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Changes in soil properties due to land reclamation and climate change in South Moravian floodplain forest

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Abstract: Land use changes together with riverbed regulations to avoid the annual floods affect the ecosystem of floodplain forests. Later subsequent revitalization measures, transboundary controlled river management, wetland restoration, and integrated planning were realized to reduce the negative effect of groundwater dropping and other environmental problems. This study aimed to follow the dynamic of groundwater level, soil properties and forest vitality as affected by climate change. The continuous dataset (2019–2022) of soil physical and hydrophysical parameters and tree radial growth parameters were obtained. Groundwater level was evaluated by *z*-score and the means, and standard deviation values were considered. The monthly assessment of soil and climatic conditions showed that the uneven distribution of rainfall and the increase in temperatures have significantly affected the soil hydrological regime and forest growth. Continual monitoring is necessary to prepare projection models, which can help better understand both the soil and tree growth parameters in the changing environment.

Keywords: Alluvial soils; groundwater level; water regime

In the Czech Republic, the typical natural floodplain forests are situated near the confluence of the Morava and Dyje rivers, at the Litovelské Pomoraví floodplain, and the Labe and Odra floodplains (Machar 2013; Menšík et al. 2015; Pospíšilová et al. 2020). According to Cornelissen et al. (2019), the typical process of alluvial soil formation is stratification, the presence of short-term extreme floods, and groundwater table fluctuations. Due to the specific water regime, these areas are essential and major reservoirs of quaternary drinking water for people (Prax 2004; Cornelissen et al. 2019). Also, Kuglerová et al. (2014) confirmed

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that unmanaged protected forest areas along rivers are important as drinking water reservoirs and water content, and quality are affected by forest management. The ongoing trends of a groundwater level decrease together with climatic extremes negatively affect the soils and their hydric regime.

The lower Morava-Dyje Rivers is one of the eight Danube tributary systems (Zinke 2000). The specific biocoenosis of the Morava-Dyje floodplain forest belongs to one of the European most important forest complexes in size. Following the former hydraulic engineering measures (the second half of the 20th century) the area and especially the soil water regime was subjected to frequent changes, which affected the whole biocoenosis. The prevention of regular inundation and floods led to a drastic change in living conditions for plants and animals. Lately, the disconnection between the Dyje River level and the water regime was documented (Klimo et al. 1999; Klimo & Hager 2001; Prax 2004; Menšík et al. 2015). Several wetland restoration projects were approved to become financed through the EU Environment Programme to protect the area (Penka et al. 1985, 1991; Klimo et al. 1999; Klimo & Hager 2001; Hřib & Kordiovský 2004; Filippovová & Pohanka 2019). The restoration took two courses – controlled flooding and restoration of water channels. Some improvements in management and restoration actions in 1999 included the new cleaning of forest channels to improve forest hydrology. Altered hydrology following the construction of a flood polder resulted in waterlogging effects. Later, the drainage and mowing systems on floodplain meadows were established (Klimo et al. 1999, 2013; Kulhavý et al. 2000). Today, controlled flooding feasibly replaced the missing floods and helped to return water to the forest. But the negative consequences of the former riverbed modifications and land-use changes are still remarkable there. Prax (1991, 2004) and Klimo and Hager (2001, 2008) studied the effect of taken management measures on soil water regime, changes in soil properties, and ecosystem stability. They stressed the importance of revitalization and continuous soil and groundwater monitoring. Similarly, Kowalska et al. (2020); Tockner et al. (2002) and Skiadaresis et al. (2019) showed that even small management changes can drastically degrade the natural landscape and modify the natural hydrological regimes of alluvial soils. Other authors confirmed that frequently occurring extreme climatic events are associated with increasing global air temperature by 3–4 °C, which affects floodplain forests and wetlands (Ravenga et al. 2000; UNEP-WCMC 2001; Kowalska et al. 2020; Fink & Scheidegger 2021). They concluded that periodical flooding is a key natural factor facilitating the sustainability and ecological stability of the floodplain forests. On the other hand, the most significant stress factor is climate change and hydrological regime changes (Kurowski 2007; Cieśla 2009). Despite the high protection of natural habitats, human-induced modifications in the past highly influenced the natural ecosystem at present. It should be also stressed, that the growing public interest to mitigate the biodiversity decline still has not been met (IPBES 2021; Papazekou et al. 2022). Much ecological research has been undertaken on the effect of spatial allocation of conservation areas and biodiversity (Krause et al. 2007; Klimo & Hager 2008; Arroyo-Rodriguez et al. 2020; Filyushkina et al. 2022). Therefore, this study can be beneficial to cover the gap of knowledge between the current situation in the floodplain forest and the future forest production and improvement of management measures.

The main objective of this study was to evaluate the long-term impact of river modification and land reclamation measures on the hydro-physical properties and soil hydric regime in South Moravian floodplain forests. The study was based on the following hypotheses:

(1) the former anthropogenic impacts such as the river modification had a profound present impact on groundwater dynamics and water availability;

(2) the hydro-physical soil properties in floodplain forests are critically affected by former land reclamation, which affects forest productivity;

(3) the data on forest growth reduction can be beneficial to establish a better future management plan.

MATERIAL AND METHODS

Study site. The climate area is T4 with an average temperature of 9–10 °C and average precipitation of 500–650 mm (Květoň 2001). For map of studied locality and detail of the studied area see Figure 1. The studied area is north of Lednice and is covered approximately by 1.5 ha of natural floodplain forest. This has been an undisturbed and protected area since the land reclamations in the 1970s. The forest type group is *Ulmeto-Fraxinetum carpineum*, forest type *Rubus caesius* L., *Deschampsia caespitosa* (L.) P. Beauv., *Dactylis polygama* (Horv.) Dom., *Viola sylvatica* Fr. (Horák 1969). The dominant plant cover is represented by ≈ 120-year-old stand of peduncu-

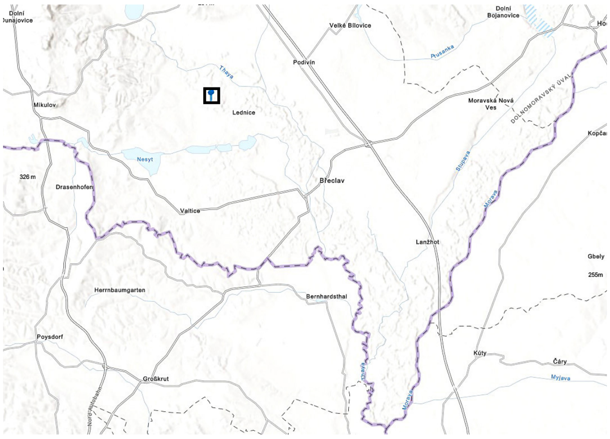

Figure 1. Map of studied locality in Lednice

late oak and narrow-leaved ash. Tree main species of *Quercus robur* L. (pedunculate oak), *Fraxinus angustifolia* Vahl. (narrow-leaved ash) with an admixture of *Acer campestre* L. (field maple), *Tillia cordata* Mill. (small-leaved lime), *Ulmus minor* (elm), *Populus alba* (white poplar) and *Salix alba* (willow) are dominant in the forest.

The soil profile GPS coordinates were N: 48.80959°, E: 17.78652°. The soil type was classified according to Němeček et al. (2011) as Gleyic Fluvisol. The soil is loamy or clay-loamy textured, with granular, resp. subangular or weak structure in the profile (Table 1). Total organic carbon (TOC) content was evaluated as high in the upper Ah humic horizon and degreased gradually within the soil profile (Table 2). Soil reaction was acidic and cation exchange capacity was medium (Table 2).

Soil sampling and laboratory analysis. Disturbed soil samples were collected monthly from the soil profile (Ah 0.02–0.10 m, AM 0.10–0.40 m, and MG > 0.40 m horizons). Basic soil properties such as texture, structure, soil reaction, soil buffering capacity, and TOC content were determined quarterly. Texture (particle size analysis) was determined by the pipette method (Marshall & Holmes 1988; Zbíral et al. 2022). The coefficient of aggregate stability was calculated according to Kandeler (1996). Soil reaction was measured in 1 : 2.5 suspension in distilled water and 1M KCl using a Hanna pH meter (Hana Instruments, Inc., Woonsocket, USA). The parameters of the soil sorption complex were determined as follows: hydrolytic acidity (H) and a sum of basic exchangeable cations (S) were determined according to Kappen's method (Hendershot et al. 2007). The cation exchange capacity (T) and degree of soil sorption complex saturation (V) were calculated according to the formula:

$$T = S + H;\ T = S/T \times 100$$ (Hendershot et al. 2007).

The oxidimetric titration method was used for TOC determination (Nelson & Sommers 1996).

Physical and hydrophysical soil properties were determined using physical cores monthly. Physical cores

Table 1. Macromorphological properties of Gleyic Fluvisol

Horizon	Depth (m)	Boundary classes (distinctness, cm)	Topography	Texture	Structure	Clay coating	Carbonates	Munsell colour of wet soil sample	Consistency
Ah	0.02–0.10	A	S	L	G	ND	ND	7.5YR2/2	FR
AM	0.10–0.40	C	ND	CL	SAB	ND	ND	7.5YR4/4	FR
MG	> 0.40	ND	ND	CL	WE	ND	ND	10YR3/3	FR

A – abrupt; C – clear; ND – not determined; S – smooth; L – Loam; CL – clay loam; G – granular; SAB – subangular blocky; WE – weak; FR – friable

Table 2. Chemical properties, structure stability and texture classes of Gleyic Fluvisol

Depth (m)	pH		Cation exchange capacity (cmol/0.10 kg)	TOC (%)	Coefficient of aggregates stability	Texture classes (%)		
	H_2O	KCl				sand 2.00–0.05 mm	silt 0.05–0.002 mm	clay < 0.002 mm
0.02–0.10	5.51 ± 0.1	5.25 ± 0.1	14.00	2.10	1.49	27.52	47.50	24.98
0.10–0.40	5.15 ± 0.1	4.90 ± 0.1	12.50	0.85	ND	25.24	35.88	38.88
> 0.40	5.15 ± 0.2	4.80 ± 0.1	12.50	0.35	ND	31.36	33.44	35.20

TOC – total organic carbon; ND – not determined were collected in triplicate from each horizon. Bulk density, moisture, porosity, and other parameters were calculated, e.g. hydrolimits such as maximum capillary capacity, water-holding capacity, gravitational water, point of limited availability, lento-capillary point, wilting point, pellicular water, hygroscopic water field capacity and plant-available capacity (Štekauerova et al. 2002; Kučera et al. 2020). Soil moisture was determined by the gravimetric method. Also, indirect moisture measurements using sensors for the dielectric constant measurements were used. The advantage of sensors was to register moisture at any time during winter. According to Kučera et al. (2020), water storage is related to the actual soil water status, and shares units and principles as plant-available capacity. Usually, the variance between the current soil moisture and the wilting point is in mm units. This represents the current moisture status of physiologically available water.

Basal area increment. During 2021, 15–20 oak and ash trees were marked in the location. Two increment cores of width 5.15 mm were extracted from the trees at breast height. Cores were dried and glued in the wooden blocks. For measuring the tree rings samples were sanded with several grades of sandpaper from coarse to fine (120–600). After sanding, the cores were measured using a dendrochronological measuring table and PAST4 software (VIAS 2004) along with a stereoscopic microscope. The mean tree ring width series of two cores of a tree was used for cross-dating.

For the analysis of the tree growth response to climate, annual basal area increment (mm^2) was used. Basal area increment was measured with the "dplR" package (Bunn et al. 2022) in R (R Core Team 2022).

Groundwater level and precipitation measurements. Groundwater tables (GWT) and precipitation were registered monthly from March 2019 to November 2022. Ten hydrological points (boreholes K1–K10) and three rain gauges were used. The average value of precipitation was calculated. The hydrological boreholes were situated in natural meanders of the Dyje River. The GE10 manual metre with optical acoustic signalization (ENVIRO GLOBAL, Czech Republic) was used for groundwater table measurements. The hydrological point K3 was measured only until October 2021 due to its strong damage. The flow rate of the Dyje River has automatically registered each hour and data set from the Czech Hydrometeorological Institute for the studied period was selected.

Statistical analysis. The data set of GWT was standardized to a common scale using z-scores, which were calculated based on the means and standard deviations of the data. This methodology allowed for the comparison of measurements taken at different locations or times on a normalized and consistent scale.

RESULTS AND DISCUSSION

Climate. The results of monthly temperature and precipitation monitoring from spring 2019 to summer 2022 are given in Figure 2. As it is noticeable, the average temperature during the studied period increased, but precipitation varied with seasons. The sum of precipitation during the whole year was similar, but their distribution differed. In Figure 3, there is the Dyje River flow rate and the gradual decrease during 2019, 2020, 2021 and 2022 were observed.

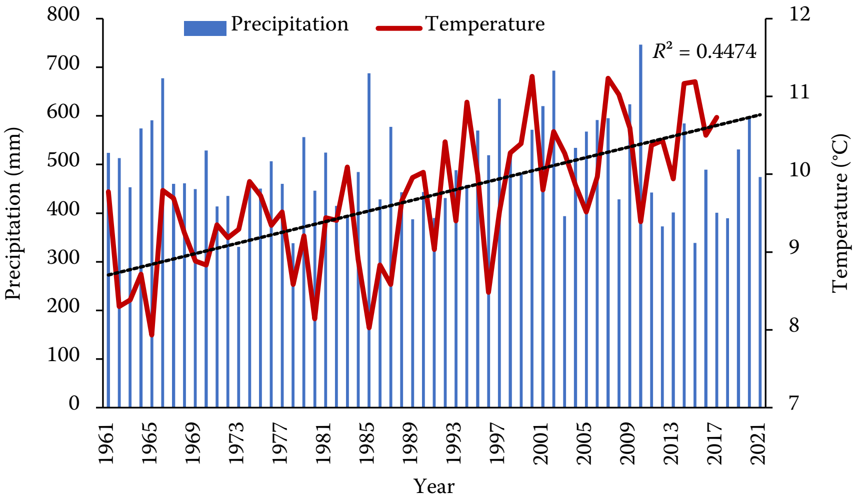

Figure 2. Graph of average temperature and precipitation (1961–2020)

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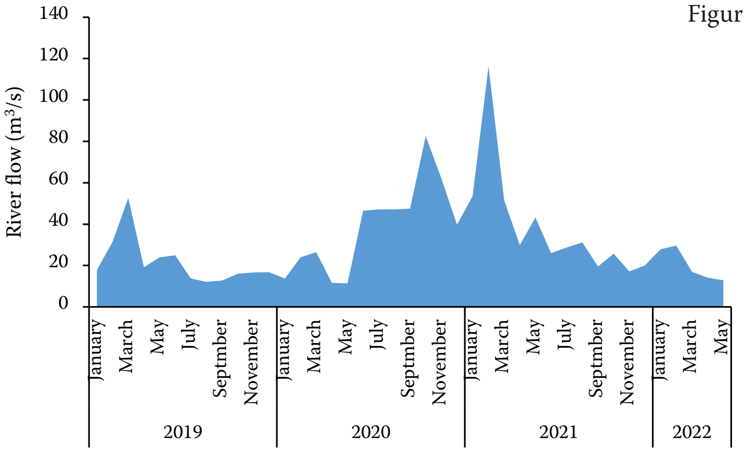

Figure 3. The Dyje River flow rate during 2019–2022

At the beginning of December 2022, there was a lot of snow but then suddenly the temperature increased, and at the end of December it was extremely warm weather. This was very unusual for December. It was evident that the Dyje River flow rate was highly affected by climatic conditions (Figure 3).

Soil properties and groundwater level. Studied Gleyic Fluvisol is loamy textured soil, with a 46.12% content of clayic particles. The average measured values of soil moisture are presented in Figure 4. As it is evident, there are dry periods in spring and autumn and soil moisture decreased. A slight increase was registered during the winter of 2020/2021. Autumn 2022 was the second driest season of the studied period. Soil moisture reached only 14.45% compared to 28.53% during the autumn of 2022. There is a tendency for gradual relative soil moisture decrease (Figure 5). For all data see Table 3.

Monthly monitoring of the GWT showed that despite enough precipitation, the GWT was quite deep. The deepest GWT was reached in the summer of 2021 (in August 2021). On the other hand, the precipitation reached 26.56 mm during this period but due to plant water usage, the soil moisture gradually decreased. Similar data were obtained by the Czech Hydrometeorological Institute. The average GWT during the studied period is listed in Figure S1 in Electronic Supplementary Material (ESM). The given data set was evaluated using statistical data processing with a *z*-score, where 1 is the baseline and the positive and negative variabilities mean the positive or negative trend for that point in time. A very deep GWT was observed at points K1, K2, and K3 (K3 until October 2021), but the differences were not statistically significant. Generally, hydrological points, which were closer to the artificial channel showed higher GWT.

Basal area increment result. Basal area increment provides an estimation of radial growth of the tree species (oak and ash) of the studied locality (Figure 6). In the Basal area increment, both of the species show similar patterns until the 1970s. But since 1970 different trends of basal area increment among species can be observed. The highest incre-

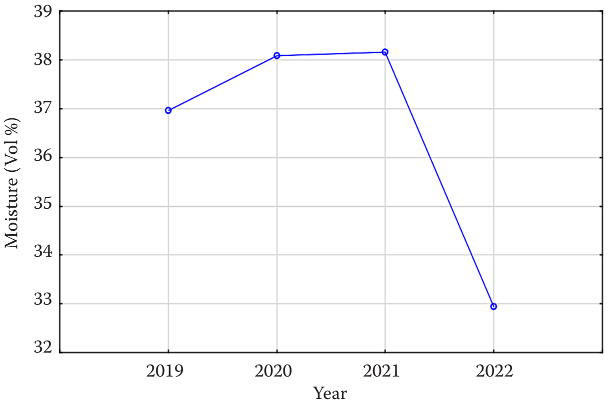

Figure 4. Average data of soil moisture (2019–2022)

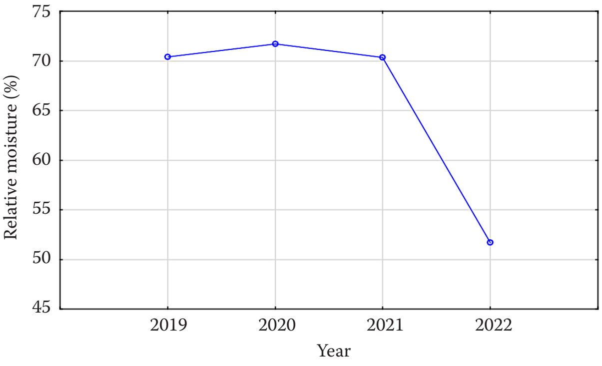

Figure 5. The average values of relative soil moisture (2019–2022)

Table 3. Data of soil moisture and relative soil moisture per season

Year	Season	Moisture (% vol.)	Relative moisture (%)
2019	spring	47.00	88.33
	summer	33.92	61.34
	autumn	29.96	61.54
2019/2020	winter	37.40	71.74
2020	spring	35.26	62.45
	summer	33.35	54.23
	autumn	46.30	98.49
2020/2021	winter	45.51	79.95
2021	spring	41.09	81.22
	summer	34.20	63.91
	autumn	31.84	56.28
2021/2022	winter	49.95	90.74
2022	spring	31.55	55.17
	summer	17.31	35.01
	autumn	14.45	25.91

ment was in ash with some deprivation from 1970 to 1995. The change of pattern can be seen from 1995 when the revitalization period started. The revitalization procedure depicts stable growth in ash. But in oak the growth scenario is quite different, after the water management when the groundwater level dropped, oak radial growth was hindered and followed stability instead of increasing. And the trend was not at all affected by the revitalization measure. This conclusion should be confirmed by further ongoing study and modelling.

DISCUSSION

This study contributes to the alluvial soils' monitoring and the obtained results show that soil properties and water regimes. Furthermore, it was demonstrated that tree production declined due to the regulation of the Dyje river, uneven distribution of rainfall and temperature increases. The growth of the forest is affected by the river management. The river management caused the diminishing seasonal dynamics of groundwater movement. As oak has a deep root system (Tatarinov et al. 2008) and ash has a shallow root system, it seems that oak root is submerged in the water for a long time during the growth period and faced root anoxia and hindered growth whereas Ash being a shallow-rooted species (Rust & Savill 2000) are getting adequate water because of the stagnancy. Therefore, we may comment the effect of river management is species-specific (Szatniewska et al. 2022). From the current year's growth (since 2015) it is evident that oak growth is significantly lower than ash growth ($P < 0.001$) (Figure S2 in ESM). Regular monitoring of soil moisture is important

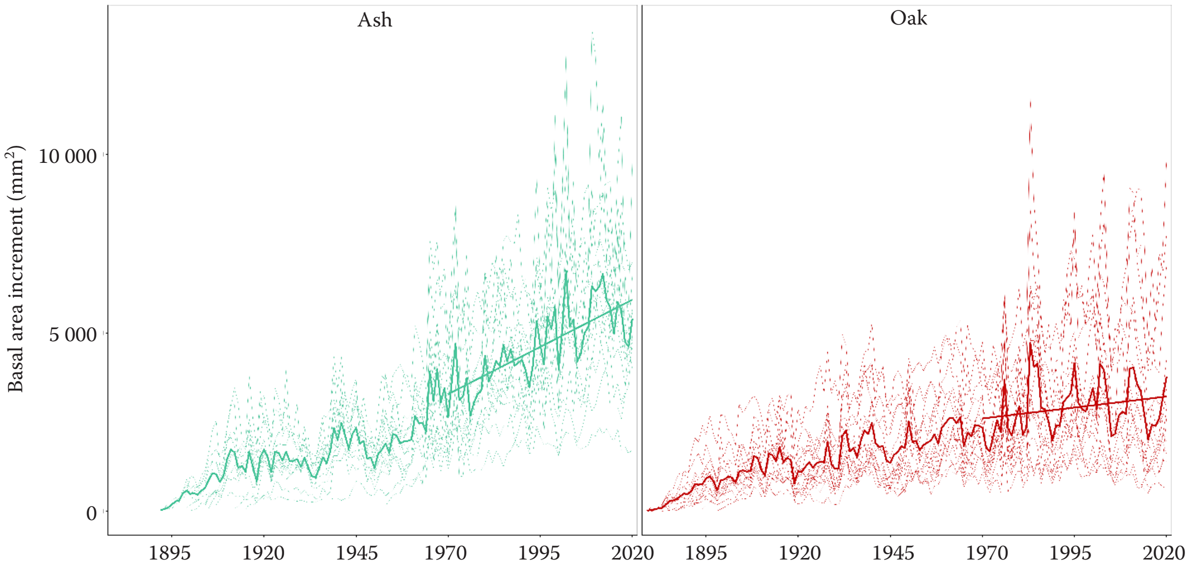

Figure 6. Basal area increment results

for artificial watering and forest management. The depth of the GWT may negatively affect not only tree growth but also the sources of drinking water for municipals. Similarly, Mikulova et al. (2020) stressed that changes in the groundwater level, soil properties, and vegetation cover are typical consequences of intensive river regulations, especially after dam construction. So, sediment retention in dams causes the river channel to be deeper and the GWT drops along the river. Consequently, nutrient availability is lower due to slower decomposition. In recent years, a noticeable increase in drought events has had significant repercussions on the ecosystem. The intensified dry conditions have led to the desiccation of the topsoil, triggering notable shifts in the species composition towards more mesohydric trees, such as hornbeam (*Carpinus betulus*) and maple (*Acer campestre*). Unfortunately, this change has also resulted in a decline in natural regeneration processes. The drying out of the topsoil has introduced several challenges to the ecosystem. Firstly, it has accelerated the decomposition process and consequently the nutrient cycling and availability. As a result, more favourable conditions for the proliferation of invasive plant species were created. Research conducted by Klimo et al. (1999); Klimo and Hager (2001, 2008) and Mikulova et al. (2020) has highlighted the concerning implications of these ecological changes. Coleman et al. (2018) stated that human-induced changes in natural ecosystems may accelerate landscape fragmentations, which impede colonization between neighbouring protected areas and thus the persistence of ecosystem disturbance decreases. Czochański and Wišniewski (2018) studied the ecological corridors of the Pomeranian region (German-Polish border) and concluded that the river valley is also an important travel corridor for aquatic and terrestrial animals. Also, Hermoso and Filipe (2021) showed that GWT in protected areas may critically influence not only forest production but also habitats and ecosystem biodiversity. Compensating for the loss of biodiversity the EU Biodiversity Strategy for 2030 (European Commission 2020) is the restoration of rivers to their free-flowing state. In our case, the revitalization measures include artificial watering and the arrangement of more favourable conditions for plant stable growth. According to Heteša et al. (2004), Klimo and Hager (2008), and Hughes et al. (2012) it helps to ensure desirable soil and water conditions, and maintenance of ecological biodiversity.

CONCLUSION

Research showed that hydrophysical soil properties and climate conditions were closely connected and affected the groundwater dynamics. Furthermore, it was documented that the climatic extremes (e.g. uneven distribution of precipitation and temperature increase) significantly affected forest production. This may have negative economic, financial, and environmental effects. Our main conclusion is that floodplain forests became even more vulnerable and dependent on climatic conditions. Detailed monitoring of the groundwater level and climate conditions is essential to improve management practices and protect the floodplain forests. It is also important for soil hydrological regime modelling, which is being considered as a possibility for our future study or research.

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