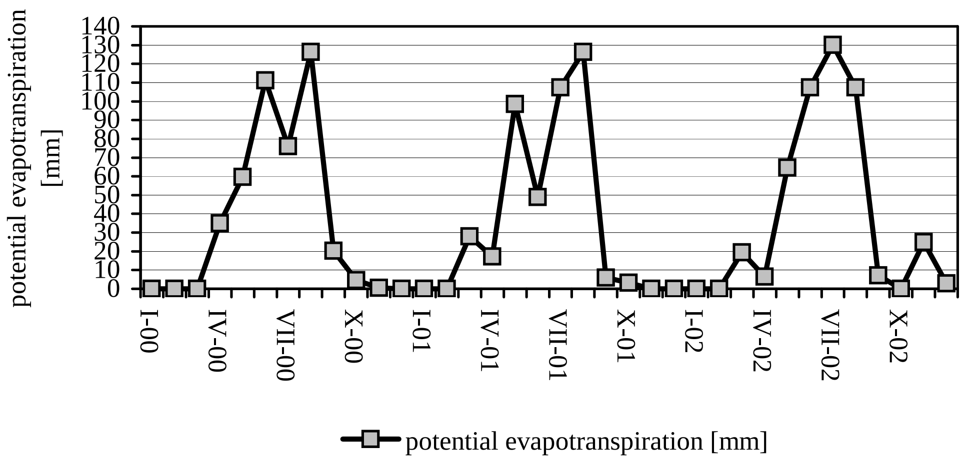


Figure 4. Average monthly totals of the potential evapotranspiration in case of the Station Kuchyňa – Nový Dvor

In case of balance of the long years duration period is possible to write a balance formula in a basic form (2):

650 mm = 492 mm + 158 mm (during 1961-1990, inputs are used from Meteorological Station Kuchyňa – Nový Dvor).

Average monthly totals of the potential evapotranspiration (Fig. 5) enter together with average totals of precipitation and monthly values of the critical and real soil humidity into the calculations of the monthly value of actual evapotranspiration and water runoff (Fig. 5).

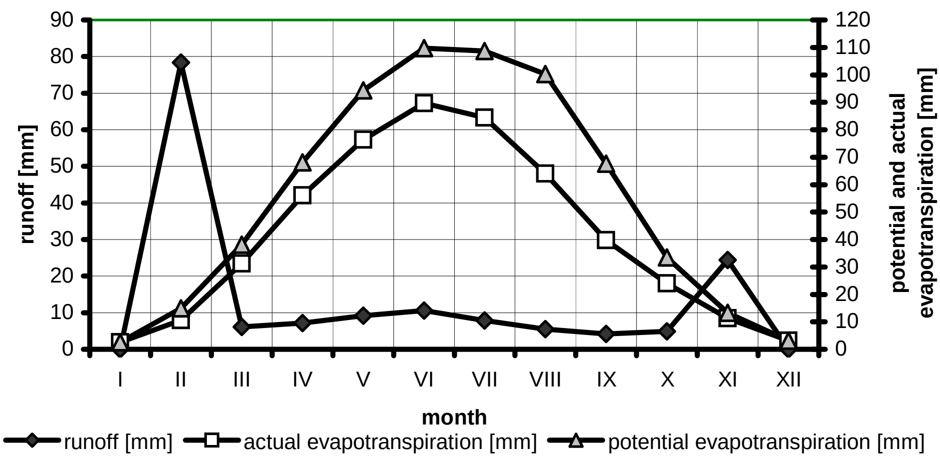


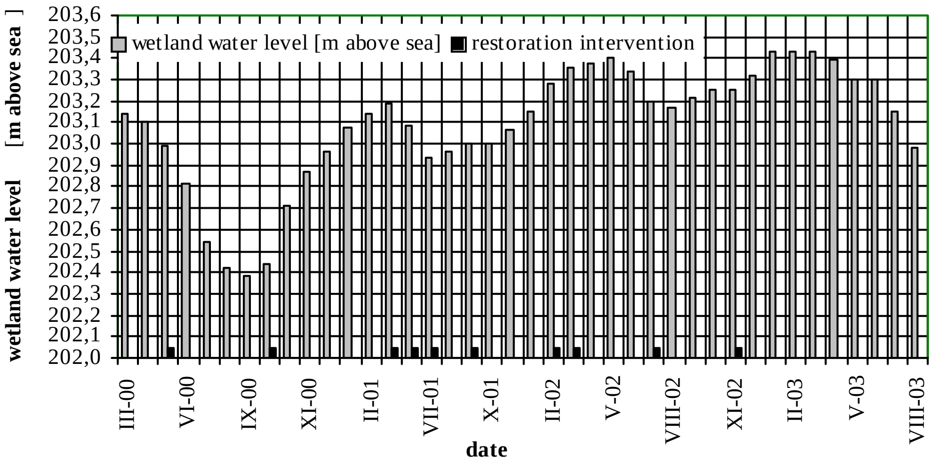
Figure 5. Average monthly totals of the potential and acual evapotranspiration and mothly runoffs values during 1961 – 1990 in case of the Meteorological Station Kuchyňa – Nový Dvor

In the past increasing agricultural land acreage was favored. For this reason drainage of the wet areas was constructed. The use of drainage ditches in the locality of Zelienka resulted in water loss. At present, when the use of the surrounding areas is not very interesting for agriculture, the restoration measures are preferred.

It came up to water lossing in coherence with given locality Zelienka by drainage ditches. There was installed a water gauge in the drainage ditch on the north-east border of the peat bog in March 2000 (Fig. 6.). In that year it began to realize the restoration measures, which led to water regime restoration in reserve area.

These measures consisted of change of drainage ditches to the irrigation cannals. Technical realisation consisted of building of barrages in main ditch to achieve a change of water level height and a decreasing of hydraulic water gradient. It was used clay – sandy material from surrounding environment. In case of other needs it could be possible to plug these barrages by geotextile or clingfilm. During years 2000 – 2001 it was built 12 barrages, which had a positive reaction on the water regime of the wetland in short period. It was achieved water level increasing about 56 cm (water level stage measured on September the 22 – th, 2001 – Fig. 6.), thereby it came to a total compensation of decreasing of water levels, which was caused by digging of drainage ditches in 1980–s; groundwater level decreased more than 50 cm. (Krippel, 1988). The underground runoff was stopped from the drainage ditches.

Figure 6. Changes of the water level regime in dependence of the restoration intervention



Water management intervention in the locality Zelienka caused sharp change of hydroecological conditions in this wetland ecosystem. Obvious decreasing of groundwater level, induced by untimely intervention in water regime, caused noticeable remission the most important phytodiversity species in this locality, mainly more ecological easily vulnerable hygrophytes and hydrophytes elements. In this locality remain only a few fragmentary developed wetland biotops. Phytocenose of asociation *Spagno warnstorfiani (Caricetum davallianae)* suffered the most, in comparing to optimal water regime condition (1970-s).

The dominant *Carex elata* was substituted by degradingly, more xerophile phytocenose *Molinio – Arrhenatheretea.* Free meadow areas are colonized intensively by association *Calamagrostietum cacens,* which is eliminative for original biotop of transition fen from ecological point of view.

Phytocenose of transitional wetlands predominated before drainage of the locality (second mid of 1970-s), especially optimally devoloped phytocenose *Peucedano – Caritum lasiocarpae and Caricetum elatae.* There dominated the number of tall sedges, such as: *Carex lasiocarpa, Carex appropinquanta, Carex paniculata, Carex davalliana*, with spacious coverage of moss covers and peat mosses. In this period was no problem to find relict, especially important species of Zahorie flora – *Rhynchospora alba. Drosera rotundifolia, Viola palustris, Comarum palustre,* *Pedicularis palustris, Menyathes trifoliata* and many other species were associated with peat mosses. Scientifically most prominent plant of locality – *Rhynchospora alba* planted on the water area border of the given peat bog (Bosáčková, 1968).

Even though the water regime was not optimal, it retained fragments of *Caricetum elatae* with interesting *Cirsium palustris* and tall sedges, especially *Carex elata.*

There are optimal developed fen alder woods *Alnetea glutinosae.*

It retained fragments of *Caricetum elatae* with interesting *Cirsium palustris* and tall sedges, especially *Carex elata, Caricetum elatae*.

There dominates threatened *Carex lasiocarpa* there. In wood layer dominate: *Alnus glitinosa, Batula pubescens*, particulary oak trees and more kinds of *Salix*

In brush layer dominate: *Frangula alnus, Sorbus aucuparia, Viburnum opulus.*

In herb layer dominate: very significant occurrence of *Iris pseudacorus, Hottonia palustris, Cardamine, Scirpus sylvaticus, Caltha palustris, Dryopteris cristata, Thelypteris thelipteriodes, Thysselinum palustre.*

From biological – protectional point of view are there optimal developed fen alder woods *Alnetea glutinosae.* A liquidation of drainage ditch benefits to their development. Fen alder woods are optimal flooded and are associated to the most representative species of whole Záhorská Lowland.

It can by noted that restoration measures made up to now and focused on hydroecological components improvement in this area, contributed to restoration of the original vegetation in significant rate. This process is very slow and results can´t be displayed in whole extent so fast in this short time period after using restoration measures. It would be suitable to continue in this restoration works and also it would be very needed to eliminate of wood seeding to assign reliable phytodiversity development.

CONCLUSION

The paper shows only a partial view on problems of evapotranspiration calculation in case of Zelienka Wetland. Assessment of evapotranspiration through prepared model is an aim of our works, the model will take into account following input of meteorological variables: daily values of precipitation [$mm.day^{-1}$], mean temperature [^oC], sunshine duration [hours], vapour pressure [hPa] and mena wind velocity [$m.s^{-1}$], input of crop parameters: leaf area index [$m^2.m^2$], roughness of evaporating surface [m], albedo of surface, root depth [cm], input of lower boundary condition.

A reconnaissance of terrain from vegetation species point of view was necessary for that reason – it goes about grass and woods typology and their percentage share on wetland´s area. The methods of potential and actual evapotranspiration calculation from meadow cenose showed in paper present simplified version, which takes into consideration a fact, that small Zelienka wetland arose in Záhorie as a result of blow away of sand from the dunes to the impermeable rest. Zelienka wetland represents non – runoff depression in the dish shape. Evapotranspiration from arbitrary surface depends on a whole range factors, from which the total radiation balance of evaporating surface, volume of water in soil a plants turbulent situation of the atmosphere are the most important one – we thought with the grass surface.

Through the revitalisation measures was runoff stopped from the drained ditches.

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