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Impact of beaver dams on watercourse hydrology and morphology change in the Roztocze National Park

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ABSTRACT

The article analyses hydromorphological changes in the stream caused by the construction of beaver dams. For the period of three hydrological half-years, water level fluctuations, changes in water retention, and the diversity of the stream morphology were examined. The influence of atmospheric precipitation and beaver activity on water depth fluctuations and the amount of water retention was found. The average water depth before the dams was 69 cm and ranged from 29 to 97 cm. The average increase in water depth caused by the dams was 48 ± 18 cm. The water retention in the stream bed (pond capacity) ranged from 15.5 to 106.5 m^3. The highest retention was recorded in August 2021 after heavy and long-lasting rainfall. The lowest retention was recorded in April 2022 due to the destruction of the D2 dam. Beaver activity also contributed to the transformation of the hydromorphological conditions of the stream. The Habitat Quality Assessment increased from 28 to 38 in places affected by beavers (an increase by 36%). The following changed: heterogeneity of the stream and riverbed material, diversity of vegetation types in the riverbed, diversity of elements accompanying woodland, and vegetation structure on the bank slopes. Extreme weather events and human activity have a significant impact on the functioning of beaver dams, which highlights their key importance in stabilizing water levels and protecting river ecosystems. The sensitivity of the river hydrological system to intense precipitation and its deficits highlights the need to protect natural channel structures that increase the retention capacity of dams and support the restoration of degraded areas by restoring natural hydrological and geomorphological processes.

Keywords: *Castor fiber*, water depth, water retention, hydro-morphology, Świerszcz stream.

INTRODUCTION

The hydrological regime is largely shaped by climatic factors, of which precipitation is the most important (Pumo et al., 2016). The impact of climate change on river hydrology leads to significant transformations in the characteristics of runoff, which in turn affects the dynamics of meander development and the formation of river channel morphology. Even small changes in the average annual temperature and precipitation can lead to significant changes in the frequency and intensity of flood phenomena. Additionally, increased erosion, denudation and landslide processes contribute to increased sediment transport to rivers (Kiss and Blanka, 2012; Probst and Mauser, 2022). Climate change has a significant impact on agricultural areas, leading to an increase in the frequency and intensity of agricultural and hydrological droughts. This phenomenon results from increased evapotranspiration and runoff variability, despite relatively stable precipitation totals (Okoniewska and Szumińska, 2020; Sojka et al., 2020). Other studies suggest that local hydrological conditions have a significant impact on the variability of seasonal low flows in lowland rivers (Raczyński and Dyer, 2020). Lowland catchments, due to their greater retention capacity, will respond to heavy rainfall in a more benign manner than mountain catchments (Tomaszewski and Kubiak-Wójcicka, 2021). Studies show that local flood events were usually triggered by rainfall lasting less than two hours, and their occurrence was observed from April to October (Bryndal, 2015).

The hydrological regime of Polish rivers is characterized by a clear sequential occurrence of wet and dry periods. There are significant and statistically significant differences between the average annual flows in rivers in wet and dry years (Karamuz et al., 2021). The variability of river flows causes periodic water shortages and excesses. Protecting areas from the effects of droughts mainly consists in increasing the natural retention capacity of these areas. Engineering elements, such as structures slowing down water flow, including beaver dams, are an integral part of small retention in planned strategies (Czerniak et al., 2020). Small hydrotechnical structures on streams significantly affect hydromorphological changes in rivers, especially due to the creation of transverse and longitudinal obstacles to water flow (Bonacci and Oskoruš, 2019). Disruptions of river continuity and instability of the flow regime have a significant impact on the structures of fish communities (Amaral et al., 2016). The reduction of base flow caused by the operation of dams negatively affects macroinvertebrate communities and riparian vegetation (Marcinkowski and Grygoruk, 2017). Dams can also significantly affect the thermal regime of runoff waters (Chandesris et al., 2019). Despite their small size, small dams have a significant impact on regional river systems, and their impact can be comparable to that of large dams (Yang et al., 2019). On the other hand, hydrotechnical structures can have a positive impact on the variability of water flows (Kubiak-Wójcicka and Kornaś, 2015). In particular, dams can increase low flows and reduce high flows, which leads to the stabilization of hydrological conditions. Reducing the variability of extreme flows is crucial not only for the protection of the ecology of coastal zones but also for reducing the risk of floods and preventing droughts (Sojka et al., 2016).

The increase in average annual temperatures and the reduction of water flows are direct effects of climate change, which emphasize the need to intensify research on effective water retention methods. In this context, natural structures such as beaver dams are gaining importance as tools supporting the mitigation of the effects of both droughts and floods (Krajewski et al., 2019). This paper analyzes the impact of natural barriers on a small lowland river in eastern Poland on water levels, pond capacity and hydromorphological changes.

MATERIAL AND METHODS

Study area

The conducted research focuses on the analysis of the functioning of beaver dams located in forest areas dominated by mixed forests. The dominant tree species in the study area are Pinus sylvestris, Abies alba, and Fagus sylvatica. The research was conducted on the Świerszcz stream, 40% of whose catchment area lies within the Roztocze National Park. The Świerszcz River Basin partially overlaps with Natura 2000 protected areas – the Roztocze Środkowe PLH060017 area of community importance and the Roztocze PLB060012 special bird protection area (Journal of Law, 2011; 2021a, b). The river begins in a system of marsh forests and raised bogs. It supplies 5 artificial water reservoirs – ponds: Florianka, Czarny, Echo complex, Pałacowy, Kościelny. The river basin area is 46.5 km^2, and the main stream is 8.8 km long. The stream is 1–3 m wide and the discharge is 60 dm^3·s^{-1}. The basin is characterized by a diversified terrain and a mosaic of environments. The dominant type of land use is forests, which cover 28.8 km^2 (62%). The land use structure is complemented by green areas (16.2 km^2 – 36%), urban areas (1 km^2), and surface waters (0.5 km^2) (Grabowski et al., 2015).

The study area is located in eastern Poland, in the Lublin province, in the Zwierzyniec commune. The Świerszcz River is a left-bank tributary of the Wieprz River, with its mouth in the area of the town of Zwierzyniec (220.2 m a.s.l., 307.2 km of the river path). The water circulation in the catchment is the result of the impact of climatic and terrain conditions. The average annual rainfall is 720 mm, and the temperature ranges from -2.4 °C in January to +19 °C in July. The critical terrain conditions are: geological structure, surface features, soil cover, and vegetation. The basic element of the geological structure is Upper Cretaceous rocks with a thickness of about 800 m. The terrain is highly diversified with numerous steep slopes. The best filtration properties are demonstrated by sandy soils dominating the catchment (Buraczyński 2002, Reszel and Grądziel, 2015). Currently, the *Castor fiber* family has settled in this area, building natural barriers, and before the beaver dams, ponds are formed to store water.

Research methods

The study included research cross-sections representing two natural barriers on the Świerszcz stream. In the period from May 1, 2021, to October 31, 2022 (3 hydrological half-years), water levels were measured in the riverbed in the vicinity of the D1 and D2 dams and at control station C (Fig. 1). Measurements were taken at five points on the river path using pile gauges (before and after dams). Data on monthly precipitation totals and average monthly air temperatures came from the Roztocze National Park Nature Monitoring (Kostrzewski et al., 2006; Journal of Law, 2018).

The geodetic measurements aimed to determine characteristic points reflecting the topography of the bottom of water reservoirs. There are several methods of field measurements in geodesy. The choice of method depends on the following factors: the size of the area, land use, relief diversity, equipment availability, and others (Sharifullin et al. 2023). Due to the location of the measurement objects in forest areas, the measurements were performed using two methods. Using the Topcon HiPer V GNSS receiver, reference points were placed in places with an open horizon, thanks to which the coordinates and heights of the measurement stations were determined. Then, using the polar method using trigonometric leveling, the coordinates and heights of the measurement points were determined in selected cross-sections. The Topcon ES-105 electronic tachymeter was used for angular and linear measurements. The measurements included the following elements: the location and height of the channel points and the valley bottom, as well as the location, height, width, and length of beaver dams. Based on the geodetic measurements carried out using the ArcGIS Pro program, the digital terrain model was generated. The obtained 3D model was the basis for determining the hydraulic parameters of beaver ponds (James et al., 2012). The effective retention of the river bed resulting from the damming of beaver dams was calculated based on the topography of the reservoir. The differences in water levels below and above the D1 and D2 dams were used to calculate the capacity of the ponds.

Hydromorphological studies of the rivers were conducted based on the British river habitat survey (RHS) method (Fox et al., 1998). The assessment of the condition of the rivers was made based on the hydromorphological river index (HIR), which allows for the valuation of flowing waters (Szoszkiewicz et al., 2017). Based on the hydromorphological data, the following indicators were calculated: habitat quality assessment (HQA) and Habitat modification score (HMS). For each research point, the hydromorphological status class was determined according to the HIR multimeter values for lowland rivers with a bottom width of ≤ 30 m (Journal of Law, 2021c; Połeć et al., 2022). In the article, special attention was paid to the HQA elements: diversity of the longitudinal profile and cross-sections, heterogeneity of the stream, channel material, natural morphological elements, diversity of vegetation and accompanying elements, and valley use.

Statistics analysis

To assess the relationships between temperature, precipitation, and water depths at the dams, as

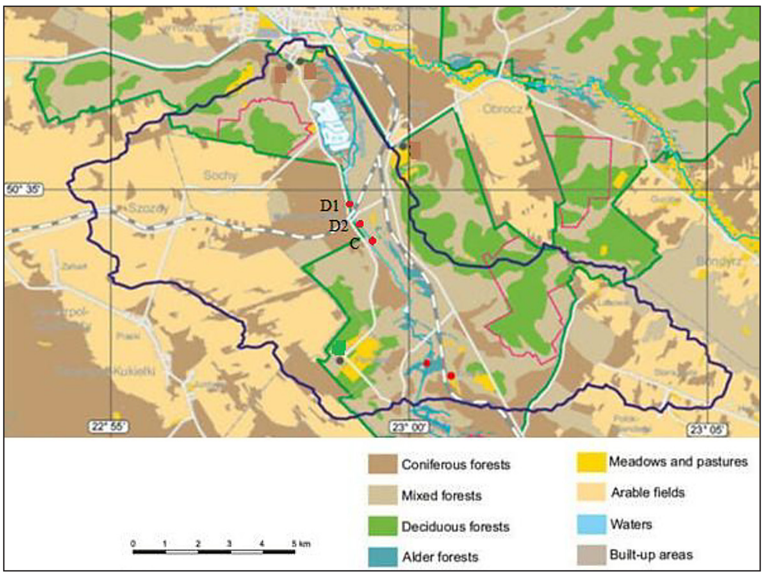

Figure 1. Location of research site. C – control station, D1, D2 – beaver dams

well as at the unaffected control station, Pearson's correlation coefficient (r) was computed quantifying the strength and direction of the associations between analyzed variables. The Wilcoxon signed-rank test was employed to evaluate the significance of differences in water levels before and after damming. All statistical analyses were conducted using R (version 4.4.2) within the integrated development of RStudio (version 2024.12.0+467.pro1).

RESULTS AND DISCUSSION

Hydrometeorological conditions

The article presents changes in precipitation and temperature over the three hydrological half-years. The changes were determined based on data from the Integrated Environmental Monitoring Base Station in Zwierzyniec, which is part of the Chief Inspectorate for Environmental Protection network. Data for the study period were compared with the results of multi-year studies presented in the literature on climate change in the RPN (Reszel and Grądziel, 2015; Grabowski et al., 2022). Studies conducted since 1986 in the Roztocze National Park (RPN) have shown a decrease in water resources. The lowest groundwater level was recorded in May 2020 and was 17.5 m below ground level. Water shortages were also visible in the case of the Świerszcz stream because the water depth at the control station dropped to 1 cm. Very low surface and groundwater levels were the cause of the lack of water in the Echo ponds in the summer season of 2020. The lack of water in recreational ponds contributed to the reduction in tourist traffic and the negative perception of the functioning of the RPN. The occurrence of extreme effects of drought in 2020 was caused by low annual precipitation totals in 2018 and 2019, which amounted to 541 and 619 mm, respectively. The annual precipitation total in 2018 was the lowest in the 21st century. The second factor responsible for the occurrence of drought was high air temperatures, which in 2019 averaged 9.8 °C, with the average from the multi-year period 2001–2020 being 8.3 °C. In addition, there was a lack of snow cover in the winter season of 2019/20. Unfavorable meteorological and hydrological conditions were the cause of the periodically negative water balance of the Świerszcz stream (Kałamucka & Grabowski 2021). For several years now, the engineering activity of beavers (*Castor fiber*) has been visible on various watercourses (rivers, streams, ditches), increasing water retention by building dams.

Analyzing the distribution of precipitation and temperatures for the three-semester period, their high temporal variability was found. The biggest monthly precipitation total was recorded in June 2021, when it amounted to 187.4 mm and was almost three times higher than the average for the multi-year period of 2001–2020 (73.4 mm). The situation was different in June 2022, when precipitation amounted to only 33.4 mm. The smallest monthly precipitation total was recorded in October 2021, it amounted to 7.4 mm and was seven times lower than the multi-year average of 51.7 mm (Fig. 2). The very big variability of monthly precipitation in 2021 is evidenced by the fact that in June and October, respectively, the biggest and smallest precipitation in the 21st century was recorded. The occurrence of big and intense precipitation in Central Europe was the cause of the extreme flood in June 2010 (Pińskwar et al., 2019). In Poland, in turn, the long-term occurrence of small precipitation was the cause of the occurrence of extreme drought during the vegetation period of 2003 (Ziernicka-Wojtaszek, 2020; Grzywna et al., 2020). Precipitation was also strongly differentiated for the summer and winter seasons. The total precipitation of the summer half-year was 640.8 and 373.8 mm in 2021 and 2022, respectively, with a multi-year average of 434 mm. The total precipitation for the summer half-year of 2021 was the biggest in the 21st century in the RPN. On the other hand, the total precipitation of the winter half-year of 2021/22 was 243.8 mm and was close to the multi-year average of 252.8 mm. It is worth noting that rain dominated the winter season. Snow occurred sporadically and formed only a short-term snow cover. The total precipitation for the hydrological year 2021/22 was 617.6 mm and was 75 mm lower than the multi-year average.

Similar trends in the distribution of monthly precipitation were observed in multi-year studies covering the Lublin Province (Bartoszek et al., 2021; Samborski, 2024). The demonstrated variability of precipitation amounts may directly impact changes in the availability of water resources and thus shape river flows (Yu et al., 2002).

The course of temperature changes is closely related to the natural variability of climatic conditions. In the temperate, transitional climate zone, July is usually the warmest month, while January is the coldest. In the analyzed period from May

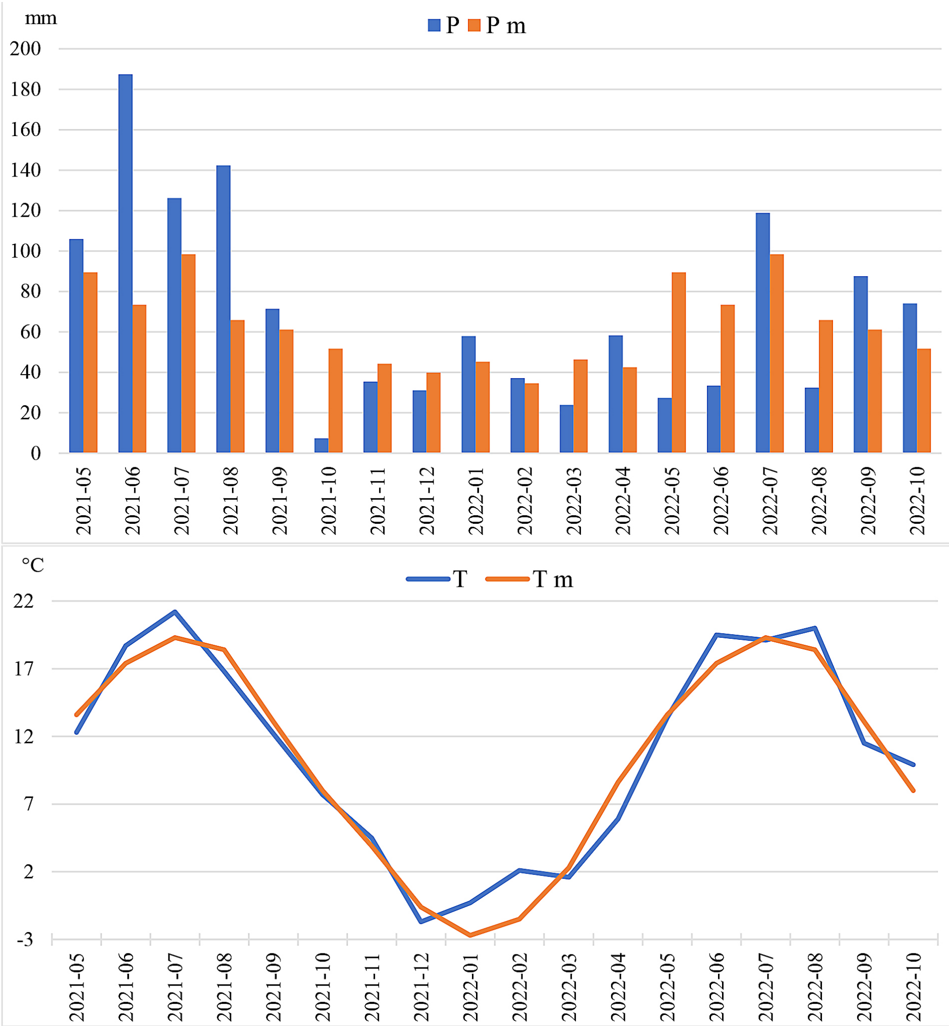

Figure 2. Meteorological conditions for the Zwierzyniec station. P – monthly precipitation, Pm – average multi-year precipitation, T – monthly temperature, Tm – average multi-year temperature

2021 to October 2022, the highest average temperature was recorded in July 2021 and August 2022, 21.2 and 20 °C, respectively (Fig. 2). The average temperature recorded in July 2021 was the highest for this month in the 21st century in the RPN. The occurrence of very high temperatures in June 2019 was the cause of the occurrence of extreme drought in Poland (Ziernicka-Wojtaszek, 2021; Wałęga et al., 2024). The lowest average monthly temperature was recorded in December 2021 and was -1.7 °C which was 1.1 °C lower than the multi-year average. The very disturbing symptom of climate change was the positive temperature in February 2022. The temperature was 2.1 °C then, as much as 3.6 °C higher than the multi-year average. High temperatures in February 2022 and low precipitation in March 2022 caused a decrease in water depth and water resources.

Both the temperature distribution and the amount of atmospheric precipitation were determined to be within the range enabling the classification of the studied region as a temperate continental climate zone with a warm summer subtype (Dfb – Köppen classification) (Kottek et al., 2006). In the studies conducted from May 2021 to October 2022, a statistically significant correlation was found between the average monthly precipitation totals and air temperature ($r = 0.58$; p-value 0.05).

Water depth

Similar morphometric features and similar building materials characterized the analyzed natural barriers. The studied beaver dams consisted mainly of wood material, including deciduous tree branches, as well as herbaceous vegetation and bottom sediments. This design allowed for four dam flow types – spillway, gapflow, underflow, and throughflow (Woo and Waddington, 1990; Ronnquist and Westbrook, 2021). The article analyzed two beaver dams that operated throughout the study period. The dams were located in the middle section of the river, where the river bed gradient was 1.2‰ while the average gradient was 3.3‰. Studies conducted in Russia show that beavers prefer to build dams located in sections of channels with relatively small average gradients (up to 1%) (Sharifullin et al., 2023).

At the beginning of the study (May 2021), the maximum water depth above both dams was 90 cm. At that time, the water depth below both dams was 20 cm, while at the control station, it was 10 cm (Fig. 3). This shows that the dams raised the water level by 70 cm. Studies conducted in the Mała River bed showed that the water level above and below the dam differed by 80 cm in May 2020 (Oleszczuk et al., 2024). As a result of extreme rainfall in June (the highest in the 21st century), the water level in the river rose. The highest water depths in the river were recorded in mid-July 2021. The water depth on the D1 dam was 97 cm and 24 cm, respectively above and below the dam. The water depth on the D2 dam was 97 cm and 30 cm, respectively above and below the dam. The water depth at station C was 18 cm (Fig. 3). This means that the maximum height of the beaver dams was 73 cm. Similar values were maintained until the end of August 2021. The occurrence of extreme temperatures in July (the highest in the 21st century) and extreme precipitation in October (the lowest in the 21st century) caused a significant decrease in the water level in the Świerszcz stream. At the end of the hydrological year 2021, the water depth above the dams was 79 cm for the D1 and D2 dams. The water

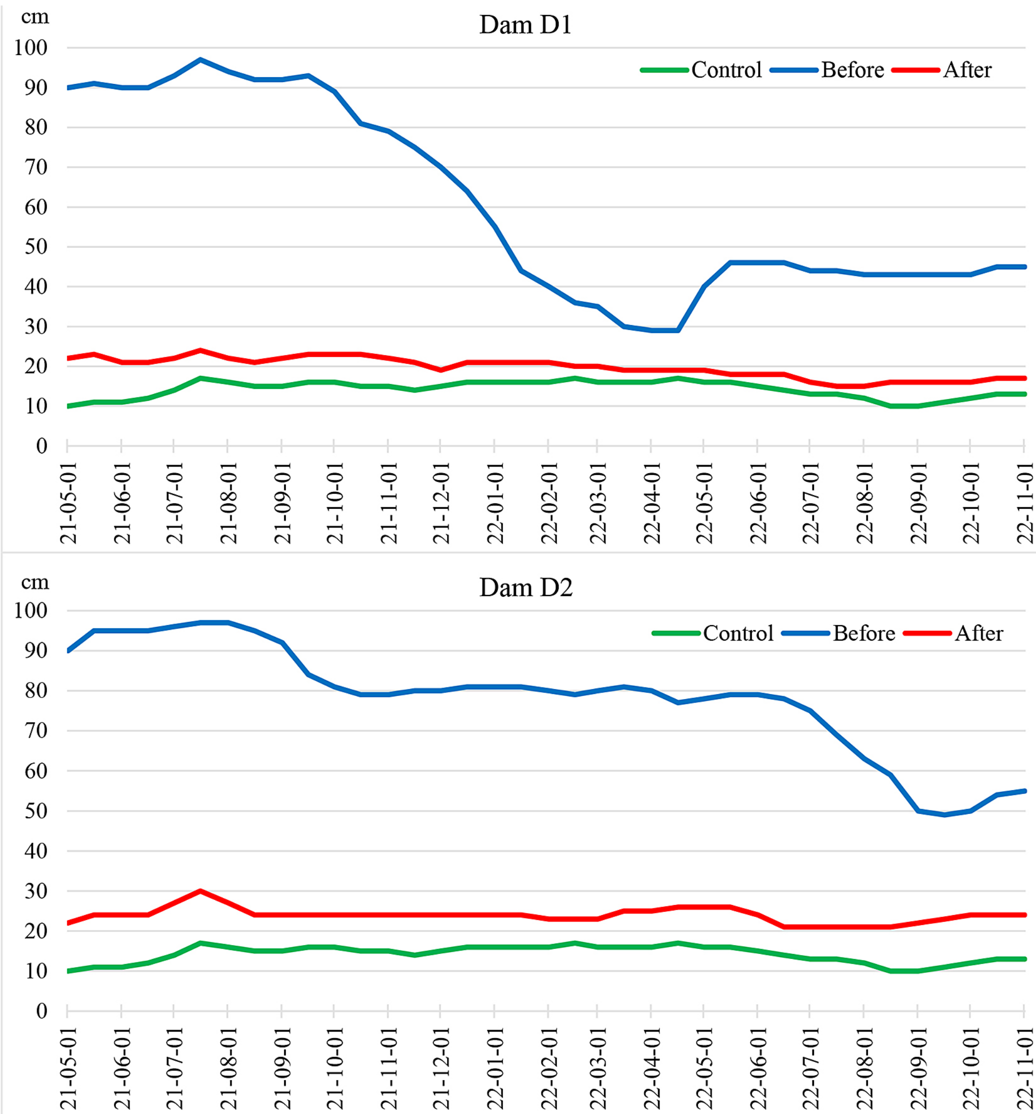

Figure 3. Water depth changes on the Świerszcz stream

depth below the dams was 22 and 24 cm, for D1 and D2, respectively, and 15 cm for station C (Fig. 3). However, the partial demolition of the D1 dam by humans caused a gradual decrease in the water depth above the dam. Additionally, in February 2022, a meltwater runoff occurred, which caused further erosion of the D1 dam. Due to low rainfall totals in March 2022 and earlier damage to the D1 dam, the lowest water depth above the dam was recorded in mid-April 2022. The water depth on the D1 dam was 29 cm and 19 cm, above and below the dam, respectively. The water depth on the D2 dam was 77 cm and 25 cm, above and below the dam, respectively. The water depth at station C was 19 cm (Fig. 3). This indicates that the minimum impoundment height of beaver dams was 10 cm. The occurrence of rainfall in April higher than the multi-year average and the partial reconstruction of the D1 dam resulted in a significant increase in the water depth above the dam. The water depth above the D1 dam in mid-June was 46 cm. Similar values remained until the end of the study period. In turn, the partial demolition of the D2 dam by humans caused a gradual decrease in the water depth above the dam. The lowest water depth above the D2 dam recorded in mid-September 2022 was 49 cm. At that time, the water depth below the D2 dam was 23 cm, which resulted in a minimum impoundment level of 26 cm. At the end of the study (October 2022), the water depth above the dams was 45 and 55 cm, for the D1 and D2 dams, respectively. The water depth below the dams was 17 and 24 cm, for the D1 and D2 dams, respectively, and 13 cm for station C (Fig. 3).

The differences in water depth before and after the D1 dam ranged from 26 cm to 71 cm, with an average difference of 54 cm. The differences in water depth before and after the natural D2 dam ranged from 10 cm to 73 cm. The average difference in water level between the before and after the D2 dam was 41 cm (Fig. 4). The Wilcoxon test showed a statistically significant lower water level in the river behind the dam than before the damming ($p < 0.001$; W=1). A statistically significant correlation was found between the water levels above and below the dam ($r = 0.84$; p-value 0.001). Building dams is a characteristic behavior of beavers aimed at creating suitable living conditions. Studies conducted in Sweden have shown that the construction of beaver dams affects the increase in the depth and width of the stream. The average water depth above the dam was 1.16 m, while below the dam it was 0.36 m. The average width of the stream above the dams was 11 m, while below the dams it was 2.5 m (Hartman and Törnlöv, 2006). Based on studies conducted in Belgium, it was found that the difference in water depth above and below the dam (average for distances 5–100 m) was statistically significant. The average water depth 10 m above the dam was 93 ± 30 cm, while 10 m below the dam was 30 ± 17 cm. The average increase in water level due to the dams was 47 ± 21 cm (Swinnen et al. 2019). Moreover, research conducted in central Poland has shown that beaver dams also contribute to the

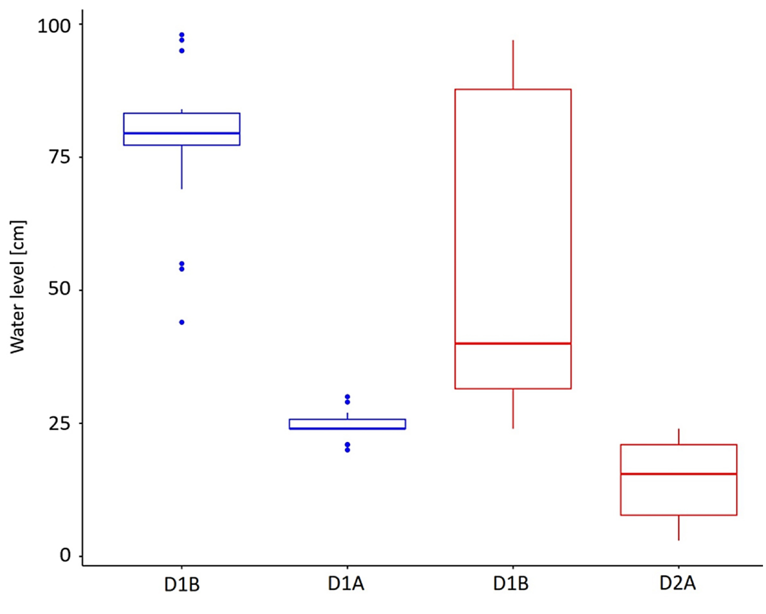

Figure 4. Assessment of the significance of water depth differences at stations - Wilcoxon test

increase in groundwater levels and soil moisture (Oleszczuk et al. 2022).

Statistical analysis did not reveal any significant correlation between monthly precipitation and water levels at control station C (Fig. 5), suggesting that atmospheric changes may be only partially responsible for the observed hydrological dynamics and that the riverbed may also be supplied by other sources. Interactions between surface water and groundwater in lowland river valleys may affect river flows, especially during periods of low precipitation. Flow dynamics are largely controlled by infiltration, and groundwater may be a key source of river recharge during periods of drought (Lambs 2004; Krause et al., 2007). Studies on the Yangtze River have shown that water levels during dry periods are significantly modified by existing dams. Barriers store water during rainy periods and release it during periods of scarcity. This phenomenon limits the impact of atmospheric variability on lower river reaches (Chen et al., 2001).

Water retention

At the beginning of the study period in May 2021, the retention volume of the Świerszcz Stream bed was 102 m^3 of water (Fig. 6). In the following months, as a result of long-term rainfall, an increase in the water depth in the river was observed and an associated increase in retention. The highest effective water retention was recorded in August 2021, when it was 106.5 m^3 of water. The occurrence of extreme

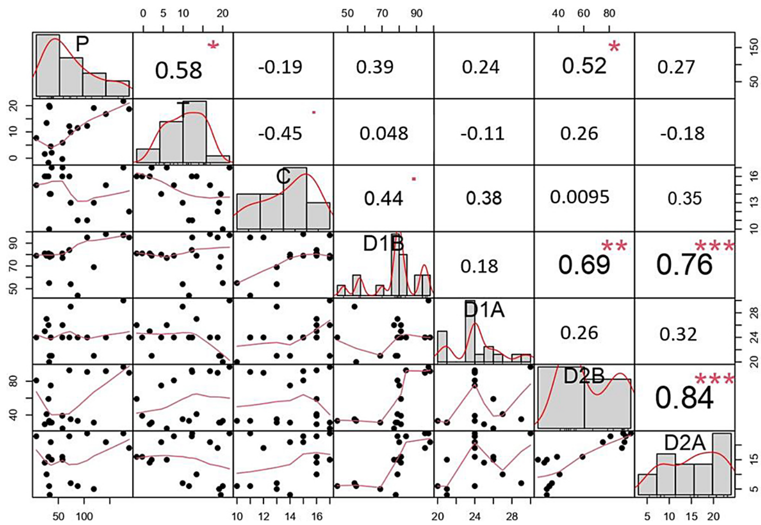

Figure 5. Pearson correlation matrix for the precipitation (P) and temperature (T) and water depth before (B) and after (A) dams D1 and D2, as at the control station C. Statistical significance is denoted as follows: *** (p < 0.001), ** (p < 0.01), * (p < 0.05), and (p < 0.1)

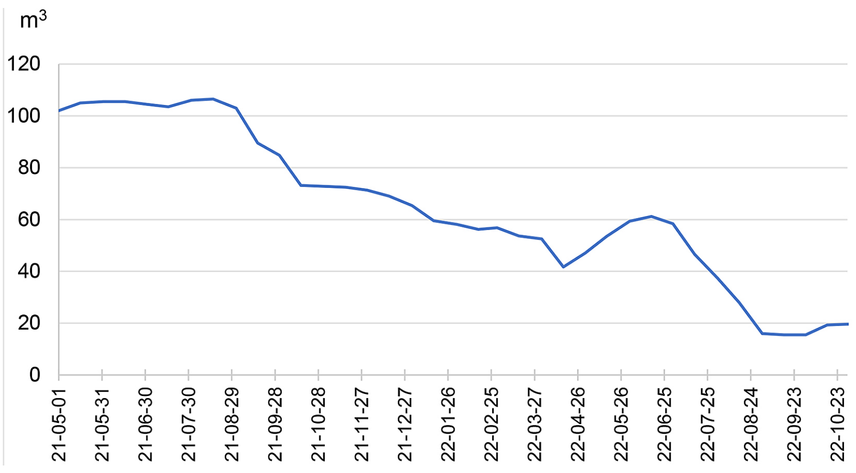

Figure 6. Effective water retention in the bed of the Świerszcz River

meteorological conditions described in previous chapters resulted in a significant decrease in the volume of water retention. At the end of the 2021 hydrological year, water retention was 73 m^3. Due to low rainfall totals in the 2021/22 winter season and damage to the D1 dam, low water retention was recorded in April 2022. The lack of snow cover contributed to the reduction of resources, which resulted in a decrease in water retention to 42 m^3. The partial reconstruction of the D1 dam by beavers increased water resources. Despite the three times lower rainfall in May 2022 (27.4 versus 89.5 mm), there was a significant increase in water retention. In June 2022, it amounted to 61 m^3. The partial demolition of the D2 dam by people resulted in a gradual decrease in water retention to 15.5 m^3 in September 2022. At the end of the study period in October 2022, the retention volume of the river bed was 19.7 m^3 (Fig. 6).

In the Tuchola Pinewoods study, significantly smaller ponds were noted, 11 m and 13 m long and 1.5 m to 5 m wide, which resulted in a smaller pond capacity (Rurek, 2021). In the studies on Spawn Creek and Logan River, pond areas ranged from 36 m^2 to 50 m^2, which allowed for the retention of an average of 9 m^3 of water. The variability in retention capacity was largely due to local hydrological and geomorphological conditions. Observations were conducted in the US on anthropogenically transformed streams, where leveled and deepened channels limited the formation of extensive floodplains (Karran et al., 2021; Murray et al., 2023). In contrast, points D1 and D2 were located in areas with limited interference with the channel structure, which allowed for the creation of extensive floodplains, favoring increased retention.

Studies have shown that beavers prefer to locate their structures in smaller streams, which do not exceed 10 m in width and 1 m in depth (Hafen et al., 2020). The choice of the location of a natural dam and the density of their occurrence in the stream also depends on the availability of construction materials (trees, curves, herbaceous vegetation), the size of the water flow, and the slope of the stream (Macfarlane et al., 2017; Dittbrenner et al., 2018). The impact of beaver dams on hydrological functioning is manifested by increased lateral connectivity, where dams cause water to spill onto nearby floodplains. Studies indicate that such changes contribute to slowing down the flow, which leads to increased water retention, an extension of the period between rainfall and peak flow, and a reduction in downstream flows in areas below beaver dams (Puttock et al., 2021). Additionally, increased water retention in catchments helps maintain minimum flows, which mitigates the effects of drought (Majerova et al., 2015; Smith et al., 2020). The construction of natural dams contributing to the formation of beaver ponds is a natural method of managing water resources. Ponds, which are fed by spring, stream, and rain waters, play a key role in reducing flood risk (Ferk et al., 2020).

Hydromorphology

Hydromorphological changes in rivers are the result of complex interactions of many factors, which include the hydrological regime, riverbed morphology, and characteristics of coastal zones. Significant differences were observed between the sites with beaver colonies (D) and the control station (C). In the beaver colony, changes in the heterogeneity of the riverbed material were observed, where sediments and silts accumulated within the beaver dam. The presence of natural morphometric structures influenced the transformation of the riverbed character. Water overflowing over the dam crest caused the formation of a fast current in the lower section of the stream (Table 1). Studies confirm that water stages affect the flow dynamics and geomorphological balance, changing the way sediments are transported and the riverbed structure (Graf, 2006). Changes in the riverbed vegetation at the sites with beaver colonies included the appearance of floating vegetation Lemna minor. It developed particularly intensively above the dam, where a beaver pond was formed, and the migration of biogenic compounds was limited. The most significant changes initiated by Castor fiber activity concerned the forest cover and the level of shading of the studied river sections. In beaver colonies, the average level of shading of the riverbed was 5% lower than at the control station, which resulted from the increased access to sunlight in the areas where beavers cut down trees and shrubs. Significant differences were also noted in the presence of woody materials on the riverbed bottom. At control station C, only fine woody debris was present on the bottom, which resulted from its location in a forested area and the natural transport of debris by the river. In beaver habitats, a significant amount of both fine and coarse debris, as well as

Table 1. The assessment habitat quality assessment (HQA)

Site	Differentiation of the longitudinal profile	Cross-section variation	Stream heterogeneity	Bed material heterogeneity	Natural morphological elements of the bed	Natural morphological elements of the bed slopes	Diversity of vegetation types in the riverbed	Vegetation structure on the bank slopes	Diversity of elements accompanying the woodlots	Structure of coastal vegetation	Width of the unused coastal zone	Naturalness and heterogeneity of the use of the valley	Connectivity of the river with the valley	HQA
C	1	1	3	4	0	0	4	2.5	2	2.5	4	4	0	28
D	1	1	4	5	1	0	5	3	7	3	4	4	0	38

fallen trees, was observed, which indicated the intensive influence of beavers on the structure of the riverbed bottom (Table 1). In habitats affected by beavers, the Habitat Quality Assessment value was 38, while in the control station, it was 28. In the upper reaches of the river, beaver activity, in particular the construction of dams, leads to intensification of lateral erosion, while slowing down the water flow limits the process of bed degradation. In the lower reaches, the impact of beaver activity is mainly focused on fragmentation of the banks, including landslides and the construction of burrows. Processes such as lateral erosion, accumulation of material at the base of the banks, and accumulation of woody debris affect local changes in the width of the riverbed. Beaver activity, in particular in artificially modified river sections, contributes to the gradual restoration of natural hydromorphological processes. Their presence may play a key role in future activities related to the renaturalization of both the upper and lower sections of the river (Gorczyca et al., 2018). The extent of the impact of beaver structures on the hydromorphology of the riverbed and water retention processes is strictly dependent on the hydrogeomorphic context of the given landscape. The key role here is the size of flooded areas of floodplains, which shapes changes in hydrological, geomorphological, geochemical, and ecosystem dynamics. In addition, an important factor determining the long-term impact of these changes is the period during which beavers can maintain a natural barrier (Larsen et al., 2021).

CONCLUSIONS

Despite similar construction parameters of the tested dams, their water retention capacity was significantly varied and dependent on hydrological conditions and anthropogenic interference. The average increase in water depth caused by the dams was 48 ± 18 cm. The differences in water depth before and after the natural dam ranged from 10 cm to 73 cm.

Extreme weather conditions, such as the biggest rainfall and highest temperatures in the 21st century, along with anthropogenic interference (dam demolitions), significantly affected the effectiveness of the dams in water retention. Reconstruction of damaged structures partially restored the water retention capacity, but these actions emphasize the importance of protecting beaver dams for stabilizing water levels in river ecosystems.

Water retention in the Świerszcz riverbed reached its highest capacity (106.5 m³) during heavy rainfall in July 2021. However, the lack of snow cover and low rainfall totals in the winter of 2021/2022 and the destruction of dams by people led to its significant reduction (15.5 m³ in April 2022). The results emphasize the significant impact of rainfall on changes in water resources, which indicates the sensitivity of the river's hydrological system to climate change.

The natural structure of the riverbed, including the lack of its transformations, plays a key role in increasing the retention capacity of beaver dams. In areas transformed anthropogenically, leveled and deepened riverbeds limited the development of riverbed retention. D1 and D2 dams located in natural areas allowed the formation of extensive flood areas, which significantly increased the amount of accumulated water.

The presence of beaver dams significantly increases the heterogeneity of the stream and the diversity of sediment materials in the riverbed. In beaver colonies, the stream changed from laminar to rapid near the dams, and sediments and mud accumulated on the bottom of the riverbed. Hydromorphological changes favor the natural retention of sediments and the enrichment of the bottom structure, which is confirmed by earlier studies (Levine and Meyer, 2014). The influence of beavers is particularly important in degraded areas, where they can support the renaturalization of rivers by restoring natural hydrological and geomorphological processes.

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