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Research Article

The Impact of the Development of the Sugar Industry on Pond Systems and Water-Powered Facilities in Moravia

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The sugar industry in Moravia not only left a significant mark on the development of industrial areas and settlements, but it also strongly influenced the use of the landscape in the hinterland of the sugar factories. In the 19th century, the development of the sugar industry and the demand for arable land resulted in the disappearance of some pond systems and, consequently, nearby water-powered facilities. Of the total area of 4,184 ha of ponds in the hinterland of the sugar factories from 1840, approximately 60% disappeared and have not yet been restored. On the contrary, the share of continuously operated and preserved ponds in the hinterland of the sugar factories is very low (18%). Preserved ponds are most often found in the higher parts of Moravia (uplands, hills). It was confirmed that a large number of water areas disappeared in the hinterland of the sugar factories in 1880, and, on the contrary, a larger number of ponds outside the hinterland of the sugar factories remained preserved. Some extinct ponds were gradually restored. Extinct ponds in the period 1880 were gradually restored in two basic waves, 380 ha of ponds by 1950 and 150 ha of ponds by 2025. Following the extinction of ponds in Moravia, water-powered facilities in the immediate vicinity of the ponds also disappeared. The sugar industry was one of the fundamental driving forces behind changes in the use of the landscape in this area in the second half of the 19th century.

Keywords: history, sugar industry, water management, water mill, Moravia

1 Introduction

The impacts of the development of the sugar industry in Central Europe are most often perceived in the context of the impact on the economic development of the region, i.e. on the development of the food industry, the engineering industry, the mining industry, the possibility of increased employment and population concentration, the development of the transport network, especially the railway (Krejčí et al., 2016; Rosado-Cubero & Martínez-Soto, 2020; Yarrington, 2018). The impact of the development of the sugar industry on the landscape is less studied (Havlíček et al., 2013). During the course of the 19th century the sugar beet industry became a crucial part of the contemporary economic and industrialisation process of the Czech lands. Some authors (e.g., Vyskočil et al., 2010) even rate the sugar beet industry among the very most important branches (with engineering and textile industries) of contemporary industry, heavily affecting the newly formed industrial society. Such booming development also naturally influenced other branches of industry, agriculture, and the dynamics of coal mining development. Simply stated, it was necessary to improve the modes and capacities of raw material transport to the processing factories and to enable quick and flexible transport of the outputs of the sugar beet industry to their final consumers (Krejčí et al., 2016). In the Czech Republic, the development of the sugar beet industry can be considered a very significant driving force of land use changes in the 19th century (Skokanová et al., 2016; Bičík et al., 2015; Havlíček et al., 2013). It especially affected agricultural areas of the lowlands and uplands, where there was a massive destruction of ponds and meadows for the needs of sugar beet cultivation. Sugar was one of the most profitable crops in Bohemia

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and Moravia and by the beginning of the 1990s, when it reached its greatest expansion, it was grown on 6% of arable land, i.e. on almost half of the potato area (Havlíček, et al., 2013). The development of sugar beet farming increased the demand for heavy, moist soils, and this meant the mass destruction of ponds in wider flat floodplains (Richter, 2023). Ponds were therefore preserved mainly in the uplands and mountains and generally in colder climatic areas in Bohemia and Moravia (Pavelková et al., 2016). The disappearance of water bodies has also another negative effect on the operation of industrial facilities. Ponds often served in the past as retention tanks for the operation of water-powered technical water management facilities (Havlíček & Svoboda, 2024; Glaser-Opitz et al., 2012; Fajer, 2015). Their extinction then led to the disappearance of some water mills, sawmills, paper mills, hammer mills, textile factories, glass factories, etc. The importance of the role of watermills in the shaping and evolution of cultural landscape has been described in several scholarly studies in traditional agricultural areas of Europe (Brykała & Podgórski, 2020; Chabudziński at al., 2018; Buchty-Lemke & Lehmkuhl, 2018; Dal Sasso & Caliandro, 2010). Rural landscape in Europe has been undergoing rapid and major changes, partly driven by European Union policies that govern the environmental impacts of human activities. These policies reflect the power of governments to directly influence local landscapes, and many traditional water mills and ponds have disappeared while others have been repurposed (Madry et al., 2015).

This article aims to evaluate the impact of the development of the sugar industry on pond systems and water management facilities in Moravia. In the case of pond systems, the particular aim is to evaluate the proportion of areas of preserved ponds, extinct ponds, or restored ponds in the hinterland of sugar mill locations. In addition to the aspect of time, it is also important to take into account spatial relationships and connections within Moravia, including natural conditions, or the concentration of objects. A partial aim is to evaluate the impacts of the development of sugar mills on the disappearance of water-powered water management objects, while objects in the immediate hinterland of ponds were examined. In addition to summary data and map outputs for the entire territory of historical Moravia, the aim was to document the direct impacts of the construction of sugar mills on the landscape at specific locations, including the use of archival historical sources.

2 Material and Methods

2.1 Study Area

The historical region of Moravia was chosen as a study area. This area includes both flat areas of lowlands and wide floodplains, as well as adjacent hills, i.e. typical and suitable areas for sugar beet cultivation. Another important aspect for the selection of this area was the economic and transport connections to the most important and capital city of Austria, Vienna, the presence of other important cities in Moravia (Brno, Olomouc), the development of mining and related industries in the vicinity of Ostrava and nearby Silesia. The historical territory of Moravia covers a total of 22,345 km^2, which is approximately 28% of the territory of the present-day Czech Republic (Fig. 1). Based on the published map of historical and current sugar factories in the Czech Republic, a digital map layer of all sugar factories in the territory of Moravia was created (Gebler et al., 2007). For the purposes of working with map data, the first sugar factories that were established before 1830 and were based on the processing of maple syrup were omitted. To assess the impact of the development of sugar industry on the landscape, pond systems and water management facilities, the locations of sugar factories processing sugar beet were selected. Since 1830, a total of 91 sugar factories has operated in Moravia (Fig. 2).

Figure 1 Study area Moravia in Central Europe
Source: own processing

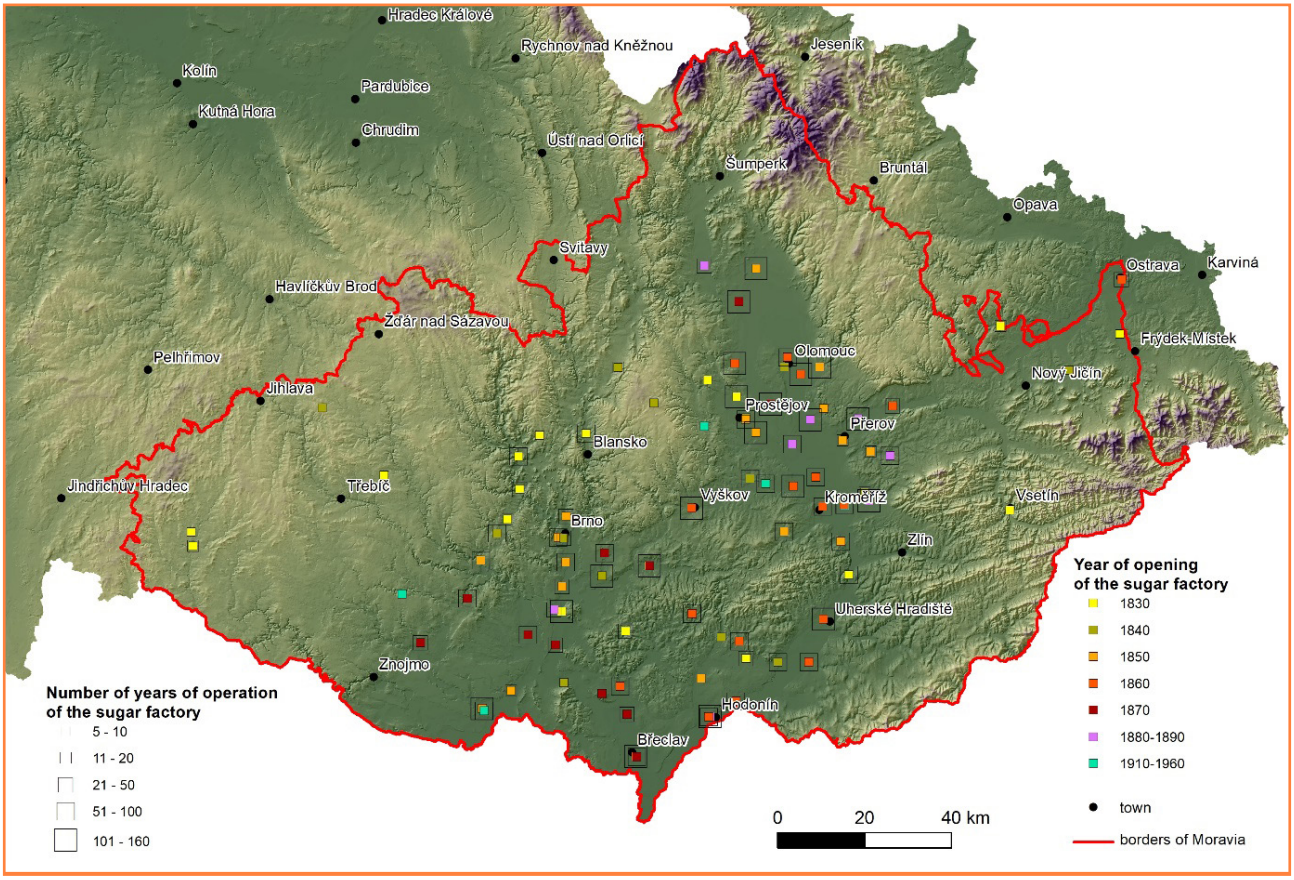

Figure 2 Sugar factories for sugar beet processing in Moravia from 1830 with year of opening and number of years of operation
Source: Gebler et al., (2007), own processing

2.2 Data Analysis in Geographic Information Systems

Data analyses were carried out in ESRI geographic information systems and were based on the creation of own datasets, or the use of existing data at the authors' workplaces. The input dataset was a map layer of sugar factories in Moravia created by the authors themselves, inspired by an analogue map and a list of sugar factories from an article in the specialized Czech magazine *Listy cukrovarnické a řepařské* (Gebler et al., 2007). Based on a search of archival materials, it was found that the radius of action of sugar beet growers to sugar factories in the 19th century ranged up to 10 km, exceptionally up to 15 km (Havlíček et al., 2013). With the development of railway transport, the possibility of transporting raw materials to sugar factories (sugar beet, coal, limestone) improved, but later the number of operating sugar factories decreased accordingly (Krejčí et al., 2016). For the purposes of impacts on the landscape at the end of the 19th century, all analyses in geographic information systems were carried out in the hinterland 10 km from the sugar factories. To assess the impacts of the development of sugar industry on pond systems in Moravia, the historical land use database based on the interpretation of old topographic maps TOPOLANDUSE, which was created in the Landscape Research Institute (Skokanová et al., 2012; Sychrová et al., 2024), was used. This database was created for five time periods (1840, 1880, 1950, 1990, 2005), and for the purposes of this article, map data from the periods 1840, 1880, 1950 were used. From this database, the map layer of water bodies in Moravia was used, with further modifications leaving only ponds, natural or semi-natural areas, including lakes, former gravel pit areas with fish farming function, and abandoned dead ends of watercourses. Artificial water reservoirs, which have various functions, mainly flood protection, energy use or recreational use, were omitted. The smallest mapping unit in this map layer is 0.8 ha. For the purposes of assessing impacts on pond systems, this resolution is optimal. For the present, data from the ZABAGED database from 2025 were used. The Fundamental Base of Geographic Data of the Czech Republic (ZABAGED®) is a digital vector geographic model of the territory of the Czech Republic (CR), which is administered by the Land Survey Office in the public interest. The water surface data layer from this database

was again modified, water surfaces over 0.8 ha were evaluated, and only ponds were included in the analyses in geographic information systems. To assess the impacts of the sugar industry on water management technical objects, water-powered objects in the immediate vicinity of ponds were selected at a distance of up to 100 m. The data source was the database of water management objects in the Czech Republic from the years 1760, 1840, 1880, 1950, which was created in applied research in the Landscape Research Institute (Havlíček et al., 2022a, 2022b; Havlíček & Svoboda, 2022). Experience from map data and archival research shows that if a pond was a source of power for water mills, sawmills, hammer mills, paper mills and other water-powered industrial facilities, this facility was always located in the immediate vicinity of the pond, but no more than 100 m from the edge of the water surface (Havlíček & Svoboda, 2024).

3 Results and Discussion

In the territory of the historical country of Moravia, a total of 91 sugar factories focused on the production of sugar from sugar beets operated from 1830 to the present. Of these, 32 sugar factories were put into operation by 1840, i.e. during the period of creation of maps of the 2nd Austrian military mapping in the territory of Moravia (Fig. 2). Another 46 sugar factories were opened in Moravia between 1850 and 1880, i.e. in the period before the creation of the 3rd Austrian military mapping. The impacts on changes in landscape use and possible disturbance of ponds in Moravia can therefore be assumed, especially between the 2nd and 3rd Austrian military mapping, so it was possible to use the TOPOLANDUSE database and specifically the map layer of water bodies. At the end of the 19th century, around 1880 and 1890, 8 sugar factories were put into operation; in the 20th century, only 5 new sugar factories were put into operation in Moravia (Gebler et al., 2007).

In the entire territory of the historical country of Moravia, a total of 7982 ha of ponds and natural water bodies with an area of over 0.8 ha were recorded in 1840; in 1880 the area of ponds was reduced by a half, which is evident in particular from the total pond area change index (Table 1). This is a general trend in most of the Czech Republic, but especially in lowland and hilly areas with a high growth in arable land areas or built-up areas (Pavelková et al., 2016; Skokanová et al., 2012). This is generally related to the driving forces of changes in landscape use in this period, when, together with population growth and industrial development, the requirements for growing agricultural crops were increased (Bičík et al., 2015; Skokanová et al., 2016). In addition to traditional crops for the production of flour, feed mixtures for cattle, beer production, etc., the increased demand for arable land was also contributed to by the increase in the cultivation of technical agricultural crops for the food industry (sugar factories, distilleries, starch factories) and for the textile industry (Havlíček et al., 2013). In the hinterland 10 km from the sugar factories, the impacts on pond disturbance were significantly greater than outside this hinterland. The main indicator relevant in this case is the total pond area change index in the hinterland of sugar factories, where the initial year 1840 was chosen as the first comparative period (Table 1). In the hinterland of sugar factories, the index fell to 0.34 in 1880, in 1950 this index increased to 0.78 and in 2025 it even exceeded the original value from 1840 (index 1.20). In the landscape outside the sugar factories, the decrease in pond areas was lower and in 2025 it reached the value of 0.96. The share of pond areas in the hinterland and outside the sugar factories is also an interesting value. In 1840, the share of pond areas outside the sugar factories prevailed in a moderate ratio of 52 to 48% (Table 1), in 1880 it turned out that the majority of preserved water ponds were preserved outside the sugar factories (68%). This confirmed the assumption that the construction of sugar factories had a significant impact on the destruction

Table 1 Characteristics of ponds in the hinterland of sugar factories

Period	1840	1880	1950	2025
Total area of ponds (ha)	7982	3942	5947	8573
Area of ponds in the hinterland of sugar factories (ha)	3798	1281	2969	4548
Area of ponds outside the sugar factories (ha)	4184	2661	2978	4025
Total area of ponds (%)	100	100	100	100
Area of ponds in the hinterland of sugar factories (%)	47.58	32.50	49.92	53.05
Area of ponds outside the sugar factories (%)	52.42	67.50	50.08	46.95
Total pond area change index	1.00	0.49	0.75	1.07
Total pond area change index in the hinterland of sugar factories	1.00	0.34	0.78	1.20
Total pond area change index outside the sugar factories	1.00	0.64	0.71	0.96

of ponds and the increase in arable land areas; similar results were found in the area of concentration of sugar factories around the Elbe River near Pardubice (Richter, 2023). Large ponds and pond systems disappeared mainly in connection with the operators of the first sugar factories in Moravia, very often these were estate owners who could use the possibility of abolishing ponds and water bodies to acquire new areas of arable land and supply the necessary amount of sugar beet for their sugar factories (Vyskočil, 2010; Havlíček et al., 2013). A large part of the sugar factories in Moravia disappeared in the first half of the 20th century, production was concentrated in several large industrial complexes (Gebler et al., 2007; Krejčí et al., 2016). After 1990, only 10 sugar factories were operating in Moravia, while in 2025 only four sugar factories were in operation. With the decreasing pressure of arable land use and the gradual disappearance of permanent grasslands in the floodplains of watercourses, new ponds were built and older ponds were also restored (Pavelková et al., 2016). The share of pond area in the hinterland of historical and current sugar factories thus increased to 53% in 2025, exceeding the share of pond area outside the sugar factories. When considering the impacts of sugar production on water bodies after 1840, not only the date of opening of individual sugar factories is key, but also the duration of their operation. In some cases, sugar factories were functional for only about 5 to 10 years (Fig. 2 and Fig. 3), so their impacts on changes in landscape use were minor or only temporary, which is typical, for example, for sugar factories and nearby ponds in the hinterland of sugar factories near the towns of Třebíč and Jihlava in the southwestern part of Moravia (higher concentration of preserved or restored ponds). A higher concentration of extinct ponds was registered especially in sugar factories with a production tradition of 50 years or more, typically 100 years or more. In addition to the development of sugar production, the disappearance of water bodies was also influenced by urbanization processes associated with the development of settlements and industrial areas, or transport areas and routes. The motivation for the restoration of original water bodies was mainly the possibility of restoring fish farming, the possibility of obtaining water for irrigation, and measures in the landscape to improve water management. In addition to the original locations of water bodies from 1840, water bodies were gradually created in other locations in the hinterland, and during the 20th century, water bodies were typically created

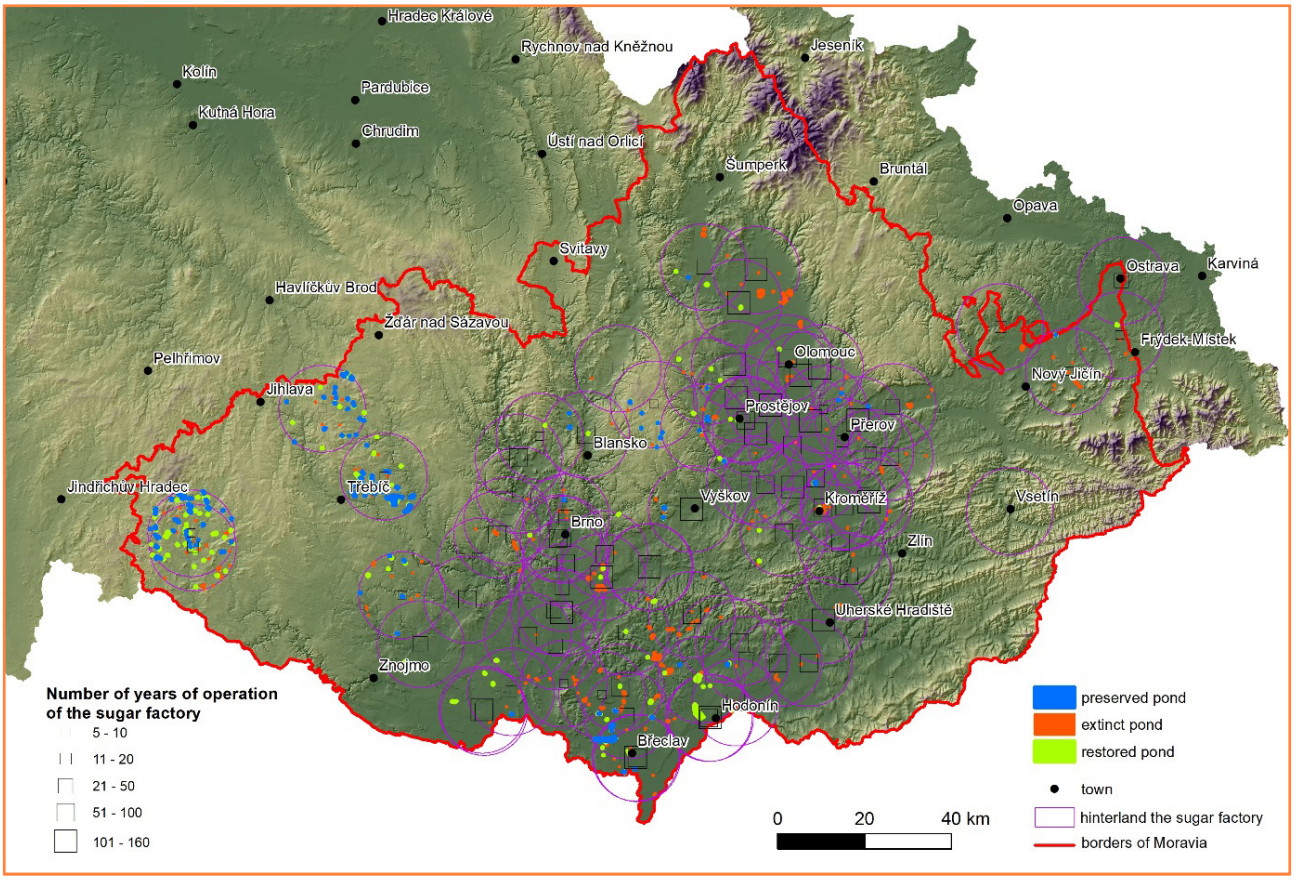

Figure 3 Preserved, extinct and restored ponds from 1840 in the hinterland of the sugar factories in Moravia
Source: own processing

for energy purposes, recreational purposes, drinking water supply or irrigation water in the form of water reservoirs. However, these were not evaluated for monitoring the development of ponds in this article. The ponds and other similar water bodies evaluated in this article include, for example, flooded gravel pits and sand pits with potential for fish farming or recreation, other smaller water bodies created as a measure in the landscape to improve water management, or as a flood control measure. The traditional use of ponds in Moravia also corresponds to some findings from other countries in Europe. For example, in France, similar results were presented as part of research in Burgundy (Madry et al., 2015). This study shows that ponds have been integral to the economy and landscape of this area for centuries, although their size, location and functions have changed a great deal over time. One constant is that farmers have continued to use ponds to generate extra income to supplement their primary agricultural activities, just as they have done for centuries, but in different ways as the times have changed. The original functions of ponds in a subsistence agricultural economy were for milling and raising fish. The introduction of electricity in the early 20th century reduced the importance of water power to run mills, and the decline of grain production forced the repurposing of mills as oil presses or sawmills. The functions of ponds have been increasingly oriented to a vacation-leisure economy since the mid-twentieth century, with farmers renting out ponds for camping and fishing. New seasonal inhabitants have also created ponds solely for leisure purposes at their vacation homes. There have been numerous examples of these new ponds being located on former pond sites (Madry et al., 2015).

The spatial distribution of preserved, extinct and restored ponds in the hinterland the sugar factories in Moravia is shown in Fig. 3. The map only captures the fate of ponds from the period of 1840; it does not capture the development of other water bodies that entered other parts of the territory based on the need to create ponds for fish farming or after the extraction of mineral resources. Of the total area of 4,184 ha of ponds from 1840, approximately 60% have disappeared and have not yet been restored (water surface area 2,264 ha). This had a major impact in particular on the disappearance of the pond system on the Trkmanka River in the Hodonín district, as well as on pond systems in the vicinity of the city of Brno, in the vicinity of the cities of Olomouc, Přerov and Kroměříž. These are mostly areas of wide floodplains, lowlands and gentle hills. Ponds in the hinterland the sugar factories in Moravia were continuously operated on 666 ha, i.e. 17.5% of the original area from 1840. Preserved ponds are most often found in the higher parts of Moravia (uplands, hills), exceptionally preserved ponds can also be found in the lowlands. In the lowlands, these are most often significant ponds in terms of cultural and historical significance, which are part of castle complexes or urban development. Some extinct ponds have been gradually restored, an example is the pond system on the Kyjovka River near the city of Hodonín (Havlíček et al., 2013). Other restored ponds can be found in the southwestern part of the historical country of Moravia (Fig. 3). Extinct ponds in the period 1880 were gradually restored in two basic waves, by 1950 380 ha of ponds were restored, and by 2025 another 150 ha of ponds. The possibilities of pond restoration were gradually made possible by the requirements for the restoration or increase of fish farming production in a specific region; in recent years, new water areas have been built in the implementation of some measures to improve water retention in the landscape.

Based on information from the database of water management facilities created in the Landscape Research Institute (Havlíček et al., 2022a), a map and list of all

Table 2 Characteristics of water-powered facilities in the hinterland of sugar factories

Period	1840	1880	1950
WPF near ponds in Moravia	219	177	77
WPF near ponds in the hinterland of sugar factories	91	59	28
WPF near ponds outside the sugar factories	128	118	49
Share of WPF near ponds in Moravia	100	100	100
Share of WPF near ponds in the hinterland of sugar factories	41.55	33.33	36.36
Share of WPF near ponds outside the sugar factories	58.45	66.67	63.64
Change index of WPF near ponds in Moravia	1.00	0.81	0.35
Change index of WPF near ponds in the hinterland of sugar factories	1.00	0.65	0.31
Change index of WPF near ponds outside the sugar factories	1.00	0.92	0.38

water-powered facilities (WPF) can be created. Typically represented here are water mills for grain, sawmills, paper mills, hammer mills, rolling mills, powder mills, etc. In this article, we were interested in a selected set of water-powered facilities in the immediate hinterland of ponds (within a distance of up to 100 m) in Moravia. In general, the number of water-powered facilities did not differ significantly across the Czech Republic between 1840 and 1880, with a decrease in the number of facilities of 9% between these periods. In the case of WPF in the near ponds in Moravia, the number of these facilities decreased by 19% in 1880 (Table 2), while this decrease is actually higher in the hinterland of sugar factories (by 35%). Based on the Change index of WPF, it is clear that despite the significantly higher decrease in pond areas between 1840 and 1880, the numbers of WPF did not decrease significantly. This is due to the original higher protection of specific water areas with retention significance for specific water-powered facilities. Nevertheless, there are documented locations in the territory of historical Moravia where both ponds and adjacent water-powered facilities disappeared due to sugar production (Havlíček & Svoboda, 2024). Based on the disappearance of these objects, it was necessary to supplement small industrial establishments with replacement operations, typically, e.g., replacing a water mill with a windmill (Havlíček & Svoboda, 2024).

In the Trkmanka River and Spálený potok stream basins, various types of pond transformations and water-powered facilities are found (Fig. 4, Fig. 5). The map of the 2nd Austrian military mapping from 1836 (Fig. 4) shows a total of five ponds and water mills adjacent to them in the immediate vicinity. Two sugar factories were gradually built around these water bodies, in the town of Ždánice and in the village of Martinice. In both cases, they were built by the owners of the estate, so it was relatively easy to allow the draining of some ponds and their replacement with arable land for growing sugar beet. On the map from 1876, the pond near the village of Dražůvky was preserved, including the adjacent water mill, and even after the pond was drained, the water mill so-called Spálený mlýn remained in operation directly on the watercourse north of the village of Násedlovice (Fig. 5). Other water mills disappeared but were gradually replaced by new windmills to meet the needs of the local population.

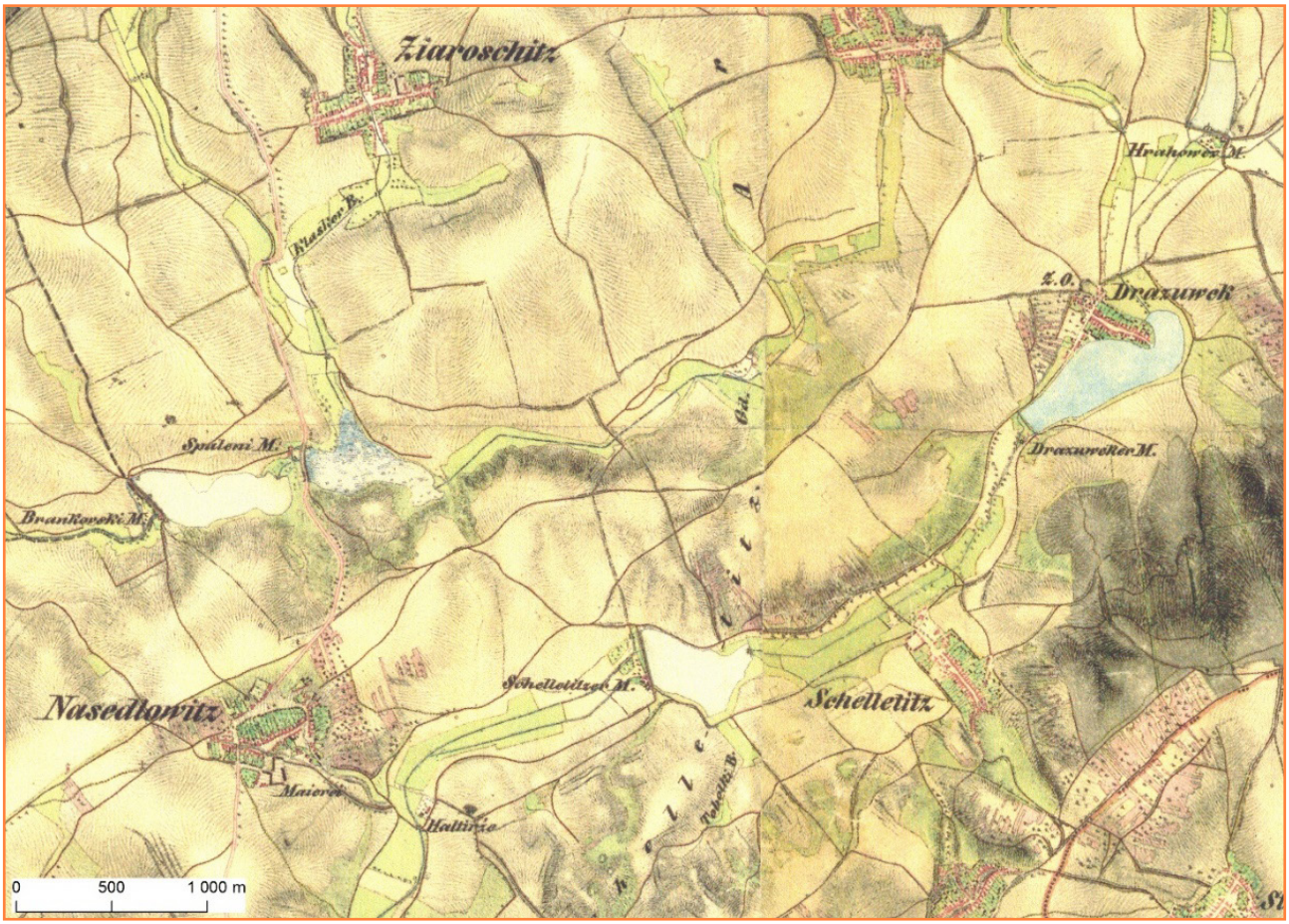

Figure 4 System of ponds on the Trkmanka River and the Spálený potok Stream (1836)
Source: 2nd Military Survey, Austrian Military Archive, Vienna, Landscape Research Institute

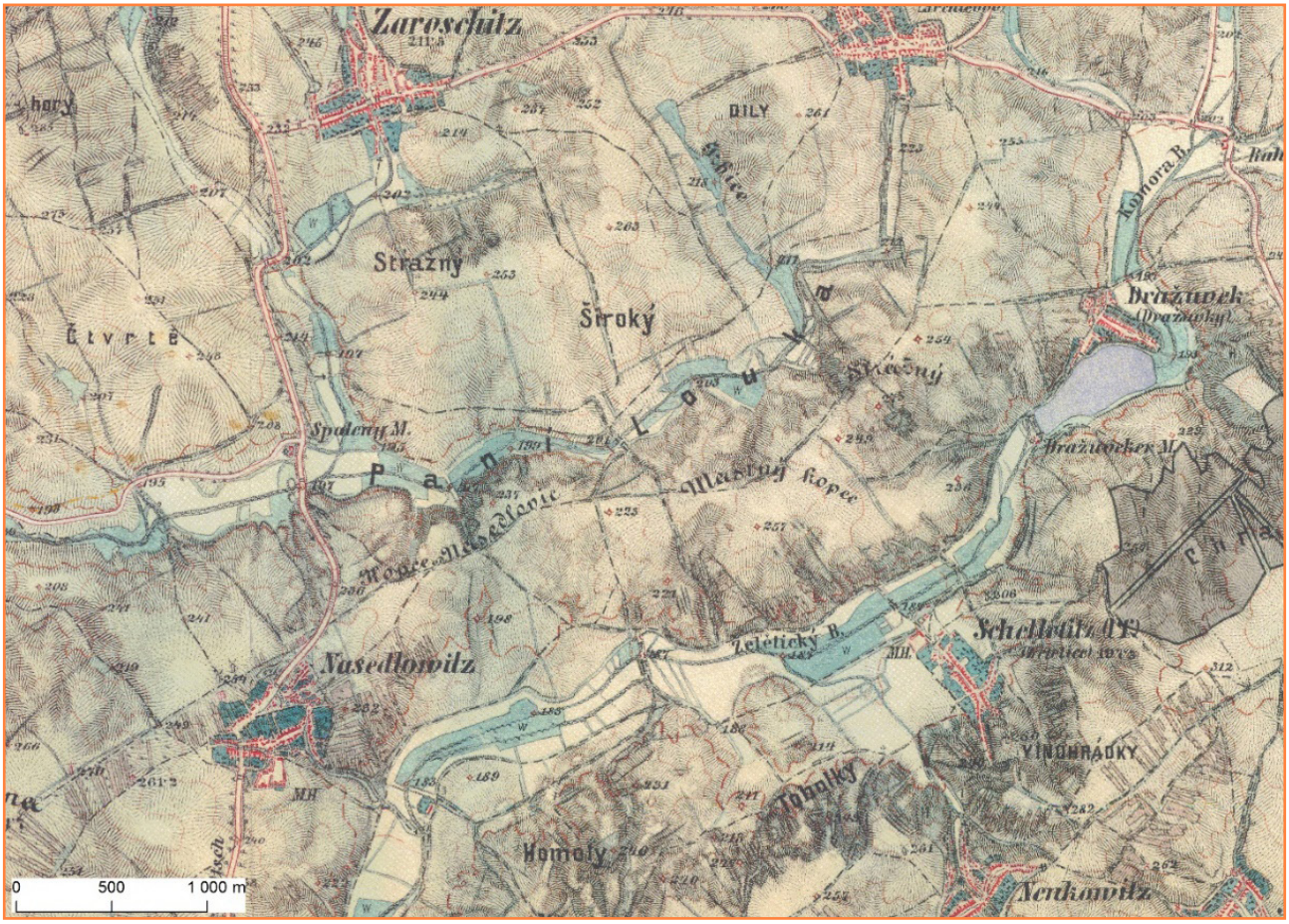

Figure 5 System of ponds on the Trkmanka River and the Spálený potok Stream (1876)
Source: Map collection, Faculty of Science, Charles University, Prague, Landscape Research Institute

An example of a pond that disappeared and was later restored is the Jarohněvický pond near the town of Dubňany. The map of the 2nd Austrian military survey from 1836 shows a pond with an area of 116 ha, in the vicinity of which there was a farm and the village of Dubňany (Fig. 6a). This pond served the main function of fish farming and was one of the largest ponds on the Kyjovka River. On the map of the 3rd Austrian military survey from 1876, this pond is already drained (Fig. 6b). At the same time, however, the map allows us to follow the development of brown coal mining in the immediate vicinity of the pond and in the vicinity of the town of Dubňany. Another interesting point is the nearby industrial area, already mentioned here as glassworks. However, from 1858 to 1875, this industrial area was used as a sugar factory. Nearby brown coal deposits in shallow subsurface mines and the possibility of acquiring new areas of arable land led to the establishment of a sugar factory near the pond. After the operation was converted to a glass factory and coal mining moved further away, the Jarohněvický pond was restored around 1950 and has been used for fish and duck farming to this day (Fig. 6c).

Over the centuries, the function of small water bodies has changed. It is evident that two functions, fish farming and water supply for mills, have been fulfilled throughout the period. Other functions of the water bodies changed over time. The ponds served a defence function in the seventeenth century and the industrial function from the beginning of the eighteenth century to the nineteenth century. Recently, their recreational function has been underlined (Chabudziński et al., 2018). These conclusions from the study Changes in the location and function of small water bodies in the upper Sanna River catchment – case study (SE Poland) can also be transferred to the results of the presented research in Moravia. The importance of watermills for landscape transformation and industrial development has been confirmed in other areas of Europe, such as Poland (Fajer, 2015; Brykała & Podgórski, 2020), Germany (Buchty-Lemke & Lehmkuhl, 2018), Italy (Dal Sasso & Caliandro 2010), France (Madry et al., 2015), Slovakia (Glaser et al., 2012). Research in Italy has confirmed the importance of the role of historical agro-industrial buildings in the study of rural territory for watermills, oil mills,

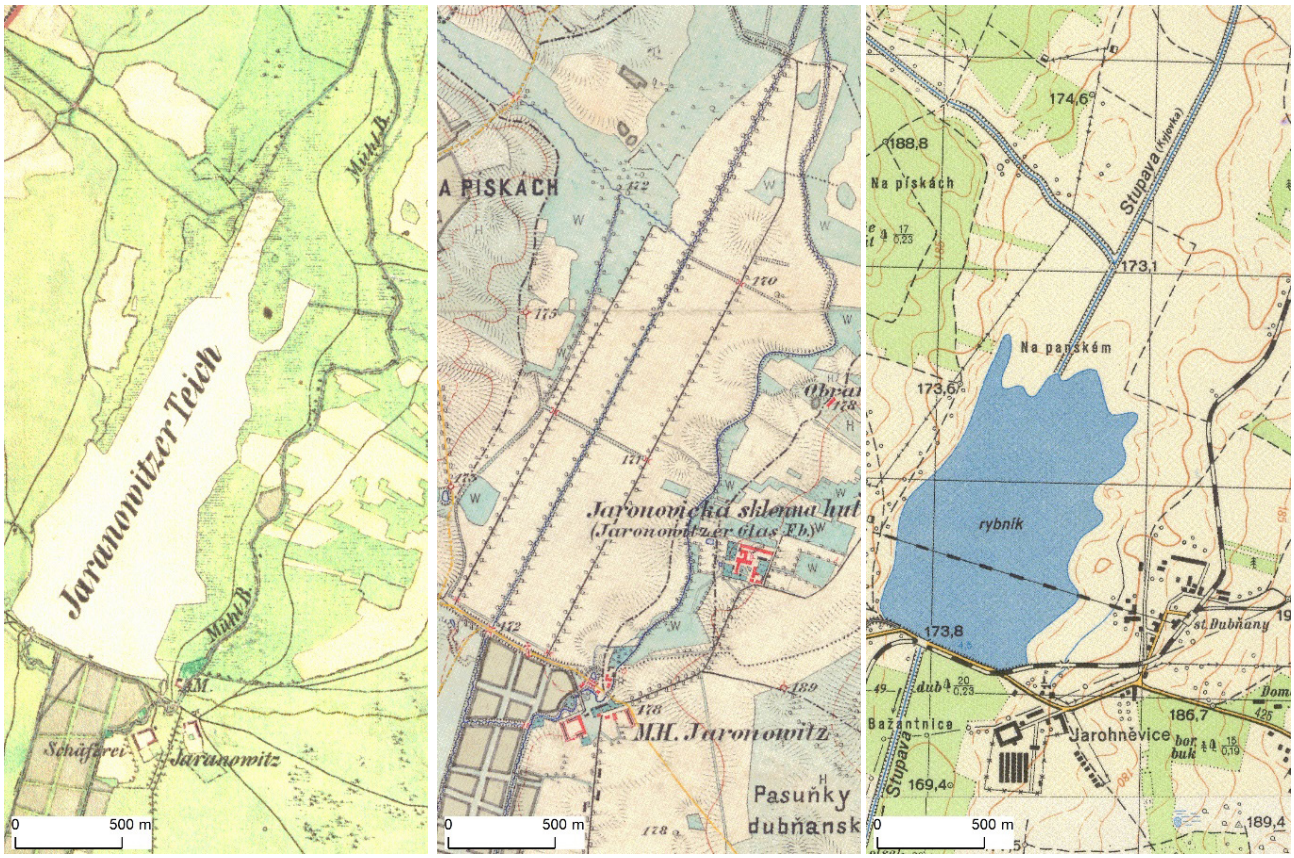

Figure 6 Jarohněvický rybník pond
Source: a – 2nd Military Survey, Austrian Military Archive, Vienna, Landscape Research Institute; b – Map collection, Faculty of Science, Charles University, Prague, Landscape Research Institute; c – Landscape Research Institute

paper mills, sawmills and other water-powered facilities (Dal Sasso & Caliandro 2010).

4 Conclusions

The impact of the development of sugar industry on pond systems and water management facilities in Moravia can be considered fundamental. The successive analyses have shown that the development of sugar industry is one of the fundamental driving forces behind changes in the use of landscape in this area in the second half of the 19th century. Of the total area of 4,184 ha of ponds in the hinterland of sugar factories from 1840, approximately 60% have disappeared and have not yet been restored. On the contrary, the share of continuously operated and preserved ponds in the hinterland of sugar factories is very low (18%). Preserved ponds are most often found in the higher parts of Moravia (uplands, hills). It has been confirmed that in the hinterland of sugar factories in 1880 a large number of water areas disappeared and, on the contrary, a larger number of ponds outside the hinterland of sugar factories remained preserved. In addition to the location of sugar factories and the effort to acquire arable land for growing sugar beet, the disappearance of ponds in river floodplains, in lowlands and uplands was also caused by the increased demand for growing other technical and common agricultural crops. Some extinct ponds were gradually restored; one example is the pond system on the Kyjovka River near the city of Hodonín. Other restored ponds can be found in the southwestern part of the historical land of Moravia. Extinct ponds in the period 1880 were gradually restored in two basic waves; 380 ha of ponds were restored by 1950 and other 150 ha by 2025. Following the disappearance of ponds, water-powered facilities in the immediate hinterland of ponds also disappeared in Moravia. Here again, the greater number of extinct ponds in the hinterland of sugar factories played a role, but the decrease in the number of water-powered facilities was not as significant as in the area of ponds. The direct impacts of the construction of sugar factories on the landscape and farming in the area were documented by specific examples from old topographical maps.

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