The Impact of River Engineering Works on the Dyje River Floodplain in the Czech Republic*

Hana Skokanova

Rivers and their floodplains are very dynamic components of the landscape. They are influenced both by natural fluvial processes, such as sediment erosion, transportation, and accumulation, and by human activities. The latter may include land use changes, such as urbanization, or the direct modification of a channel. Nowadays, many rivers have been modified by anthropogenic actions. The most common modifications include weir and dam building, channel straightening and embankment, channel enlargement, and the removal of riparian vegetation. The main purposes of these works are flood control, drainage improvement, ensuring navigability, and preventing erosion.[1]

Depending on the type of engineering works, their impact is reflected in changes in flow velocity, transport capacity, channel gradient and other aspects of channel morphology, and sediment load. Direct influences on a channel's floodplain include the modification, formation, or destruction of oxbows and pools, changes in the groundwater table, changes in soil moisture, and, consequently, the changing of habitats. The indirect effects of river engineering works are observable in the relationship between these works and the land use of the floodplain.

The lower reaches of the rivers that flow through alluvial sediments often follow a meandering or anastomosing channel pattern. Various types of evidence and measurements can be used to analyse channel changes. Frequently, and especially in the lower reaches of a river, the rate of change is too slow or the period of assessment of instability too short to allow direct measurement, so the use of field or documentary evidence is needed. Historical sources provide readily accessible sources on an appropriate timescale to detect changes, fluctuations, and trends. The most widely used sources to study river modifications over time are old maps and aerial photographs. Such data, however, have several shortcomings, the main one being that they only provide snapshots,[2] i.e., the documentary evidence is not continuous. It is also often not clear what exact state of the channel is displayed on a map or photograph.

The impact of river engineering works on a river channel and its floodplain has been researched, for example, by Erskine et al. (1992),

* Acknowledgement: The present investigation was supported by research project MSM 6293359101 "Research into sources and indicators of biodiversity in a cultural landscape in the context of its fragmentation dynamics".

[1] D. Knighton, *Fluvial forms and processes*, Arnold Publishers, London 1998, p. 312.

[2] J.M. Hooke, "Styles of Channel Change", in *Applied Fluvial Geomorphology for River Engineering and Management*, C.R. Thorne, R.D. Hey, M.D. Newson (eds), Wiley, Chichester 1997, p. 238.

Ward and Stanford (1995), Amoros and Roux (1998), Surian (1999), Shields et al. (2000), Peacock (2003), Marston et al. (2005), Martykán (1987), Bínová et al. (1992), Vybíral (1995), Bagar and Klimánek (1999), Marschalko et al. (2002), Hradecký (2002), Langhammer et al. (2004), Matoušková (2004), and Skokanová (2005).[3]

[3] W. Erskine, C. Mc Fadden, P. Bishop, "Alluvial cutoffs as indicators of former channel conditions", in *Earth Surf. Process. Landforms*, 17, 1, 1992, pp. 23-37; J.V. Ward, J.A. Stanford, "Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation", in *Regulated rivers*, 11, 1, 1995, pp. 105-119; C. Amoros, A.L. Roux, "Interaction between water bodies within the floodplains of large rivers: function and development of connectivity", in *Connectivity in landscape ecology. Proceedings of the International association for Landscape Ecology*, K.L. Schreiber (ed.), Munsterische Geographische Arbeiten, 29, Munster 1998, pp. 125-130; N. Surian, "Channel changes due to river regulation: the case of the Piave River, Italy", in *Earth Surface Processes and Landforms*, 24, 12, 1999, pp. 1135-1151; F.D.J. Shields, A. Simon, L.J. Steffen, "Reservoir effects on downstream channel migration", in *Environmental Conservation*, 27, 1, 2000, pp. 54-66; C. Peacock, *Rivers, Floodplains and Wetlands: Connectivity and Dynamics*, RSPB publications 2003, p. 64; R.A. Marston, J.D. Mills, D.R. Wrazien, B. Basset, D.K. Splinter, "Effects of Jackson Lake Dam on the Snake River and its floodplain, Grand Teton National Park, Wyoming, USA", in *Geomorphology*, 71, 1-2, 2005, pp. 79-98; Z. Martykán, *Změna nivních krajin řeky Dyje mezi Znojmem a Břeclaví v 19. a 20. století,* Katedra geografie, UJEP, Brno, 1987 (diploma thesis, in Czech); L. Bínová, M. Kynčl, J. Horák, V. Štěpánek, P. Kubíček, V. Herber, P. Fiala, T. Vrška, I. Vácha, *Projekt trvale udržitelného vývoje dolního Pomoraví,* Brno 1992 (in Czech, unpublished); J. Vybíral, "Vliv nového vodního režimu na lužní lesy po regulaci Moravy a Dyje a možnosti optimalizace hydrologických podmínek", in *Sborník trilaterální konference Revitalizace údolní nivy Moravy a Dyje,* Daphne, Mikulov 1995, pp. 25-28 (in Czech); R. Bagar, M. Klimánek, "Hlavní příčiny a důsledky změněných ekologických podmínek v lesních ekosystémech lužní oblasti jižní Moravy", in *Ochrana přírody*, 54, 6, 1999, pp. 178-182 (in Czech); M. Marschalko, R. Grygar, V. Bradáč, T. Skokan, "Sledování časového vývoje údolní nivy řeky Odry s využitím GIS", http://gis.vsb.cz/GIS_Ostrava/GIS_Ova_2000/Sbornik/Marschalko/Referat.htm, 2000 (in Czech); J. Hradecký, "Hodnocení časových změn morfodynamiky beskydských toků za využití historických map a leteckých snímků", in *Geomorphologia Slovaca*, 2, 2002, pp. 31-39 (in Czech); J. Langhammer, B. Janský, I. Bičík, Z. Lipský, V. Vilímek, Z. Kliment, J. Stehlík, P. Červinka, L. Šefrna, M. Matoušková, M. Křížek, Z. Engel, L. Kupková, M. Stehlík, T. Vlasák, J. Chalušová, M. Hais, A. Králová, F. Hartvich, V. Vajskebr, K. Macháčková, I. Kinská, P. Štych, S. Němečková, M. Bicanová, M. Kaplická, *Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní. Závěrečná zpráva,* Katedra fyzické geografie a geoekologie, PřF UK, Praha 2004 (in Czech); M. Matoušková, "Antropogenní transformace říční sítě", in *Sborník příspěvků z konference říční krajina*, J.

The aim of the present study is to investigate changes in the channel morphology and land use of the lower part of the Dyje River floodplain as a result of river engineering works. I divided the whole study area into five sections, calculated morphometric characteristics – such as the total length of the Dyje, total river network density, total water body density, and sinuosity –, and investigated the influence of the river engineering works on land use.

Delimitation of the study area

The study area, which encompasses the lower course of the Dyje River, is situated in South Moravia, in the Czech Republic. The Dyje River flows around the Dunajovické vrchy hills, the Pavlovské vrchy hills, and the Valtická pahorkatina upland, where it forms a vast floodplain ranging in width from 2 to 5 km.

The floodplain is formed of Neogene sediments covered by Quaternary fluvial sediments. These sediments consist of fluvial gravel and sand that began to deposit during Würm. Their upper layers shifted a number of times, in some spots as late as the upper Holocene. The sediments in the area of the confluence of the Dyje and Morava rivers attain thicknesses up to 30 m.[4] During the Holocene, flood loams began to accumulate. This phenomenon probably started in the 7th century as a consequence of colonisation of the upper Dyje basin. The speed of the sedimentation of these flood loams increased from the 11th century onward as a result of the massive deforestation of the upper Dyje basin.[5] These flood loams range in thickness between 1 and 5.5 m, with most falling within the 2-3 m range.[6]

Měkotová, O. Štěrba, (eds), Univerzita Palackého, Přírodovědecká fakulta, Olomouc 2004, pp.168-177 (in Czech); H. Skokanová, "Změny koryta Dolní Dyje v období 1830-2001 způsobené antropogenní činností", in *Geografie. Sborník České geografické společnosti*, 110, 4, 1995, pp. 271-285 (in Czech).

[4] H. Skokanová, *Hodnocení krajiny Dolního Podyjí,* Geografický ústav PřF MU, Brno 2006 (Dissertation thesis, in Czech), p. 32.

[5] J. Švanda, *Hydrologické poměry údolní nivy Dyje mezi Lednicí a Ladnou*, PřF UJEP, Brno 1974, p. 14 (rigorous thesis, in Czech).

[6] Z. Kouřil, J. Prokop, "Podzemní vody údolí řek Dyje, Jevišovky a Svratky s

The floodplain has an inclination of approximately 1.55‰ and a gently undulating surface. Along it one finds numerous oxbows, wet depressions, Aeolian mounds (i.e., remnants of low river terraces), and gravel accumulations. The floodplain is bordered by river terraces that are preserved on both sides of the Dyje to varying degrees. These terraces are found up to a relative elevation of 50 m above the river. Demek and Macka[7] distinguish five river terraces at relative elevations of 40, 30, 20, 9-13, and 3-5 m in the western and northern part of the study area. According to Švanda, remnants of low terraces are still to be seen in the eastern Dyje floodplain.[8] The left side of the floodplain is bordered by a low terrace that lies at a relative elevation of 0-3 m above the Dyje. A more complicated system of terraces is observable on the right side of the Dyje floodplain. However, these terraces do not form a distinctive pattern in the terrain morphology. The lower ones extend over narrow strips at the border of the floodplain. Broader terraces occur at medium elevations (ca. 13 m above the floodplain surface), whereas terraces at relative elevations of 30 and 40 m are narrower.

The present study focuses on the lower course of the Dyje River; more precisely, the last 85.5 km of its course. The average annual discharge of the Dyje is 41.7 m^3/s. Its average annual water level is approximately 70 cm. The variability of its daily flow is comparatively low. Higher water levels are mainly reached during winter floods caused by snow or rain, with a secondary peak in April. Floods are less frequent from July to October. The lowest flow rates are usually recorded from August to October.[9]

The study area lies within a warm dry region with an average annual temperature of 9.8°C and an average annual precipitation of 483 mm.

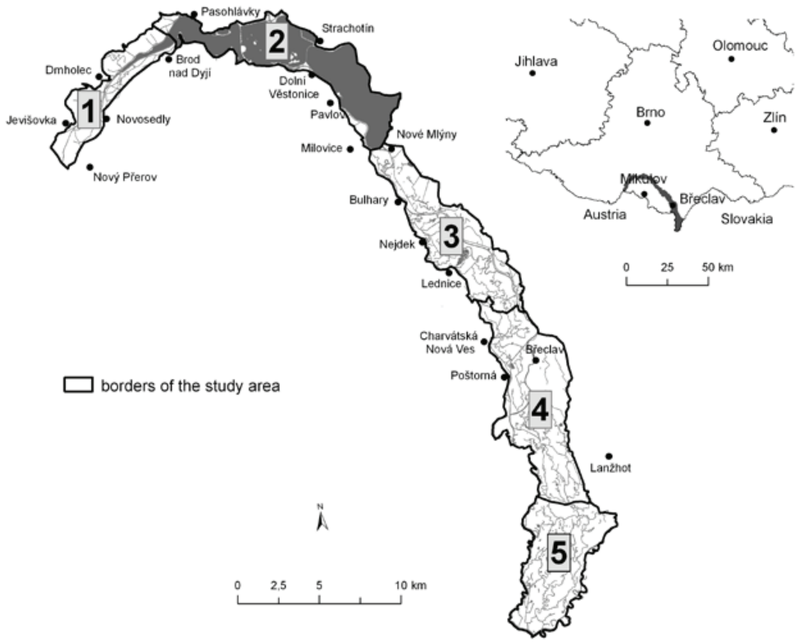
Jihlavou v Dyjsko-svrateckém a Dolnomoravském úvalu", in *Studia geographica* 58, GgÚ ČSAV, Brno 1977, p. 10 (in Czech).

[7] Collective, *Pavlovské vrchy a jejich okolí. Regionální geografická studie. Textová část,* GGÚ ČSAV, Brno 1970, p. 15-16 (in Czech).

[8] J. Švanda, *Hydrologické poměry údolní nivy Dyje mezi Lednicí a Ladnou*, PřF UJEP, Brno 1974, p. 12-13 (in Czech).

[9] Z. Kouřil, J. Prokop, "Podzemní vody údolí řek Dyje, Jevišovky a Svratky s Jihlavou v Dyjsko-svrateckém a Dolnomoravském úvalu", in *Studia geographica* 58, GgÚ ČSAV, Brno 1977, p. 21 (in Czech).

Figure 1. Subdivision of the study area



Fluvisols, especially their gleyic subtype, are the most common soils in the floodplain. Dystric gleysols can be found mainly in the southern part of the study area, especially at the Dyje and Morava confluence. Chernozem is typical of the western part of the area, fluvi-gelyic phaeozem of its eastern part.

According to the Natura 2000 classification,[10] the area's most common vegetation is mixed ash-alder alluvial forests, typical for temperate and boreal Europe (Alno-Padion, Alnion incanae, and Salicion albae), and mixed riparian forests of Quercus robur, Ulmus laevis, Ulmus minor, Fraxinus excelsior or Fraxinus angustifolia, normally found along large rivers in Atlantic and Middle-European regions.

[10] M. Chytrý, T. Kučera, M. Kočí (eds), *Katalog biotopů České republiky*. AOPK ČR, Praha 2001, pp. 174-176 (in Czech).

I divided the study area into five sections, approximately corresponding to different phases of river engineering works. The first section lies between the state border and the dam of the upper Nové Mlýny reservoir. The second one encompasses the Nové Mlýny water body. The third one begins below the dam of the lower Nové Mlýny reservoir and ends above the town of Břeclav (on the former Austrian–Moravian border). The fourth one ends approximately 8.5 km south of Břeclav. Finally, the fifth section comprises the Dyje and Morava Rivers confluence (see Fig 1).

River engineering works

River engineering works were carried out along the Dyje to protect settlements and their immediate surroundings. As a result of deforestation of the upper stretch of the Dyje catchment area during the 17th and especially the 18th century, runoff conditions worsened and many floods occurred. Before major channel adjustments were carried out, floods where prevented by building levees.

The first major efforts to modify the Dyje channel were made between 1834 and 1855. During this period, the river channel between km 120.0 and 85.5 (outside the study area) was straightened and widened, and a series of levees were built along it. It is presumable that these works disturbed natural fluvial processes, and thus had an indirect impact on the study area.

Similar works were conducted in 1888-1902 along a stretch extending from km 85.5 and 64.0 (section 1 and part of section 2). In 1911, local modifications of the channel were carried out in Břeclav. In 1934-1936, further work was conducted between km 67.0 and 64.0.[11]

The deepest modifications of the channel and the floodplain, however, were the result of major river engineering works carried out between 1975 and 1988. During this period, a stretch running from Dolní Věstonice village down to the confluence of the Dyje and Mora-

[11] D. Veselý, "Vodní hospodářství v oblasti dolního toku řek Moravy a Dyje, povodně a regulace toků od historie po současnost", in *Lužní les v Dyjskosvratecké nivě*, M. Hrib, E. Kordiovský (eds), Moraviapress, Brno 2004, pp. 63-79 (in Czech).

va rivers was modified, and a large water body called Nové Mlýny, comprising three reservoirs, was built in the area between the village of Brod nad Dyjí, the confluence of the Jihlava, Svratka and Dyje rivers, and the village of Nové Mlýny. The sections mainly affected by these works were nos. 2, 3, 4, and 5.

As a consequence of these works, the Dyje floodplain was cut off from its channel and flood inundations were drastically reduced. This led to minimal flow capacity into oxbows and pools, their subsequent silting up or drying up, increased eutrophication, water pollution, and the cutting off of the nutrient supply. Along with the pools, aquatic plants disappeared, e.g., water soldier (Stratiotes alloides), white water-lily (Nymphaea alba), yellow water-lily (Nuphar lutea), and fringed water-lily (Nymphoides peltata). In spring, the period of flooding of the surviving pools was frequently too short for amphibians to complete their development.[12] More than 3000 ha of the floodplain, including 1100 ha of forestland, were flooded to create the Nové Mlýny water body. This caused the destruction of unique biotopes of endangered plant and animal species. A ca. 50-100 cm decrease in the level of the underground water table was observed, and the high underground water level period was shortened. This decrease of gravitation water determined a significant reduction of herb and shrub layers.[13] The trees – especially of species requiring more water, such as poplar, willow, alder and ash – showed a thinning of their crowns and an incremental weakening of vital functions. In the drier periods there was premature yellowing of leaves and early leaf fall.[14]

After 1990, revitalization works were undertaken, both in the floodplain forests and on the Nové Mlýny water body, to compensate for the worsened hydrological conditions of the floodplain. The

[12] M. Kloupar, "Restoration of the hydrological system of the Kančí obora floodplain forest", in *Hydroecology of wetland "Kančí obora"*, O. Pražák, J. Vybíral (eds), Lesy České republiky, Židlochovice 2002, pp. 7-14.

[13] A. Prax, M. Kloupar, P. Hadaš, "Soil moisture regime in floodplain forests", in Pražák, Vybíral, *Hydroecology of wetland "Kančí obora"* cit., pp. 15-20.

[14] M. Penka, M. Vyskot, E. Klimo, F. Vašíček, *Floodplain forest ecosystem. II. After water management measures*, Academia, Praha 1991, p. 67.

revitalization of floodplain forests took two courses: the simulation of spring floods using water from the Nové Mlýny water body ("controlled flooding"), and the restoring of forest water channels and several oxbows and pools.[15] Other projects included the restoring of channel penetrability to allow fish migration (notably, fish passages were created near two weirs along the Dyje), reconnection of cut-off meanders and the Dyje River channel on the Czech side, and reconnection of floodplain forests by means of creating biocorridors on the northern and southern banks of the Nové Mlýny water body and across the middle reservoir. Of the project to reconnect floodplain forests around the Nové Mlýny water body, only the part concerning the middle reservoir was completed. It involved decreasing the reservoir water level by about 1 m and building two artificial islands from the sediments extracted from the bottoms of the reservoir. These islands were planted with 41 tree species belonging to the potential vegetation of the floodplain. In addition to this planting, spontaneous primary succession occurred.[16] The decrease in water level exposed some parts of the reservoir bottom, and spontaneous primary succession was observed here as well.

While river engineering works, especially from the second half of the 20th century, had strongly negative effects on the natural components of the Dyje floodplain, socio-economic activities in the floodplain were influenced rather positively. Positive effects included less crop and property damage from floods, establishment of recreational areas around the upper and lower Nové Mlýny reservoirs, creation of a new source for agriculture irrigation, and improvement of health conditions thanks to the reduction in the numbers of mosquitoes. From the aesthetic point of view, the creation of the Nové Mlýny water body introduced artificial elements into the floodplain landscape and its impact was hence negative.

[15] J. Vybíral, M. Hrib, *Revitalizace v lužních lesích na LZ Židlochovice*, Lesy České republiky, Lesní závod Židlochovice, Židlochovice 2002, p. 5 (in Czech).

[16] A. Buček, P. Maděra, P. Packová, "Stav a vývoj nadregionálního biokoridoru vybudovaného ve střední nádrži VD Nové Mlýny", in *ÚSES. Zelená páteř krajiny, Sborník ze semináře*, A. Petrová, P. Matuška (eds), CD ROM, AOPK ČR, Brno (in Czech).

Methods

For my research on the Dyje channel and land use changes, I used the following maps and aerial photographs: maps from the 2nd Austrian military survey (1827-1852) at a 1:28 800 scale for the first period (when the Dyje was least impacted by river engineering works); maps from the 3rd Austrian military survey (1876-1883) and their revised forms (1921-1952) at a 1:25000 scale for the second and third period; Czechoslovak military topographic maps (1952-1955 and 1991-1992) at a 1:25000 scale for the fourth and fifth period; and Czech topography base maps at a 1:10 000 scale and contemporary aerial photographs (2002-2006) for the sixth period.[17] All the maps were scanned, georeferenced, and vectorized in the ArcView program, version 9.2.

I calculated morphometric characteristics both for the study area as a whole and for individual sections. These characteristics include total river length, total river network density, total water body density (the number of water bodies per km^2), and sinuosity (Tables 1-6). I also calculated land use changes for both the whole study area and individual sections (Tables 7-12), distinguishing the following categories: arable land, permanent grassland, orchard, forest, water area, built-up area, and recreational area.

Sinuosity (S) expresses the ratio of channel length to straight-line valley length.[18] I used the following scale, which expresses channel pattern, to assess the sinuosity of individual sections of the Dyje: absolutely straight – S = 1.0; straight – S = 1.01 – 1.05; slightly sinuous – S = 1.06 – 1.25; moderately sinuous – S = 1.26 – 1.50; and meandering – S > 1.50.[19]

[17] In the following tables and graphs, maps and their respective periods are expressed as 1840 for the period 1827-1852, 1880 for the period 1876-1883, 1930 for the period 1921-1952, 1950 for the period 1952-1955, 1990 for the period 1991-1992, and 2006 for the period 2002-2006.

[18] D. Knighton, *Fluvial forms and processes*, Arnold Publishers, London 1998, p. 207.

[19] M. Lehotský, A. Grešková, *Slovensko-anglický hydromorfologický slovník (výkladový slovník hydromorfologických termínov),* SHMÚ, Bratislava 2004, p. 46 (in Slovak).

Table1 Morphometric characteristics of the whole study area

Period	Total area [km^2]	Length of the Dyje [km]	Total river network density [km/km^2]	Total water body density [number/km^2]	Sinuosity
1840	32.77	21.24	2.07	1.34	1.59
1880	32.77	20.60	1.68	0.95	1.54
1930	32.77	20.31	1.37	1.46	1.52
1950	32.77	22.21	1.42	3.17	1.66
1990	32.77	15.74	2.87	1.56	1.18
2006	32.77	15.71	2.77	2.14	1.18

Table 2 Morphometric characteristics of section 1

Period	Total area [km^2]	Length of the Dyje [km]	Total river network density [km/km^2]	Total water body density [number/km^2]	Sinuosity
1840	41.12	17.83	2.27	0.27	1.58
1880	41.12	18.26	2.26	0.36	1.62
1930	41.12	16.51	1.36	0.83	1.46
1950	41.12	16.73	1.63	0.71	1.48
1990	41.12	14.89	2.13	0.80	1.32
2006	41.12	14.91	2.80	1.24	1.32

Table 3 Morphometric characteristics of section 2

Period	Total area [km^2]	Length of the Dyje [km]	Total river network density [km/km^2]	Total water body density [number/km^2]	Sinuosity
1840	30.82	13.43	4.01	0.36	1.60
1880	30.82	12.50	2.52	0.32	1.49
1930	30.82	12.55	1.75	0.71	1.49
1950	30.82	12.96	1.88	1.07	1.54
1990	30.82	11.19	2.46	1.43	1.33
2006	30.82	11.40	2.78	1.95	1.36

Table 4 Morphometric characteristics of section 3

Period	Total area [km^2]	Length of the Dyje [km]	Total river network density [km/km^2]	Total water body density [number/km^2]	Sinuosity
1840	32.77	21.24	2.07	1.34	1.59
1880	32.77	20.60	1.68	0.95	1.54
1930	32.77	20.31	1.37	1.46	1.52
1950	32.77	22.21	1.42	3.17	1.66
1990	32.77	15.74	2.87	1.56	1.18
2006	32.77	15.71	2.77	2.14	1.18

Table 5 Morphometric characteristics of section 4

Period	Total area [km^2]	Length of the Dyje [km]	Total river network density [km/km^2]	Total water body density [number/km^2]	Sinuosity
1840	41.12	17.83	2.27	0.27	1.58
1880	41.12	18.26	2.26	0.36	1.62
1930	41.12	16.51	1.36	0.83	1.46
1950	41.12	16.73	1.63	0.71	1.48
1990	41.12	14.89	2.13	0.80	1.32
2006	41.12	14.91	2.80	1.24	1.32

Table 6 Morphometric characteristics of section 5

Period	Total area [km^2]	Length of the Dyje [km]	Total river network density [km/km^2]	Total water body density [number/km^2]	Sinuosity
1840	30.82	13.43	4.01	0.36	1.60
1880	30.82	12.50	2.52	0.32	1.49
1930	30.82	12.55	1.75	0.71	1.49
1950	30.82	12.96	1.88	1.07	1.54
1990	30.82	11.19	2.46	1.43	1.33
2006	30.82	11.40	2.78	1.95	1.36

Table 7 Land use changes in the whole study area

Category\Period	1840	1880	1930	1950	1990	2006
arable land	11.17	14.93	15.17	19.91	24.11	21.67
permanent grassland	42.49	40.01	38.81	32.19	13.14	13.99
orchard	0.24	0.27	0.15	0.09	0.25	0.35
forest	43.87	42.52	41.78	43.1	36.17	38.29
water area	1.02	0.73	1.18	1.51	21.67	20.77
built-up area	1.17	1.52	2.75	2.97	4.25	4.44
recreational area	N/A	N/A	N/A	0.14	0.38	0.46

Table 8 Land use changes in section 1

Category\Period	1840	1880	1930	1950	1990	2006
arable land	23.24	27.56	28.52	43.31	63.97	62.32
permanent grassland	62.11	54.66	51.02	35.03	12.64	11.51
orchard	0.24	0.7	N/A	0.15	N/A	0.06
forest	12.32	15.04	16.87	18.38	16.09	18.54
water area	0.57	0.21	1.41	0.7	5.1	5.1
built-up area	1.48	1.84	2.18	2.44	2.21	2.48

Table 9 Land use changes in section 2

Category\Period	1840	1880	1930	1950	1990	2006
arable land	15.35	20.28	19.67	23.23	8.11	6.44
permanent grassland	52.31	50.69	48.1	43.44	0.97	3.98
orchard	0.17	0.08	0.02	N/A	0.22	0.02
forest	29.08	26.67	28.31	28.07	0.82	4.12
water area	1.78	1.05	2.06	3.21	88.61	83.89
built-up area	1.2	1.15	1.49	1.75	0.71	0.95
recreational area	N/A	N/A	N/A	N/A	0.56	0.59

Table 10 Land use changes in section 3

Category\Period	1840	1880	1930	1950	1990	2006
arable land	6.68	9.49	8.22	13.45	36.25	31.22
permanent grassland	54.53	52.04	54.54	46.68	23.75	24.28
orchard	0.66	0.77	0.66	0.01	0.58	0.92
forest	34.99	34.78	33.49	36.32	35.17	38.72
water area	2.21	1.86	1.99	2.48	2.61	3.27
built-up area	0.93	1.06	1.04	1.03	1.54	1.48
recreational area	N/A	N/A	N/A	N/A	0.04	0.07

Table 11 Land use changes in section 4

Category\Period	1840	1880	1930	1950	1990	2006
arable land	14.15	19.83	22.27	26.78	27.42	25.6
permanent grassland	35.72	32.69	28.58	21.7	14.77	14.42
orchard	0.15	0.03	0.05	0.27	0.31	0.56
forest	47.67	44.02	40.96	42.24	42.17	43.2
water area	0.22	0.21	0.33	0.35	0.76	0.93
built-up area	2.09	3.22	7.54	8.06	13.51	13.99
recreational area	N/A	N/A	N/A	0.56	0.94	1.2

Table 12 Land use changes in section 5

Category\Period	1840	1880	1930	1950	1990	2006
permanent grassland	15.9	15.93	17.7	15.98	14.17	15.63
forest	83.76	83.41	82.02	83.49	82.27	82.74
water area	0.34	0.17	0.28	0.53	1.47	1.42

Results

The Dyje river engineering works were first initiated along *Section 1* (Fig 2) at the turn of the 19th century. In the maps from the 2nd and 3rd Austrian military survey, the Dyje still meanders and some of its reaches show a nearly anastomosing pattern (notably the middle stretch of the section). Cut-offs, oxbows and pools occur in the middle and northern stretches of the section. The engineering works resulted in the creation of many cut-offs and oxbows, which, however, are no longer extant. They lay along the left bank of the southern stretch of the section, and both banks of the middle and northern stretches. The only preserved oxbow from this period is situated north of the Jevišovka and Dyje rivers confluence, in the southern stretch. The hydrological conditions of this section were changed by the digging of many irrigating and draining canals on both sides of the Dyje in 1990. As a result, the total river network density significantly increased. In the same year, the creation of the Nové Mlýny water body determined the impoundment of the Dyje and, hence, a major increase in water-body surface. The increase in the total water body density in 1921-1952 was a result of the straightening of the Dyje. In 1952-1955 there was a decrease in total water body density, a consequence both of the natural silting up of the oxbows and of their artificial filling up. In total, the Dyje was shortened by approximately 5 km and its sinuosity decreased by about 0.5 (from 1.57 to 1.06). The course of the river channel thus changed from meandering (in the 1827-1852 period) through moderately sinuous (1876-1883) to slightly sinuous (1921-2006).

The land use changes in this section were dramatic as regards the categories of permanent grassland and arable land. While in the first half of the researched period (1827-1952), the dominant land type was permanent grassland, which occupied more than 50% of the total area, the second half of the researched period was dominated by arable land. This change is very noticeable, especially in 1991-1992 and 2002-2006, when the proportion of permanent grassland dropped to 11-12% while that of arable land rose to 62-64%. However, these changes were not primarily the result of river engineering works, but of state agricultural policy after 1948.

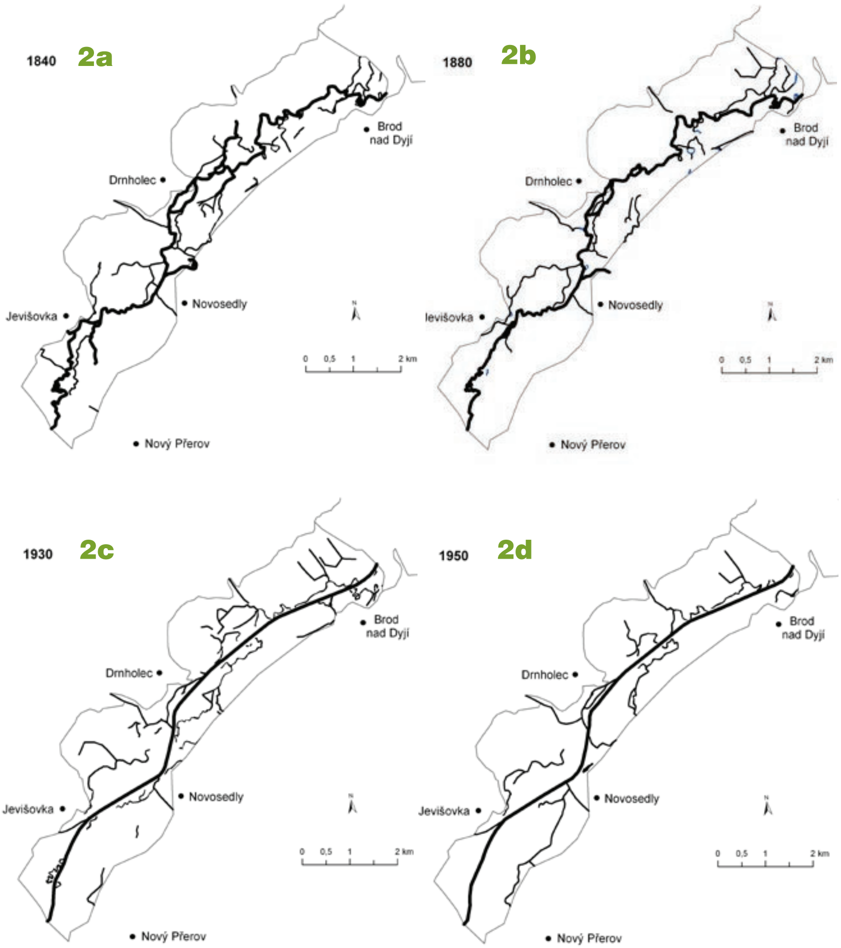
Section 2 (Fig 3) was completely flooded when the Nové Mlýny water body was built. All wetland biotopes in it were thus destroyed and its hydrological conditions transformed. The only vestiges of the Dyje channel in this section are two oxbows near Dolní Věstonice village, in the middle part of the section.

The straightening of the Dyje channel resulted in an overall decrease in its length and sinuosity. In this section, however, the Dyje maintained a meandering pattern through all four periods preceding the construction of the Nové Mlýny water body. The increase in total water density in 1921-1952 was a result of river engineering works at the end of the 19th and beginning of the 20th century. The increase in water body surface in 1952-1955 was mainly a consequence of the restoration of the Strachotínský pond.

As far as land use is concerned, if we compare the first four periods, we can say that there were no significant changes in this section. Yet a slight decrease of permanent grassland in favour of arable land can be noted, especially along the Dyje and in the vicinity of settlements. Following the construction of the Nové Mlýny water body, recreational areas were created in the northern part of the section.

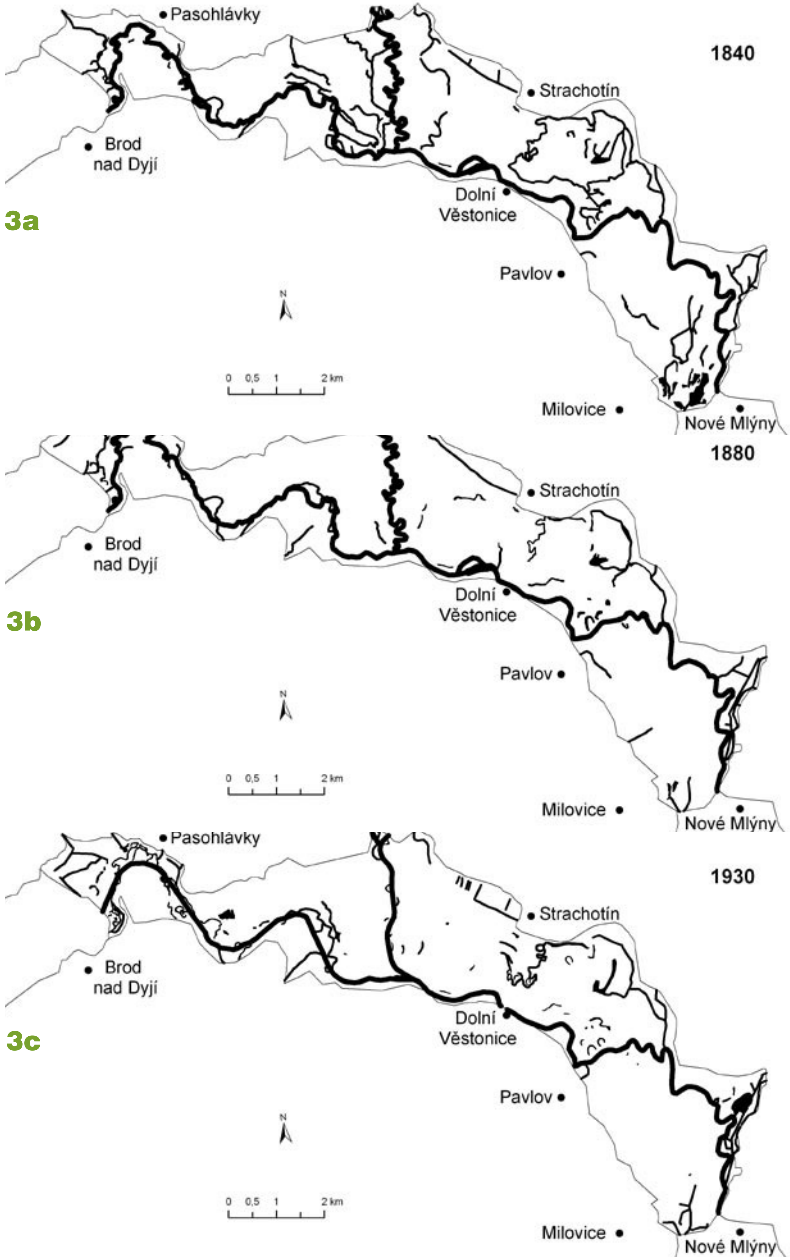
One of the most significant changes in *Section 3* was the digging of a completely new channel for the Dyje and its embankment from Bulhary village to Janův castle (river km 33.5), in the middle stretch of the section, between 1975 and 1988. The maps (Fig 4) clearly show the effects of the dry periods that occurred at the end of the 19th century and in the 1910s and '20s, when many streams and oxbows dried up and were used as meadows or pastures. This is especially evident along the left bank of the Dyje and in the southern part of the section. The situation changed during the 1930s-40s, when the groundwater supply of some oxbows, mainly along the right bank in the middle part of the section, between the villages of Lednice and Nejdek (river km 36-40), was renewed. This situation is illustrated by the map for the 1952-1955 period. In 1990-1999, forest water channels in the forest districts of Horní les (between Lednice and Nejdek) and Dolní les (north of Včelínek creek in the southern part of the section) were restored, as can be seen in the maps for the 1991-1992 and 2002-2006 periods. A comparative

Figure 2. Changes in section 1 of the Dyje River



examination of sinuosity in this section at different periods clearly indicates that it was high in the first two periods and subsequently decreased, to increase again in the 1950s. Throughout all four periods, the Dyje maintained a meandering course. The last two periods are characterised by very low sinuosity as a consequence of river en-

Figure 3 Changes in section 2 of the Dyje River

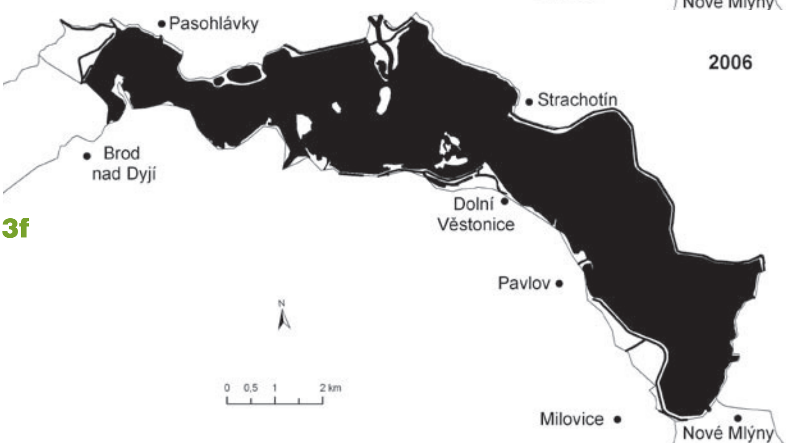



Pasohlávky
1950
Strachotín
Brod nad Dyjí
Dolní Věstonice
Pavlov
N
0 0,5 1 2 km
Milovice
Nové Mlýny

3d


1990
Strachotín
Brod nad Dyjí
Dolní Věstonice
Pavlov
N
0 0,5 1 2 km
Milovice
Nové Mlýny

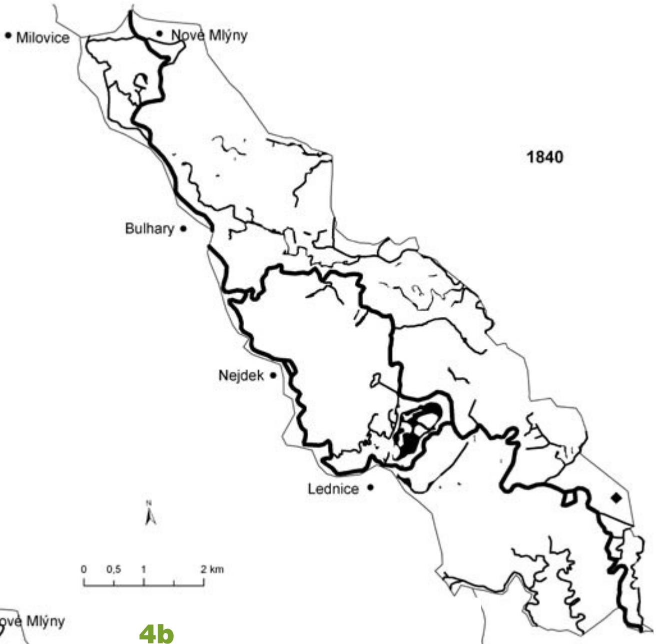
3e


Pasohlávky
2006
Strachotín
Brod nad Dyjí
Dolní Věstonice
Pavlov
N
0 0,5 1 2 km
Milovice
Nové Mlýny

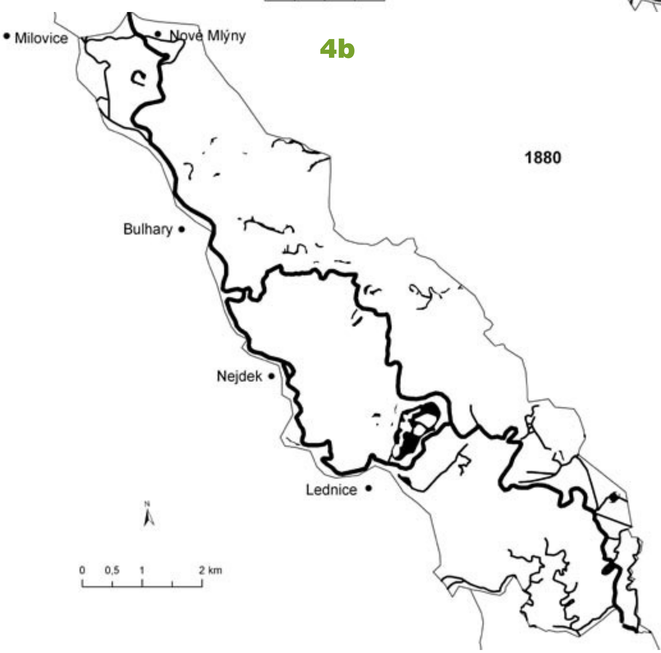
3f

Figure 4 Changes in section 3 of the Dyje River

4a



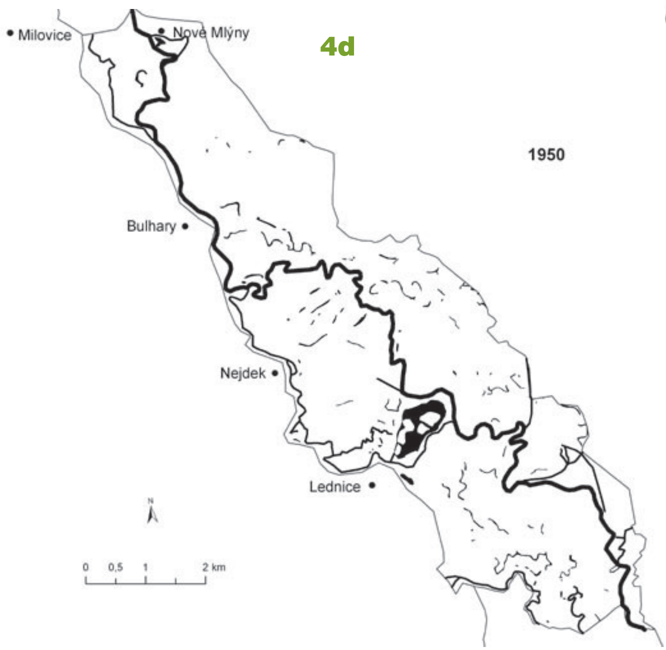
4b



4c

Milovice
Nové Mlýny
1930
Bulhary
Nejdek
Lednice
N
0
0,5
1
2 km

4d



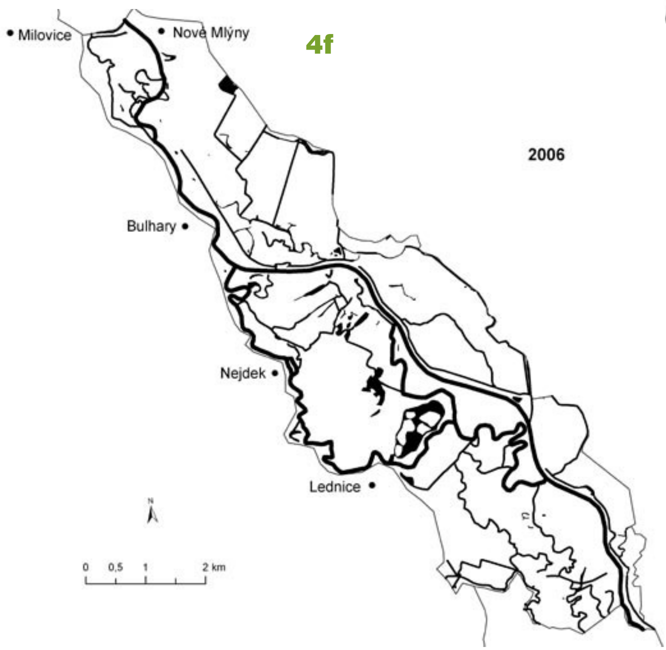
Milovice
Nové Mlýny
1950
Bulhary
Nejdek
Lednice
N
0
0,5
1
2 km

GE

4e


Milovice
Nové Mlýny
1990
Bulhary
Nejdek
Lednice
N
0 0,5 1 2 km

4f


Milovice
Nové Mlýny
2006
Bulhary
Nejdek
Lednice
N
0 0,5 1 2 km

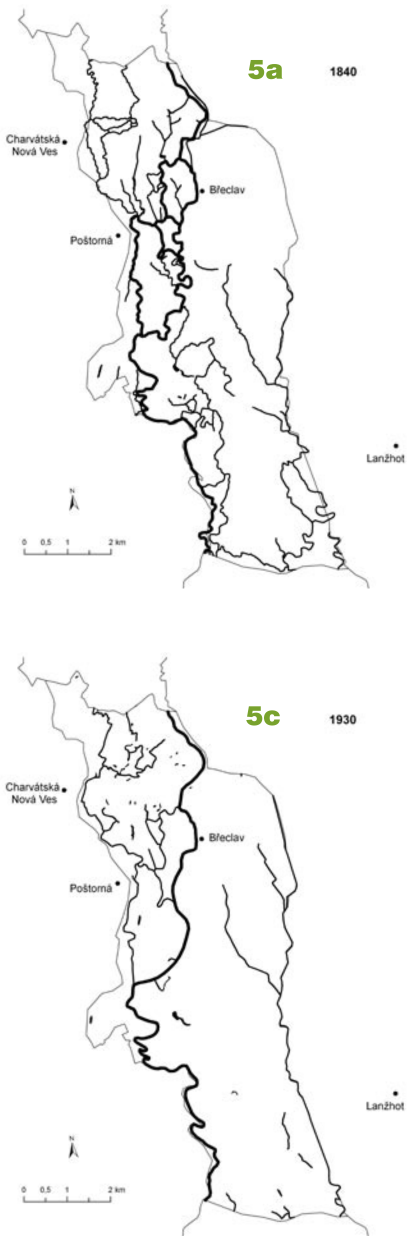
gineering works, notably the digging of the new channel mentioned above. Thus, in both periods the Dyje had an only slightly sinuous channel. The decrease in sinuosity documented in the maps from the 1921-1952 period may have been the result of natural fluvial processes.

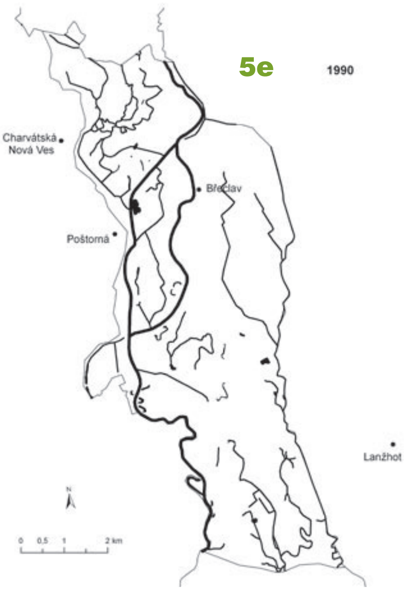
This section presents an excellent example of the impact of river engineering works on land use. The engineering works allowed the ploughing of permanent grassland, especially along the left bank of the Dyje. Since the works started in the second half of the 20th century, a significant decrease in permanent grassland and a concomitant increase in arable land is observable in 1991-1992 and 2002-2006.

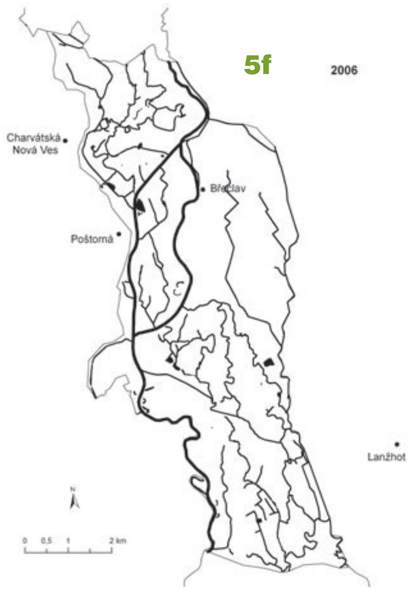
In *Section 4*, the areas along the left and right banks of the Dyje exhibit quite different characteristics. The right bank area is characterised by high density of water streams (the Včelínek creek and its tributaries). The high dispersion of pools on this side of the river during the 1921-1952 period was probably a consequence of the dry spell of the 1910s-20s. Some pools were reconnected in the 1950s, but the biggest changes can be seen in the maps from 2002-2006, which show the effects of revitalization works undertaken from the 1990s onward. There were hardly any oxbows or pools along the left bank of the Dyje at the end of the 19th century. The only exceptions were a few oxbows south of the Dyje and its flood channel (river km 21) and along the left bank between river km 17 and 18. This situation lasted until the 1990s, when forest water channels and some oxbows were restored as part of revitalization works. Some oxbows were formed as early as the 1970s as a result of the cutting off of meanders during river engineering works. The Dyje shows an anastomosing pattern near Břeclav between 1827 and 1883. Its sinuosity reached a peak towards the end of this period. In terms of degrees of sinuosity, the Dyje channel shows a meandering pattern in the first two periods (1827-1852; 1876-1883), and a moderately sinuous one throughout the 20th century.

Accelerated decreases in permanent grassland are documented in the 1952-1955 and 1991-1992 periods. While the decrease in the first period was caused by ploughing of the grassland, the 1991-1992

Figure 5 Changes in section 4 of the Dyje River







decrease was a consequence of the expansion of Břeclav. River engineering works in this case did not significantly influence ploughing of the floodplain, but they did affect the town's expansion, because they prevented the Dyje from inundating its surroundings. In the 1950s a new phenomenon manifested itself near Břeclav, viz., the foundation of garden colonies providing recreational areas for the city's inhabitants.

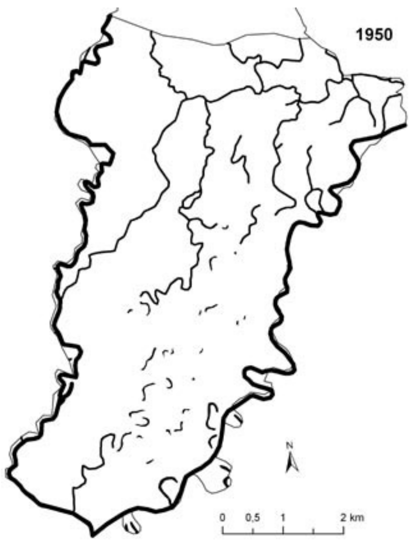
In *Section 5,* the highest total river network density together with the highest sinuosity is observable during the 1827-1852 period. At this time the Dyje had an anastomosing pattern. The maps from 1876-1883 and 1921-1952 show that in those periods most of the forest water channels had dried out; only a few pools remained. As can be seen in the map, these pools were partly reconnected in the 1950s. Restoration of forest water channels in the 1990s led to an increase in total river network density. Also, new pools were created and some oxbows restored. In 1827-1852, the period of highest sinuosity, this

Figure 6 Changes in section 5 of the Dyje River

6a

6b

6c



6d

6e

6f

section of the Dyje had a meandering pattern. Sinuosity decreased at the end of the 19th century to a moderately sinuous pattern. This decrease was caused by natural fluvial processes (meander cut-offs). The map for 1952-1955 once again shows a meandering pattern. River engineering works from the 1970s onward caused a decrease in sinuosity and thus changed the pattern back to a moderately sinuous one.

This section is characterised by stable land use with more than 80% occupied by floodplain forest. This stability can be attributed to several factors: not very favourable hydrological and soil conditions for agriculture; relatively worsened accessibility from settlements; to some extent, its location at the border with Austria (which was closed during the Cold War); but, above all, economic considerations (higher yields from floodplain forests and meadows than from agricultural crops).

Discussion

Throughout the 19th and 20th centuries, the water management of rivers and their floodplains was mainly carried out by means of technical adjustments, and its main purposes were the drainage of waterlogged soil and protection from floods. River engineering works narrowed down creek and river channels, replaced natural channels with artificial ones with simplified shapes, and eliminated cut-off meanders, oxbow lakes, pools, and swamps. Gradually, a growing awareness set in that such actions were unilateral and counterproductive from the standpoint of both landscape and water management.[20] This led to the undertaking of revitalization works or river restorations. Such works affect both the channel itself and the surrounding floodplain. They should be based on an understanding of the processes whereby biological communities are maintained, rather than being exclusively aimed at the improvement of channel conditions. They should be aimed at the reinstatement of natural flow regimes and flooding patterns, and the creation of floodplain water bodies and side channels. Such restoration would help the government to meet its obligations to wetland biodiversity, contribute to the management of pollution, mitigate the impact of flood and droughts, and provide opportunities for people to enjoy, and benefit from, rivers and their environs.[21]

With revitalization works, it is necessary to pay attention not only to single problems caused by river regulation, i.e., to carry out single-purpose projects, but to take into account all aspects of a river or floodplain habitat. The artificial spring flooding of meadows and reconnection of cut-off meanders in Section 5 of the study area are clear examples of conflicts between different spheres of interest. In the first case, the flooding of the meadows was meant to favour fish

[20] T. Just, V. Matoušek, M. Dušek, D. Fischer, P. Karlík, *Vodohospodářské revitalizace a jejich uplatnění v ochraně před povodněmi,* 3. ZO ČSOP Hořovicko, Ekologické služby, AOPK ČR, MŽP, Praha 2005, p. 7 (in Czech).

[21] C. Peacock, *Rivers, Floodplains and Wetlands: Connectivity and Dynamics,* RSPB publications, 2003, p. 2.

spawning, but at the same time it endangered the bird populations that nested in the meadows. In the second case, the reconnection of the cut-off meanders was meant to restore the diversity of hydrological and physical characteristics of the straightened channel, but threatened, at the same time, the survival of the protected plant species and communities of algae and cynophytes that had developed in the meanders in the meantime.[22] These two examples show that revitalization project should adopt an ecosystemic approach rather than focus exclusively on a particular species. Natural processes, like floods, invariably have both negative and positive consequences on individual plant and animal communities, and this is hence also true of revitalization works simulating particular natural processes and/or influences.

As was mentioned earlier, old maps and aerial photographs are valuable sources for research on river channels and the spatial distribution of land use, because they are easily accessible and spaced out over time at intervals allowing the researcher to detect changes, fluctuations and trends. However, the reliability of the results derived from maps and photographs depend on several factors, such as difficulties in the interpretation of a map due to faded colours and hatches, the type of projection employed by a map, accuracy of mapping at a given period, and, to some extent, the accuracy of scanning and georeferencing, as well as the subjectivity of the interpreter of the map.

Conclusion

The aim of this article was to analyze the impact of engineering works carried out from the 19th century onward on the Dyje floodplain, mainly as regards changes in the course of its bed, the cutting off of meanders, the forming of oxbow lakes, and changes in land

[22] S. Lusk, K. Halačka, V. Lusková, L. Vetešník, "Rehabilitační záměry v aluviu řeky Dyje a ochranářské kontroverze", in *Říční krajina. Sborník příspěvků z konference*, J. Měkotová, O. Štěrba (eds), UPOL, Olomouc 2004, pp. 150-155 (in Czech).

use. I also investigated changes in the water table and biodiversity as a result of these works.

In the 1827-1852 and 1876-1883 periods, two sizes of meanders can be distinguished: big – kilometres long –; and small – metres long. During these periods, the course of the Dyje followed an anastomosing pattern throughout its whole length, the highest sinuosity being observable in sections 1, 4, and 5.

All sections exhibit a sharp reduction both in the length of watercourses and in water surface in the late 19^{th} and early 20^{th} century. This anomaly can be explained by dry spells, deliberate draining of wetlands, or inaccurate mapping.

Major river engineering works carried out in the 1970s caused the disappearance of many cut-off meanders and oxbow lakes, because they were no longer inundated during floods or replenished by water from the river or groundwater. This phenomenon is mainly observable in sections 3 and 4. On the other hand, revitalization works from the 1990s resulted in an increase in water body area and the total length of watercourses, mainly in sections 4 and 5.

Within the whole study area, sinuosity was reduced by about 77%. The Dyje had a meandering channel in the 1827-1852 and 1876-1883 periods. The maps from 1921-1952 and 1952-1955 show a moderately sinuous channel, those from 1991-1992 and 2002-2006 a slightly sinuous one. This decrease in sinuosity was a result of channel shortening caused by the cutting off of meanders.

The most significant changes in land use involved the categories of arable land, permanent grassland, and water area; to a lesser extent, forest, built-up areas, and recreational areas. The most dramatic changes were recorded for permanent grassland, which shows significant reduction between 1921 and 1992. These changes were influenced by several factors, viz., state agricultural policy (notably in Section 1), river engineering works (notably in Section 3), and settlement expansion (notably in Section 4). The increase in water area in 1991-1992 was a result of the construction of the Nové Mlýny water body, which also entailed a decrease in permanent grassland and had a negative impact on forestland. From the 1950s onward, recreational areas were created in Sections 2, 3, and 4. Some of them spontaneously sprang up near settlements, especially cities, as a refuge from the hustle and bustle of the city, but also for the production of fruit and vegetables for private consumption (notably in Section 4), while others were catalyzed by the construction of the Nové Mlýny water body (in section 2).