

Original article

Changes in river channel pattern as a result of the construction, operation and decommissioning of watermills – the case of the middle reach of the River Liswarta near Krzepice, Poland

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ABSTRACT

Changes in river channel pattern in the middle reach of the River Liswarta and in the lower reaches of its tributaries near Krzepice were analysed, and were related to the construction, operation and decommissioning of watermills. For this purpose, old maps which covered the period from the beginning of the 18th century until the 20th century were used alongside written historical sources. Maps from the first half of the 19th century provided valuable source material. Traces of old mill water systems in the valley floor were analysed on the basis of a numerical terrain model and aerial photographs as well as on the basis of detailed geomorphological mapping. The research made it possible to determine the locations of former mills mentioned in written historical sources and also changes in the course of river channels related to mill construction. It was found that some reaches of the River Liswarta channel and the estuary reach of its tributary River Bieszczka were in fact old mill races. These mill races account for around 31% of the length of the river channel reaches analysed. Analysis of old maps indicated that in the 19th century, the River Liswarta near Krzepice had multiple channels. This development of the River Liswarta channel was not only the result of natural geological, geomorphological and climate conditions, but also the product of watermill construction, since some channels within this network were artificial canals, including mill races. As a result of the construction of mill races, river channel reaches ranging from 1 to 2.5 km in length were shifted. Of the mills studied, as many as 80% ceased to exist in different parts of the period covered by the research. Traces of some of them can still be found in the form of ruins of foundations or of a water system with the remains of hydraulic structures, while some have only left their mark on the river channel pattern.

KEY WORDS: watermill, multi-channel river pattern, old maps, mill race, River Liswarta

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1. Introduction

River valleys have long been preferred by settlers owing to their economic benefits related to agriculture, fishing, transport and the use of hydropower (BROWN, 1997; SQUATRITI, 2000; RHODES, 2007; HOFFMANN, 2014). Such settlement patterns necessitated certain works, which had already started to be conducted in Poland in the Middle Ages and resulted in changes to the shape of valley floors. One of the main factors in the modification of river channels were watermills, which from the 12th and 13th centuries onwards became common features of the riverside landscape (DEMBIŃSKA, 1973). In the

territories that are now Poland, ca. 10,500 watermills operated in the late 18th century. The overwhelming majority of these (around 82.4%) were located in rural areas (BARANOWSKI, 1977).

Water wheels were originally used to drive mill machinery. They were used not only in grain mills, but also in industrial mills of the time, e.g. iron smithies, fulleries and saw mills (KAMLEROWA, 1966). In the 1920s and 1930s, water wheels were generally replaced with water turbines (mainly of the Francis type), which were 25–40% more efficient than the water wheel (BARANOWSKI, 1977). The introduction of the steam engine in the second half of the 19th century, followed by the internal

combustion engine and electric motors, gradually made the mills independent of the cheap energy source that was water. Some small rural mills retained two sources of energy – water and an engine/motor – until the end of their operation (WESOŁOWSKA, 1969; SZUROWA, 2015).

The construction and operation of a watermill required the installation of a system that supplied water to the mill and drained it afterwards; this consisted of mill races (head and tail), damming structures (weirs) and dykes, which were used to dam water and retain it in mill ponds. Rivers were adapted to the mills' operation by modifying the course of the river channel and its geometry, dredging and reinforcing the banks as well as changes to valley floor relief (PODGÓRSKI, 2004; DOWNWARD & SKINNER, 2005; WALTER & MERRITS, 2008; URIBELARREA & BENITO, 2008; KANIECKI & BRYCHCY, 2010; LEWIN, 2010; FAJER, 2011; FAJER & WAGA, 2002, 2010; KANIECKI ET AL., 2012; BISHOP & MUÑOZ-SALINAS, 2013; GRANO ET AL., 2016; VERSTRAETEN ET AL., 2017).

Originally, mills were located in places that did not require much investment and offered the most favourable conditions in terms of the facility of directing water to the water wheel. Later, as demand increased, areas around rivers and river channels themselves began to be adapted to an ever greater extent. The situation of some mills was so favourable that they continued to operate in a single place even for several centuries, while in other locations they only operated briefly (FAJER & WAGA, 2002; PODGÓRSKI, 2004; BRYKAŁA, 2005; KOBOJEK, 2009; KANIECKI ET AL., 2012; FAJER & WOSKOWICZ, 2016). After the source of power for the mill had changed, or after it had been decommissioned, its water system was usually subject to degradation. However, after mill decommissioning, parts of this water system, e.g. remains of a mill pond dyke or of a mill race, often remained discernible in the relief of the surrounding area.

Written historical sources provide information on these mills, but without stating their exact locations. An abundant source of knowledge about the river network and its changes (both natural and man-made) are old maps and plans (GRAF ET AL., 2008). Properly selected, old maps can provide an independent source of information and corroborate the credibility of written sources (LOREK, 2014). They are also a valuable source of information about the location of former watermills.

This study aims to identify changes in the pattern of River Liswarta channels in its middle reach

and in the lower reaches of its tributaries near Krzepice that occurred as a result of the construction, operation and finally disappearance of watermills in the period from the beginning of the 18th century until the 20th century. The 11 kilometre long reach of the River Liswarta together with the lower reaches of the Rivers Bieszczza and Piskara were analysed. Changes to the River Liswarta channel were analysed on the basis of remote sensing and geomorphological studies as well as the analysis of historical sources.

2. Materials and methods

In the research conducted, a range of different methods were used: 1) the analysis of old maps; 2) studies of written historical sources; 3) the analysis of relief on the basis of a numerical terrain model and aerial photographs as well as on the basis of detailed geomorphological mapping.

Archival maps and plans covering the period from 1702 to 1988 were used (Table 1). Their value as sources of information varied. 18th century maps are spatially inaccurate and cannot serve as a basis for measurements but still are a valuable source of knowledge about historical watermills, ponds and approximate courses of river channels. However, in order to determine changes in the pattern of river channels in the River Liswarta valley, maps and plans published in the 19th and 20th centuries were predominantly used. Very important data on the characteristics and courses of river channels and on mill locations were included, for example, in large-scale maps and plans of the former Krzepice estate dating from 1810 to 1847. Maps were selected that enabled the reconstruction of the course of the river channel over several periods.

The course of the River Liswarta channel near Krzepice was analysed along with a network of man-made canals and the mills that operated in the period covered by the study. A visual analysis of maps was conducted, during which the course of the River Liswarta channel together with reaches of its tributaries the Rivers Bieszczza and Piskara presented on maps from the 18th and 19th centuries were compared to fully accurate maps from the 1933–1961 period. The distortions present on old maps were estimated using the MapAnalyst application (<http://mapanalyst.org>). Objects that did not change their locations over time (churches, castles, road intersections) were used as reference points.

Table 1. Maps and plans used in the study

No.	Map	Publication year	Source
1.	Campem: Beÿ Crepitz. vom 13. Aug: A.1702, biss d:16. Aug	1702	Swedish National Archives Riksarkivet ¹
2.	Mappa szczegulna Woiewodztwa Krakowskiego i Xięstwa Siewierskiego [Detailed Map of the Kraków Province and the Duchy of Siewierz], K. de Perthées, ca. 1:225,000 scale	1787	Jagiellońska Biblioteka Cyfrowa
3.	Południowa część województwa sieradzkiego [Southern Part of the Sieradz Province], F. Czajkowski, ca. 1:185,000 scale	1789	Biblioteka Narodowa
4.	Special Karte von Südpreussen, D. Gilly, ca. 1:150,000 scale	1803	Biblioteka Cyfrowa Uniwersytetu Łódzkiego
5.	Wermessungs-Plan betreffend die Landereien der Dorfes Kuzniczka, ca. 1:12,000 scale	1810	Archiwum Główne Akt Dawnych
6.	Plan sytuacyiny Miasta Nowo Krzepice po pogorzeli w dniu 27 Kwietnia 1822 r. [Plan of the Nowokrzepice Town After the Fire of 27 April 1822], ca. 1:2,500 scale	1822	Archiwum Państwowe w Częstochowie
7.	Plan miasta rządowego Krzepic [Plan of the Government Town of Krzepice], 1824, ca 1:620 scale	1824	Archiwum Główne Akt Dawnych
8.	Plan sytuacyiny Sporu Granicznego między Wsiami Rządowymi Zaiączki i Kuźniczka a z drugiej Strony Miastem Krzepice [Plan Depicting the Border Dispute Between the Government Villages of Zajączki and Kuźniczka and the Town of Krzepice], ca. 1:8,500 scale	1837	Archiwum Główne Akt Dawnych
9.	Topograficzna Karta Królestwa Polskiego (Mapa Kwatermistrzostwa) [Topographic Map of the Kingdom of Poland (Quartermaster's Map)], ca. 1:126,000 scale	1839	Repozytorium Cyfrowe Instytutów Naukowych
10.	Topographische Specialkarte des Preussischen Staats und der angrenzenden Länder, G.D. Reymann, C.W. von Oesfeld, ca. 1:200,000 scale	1845	Repozytorium Cyfrowe Instytutów Naukowych
11.	Mapa Dóbr Rządowych Krzepice [Map of the Krzepice Government Estate], ca. 1:8,200 scale	1845	Archiwum Główne Akt Dawnych
12.	Mappa powiatu wieluńskiego [Map of the Wieluń District], ca. 1:126,000 scale	1847	Repozytorium Cyfrowe Instytutów Naukowych
13.	Karte des Deutschen Reiches, 1:100,000 scale	1893	David Rumsey Map Collection
14.	Karte des Westlichen Russlands, 1:100,000 scale	1897	Mapster
15.	Mapa Taktyczna Polski [Tactical Map of Poland], WIG [Military Geographic Institute], 1:100,000 scale	1926, 1933	Archiwum Map WIG
16.	Mapa Szczegółowa Polski [Detailed Map of Poland], WIG [Military Geographic Institute], 1:25,000 scale	1933	Archiwum Map WIG
17.	Генеральный Штаб Рабоче-Крестьянской Красной Армии – topographic map, 1:50,000 scale	1944	Archiwum Map WIG
18.	GUGiK [Head Office of Geodesy and Cartography] – topographic map, 1:10,000 scale	1960–1966	Geoportal Województwa Śląskiego ORSIP
19.	GUGiK [Head Office of Geodesy and Cartography] – topographic map, 1:10,000 scale	1973–1988	Geoportal Województwa Śląskiego ORSIP

¹The map posted on the Krzepice Castle website <https://www.facebook.com/pg/zamekwkrzepicach>

The analysis of orthophotomaps from 1996, 2003, 2009 and 2015 and of the numerical terrain model produced on the basis of aerial laser scanning (LiDAR survey) made it possible to find traces of an old outflow in the River Liswarta valley. Detailed mapping of visible remnants of old river channels and artificial canals as well as other elements related to the past development of the valley floor, including the operation of mills, was also conducted. Natural and artificial geological pits were examined and shallow probing of sediments forming the valley floor was conducted, followed by lithological tests.

In order to determine the number of mills and the manner in which water was fed to them, written historical sources ranging from the 16th to the 18th centuries were analysed (REVISIA..., 1564; LUSTRACJA..., 1569, 1636, 1660, 1789).

3. Study area

The study was conducted in the middle reach of the River Liswarta near Krzepice (Fig. 1). This area is located in the Krzepice Depression, which was formed in Middle Jurassic sandy clays and filled

with Quaternary sediments: glacial tills and fluvioglacial and fluvial sands and gravels, and also silts locally (HAISIG & WILANOWSKI, 1985, 1990). Near Krzepice, the River Liswarta flows in a characteristic arc around forms resulting from the accumulation of material in ice sheet cracks during the Odra glaciation period (KLIMEK, 1966).

The valley floor is almost flat, with a width of 600 to 800 m (up to 1 km downstream of Krzepice); it lies at an altitude of 210–214 m a.s.l. Holocene alluvia are present in the form of sandy and sandy-gravelly sediments with organic silt interbeddings and plant detritus, and thin layers of peat in some places. The thickness of these alluvia in this reach ranges from 2.5 to 3.5 m. A number of palaeochannels of different ages, which were completely filled with mineral and organic sediments and masked by flood sediments, were documented there (FAJER, 2004). On both sides of the flood plain, ledges of the Vistulian meadow terrace are present. These rise 2.5–4.5 m above the flood plain level, and locally only up to 1 m above it.

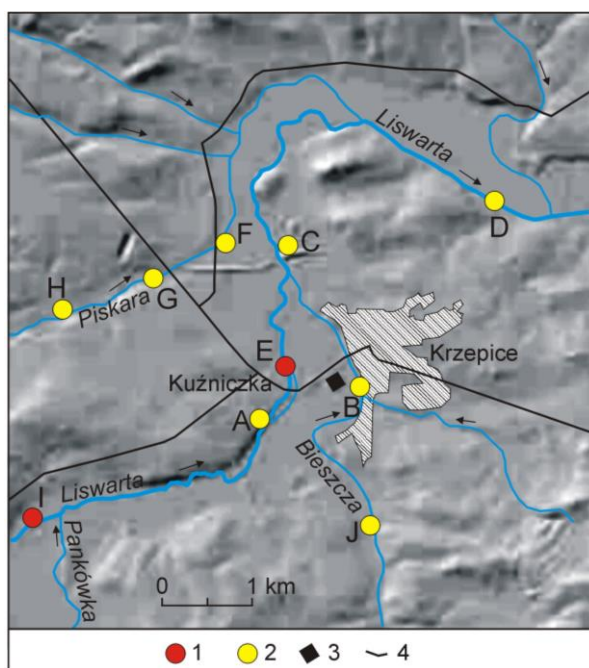


Fig. 1. Locations of the mills analysed

1 – existing mill, 2 – mill no longer exists, located on the basis of archival materials, 3 – castle, 4 – major contemporary roads; Mills: A – Zamkowy, B – Piaskowy, C – Folszowy, D – Magreta, E – Marcelin, F – Drozdkowy, G – Pachały, H – Siekiery (Lutrowski), I – Starokrzepice, J – Kuków

Near Krzepice, two morphological levels can be discerned in the floor of the River Liswarta valley (Fig. 2), with a difference in relative height of 1–1.5 metres between them. The higher level is present in the western part of the valley floor, nearer to Kuźniczka. It is overlain by flood sediments in the form of crevasse splays and sandy ribbons as well as river channels completely filled with mineral

deposits. This area is used for agriculture, partly as arable fields (in places where oak-hornbeam forests used to grow). The lower level extends around the castle and reaches as far as the eastern edge of the valley floor and developed urban areas. In this level, there are visible traces of old channels that mark the former drainage route, and downstream of the castle and of the dyke along which the road that connects both sides of the valley runs, there is a network of branching channels with islands between them. Their pattern resembles anabranching river channels. These start along the extension of the old River Liswarta Channel, near the dyke along which the road runs (Fig. 2). This part of the valley was waterlogged and bogs were present in some places, which can be seen on 19th century maps. Historical sources also mention the boggy River Liswarta valley (LISKE, 1876; MUZNEROWSKI, 1914). Nowadays, this part of the valley floor consists of waterlogged, periodically flooded meadows (carrs), mostly laying fallow. In the 1950s, the land at the bottom of the valley was drained and levees were constructed along the river channel. The River Liswarta channel near Krzepice has a small gradient (0.565 ‰), variable width (from 10 to 40 m) and it cuts from 1 to 1.5 m deep into the flood plain. At the bottom of the valley, there are man-made structures: road embankments, dykes, levees and a network of drainage ditches.

The River Liswarta is fed by water runoff, rain and snowmelt and it exhibits an even hydrological regime. Floods occur in the spring season (most often in March) and in the summer season (most often in July and August) (DYNOWSKA, 1971). The average flow rate in the middle reach of the River Liswarta in Starokrzepice is around 5.0 m³/s (BUJAKOWSKI, 2006). Fluctuations in water levels range from 120 to 140 cm on average. During such large floods as that which occurred in July 1997, the entire floor of the valley is flooded. Low water stages, which occur in summer, with a clear maximum in June and August, are not extreme, which reflects the large share of underground feeding (DYNOWSKA, 1971). In the study area, near Krzepice, are the mouths of the Liswarta's right-bank tributary (the Bieszczka) and the left-bank tributary (the River Piskara).

In the past, both floods and low-water stages created problems for the mills operating on the River Liswarta. This is mentioned, *inter alia*, in the record from the 1564 land register concerning the mill in Krzepice: "This mill is built on stilts by the river bank behind the weir. Everyone states that it is flooded at high water stages and often idle at low water stages, so bakers and burghers must frequently go to the nearby mills with their grain; the height of the levee and of the dyke would have to be increased to elevate the mill

more, then the slope would be better and it would not be flooded" (REVISIA..., 1564; AKTA MIASTA..., 1783).

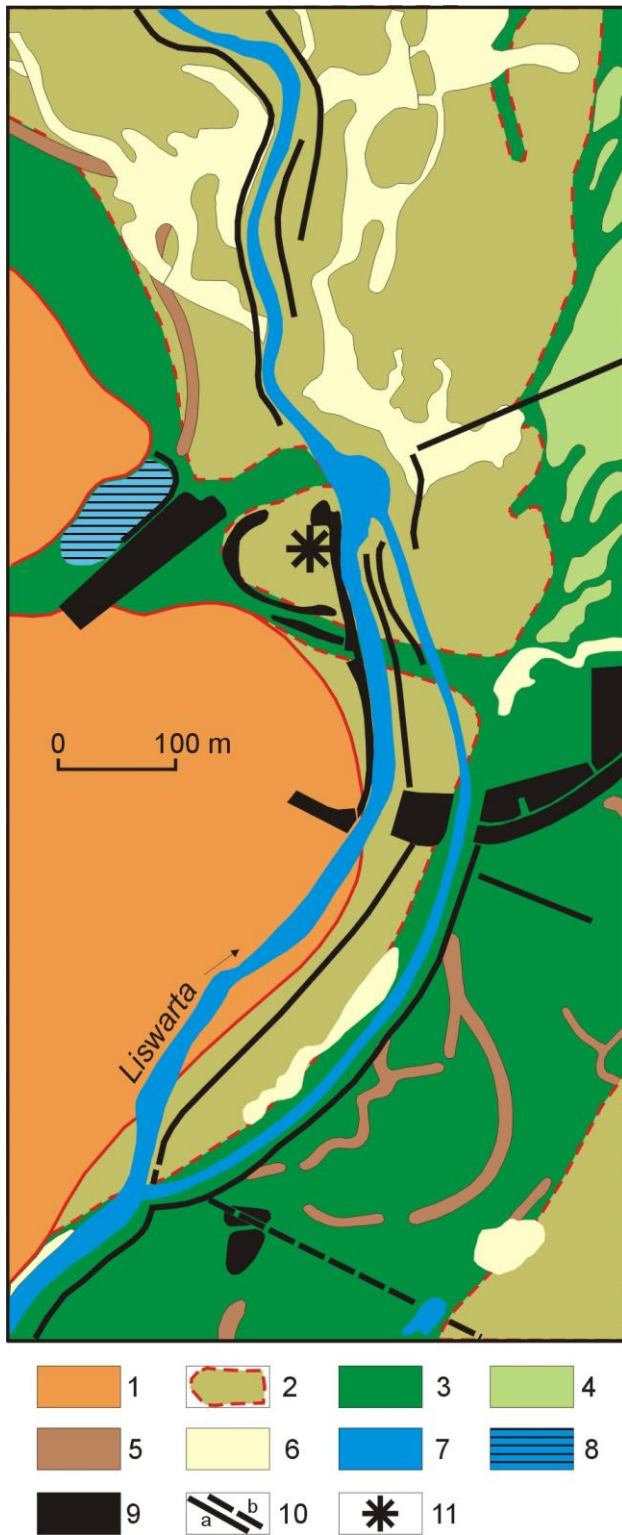


Fig. 2. Geomorphological outline of the left-bank reach of the River Liswarta valley near Krzepice (own research)

1 – plateau, valley floor; 2 – splay and terrace level (late Pleistocene-Holocene); 3 – flood plain; 4 – older bars formed during floods and interchannel islands; 5 – palaeochannels; 6 – younger landforms created by floods (crevasse splays and sand shadows); 7 – flowing and stagnant waters; 8 – pond filled with water in the first half of the 19th century; 9 – embankments and artificial terraces; 10 – dykes and levees (a – existing; b – dismantled, marked on old maps); 11 – Marcellin watermill

4. Outline of the history of watermills in the vicinity of Krzepice

The oldest mention concerning a watermill in the vicinity of Krzepice dates back to 1374 and refers to the Herbultowska iron smithy on the River Pankówka, a tributary of the River Liswarta (ZIĘTARA, 1954). In 1419, a mill in Danków, 6.5 km away from Krzepice, was mentioned (GRABARCZYK & NOWAK, 2015). In 1466, the Sośnieszów mill (later referred to as Lutrowski) on the River Piskara was mentioned (MUZNEROWSKI, 1914). More information about mills in the vicinity of Krzepice comes from the 16th–18th century period. The increase in their number reflected the increased use of hydropower at that time (KAMLEROWA, 1966).

From the late 18th century until the mid-20th century the number of mills in the River Liswarta catchment decreased to less than a third of the original figure (FAJER, 2011) (Fig. 3). After World War II, small mills that served the local population disappeared rapidly. The shift from using hydropower to electrical power as well as the regulation of river channels conducted on the River Liswarta and on its tributaries from the 1950s to the 1980s caused some mills to be cut off from water, which had provided a cheap source of energy. Some mill races, dams and mill ponds were filled in at the time.

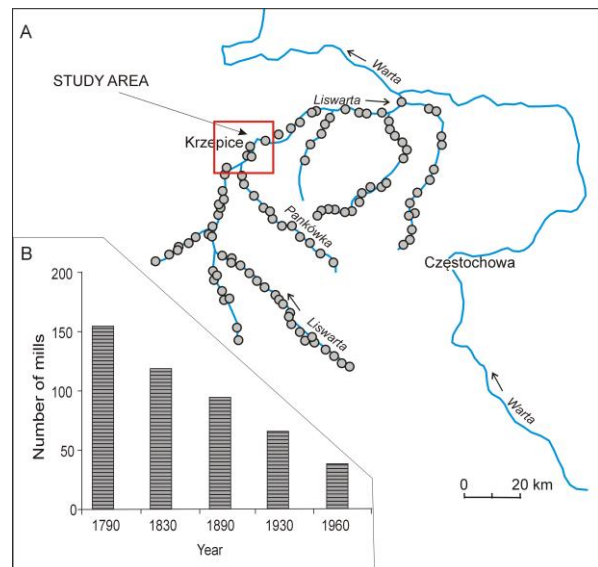


Fig. 3. Locations of watermills in the River Liswarta catchment (A) and changes in their numbers from 1790 to 1960 (B) (based on Fajer, 2011, modified)

5. Results

On the basis of the analysis of written historical sources from the 16th and 17th centuries (LUSTRACJA..., 1564, 1569, 1636), it was found that in the old mills on the River Liswarta and on its tributaries,

both undershot wheels and overshot water wheels were used. In the River Liswarta channel, mills with undershot wheels were operated more commonly, whereas on its tributaries, among others on the River Górnianka in Rębielice and on the River Biała Oksza in Kłobuck, mills with overshot wheels were recorded. These mills required that a pond be constructed and water dammed, but were more efficient and thus represented an advance in mill technology. The source materials often did

not include any information about the type of wheel installed in the mill. The mills with small ponds which were mentioned in the land register (e.g. on the River Piskara in Siekiery and Pąchały) were probably equipped with overshot wheels. Among the mills studied in Krzepice and its vicinity, there were mills with a single wheel, but also ones equipped with two, three or even four water wheels (Table 2).

Table 2. Outline of the history of the watermills included in the study, own research based on: Revisia..., 1564; Lustracja..., 1569; Lustratio..., 1636; Lustracya..., 1660; Lustracja..., 1789; Akta miasta Krzepice, 1783; Drzewiecki et al., 1904; Wystawa przemysłu..., 1909; Muznerowski, 1914; Rybczyński, 1931; Rocznik przemysłu..., 1938 Słownik..., 2010; CBN Polona <https://polona.pl/>

Letter denoting the mill (Fig. 1) and its name	Location		Mill history
	River	Town / village	
A Zamkowy	Liswarta	Krzepice-Kuźniczka	1569 – mill newly built by district governor Wolski, with three undershot wheels for producing flour and a single wheel for producing groats; 1588, 1592, 1636 – mill with two flour wheels and a single groat wheel; 1660 – mill with three wheels, destroyed by the Swedes; 1789 – district governor's mill; the mill does not exist any longer
B Piaskowy	Bieszczza	Krzepice	1636 – mill with a single wheel on the Liswarta River (!) between urban areas, 1660 – burned by the Swedes; 1702 – marked on a Swedish map; the mill does not exist any longer
C Foluszowy	Bieszczza	Krzepice	1558 – alderman's mill with a fullery on the Liswarta River (!), 1564 – mill with two undershot wheels, the third wheel "is to be placed where the fullery wheel used to be"; 1569 – alderman's mill with two undershot wheels and a fullery wheel; 1660 – alderman's mill with a three-wheel and a fullery; the mill does not exist any longer
D Magreta	Liswarta	Krzepice	1562, 1564, 1569 – Ziaija mill with two undershot wheels; 1789 – Margreta mill; remains of building foundations and of the wooden structure in the river channel
E Marcelin	Liswarta	Krzepice-Kuźniczka	1876 – mill construction; the mill was equipped with a water wheel with a capacity of 15 hp, which operated until 1909; 1904 – 30 hp motor; 1917 – a 30 hp water turbine was installed, which also drove the power plant's generator; 1931 – mill and power plant with a total capacity of 105 hp; a sawmill was built next to the mill. In 1938, the mill was equipped with a 70 hp water turbine and a 40 hp wood gas motor; the mill is now closed
F Drozdki	Piskara	Drozdki	1636 – Drozdek mill; 1702 – present on the Swedish map; 1789 – the Drozdek brothers' mill granted by a 1782 privilege; the mill does not exist any longer
G Pąchały	Piskara	Zajączki-Pąchały	1636 – mill with a single wheel; 1789 – mill with a single wheel; mill pond reconstruction
H Lutrowski	Piskara	Krzepice-Siekiery	1446 – mentioned in the founding act of the Canons Regular monastery in Krzepice; 1590, 1789 – mill with a single wheel; mill pond remnants
I Starokrzepice	Liswarta	Starokrzepice	1789, 1803 – an older mill located around 1 km west of the Starokrzepice mill; 1893 – Ligenza mill; 1845 – mill with a single undershot wheel, located around 300 m downstream of the Starokrzepice mill; neither mill exists any longer; 1909 – construction of the Starokrzepice mill; the mill is now closed and a small hydro power plant operates at the dam
J Kuków	Bieszczza	Krzepice-Kuków	1789 and 1803 – marked on maps, no other details; the mill does not exist any longer

5.1. Location of watermills in Krzepice based on the analysis of archival maps

The analysis of archival maps from the 18th century and from the first half of the 19th century made it possible to determine the location of watermills mentioned in written historical sources

ranging from the 16th to the 18th centuries. The oldest map on which the mills near Krzepice were marked dates back to 1702. There are two mills on this map – on the River Bieszczza in Krzepice (the Piaskowy [Sandy] mill) and on the River Piskara in Drozdki. Perthées's (1787) and Czajkowski's (1789) maps contain many errors in village and town locations

and in the course of the rivers shown, but approximate locations of mills can be established on their basis. In the late 18th century, a mill operated near the manor in Kuźniczka (the Zamkowy [Castle] mill) and there was also the Magreta mill. The Piaskowy mill was not marked on the map, as it had probably fallen into disuse by that time. Mills also operated on the River Piskara in Pąchały and on the River Bieszczą in Kuków. In addition, there was a pond in the lower reach of the River Bieszczą. On Gilly's map (1803), apart from the mills mentioned above, there was also a mill on the River Piskara in Siekiery (Lutrowski). Reymann's map (1845) shows a similar picture of mill locations. On the Kwatermistrzostwo [Quartermaster's] map (1843) and on the map of the Wieluń district (1847), only the Magreta mill on the River Liswarta and the two aforementioned mills on the River Piskara were recorded. Late 19th century maps (1893 and 1897) present a similar channel pattern, but only mills on the River Piskara are marked. In this case, there is a difference compared to written sources, because at that time the Marcelin mill in Kuźniczka already operated. The state of affairs presented on the maps probably predates the construction of this mill. In 1933, the Marcelin and Magreta mills and two mills on the River Piskara were extant.

The analysis of archival maps made it possible to determine the locations of four already non-existent mills that were mentioned in land registers from the years 1564–1789, i.e. the Zamkowy, Piaskowy, Folszowy and Drozdkowy mills. The location of the mill in Kuków is approximate owing to the small scale and limited accuracy of the maps on which it is marked.

Locations of some mills were quite permanent as they operated in the same place for several hundred years. In the study area, the Magreta mill on the River Liswarta (from 1562) and the mills on the Piskara in Siekiery (from 1499) and in Pąchały (from 1636) were the most long-lived. Locations of the other mills changed as exemplified by those in Kuźniczka – the Zamkowy mill disappeared and the Marcelin mill was constructed in a new location.

5.2. Changes in the course of river channels near Krzepice and locations of former watermills changes to the River Liswarta channel

Changes in the course of the river channel were related to the construction and operation of two mills on the River Liswarta in Kuźniczka – the Zamkowy and Marcelin mills – which were located close to each other, although they existed in different periods, and also of the Magreta Mill.

The analysis of maps shows that between 1787 and 1837 in Kuźniczka, a mill operated which was located on the left bank of the river channel, near the former estate that belonged to the castle, around 400 m upstream from the modern bridge. On an 1810 map, it is marked as a mill with two water wheels, which is situated in the main river channel. Upstream of the weir, there was a small dam (Fig. 4).



Fig. 4. Section of the Kuźniczka village plan from 1810 with a multi-channel reach of the River Liswarta and a watermill with two wheels (source: Wermessungs-Plan..., 1810, original scale ca. 1:12,000, AGAD, ZK 402, Ref. No. 293-9)

Downstream of the mill, a long mill race began, which was dug along the edge of the meadow terrace and the slope of the plateau; it was already disused at that time. In its lower reach, the mill race was dug by cutting through the river bend. It cannot be ruled out that the mill race had already been dug earlier for the purposes of an older mill or iron smithy (the name of the village of Kuźniczka, i.e. "Smithy Village", could indicate this). The operation of the smithy appears to be confirmed by the presence of a layer of metallurgical slag deposited in the location where the synagogue was later built (CIEŚLA, 1997). In 1845, the mill was no longer marked on the map, and the mill race was disused, cut off from the main channel and disconnected from the outflow (Fig. 5). As early as in 1838, the mill was no longer listed in the register of Krzepice government estates (MUZNEROWSKI, 1914). An approx. 600-metre long dyke ran from the mill, which cut across the entire valley floor. It remained in place until drainage works were carried out in the 1950s. Similar dykes, which are still extant in Danków and in Rębiełice Szlacheckie, served as head dykes of former ponds, which had been constructed for defensive reasons and also

to serve the pig iron forges and grain mills that operated there. The pond at Rębielice Szlacheckie existed until the beginning of the 19th century, and the pond in Danków was filled in during drainage works in 1970. This similarity suggests that in this case, the remaining structure could also have been the head dyke of a pond that was used to feed water to a mill or to an iron smithy that operated at some indeterminate time in Kuźniczka and could have been part of the castle's defence system at the same time. According to

MUZNEROWSKI (1914), in the event of a threat, water from this pond was used to flood the boggy area surrounding the castle. In addition to the mill sluice, there were three other sluices in the dyke, which can be seen on the 1810 map. In the place of one of them, a small pond is now present. It cannot be ruled out that during floods, earth was washed out around these old sluices. The emergence of similar erosion forms after levees had been breached was observed after the 1997 flood in the River Liswarta valley downstream of Krzepice.

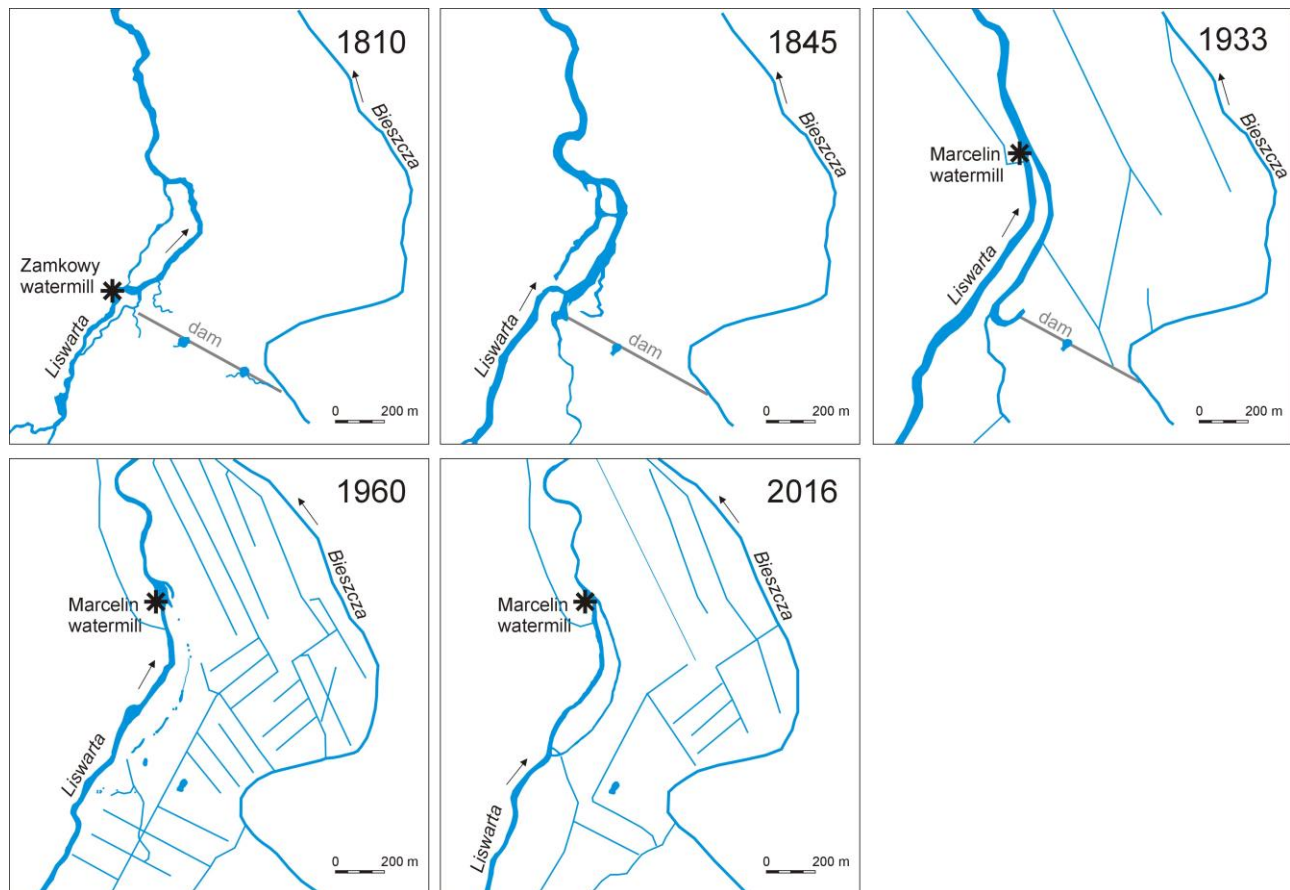


Fig. 5. Changes to the River Liswarta channel in Kuźniczka as a result of the decommissioning of the older (Zamkowy) watermill and the construction of the Marcelin mill in a new location (own research)

Further changes in the river channel in this reach were related to the construction of the Marcelin mill, around 650 m downstream of the old Zamkowy mill. At that time, the old mill race was cleaned and as a result the water flow, almost non-existent by then, was restarted. A section of the river channel, around 300 m long, was shifted as well. For this purpose, a canal was dug, the river bend was cut off and a small dam was constructed in the channel by the mill. At that time, the old River Liswarta channel started to function as a flood channel bypass, which accepted excess water, reducing the threat to the mill during floods.

At the beginning of the 19th century, the Rivers Piskara and Bieszczka flew into the side channels

of the River Liswarta, as shown in Gilly's map. Traces of these old channels are still visible in the relief of the valley floor. Downstream of the Marcelin mill, the meandering channel undergoes partial avulsion during floods. Avulsion channels are completely filled with mineral sediments (sand and gravel), and their course corresponds to the course of the former depression formed by the side channel.

6 km downstream of the Marcelin mill, the Magreta mill stood until the 1960s. It was among the oldest of the Krzepice mills, recorded in sources that dated back to the 16th century. It was situated on an artificial 1.38 km long mill race (Fig. 6), which was dug at the beginning of the 19th century.

On an 1837 map, there is an annotation near the mill race that it was a “river newly dug”, although in fact it had already been marked on Gilly’s map. Given the old location of the mill, it was probably much earlier that the course of the River Liswarta channel had been modified in that reach. The digging of the mill race and keeping it passable at a later stage resulted first in a reduction and subsequently the cessation of flow in the old river channel, which gradually dried out. The construction of fish ponds on the River Liswarta valley floor in Zbrojewsko and 20th century drainage works caused the old river channel to be finally cut off and filled in.

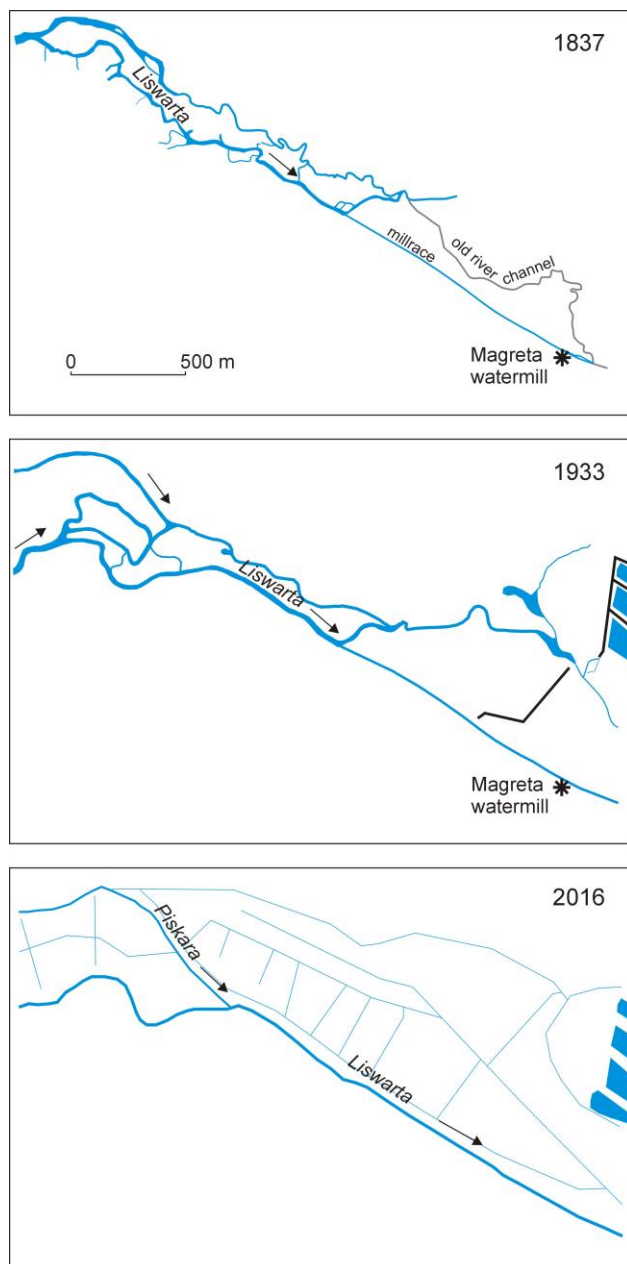


Fig. 6. Changes to the River Liswarta channel in the vicinity of the Magreta mill (own research)

The mill in Starokrzepice is located on the River Liswarta channel, but a 500-metre reach of the channel downstream of the mill is a former mill race.

5.3. Changes in the course of the River Bieszczka and Piskara channels

The construction and operation of watermills also involved changes to the channels of River Liswarta tributaries. This concerned especially the mouth reach of the River Bieszczka where the Piaskowy and Folszowy mills operated. The Piaskowy mill was situated around 350 m south of the bridge on the Bieszczka, and the Folszowy mill was built at the confluence of the Rivers Bieszczka and Liswarta. Originally, the River Bieszczka entered the old River Liswarta channel upstream of the castle. It can be assumed that at least from the 16th century, the river was flowing close to the town. In order to feed water to the mills, an artificial mill race was dug and the mouth reach of the River Bieszczka was shifted to the right edge of the valley near the western outskirts of Krzepice. However, given the multi-channel pattern of the River Liswarta in this valley section, it cannot be ruled out that one of its branches ran between the castle and the town. In 1824, the River Bieszczka was already a regulated watercourse and its channel was an artificial canal marked as the Rudawa Canal on the map. A similar picture can be seen on an 1847 map, where it is evident that the River Bieszczka flew into the old River Liswarta channel along a straight canal upstream of the dyke where the road runs while the course of the second channel was similar to the modern one. As a result of the channel being shifted to the eastern edge of the valley, the mouth section of the River Bieszczka was extended by 2 km.

In the 11 kilometre reach of the Rivers Liswarta and Bieszczka covered by the study, artificially dug canals that served watermills (Fig. 7) have a total length of 3.5 km, i.e. 31% of the length of the river channels in the study area.

Close to the mills on the River Piskara, there were damming dykes and small ponds with an area of around 0.04 km². The mill in Pąchały operated within the river channel while the canal that fed the pond served as a bypass. In Siekiery, the mill operated within a mill race that was dug through a meander neck. After these mills had ceased to operate, their water systems were degraded, but in both cases the current River Piskara channel still branches out because although the river was regulated, the old channel and the canal of the former mill race were preserved.

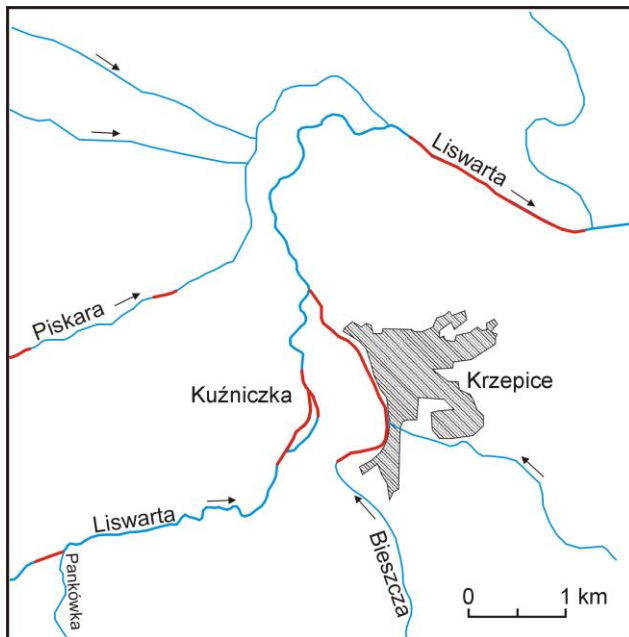


Fig. 7. Reaches of the Rivers Liswarta and Bieszczka channels (marked in red), which are old mill races and channel sections whose location was changed in order to serve watermills (own research)

6. Discussion

The use of large-scale maps from the first half of the 19th century as a direct source of information made it possible to determine the spatial relationships between the mills studied, which were difficult to find in written historical sources.

Maps of the River Liswarta near Krzepice in that period indicate that the river exhibited a multi-channel pattern. Next to the main channel, there were side channels and numerous narrow branches, often exhibiting significant sinuosity. The analysis of valley floor relief also showed a considerable variety of fluvial relief with traces of a multi-channel river pattern. Traces of old channels with small meander radii, which were side channels within the River Liswarta multi-channel pattern, are still visible as shallow depressions (around 0.5 m) in flood plain relief.

Until the 19th century, multi-channel rivers were a frequent phenomenon. This channel pattern was found both in rivers in the Sudetes, e.g. the Rivers Bóbr and Kwisa (TEISSEYRE, 1990, 1991, 1992), as well as in lowland rivers, e.g. the middle reach of the River Bzura (KOBOJEK, 2009) and the middle reach of the River Warta, where the multi-channel pattern persisted from the Subboreal until the 19th century (FORYSIAK, 2005, 2010). In the second half of the 18th century, in its lower reach the River Warta had several branches within a marshy valley (GRAF ET AL., 2008). Some of its side channels were only filled with water during high and medium water stages, while during low water stages some

low-lying areas became endorheic (KANIECKI, 2014). The situation was similar in the valley in the middle reach of the River Liswarta. The limited longitudinal gradient of the valley floor and thus of the river channel hindered the flow of flood waters. Endorheic areas formed, which were periodically flooded and became waterlogged or even boggy in some places. The river flowed in several branches along the valley floor, which was boggy in some places. Such reaches of the valley are marked on old maps. Historical sources also mention bogs and marshy meadows around the castle in Krzepice. In the second half of the 19th century, those areas were drained using a network of drainage ditches, and as a result they were almost dry at the beginning of the 20th century as mentioned by MUZNEROWSKI (1914).

KOBOJEK (2009) pointed to the impact of colder and more humid climate conditions during the Little Ice Age on the shape of multi-channel reaches of the River Bzura. The rise in groundwater level caused the amount of water on the valley floor to increase and additional channels developed as a result. Watermills with ponds were an additional factor that hindered surface runoff, thus making the valley floor boggier and promoting the emergence of multi-channel patterns. Similar conditions prevailed in the River Liswarta valley. The construction and operation of watermills contributed to the emergence of the multi-channel River Liswarta pattern. The mills' operation involved the construction of a water supply and drainage systems (mill races, weirs, ponds) and ensuring that the water dropped onto the water wheel from the greatest height possible. In the first half of the 19th century, some reaches within this multi-channel River Liswarta pattern were artificial canals (Fig. 7), which can be seen on old maps. Several served as mill races. Mill races could have played a role similar to the flood channels (bypasses) that are used in flood protection systems nowadays.

Mill races and mill ponds often fulfilled other functions as well, including defensive ones. An example from Wales is given by BROWN (1997) – a landowner was allowed to build a watermill provided that the mill race would run along the town's perimeter to serve as a defensive barrier. The River Bieszczka channel in Krzepice had a similar function. Nowadays, the channel of the River Liswarta in Kuźniczka is a former mill race and the channel of the lower River Bieszczka within the Liswarta valley is an artificial canal, which served as a mill race in the past; the same applies to the section of the river channel in the vicinity of the former Magreta mill. Side branches of the River Liswarta channel probably functioned as mill

races as well after they had been dredged and adapted to the millers' needs. It cannot also be ruled out that some of those side channels were originally artificial canals constructed for the watermills operating in Krzepice, which were transformed into natural watercourses after the mills in question had been decommissioned. Similar observations were made by BROWN (1997) who examined rivers in England. He believed that natural reaches of anastomosing rivers were used as watermill locations, but the operation of those mills also had an impact on the formation of branching river reaches. However, it is very difficult to determine the impact of mills on the presence of such reaches. RHODES (2007) even claims that the construction of mills was among the main reasons for man-made modifications of river channels.

At the beginning of the 19th century, when many watermills continued to operate, SUROWIECKI (1811) pointed out that rivers, e.g. the Warta, the Pilica and the Prosna, were blocked by multiple dykes, weirs and mills, and divided into many small branches which hindered water outflow. He believed that weirs and mills on the rivers were the main factor that caused flooding and resulted in flood plains being turned into marshes. When studying multi-channel rivers in the Sudetes, TEISSEYRE (1985) concluded that in many valleys, the mill races that had been neglected after 1945 tended to transform into meandering rivers, resulting in a multi-channel pattern which TEISSEYRE (1985) described as an anthropogenic anastomosing system.

The development of multi-branch channels is facilitated by the avulsion process (NANSON & KNIGHTON, 1996). This often occurs during floods, but is also conditioned by the topography of the valley floor, e.g. a low valley floor and river channel gradient, the geometry of the channel and the presence of beaver dams or trees that fell into the river channel (SLINGERLAND & SMITH, 2004). The effect of small mill weirs is in many respects similar to that of natural beaver dams (BROWN, 1997), which facilitate the avulsion process and the emergence of multi-channel flow (JOHN & KLEIN, 2004; POLVI & WOHL, 2012, 2013; FAJER ET AL. 2017). PERIGNON (2007) believes that mills built on rivers could have promoted avulsion, reducing the gradient of the mill race upstream of the mill dam. In the case of the River Liswarta channel in Kuźniczka, traces of the avulsion process are visible downstream of the Marcelin mill, i.e. downstream of the channel section that was shifted towards the left slope of the valley. Subsequent avulsion in this section was probably contributed to by the characteristics of the channel

such as its broadening and low banks in the zone where material was washed out by erosion below the weir and the development of meanders downstream of this zone.

The multi-channel pattern of the River Liswarta near Krzepice persisted until drainage works were conducted and riverside areas were drained in order to use them as pastures and arable fields. While a few drainage ditches were already present in the River Liswarta valley as early as in the first half of the 19th century, a network of ditches only becomes visible on maps from the 1890s. Remnants of this multi-channel River Liswarta pattern could still be seen on WIG [Military Geographic Institute] maps from 1933, but they were already significantly altered by human activity by then, and extensive regulation and drainage works in the 1950s removed all such remains when riverside meadows were drained with a dense network of drainage ditches.

7. Summary and conclusions

The studies conducted demonstrate that in the middle reach of the River Liswarta and along its tributaries (the Rivers Bieszczka and Piskara), the construction of mills had a large impact on river channel modifications through the construction of mill races, weirs and dykes. Two such cases were pointed out within the examined reach of the River Liswarta. In the first case, the mill was built on the main river channel which exhibited higher flow rates while the side channel served as a bypass (e.g. the old Zamkowy mill in Kuźniczka). In the second case, a mill race was dug and the main channel was turned into a bypass. With time, the mill race took over the role of the main channel (e.g. the Marcelin and Magreta mills). In the study area, until regulation and drainage works were carried out, watermills had been among the main factors that caused changes in river channel patterns.

Old maps dating back to the first half of the 19th century show a multi-channel River Liswarta. Some channels within that network were artificial canals, including mill races. As a result of the construction of mill races, river channel reaches ranging from 1 to 2.5 km in length were shifted. Those changes affected 31% of the 11 kilometre long River Liswarta reach included in the study area.

Among the watermills included in the study, the closed Marcelin mill in Kuźniczka and the mill in Starokrzepice, in which a small hydropower plant operates, are extant. The remaining mills – as many as 80% – ceased to exist in different parts of the period covered by the research. Their traces can sometimes still be found in the form of ruins

of foundations or of a water system with the remains of hydraulic structures, while some have only left their mark on the river channel pattern and on the local relief of the valley floor. Artificial sections of river channels become permanent and are subject to naturalisation. After some time, it is often difficult to distinguish artificial (and later naturalised) mill races from natural channels.

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