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REMOTE INFILTRATION AREAS AS A MAIN SOURCE OF GROUND WATER FOR FLOODPLAIN FOREST WITHOUT FLOODS

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Abstract

This article brings new information about phenomenon of the growth of floodplain forest without influence of floods over 50 years. Floodplain forest and its hydrogeological regime are under detail research for 10 years and detail 10 years data from hydrogeological well is used in this study. The area of interest belongs to nature reserve Plackuv les what together with brook Satava represents a unique relic of a floodplain forest in the confluence area of the rivers Svratka and Jihlava in southern Moravia (South-Moravian Region). The damming of the channel of the river Svratka has caused the end of floods. Despite the anthropogenic regulations performed, the hydrogeological conditions have remained preserved at the site. Stream channel was rised due to the regulation at the above the level of the existing ground; this eliminated its drainage functions for groundwater. The contact between the base of floodplain loams and the groundwater Tab. is not lost and the capillary rise in them remains preserved. Analysis of groundwater level confirmed multi-component refilling of the hydrogeological structure, which is drained in Plackuv les and the river Satava. All last 10 years, the maximum of the groundwater level measured is from July to September. It means, that groundwater reaches the highest level in the period, when the minimum flow rates are recorded on the surface flows. In this period, the locality displays the maximal infiltration of the precipitation from the last hydrological year from distant infiltration area. Because of the absence of floods, groundwater at this site is the most significant resource of water, and it represents a key-factor which enables the growth and thriving of the floodplain forest ecosystem.

Keywords: floodplain forest, groundwater, cumulative values of groundwater level

INTRODUCTION

The issue of drought begins to be tackled in the context of ongoing global climate changes not only among experts, but it also becomes more and more actual and very serious political topic. Since the 1970s, the perception of water in the landscape has been shifted. In the period of the second half of the last century, water resources were evaluated only from the point of view of the needs of human civilisation. At the present time, water is perceived in the context of landscape and ecosystems in general and as the limit for sustainable evolution of life and biodiversity on the planet.

Floodplain forests are unique ecosystems which are typical of the diversity of plant and animal species (Trèmoliéres *et al.*, 1998). The rich biodiversity and prosperity of floodplain habitats is governed particularly by specific hydrological and hydrogeological conditions which ensure the year-round high recharge of groundwater and surface (flood) water (Johnson *et al.*, 1976; Trèmoliéres *et al.,* 1998; Tewari *et al.*, 2003). The ecosystems of floodplain forest in the Czech Republic are currently rare; these habitats are intensively influenced adversely by man for more than 10,000 years, respectively during the entire Holocene (Opravil, 1983; Pokorný *et al.*, 2000; Řehořek, 2001). It started by early man made forest fires in stone age, exponentially growth as forest jumping continued by the first farmers in bronze age and due wood exploration and burning charcoal in iron age and later still more effectively in medieval age. Total change of flood regimes and the final stages of floodplain forest degradation is related to regulation of rivers during Communism regime.

Regulation (e.g. river straightening and damming) of watercourses can be considered as one of the most serious interventions into the landscape, which significantly affect the functioning of floodplain forest (Schabuss *et al.*, 2006). One of the most dangerous consequences of watercourses regulation to herbaceous vegetation (Unar and Šamomil, 2008) and trees in floodplain forests is decline of ground water level (Horner *et al.* 2009). Lower availability of ground water cause extensive dieback (Cunningham *et al.*, 2011) and withdrawal of floodplain forest (Brus *et al.*, 2013). Intensive and systematic regulation of watercourses in Czech Republic began in the 1950s; work on river regulation has so far culminated in the 1970s (Just *et al.*, 2003). River regulation was carried out to a greater extent after devastating floods in the 1890s (Zuna, 2008). At the present time, in the Czech Republic, approximately 27% of watercourses with a catchment area of 5 km^2 or more are regulated (Skácel, 2000).

An essential change in the character of the study site (in a broader sense, the river Dyje floodplain) did not occur until the 1970s. The current situation of the site results from modifications for the construction of the Nove Mlyny water reservoir (WR), which took place in the years 1977–1979. When the Nove Mlyny WR had been completed, the ground surface was elevated by damming and, as a consequence, the need arose to raise the channels of the rivers Jihlava and Svratka. These interventions resulted in significant changes in the hydrological regime in the floodplain of the river Dyje (Mráz, 1979). 10 years after the finishing of new channel for the river Dyje in 1972 was in floodplain forest near Lednice na Morave measured 90 cm decrease of ground water level during the spring maxima (Prax, 1991). Holubová and Lisicky (2001), reported decrease of 0.9–1.2 m of groundwater level in confluence area of the rivers Dyje and Morava during the years 1954–1994.

The site of the Nature Reserve Plackuv les and the brook Satava represents a relic of floodplain forests of the confluence area of the rivers Dyje, Svratka and Jihlava in the southern part of the Dyje–Svratka Valley. Due to the damming of the river Svratka, no floods have occurred at the site since the end of the 1980s. Yet, the softwood floodplain forest has remained preserved there – mire willow scrub (ÚHÚL, 2018), with its existence depending on the sufficient year-round availability of water (Trèmoliéres *et al.*, 1998).

In the years 1974, 1988 and 2009, surveys were carried out at the site, the aim of which was to verify the possibility of constructing a water withdrawal area (Štefan, 1974; Franzová, 1988; Novotná, 2009; Sedláček, 2009). The work performed has proved high contents of sulphates, iron and manganese in groundwater. The groundwater has a high content of minerals (in excess of 1,000 $mg.l^{-1}$), high contents of sulphates (in excess of 250 $mg.l^{-1}$) and does not contain nitrates. In terms of hydrochemistry, according to c_iz_i% (20% is considered), the water is of the types from Ca-Mg-HCO_3-SO_4 to Ca-Mg-SO_4-HCO_3 (Novotná, 2009).

The aim of this publication is (i) to confirm the hypothesis of the effect of groundwater as the main factor compensating the absence of the flood and enabling the growth and good thriving of a relic of the floodplain forest Plackuv les; and (ii) to confirm the hypothesis that the infiltration of precipitation recharging the hydrogeological aquifer of fluvial gravels (as the main resource of water for the forest) at the site of interest occurs outside this area.

MATERIALS AND METHODS

Topography, geological and soil characteristics

Topographically, the site lies in the system of the Outer Carpathian Depressions, the sub-system of Western Outer Carpathian Depression and the unit of the Dyje–Svratka Valley (Demek *et al.*, 2006). Geologically, the site represents the western rim of the frontal Carpathian Foredeep in close proximity to the fronts of nappes of the Flysch Belt. The study site is shown in Fig. 1.

At the site, three stratigraphic-lithological units have been encountered, the Flysch Belt, the sediments of the frontal Karpatian Foredeep, and the Quaternary. The Flysch Belt forms the front of nappes thrust over Neogene sediments. The sediments of the frontal Foredeep are represented by Karpatian and Badenian. The oldest sediments are calcareous clays of Karpatian. The sediments of Lower Badenian are developed in two facies, namely as basal and marginal clastics (calcareous sands and calcareous gravels) and calcareous clays and sands. The Quaternary is areally the most widespread; this concerns fluvial sandy loamy sediments (floodplain formation; floodplain loams underlain by fluvial gravels). In addition, a relic of an outwash fan (proluvial cone) is areally important. Other Quaternary sediments at the site include fluvial sandy gravels of terraces of various ages, deluvial sandy loamy sediments (of Pleistocene age and Holocene age), aeolian sediments (blown sands and loess) and organic sediments (fens, nekron mud). Soils are represented mostly by a gleyic fluvisols (Česká geologická služba, 2018) less them gley and stagnogley soils (Horák, 1961).

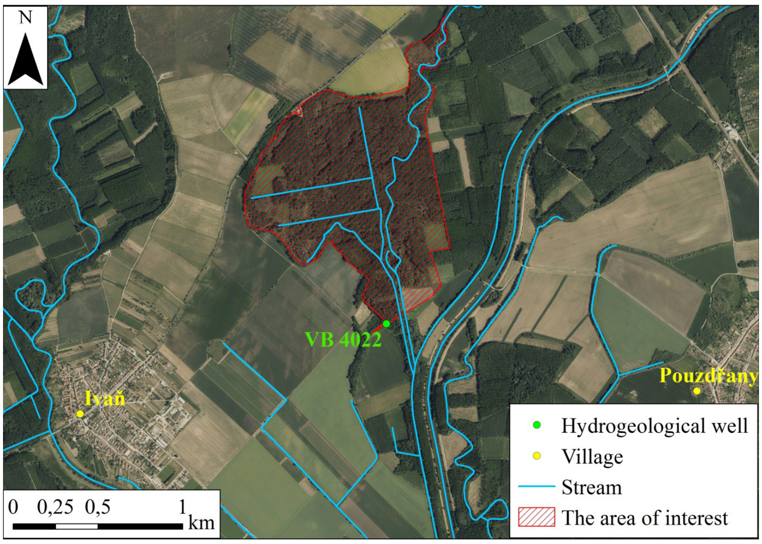
Hydrogeological characteristics

Hydrologically, the site belongs to the confluence area of the rivers Jihlava and Svratka. The territory of Plackuv les belongs to the brook Satava catchment area (Number of hydrological order 4-15-03-1280-0-00) with a total area of 22.49 km^2. In terms of the applicable hydrogeological zoning (Olmer *et al.*, 2006), the territory belongs to the hydrogeological zone of the upper layer of 1,643 Svratka Quaternary and to the hydrogeological zone of the base layer of 2,241 Dyje-Svratka Valley. The boundaries of the zones are shown in Fig. 2. The areas of the zones of the upper layers (of the Quaternary zones) are marked by hatching.

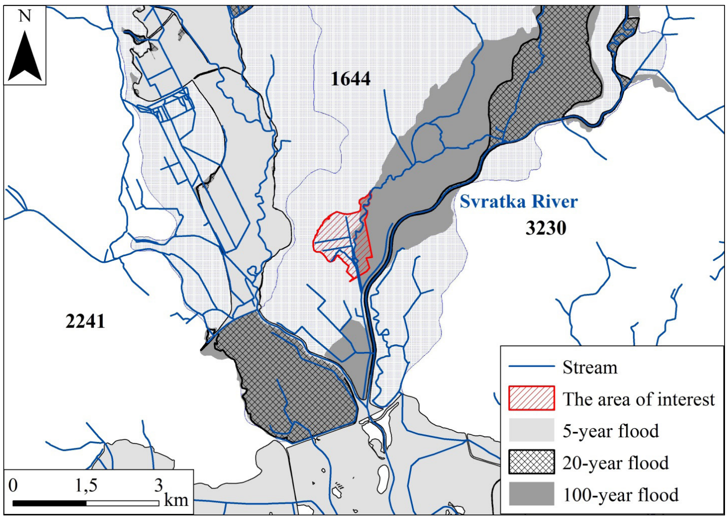
The potential area of recharging the hydrogeological aquifer is Karpatian sands – outcrops of Karpatian at the w. rim of the frontal Foredeep, the rim of the Bohemian Massif at the contact with sandy sediments of Karpatian and fluvial sandy gravels.

Forest characteristics

Natural reservation Plackuv les is composed from Querci roboris – fraxineta inferior and Alni glutinosae – saliceta inferior group of geobiocene types (GGT). Querci roboris – fraxineta inferior GGT occupies 52% from the area of natural reservation. This GGT is composed maily from *Fraxinus augustifolia* and *Quercus robur*. *Fraxinus augustifolia*



1: *Study site*



2: *Main hydrozones. 1664 in blue.*

commonly reaches more than 4 m in diametre at the breast height. To a little extent are occurs *Ulmus carpinifolia, U. Levis, Tilia cordata, Carpinus betulus, Populus x canadensis, Robinia pseudoacacia, Acer negundo* and *Fraxinus americana*. Alni glutinosae – saliceta inferior GGT occupies the rest of the area of natural reservation. This GGT is composed maily from *Salix alba, Salix fragilis* and *Alnus glutinosa*. Willows commonly reaches at this place more than 4m in diametre at the breast height, and heigt about 30 m (Chalupa, 2007).

Data

For the evaluation of a wider area, precipitation data were compiled for the South Moravian Region. Tab. I gives the precipitation characteristics of an evaluated period from 2008 to 2017, for which groundwater level measurements have been available.

For the assessment of the response of groundwater to the infiltration of precipitation, data from hydrogeologic well VB0422 of the Czech Hydrometeorological Institute (CHMI) have been evaluated. The location of the well is shown in Fig. 1 and its identification is given in Table II. The well encountered the contact between Quaternary fluvial sandy gravels and Karpatian sands (Česká geologická služba, 2018b).

Raw data of time series of daily averages of the groundwater levels obtained from hydrogeologic well VB 0422 (continuous

I: *Precipitation characteristics from 2008 to 2017*

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Precipitation total (mm)	487	670	780	442	501	601	622	430	533	473
% of normal	87	120	140	79	90	108	111	77	95	87
Difference from normal (mm)	–72	111	221	–117	–58	42	63	–129	–26	–86

(CHMI, 2018)

II: *Description of hydrogeologic well VB0422*

Identifier	VB0442
Designation of object	Ivaň, VB0329N
Altitude	170.44 m a.s.l.
Hydrogeological zone	1,643
Number of hydrological order	2-4-15-03-1270
Cadastral area	Ivaň

source: Česká geologická služba, 2018a

measurement of groundwater levels took place in the well from December 2007) was analysed in Statistika 12. The values of the range were computed as the differences between the minimum and maximum values. The cumulative values of groundwater levels (C_{GWL}; Kryštofová and Burda, 2016) were computed as the sums of the positive values of the differences of groundwater levels (daily averages) for hydrological years using the following function:

$$C_{GWL} = \Sigma\,(n_i - n_i - 1) > 0\ [\mathrm{m}]$$

n_i – daily average.

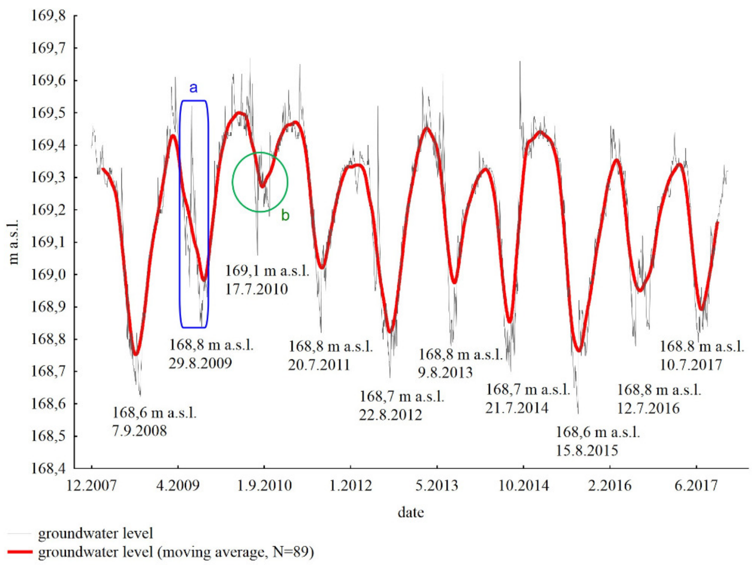
The data series was evaluated graphically in the program Statistika 12. The curve is smoothed using the method of moving averages with a segment of the time series over a period of 89 days. The period was selected based on a qualified estimate to be best shown the seasonal differences.

RESULTS AND DISCUSSION

The evaluation of data from Tab. III has shown the maximum values of groundwater level, except fluctuation, occurred in 2010. The minimum values of groundwater level, except fluctuation, were detected from 2015 to 2017. Minimum

III: *Data analysis. Maximum values of indicators are highlighted in blue, minimum values in red.*

	Median	Mode	Max.	Min.	Sample variance	Offset	Range	Cumulative value	Quantity
year	**m a.s.l.**	**m a.s.l.**	**m a.s.l.**	**m a.s.l.**	**m²**	**m**	**m**	**m**	**day**
2008	169.20	169.29	169.46	168.62	0.06570	0.2563	0.84	2.15	335
2009	169.18	169.16	169.61	168.84	0.03237	0.1799	0.77	2.67	364
2010	169.41	169.43	169.67	169.06	0.01292	0.1136	0.61	3.04	364
2011	169.38	169.43	169.65	168.82	0.03701	0.1924	0.83	2.29	364
2012	169.26	169.34	169.52	168.68	0.05095	0.2257	0.84	2.33	365
2013	169.31	169.33	169.62	168.78	0.03974	0.1993	0.84	2.66	364
2014	169.26	169.33	169.66	168.70	0.04605	0.2146	0.96	2.63	364
2015	169.35	169.41	169.49	168.57	0.08691	0.2948	0.92	1.75	364
2016	169.12	168.99	169.46	168.78	0.03101	0.1761	0.68	2.37	365
2017	169.21	169.33	169.44	168.79	0.03181	0.1784	0.65	1.74	364



3: *Daily averages of groundwater level in hydrogeologic well VB0442* fluctuation occurred in 2010. The maximum fluctuation of groundwater level occurred in 2014 and the minimum one in 2010. The assessed period includes both rainfall periods (2009–2010) and rainfall delays (2011–2012, 2015). In case the period without precipitation was preceded by a rainy period, the decrease of the underground water level is significantly lower (2011).

In addition to the computed statistical values, analysis of the time series of groundwater levels was also carried out (Fig. 4). Within the time series of data, in general, it is possible to earmark the following components (Litschmannová, 2010):

i) The seasonal component that reflects periodic changes. In case of the evaluated data, this concerns the annual periodicity of change in groundwater level.
ii) The random component (RC). RC It is made up of random fluctuations that have no systematic character. The RC is shown in the data by the time-limited rises of groundwater level.
iii) The cyclic component which is periodic changes not relating to time periodicity. This component does not appear in the evaluated data.

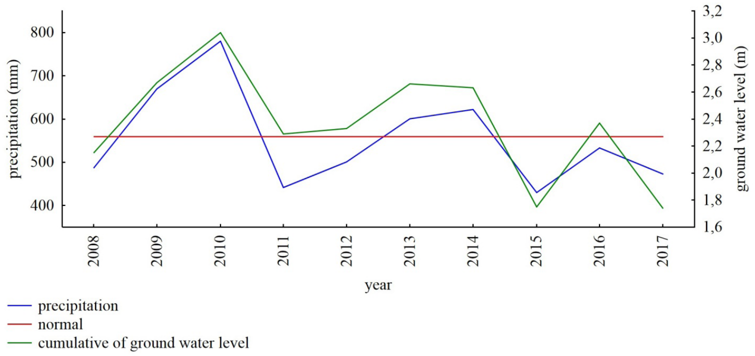
Fig. 3 shows the average daily values of groundwater levels in well VB0442. In terms of changes in the values of groundwater level, the recharge of the hydrogeological aquifer by precipitation has an essential effect. At the site of well VB0442, two hydrogeological aquifers become interconnected. Closer to the ground surface, there is a first hydrogeological aquifer of Quaternary fluvial gravels. Deeper, without being separated by a hydrogeological aquiclude, there is a hydrogeological aquifer of Neogene sediments of Karpatian age.

The basic component of the evaluated time series is the seasonal component that is demonstrated by the minimum in the period from July to September of the relevant year. Afterwards, the groundwater level rises to the maximum in the period from December to June of next year. The seasonal component of data relates to the recharge of groundwater from a remote infiltration area – water infiltrates at the eastern margin of the hydrogeological basin of the frontal Carpathian Foredeep and on the hydrogeological massif of the Bohemian Massif rocks. The groundwater level begins to rise in the summer season when evapotranspiration prevails over the recharge of precipitation in the usual course of the hydrogeological year and the groundwater level decreases.

The groundwater, which is the foundation of the prosperity of the Plackuv les, is formed in the distant area of the sediments of Karpatian, approximately 15–20 km west to northwest from the site. The contact between groundwater and the sediments of Karpatian is also confirmed by its quality. The water has a higher total content of minerals (the content of dissolved substances) and a very significantly abundant anion is sulphates, giving rise to the hydrogeochemical types from Ca-Mg-HCO_3-SO_4 to Ca-Mg-SO_4-HCO_3, which is for groundwater from sediments of Karpatian typical (Kryštofová and Burda 2016). The water is free of nitrates. At the same time, the water has high contents of iron and manganese, which indicates a reducing environment of the groundwater body. The water becomes significantly affected anthropogenically w. of the site in the area of a proluvial cone. The content of nitrates in the groundwater markedly increases up to the values exceeding 100 mg.l^{-1}. The contents of iron and manganese are low. The high contents of nitrates were also detected in the past (Novotná, 2009).

The random component of the time series is made up of the time-limited rising and subsequent lowering of groundwater level. The cause of the periodic component of data is the infiltration of precipitation into a hydrogeological aquifer at the site of groundwater level monitoring, which is the hydrogeological aquifer of Quaternary fluvial gravels. The response to precipitation infiltration is rapid; the effect of the rise quickly diminishes – the groundwater level decreases. In case of high precipitation totals, the random component has an effect on the pattern of the seasonal component. The short-lasting effect of the random component is marked in Fig. 4 as a blue rectangle (a) in the year 2009. The long-lasting effect of the random component is demonstrated in the year 2010 by a significant reduction of the seasonal minimum (ellipse b, Fig. 4).

Fig. 4 compares annual precipitation totals for the South-Moravian Region and annual groundwater level cumulative values. The graph shows that, in case of low annual precipitation totals, groundwater constitutes a stabilisation element in the system. By comparing two precipitation similar years – 2011 (a total of 442 mm) and 2015 (a total of 430 mm) – it is evident that the groundwater which infiltrated in the preceding period (in the years 2009 and 2010) equalises the deficit of precipitation for the ecosystem of floodplain forest in the given year by a larger volume of groundwater reserves. These are demonstrated by the rise of groundwater level. Naturally, the long-term precipitation deficit



4: *Comparison of annual precipitation totals and cumulative values of groundwater levels in hydrogeologic well VB0442*

is also indicated by the volume of available water in hydrogeological aquifers (in the years 2015–2017).

The dependence of the ecosystem on groundwater is documented also on Fig. 2, which shows the flood area 5, 20 and 100 year water. Only small parts of the area on its east edge interfere to rising of 100-year water from the Svratka River. The interval 100 years between floods cannot has a significant impact on the water conditions in the area.

Despite the intense regulation of the Svratka and Jihlava rivers in their confluence, there was no significant decrease of the underground water level in Plackuv les, which would mean the massive mortality of the floodplain forests as described by Horner *et al.* (2009). A major factor in the existence of Plackuv les is the fact that groundwater comes from a remote infiltration area. The influence of Svratka and Jihlava Rivers regulation on the groundwater level is therefore lower than in other areas where the groundwater level is more dependent on local precipitation (Spittzer and Bufková 2008), water from flood or closely connected with the water in the flows (Penka *et al.* 1991).

Effective protection of floodplain forest Plackuv les will be very difficult. Due to the regional extent of the infiltration area, it will have to be realized a system solution that should protect these remote infiltration areas. In 2017, Forests of the Czech Republic, state enterprise, realized project to renovation of water canals (Project No. CZ.05.4.27/0.0/0.0/16_032/0002686) in Plackuv les. We find these activities from a long-term point of view as ineffective.

CONCLUSION

The site of the nature reserve Plackuv les and the brook Satava represents a relic of floodplain forests of the confluence area of the rivers Dyje, Svratka and Jihlava in the southern part of the Dyje–Svratka Valley. As a result of damming the river Svratka, no floods have occurred at the site since the end of the 1980s. The territory of southern Moravia is evaluated as an area threatened by drought. Yet, the floodplain is in very good condition and a softwood floodplain forest has also remained preserved there – with a high abundance of *Salix alba* and *Salix fragilis*.

The site is located in the area of drainage of groundwater from the Neogene sediments of Karpatian of the frontal Carpathian Foredeep. The analysis of the time series of daily averages of groundwater level has proved a complicated recharge of groundwater reserves. The seasonal component of groundwater level fluctuation is indicated by the minimum in a period of July to September of the relevant year. Afterwards, this is followed by the groundwater level rising to the maximum in a period of December to June of next year. This is demonstrated by water recharge from a remote infiltration area – the western rim of the Dyje–Svratka Valley and the neighbouring hydrological massif of the crystalline complex. The recharge of the site by groundwater from the Karpatian sediments is also confirmed by the hydrogeochemistry of groundwater of the type from Ca-Mg-HCO_3-SO_4 to Ca-Mg-SO_4-HCO_3. At the same time, at the site, recharge also takes place from water as a random component when a rapid response of water level occurs.

The cumulative values of groundwater level appear as a suitable criterion for evaluating the stability of the hydric conditions of water-bound ecosystems. At the same time, it is possible from their analyses to derive the stabilisation function of groundwater for floodplain forests. In the event that the sites are bound to the areas of drainage of hydrogeological structures, they are capable of thriving even in the areas which are becoming almost arid, such as southern Moravia.

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