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THE LONG-TERM DEVELOPMENT OF WATER BODIES IN THE CONTEXT OF LAND USE: THE CASE OF THE KYJOVKA AND TRKMANKA RIVER BASINS (CZECH REPUBLIC)

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Abstract

The long-term development of water bodies is investigated in this article using the cases of two river basins with similar natural conditions: the Kyjovka and Trkmanka River Basins in the Czech Republic. Using old topographic maps, land use development was assessed and the analysis of driving forces of land use changes was carried out. The essential land use changes in these areas are connected with the processes of agricultural intensification and urbanisation. The largest area of water bodies was recorded in both river basins in 1763. In the second half of the 19th century, the disappearance of most water bodies in the two basins was significantly affected by the above-mentioned driving forces. After World War II, some of the water bodies in the Kyjovka River Basin were restored and new ponds were established. In contrast, no significant water bodies were restored in the Trkmanka River Basin.

Shrnutí

Dlouhodobý vývoj vodních ploch v povodí Kyjovky a Trkmanky v kontextu využití krajiny (Česká republika)

Tato studie zkoumá dlouhodobý vývoj vodních ploch na příkladu dvou povodí s podobnými přírodními podmínkami (Povodí Kyjovky a povodí Trkmanky v České republice). S využitím starých topografických map byl vyhodnocen vývoj využití krajiny a proveden rozbor hybných sil změn využití krajiny. Zásadní změny využití krajiny jsou v tomto území spojeny s procesy zemědělské intenzifikace a urbanizace. Nejvyšší výměra vodních ploch byla zaznamenána v obou povodích v roce 1763. V druhé polovině 19. století se významně projevily zásadní hybné síly vedoucí k zániku většiny vodních ploch v obou povodích. Po druhé světové válce došlo k obnově některých vodních ploch v povodí Kyjovky, zároveň byly zakládány i nové rybníky. Naopak v povodí Trkmanky nebyly obnoveny žádné významné vodní plochy.

Key words: *water body, fishpond system, land use, Kyjovka and Trkmanka River Basins, Czech Republic*

1. Introduction

The historical development of water bodies is an important indicator of the overall development of land and, therefore, is generally perceived as part of long-term land use studies. Land use development is of considerable significance for understanding existing as well as historical links and relations in the landscape. Studying the driving forces of land use changes allows researchers to evaluate impacts of the activities of society on the historical and present landscape structure (Bičík et al., 2001; Hersperger and Bürgi, 2009; Havlíček and Chrudina, 2013).

One of the fundamental prerequisites for evaluating long-term land use and the development of water bodies in an integrated river basin is the study of old topographic maps, preferably at a medium scale (Palang et al., 1998; Haase et al., 2007; Swetnam, 2007; Van Eetvelde and Antrop, 2009; Mackovčin, 2009; Skaloš et al., 2011; Demek et al., 2011; Skokanová et al., 2012; Havlíček et al., 2012; Mojses and Petrovič, 2013). When evaluating the development of water bodies and driving forces of land use changes, it is extremely appropriate to combine old topographic maps with historical data sources and available regional literature (Demek et al., 2011; Havlíček and Chrudina, 2013). The long-term development of water bodies was studied on the basis of old topographic maps in several European countries – e.g. in Poland (Pieńkowski, 2003), France (Passy et al., 2012) and Great Britain (Wood and Barker, 2000). Water bodies, however, are often addressed in the context of overall land use (Haase et al., 2007; Swetnam, 2007; Skaloš et al., 2011; Demek et al., 2011). In the Czech Republic, the long-term development of water bodies has been evaluated in research published by Pavelková Chmelová et al. (2012), Frajer et al. (2013) and Havlíček et al. (2013b).

Topographic maps at a medium scale (from 1:10 000 to 1:100 000) make it possible to study relatively accurate changes in Central European landscapes from the mid 19th century. The oldest usable map sets in the territory of the Czech Republic are topographic maps of the 1st and 2nd Austrian Military Surveys (1836–1852, 1876–1880). The usability of the maps from the 1st Austrian Military Survey for detailed analyses of land use changes is limited by their insufficient planimetric accuracy (Brůna et al., 2002; Mackovčin, 2009). Yet, it is possible to use these maps for a provisional identification of the development of some land use categories. They are very valuable for the development of water bodies (Demek et al., 2011; Havlíček et al., 2013b). The first studies on the development of water bodies in South Moravia worked also with older maps, e.g. Müller's map of Moravia from 1716 (Koláček, 1930).

In the Czech Republic, small water reservoirs have a significant historical tradition. This tradition links particularly with fish farming and pond construction (Pavelková Chmelová et al., 2012). Pond construction was closely connected with the activities of religious orders and the use of fish as a fasting meal. Systematic construction of ponds by religious orders dates back to the 11th and 12th centuries Urbánek, 2012). The greatest boom of fish farming took place in the Czech Lands in the 15th and 16th centuries, in conjunction with the boom of the economically profitable fish breeding managed by distinguished noble families. Available historical sources, however, enable a more or less accurate mapping of fishpond systems and ponds only from the end of the 18th century and the mid-19th century.

This study investigates the development of water bodies since 1763 until the present, including the analysis of land use development and driving forces of land use changes, using the cases of the Kyjovka and Trkmanka River Basins. The aim is to find out whether a similar development of water bodies and similar processes of land use change took place in these two river basins, given their similar natural conditions.

The historical development of fishpond systems in the Kyjovka and Trkmanka River Basins was researched especially by Hurt (Hurt, 1954; Hurt et al., 1970); water bodies in parts of the Kyjovka and Trkmanka River Basins were also studied in other papers (Koláček, 1930; Hlavinka and Noháč, 1926).

Long-term land use has been studied in different parts of the Kyjovka River Basin, for instance in research focusing on the development of land use in the Hodonín District (Havlíček et al., 2012), in the Dolnomoravský Úval Graben (Demek et al., 2009), in the South-Moravian grabens and river floodplains (Demek et al., 2011), and in the upper part of the Kyjovka River Basin. The land use in the entire Trkmanka River Basin was studied by Kilianová et al. (2008). A more detailed evaluation of the development of water bodies based on the study of old topographic maps was part of a monograph focusing on ecotones in the landscape of the Trkmanka River Basin (Kilianová et al., 2009).

2. Study area

The Kyjovka River Basin is located in south-eastern Moravia (Fig. 1). It is a river basin of order IV according to Gravelius. Its total area is 678.28 km^2. The Kyjovka R. is a left-bank tributary of the Dyje River and originates in the Chřiby Highland at an elevation of 518 m a.s.l., close to the highest elevation of Bradlo (578.5 m a.s.l.). The Kyjovka River flows through the Chřiby Highland, then through the Kyjovská Pahorkatina Hilly Land and enters the Dyje River in the Dolnomoravský Úval Graben at an elevation of 152 m a.s.l.

The Trkmanka River Basin borders on the Kyjovka River Basin (Fig. 1). It is a river basin of order IV according to Gravelius. The total area of the Trkmanka River Basin is 363.26 km^2. The source of the Trkmanka River lies at an elevation of 249 m a.s.l. below the elevation of Radlovec (426.0 m a.s.l.) in the Ždánický les Highland. The highest point of the entire river basin is the highest peak of the Ždánický les Highland – U Slepice (437.4 m a.s.l.). The lowest point of the Trkmanka River Basin is the confluence

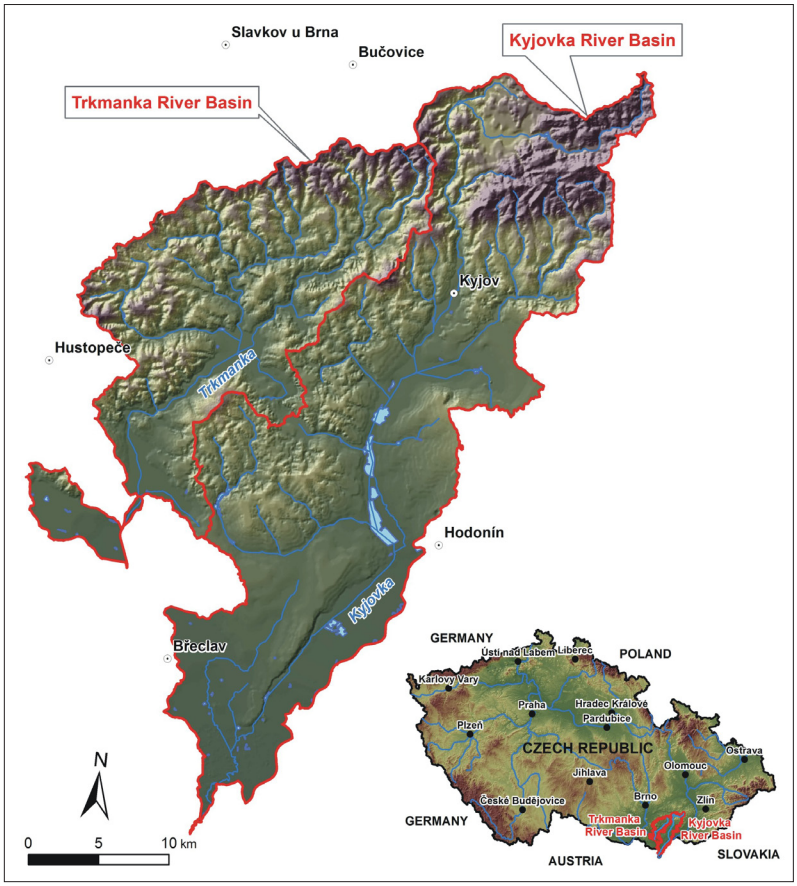

Fig. 1: The study area of the Kyjovka and Trkmanka River Basins, marking the current water bodies and watercourses; location of the study area in the Czech Republic (right down)
Source: The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, v. v. i.; the geographic base data of the Czech Republic (ZABAGED®)

with the Dyje River at an elevation of 152 m a.s.l. The Trkmanka River Basin has an asymmetrical shape; right-bank tributaries are more significant and longer.

The relief of both river basins shows some similar features – approximately 83% of the area in the Kyjovka River Basin and approximately 84% of the area in the Trkmanka River Basin are located at elevations up to 299.9 m a.s.l. (see Fig. 2 – cover p. 4). The difference, however, is in a notably higher proportion of the area with an elevation below 200 m a.s.l. in the Kyjovka River Basin (Tab. 1). In the Kyjovka River Basin, there is a higher proportion of flat area with a slope of 0–1.9 °, which is ideal for the construction of ponds and fishpond systems (Tab. 2). By contrast, the Trkmanka River Basin is characterised by a higher proportion of steeper slopes.

Rocks of the Flysch Belt of the Western Carpathians and Miocene sediments of the Vienna Basin and the Carpathian Foredeep can be found in the Kyjovka and Trkmanka River Basins. The Quaternary sediments in the Kyjovka and Trkmanka River Basins are represented by loess and loess loam, aeolian sands and floodplain sediments (Hrnčiarová et al., 2009).

Average annual air temperature in the two river basins ranges between 7 °C in spring areas and 9 °C in the lower parts of the river basins (Hrnčiarová, et al., 2009). Average annual precipitation in the source area of the Kyjovská pahorkatina Hilly Land reaches up to 650 mm and in the source area of the Trkmanka River up to 550 mm. Most areas of both river basins, however, feature an average annual precipitation between 450 and 500 mm. The Kyjovka and Trkmanka River Basins therefore are parts of the warmest and driest areas of the Czech Republic. They are in essence highly comparable.

3. Materials and methods

The historical development of water bodies and land use changes were analysed from layers of spatial objects created by vectorisation of old maps in the GIS software ArcGIS. For studying land use changes and the development of water bodies, a total of five map sets was used:

Category of elevation (m a.s.l.)	Kyjovka River Basin	Trkmanka River Basin
up to 199.9	43.99	27.09
200.0 – 299.9	38.92	56.52
300.0 – 399.9	10.91	15.56
more than 400.0	6.19	0.83

Tab. 1: Proportions of elevation categories in the Kyjovka and Trkmanka River Basins (%)

Category of slope angle (°)	Kyjovka River Basin	Trkmanka River Basin
0–1.9	54.98	28.79
2.0–4.9	17.63	21.58
5.0–9.9	18.72	33.05
10.0–14.9	8.38	16.35
15.0–24.9	0.28	0.22
25.0 and more	0.01	0.01

Tab. 2: Proportions of slope categories in the Kyjovka and Trkmanka River Basins (%)

- 2nd Austrian Military Survey on a scale 1:28 800 (1836–1841) – source: Austrian State Archive/Military Archive, Vienna; Geoinformatics Laboratory, J. E. Purkyně University, Ústí nad Labem;
- 3rd Austrian Military Survey on a scale 1:25 000 (1876) – source: Map Collection, Faculty of Science, Charles University in Prague; Silva Tarouca Research Institute for Landscape and Ornamental Gardening;
- Czechoslovak military topographic maps on a scale 1:25 000 (1953–1955) – source: Department of Military Geography and Meteorology, University of Defence, Brno; Silva Tarouca Research Institute for Landscape and Ornamental Gardening;
- Czechoslovak military topographic maps on a scale 1:25 000 (1991) – source: Military Geography and Hydrometeorology Office, Dobruška; Silva Tarouca Research Institute for Landscape and Ornamental Gardening; and
- Czech base maps on a scale 1:10 000 (2010) – source: digital vector model ZABAGED (already rectified), Czech Office for Surveying, Mapping and Cadastre.

Maps from the first four periods were originally in analogue format. They were scanned using a large-format scanner at a resolution of 400 dpi. They were subsequently transformed into the S-JTSK (System of Unified Czech/Slovak Trigonometrical Cadastral Net) co-ordinate system and mosaiced. For the transformation, pre-defined global transformation keys and non-residual Jungman transformation (Skokanová et al., 2012), as well as control points (minimum 4, average 8–14) and polynomial transformations of the first order were used. Maps from the 2nd and 3rd Austrian Military Survey were geo-referenced at a planimetric accuracy of 13–30 m. The geo-referencing of maps from the Czechoslovak and Czech military mapping in the periods 1953–1955 and 1991 was carried out in the programme ArcGIS, version 9.x, using the control points, and the mean planimetric accuracy was 10–15 m (Mackovčin, 2009).

Maps from the 1st Austrian Military Survey at a scale 1:28 800 (1763) represented a supplementary map set used for the assessment of the development of water bodies in the Kyjovka and Trkmanka River Basins. This map set enables the identification of the approximate values of the surface areas of individual water bodies and the approximate location of these water bodies, using the present relief and suitable areas for surface water accumulation. The methodology of the Silva Tarouca Research Institute for Landscape and Ornamental Gardening, v. v. i. (Mackovčin, 2009; Skokanová, 2009) was used for data preparation and subsequent analyses. This methodology distinguishes nine basic land use categories: 1 – arable land; 2 – permanent grassland; 3 – orchard; 4 – vineyard and hop-field; 5 – forest; 6 – water area; 7 – built-up area; 8 – recreational area; and 0 – other area.

Vector data derived from the old topographic maps were overlaid in GIS. As a result, a GIS database for further analyses was created. This database, however, had to be first adjusted by overlaying the vector data as sliver polygons were produced. The sliver polygons were eliminated with the use of the ArcGIS software according to its predefined criteria (area smaller than 5,000 m and width less than 10 m). These criteria were chosen based on a series of tests conducted at the authors' workplace (Skokanová, 2009).

Maps of land use change processes were created by comparing the land use change between two adjacent time periods. In total, nine types of processes were distinguished: transition into arable land; transition into permanent grassland; transition into orchard; transition into forest; transition into water area; transition into built-up area; transition into recreational area; transition into other area; and, areas under stable land use (Skokanová et al, 2012). For evaluating changes in water area, types of land use change were studied, comprising a combination of the land use categories from all five periods. These types were defined by five-digit codes, which corresponded to the number of used map sets. Each digit in the code is a land use record for each study period. With respect to the subject of this study, attention was focused on codes with the occurrence of digit 6 (water area), and their digit combinations in the overall type of land use changes.

4. Results and Discussion

4.1 Development of water bodies in the Kyjovka River basin and the Trkmanka River Basin

Using the maps from 1763, 55 water bodies with a total area of 1,256 ha were identified in the Kyjovka River Basin (Tab. 3). In particular, the Nesyt Pond with an approximate area of 262 ha was among the largest water bodies in this basin. According to Koláček (1930), its area was 562 ha. The figure can be considered as overestimated with respect to the accuracy of Müller's Map of Moravia from 1716. The Nesyt Pond was also considered as one of the largest water bodies in Moravia by other authors (Hlavinka and Noháč, 1926), who state that the Nesyt Pond was supplied both by the Kyjovka River and the Morava River. A drawing of the Nesyt Pond in the maps from the year 1763 supports the statement.

Other important ponds from 1763 included the Mistřínský rybník Pond (209 ha), the Jarohněvický rybník Pond (156 ha), the Písečný rybník Pond (143 ha), the Brodský rybník Pond (115 ha), and the Svatobořický rybník Pond (76 ha). All these ponds were located directly on the Kyjovka River and in its immediate vicinity. At the same time, there were also fishpond systems on the Kyjovka River tributaries. A significant number of these ponds in this period were bound to watermills, because they partly served as their retention basins (Hurt, 1970). There were also natural small lakes existing near the villages of Vracov and Vacenovice. Originally, these natural lakes were larger but gradually became silted up (Břízová, 2001).

In the maps from the years 1836–1841, 41 water bodies with a total area of 508 ha were identified (Tab. 3). The number of water bodies decreased very significantly in contrast to the previous period; the Nesyt Pond, the Mistřínský rybník Pond, the Svatobořický rybník Pond and many smaller ponds both on the Kyjovka River and its tributaries disappeared. The Písečný rybník Pond – Sand Teich (264 ha) and the Jarohněvický rybník Pond (117 ha) can be mentioned as examples of the largest ponds preserved to the present.

Year	Number of water bodies	Number of water bodies larger than 1 ha	Total area in ha
1763	55	46	1256
1836–1841	41	18	508
1876	61	11	71
1953–1955	69	34	439
1991	94	69	712
2010	284	80	723

Tab. 3: The number and area (ha) of water bodies in the Kyjovka River Basin

Maps from the year 1876 indicate a fish-farming decline. Although 61 water bodies were identified in that period, only 11 of them were larger than one hectare (Tab. 3) and the total area of all water bodies was only 71 ha. A significant decrease of water bodies was also recorded in other parts of South Moravia in that period (Demek et al., 2009, 2011; Havlíček et al., 2012; Kilianová, 2008). The largest pond in the basin was the Písečný rybník Pond (20 ha) near Milotice: its important compositional function within the wider settings of the Milotice Castle park prevented the conversion of this water body into arable land. The high number of small water bodies was represented by small ponds in villages (used as fire protection reservoirs), by smaller reservoirs near industrial premises, by anthropogenic reservoirs resulting from lignite mining at small depths below the surface, and by natural lakes in the area of Aeolian sands.

The disappearance of most fishpond systems in the second half of the 19th century resulted principally from the development of the sugar industry and lignite mining in this region (Havlíček et al., 2012, 2013a). There were 13 sugar factories operating in the basin and its surroundings (Gebler et al., 2007). Moreover, these predominant driving forces were intensified by a growing demand of the industry for technical crops. Owners of large estates responded to the trend by a large-scale drainage of ponds – to increase the area of arable land (Hurt, 1970; Havlíček et al., 2013a; Demek et al., 2009).

Maps from the years 1953–1955 show a restoration of some water bodies. In this period, 69 water bodies with a total area of 439 ha were identified, 34 of them being larger than 1 ha (Tab. 3). This high number was a result of the establishment of smaller ponds for fish breeding and for poultry farming on the sites of the original Písečný rybník and Brodský (Zbrodský) rybník Ponds. The Písečný state farm was established and later converted into the Fishery Hodonín, which played a crucial role in restoring water bodies in this basin. The largest water body in this period was the fishpond system of the Písečný rybník Pond in the surroundings of Hodonín (180 ha), consisting of seven ponds. The second largest water body was the Jarohněvický rybník Pond (104 ha) and the fishpond system of the Brodský rybník Pond (86 ha) with 11 fish-breeding ponds. Neither the Nesyt Pond near Hodonín, the former largest pond in the study basin, nor the Mistřínský rybník Pond, or the majority of ponds on the Prušánka Creek (a right tributary of the Kyjovka R.), were restored (Demek et al., 2009; Havlíček et al., 2012).

In 1991, 94 water bodies with a total area of 712 ha were identified (Tab. 3). In addition to the further development of water bodies intended for fish breeding and water poultry farming, new reservoirs were established in the second half of the 20th century and were used as drinking water sources (water reservoir Koryčany – 34 ha) or for irrigation (Velký Bílovec – 38 ha). The largest water bodies again included the fishpond systems of the Písečný rybník Pond near Hodonín (237 ha), the Brodský rybník Pond (105 ha) and the Jarohněvický rybník Pond (104 ha – see Fig. 3, cover p. 4). Water bodies formed after sand extraction, e.g. near Moravská Nová Ves (67 ha), became notable too.

Current base maps (2010) show that 284 water bodies with a total area of 723 ha occur in the Kyjovka River Basin (Tab. 3). This high number mainly results from the different scale of these maps (1:10 000). The number of water bodies larger than 1 ha (80 bodies), however, is comparable with the previous period. The fishpond system on the Kyjovka River represented again one the largest water bodies. In contrast with the year 1991, the most significant change was the construction of the Třetí Zbrod Pond (32 ha), which is part of the fishpond system of the Zbrodský rybník Pond near Mutěnice. Flood prevention measures partly increased the number of water bodies in this period. The construction of new water bodies based on the identification of old ones from the old maps was not common. Therefore, water bodies were constructed at places with no previous occurrence of ponds. In some localities of the former ponds (e.g. on the Prušánka Creek), natural processes caused the development of temporary or even permanent wetlands.

In 1763, 57 water bodies were identified in the Trkmanka River Basin, with a total area of 996 ha (Tab. 4). Compared to the maps of the Kyjovka River Basin, the drawings of significant water bodies in the Trkmanka River Basin are inaccurate. The largest water bodies on the maps are the Schön Sthras Pond in the Násedlovice surroundings (109 ha), a water body in the surroundings of Velké Pavlovice and Bořetice (101 ha), and the Kobylské jezero Lake (99 ha). All of these water bodies were adjacent to the Trkmanka River.

The most questionable is the delineation of the two originally largest water bodies in this basin. While the topographically inaccurate map from 1763 shows the Kobylské jezero Lake as very narrow and long-shaped and only 99 ha in area, a much more accurate map from 1836 indicates its area to be 414 ha. A similar discrepancy was also found in the case of the Čejčské jezero Lake, which was strongly undersized (32 ha) in 1763, whereas in 1836 it reached 114 ha, being the second largest water body in the Trkmanka River Basin in this period. The total area of water bodies in 1763 could therefore range from 1,100 to 1,300 ha.

In total, 730 ha of water bodies were still recorded in 1836–1841 but the number of water bodies decreased by more than one half (Tab. 4).

As in the case of the Kyjovka River Basin, a crucial decline of water bodies occurred between 1836–1841 and 1876 in the Trkmanka River Basin (Tab. 4). Efforts to extend arable land for growing technical crops, including sugar beet, can also be considered as predominant driving forces in this basin. In total, seven sugar factories were operating in the region and its close vicinity (Gebler et al., 2007). The occurrence of two large lakes – the Kobylské jezero and the Čejčské jezero Lakes – was a unique feature. These natural lakes were formed in the Late Glacial and Holocene. Their formation is connected with the tectonic activation of cross faults in this region (Břízová, 2002). Drainage works of the Kobylské jezero Lake started in 1834 and the Čejčské jezero Lake was drained during 1857–1858. The latter drainage is directly connected with the development of lignite mining at the edge of the lake, and with a rising demand for new arable land needed for sugar beet growing (Havlíček et al., 2013a).

Year	Number of water bodies	Number of water bodies larger than 1 ha	Total area in ha
1763	57	53	996
1836–1841	27	23	730
1876	36	10	50
1953–1955	23	11	28
1991	27	15	38
2010	103	22	75

Tab. 4: The number and area of water bodies in the Trkmanka River Basin

During 1953–1955, only 28 ha of water bodies were documented and the number and total area of water bodies did not significantly increase in later periods (Tab. 4). In contrast to the Kyjovka River Basin, there was no important enterprise engaged in fish breeding. This could be explained by different natural conditions in the Trkmanka River Basin: e.g. by the lower proportion of flat plains and by a consequent pressure to use these areas as arable land.

The high number of water bodies in 2010 was a result of different map scales (Tab. 4). In contrast to the Kyjovka River Basin, a positive trend was observed in the development of water bodies as a slight increase in the number was recorded for water bodies over 1 ha. Here, flood prevention and water retention measures contributed to the increased number of water bodies. The new water bodies are situated primarily in localities with occurrence of previous ones; however, their size is significantly smaller.

4.2 Land use development in the Kyjovka and Trkmanka River Basins

Long-term land use development was evaluated based on five land use maps from 1836–1841, 1876, 1953–1955, 1991 and 2002–2006. Arable land dominated in all of these periods (Figs. 4 and 5). The steepest decline was found in the category of permanent grassland (Figs. 4 and 5). Most of the permanent grassland areas disappeared in both study basins and their last remnants are often subject to nature conservation. In contrast, orchards gradually increased their proportion. They were mostly planted on the slopes around villages in the Kyjovská pahorkatina Hilly Land, often on new large-scale terraces. Vineyards reached their maximum in 1991, mainly as a result of large-scale farming in this region. The proportion of forests was slowly increasing both in the Kyjovka River Floodplain and in the Chřiby and Ždánický les Highlands (Figs. 4 and 5). The specific development in the water area was described in detail previously. In the Kyjovka River Basin, recreational areas are located mainly at the edges of forested slopes of the Chřiby Highland and in the surroundings of the town of Kyjov; in the Trkmanka River Basin, they can be found only sporadically.

Similar results in land use development were also recorded in other studies dealing with adjacent areas. A very significant decline of permanent grassland was found, for example, in the Dolnomoravský úval Graben (Demek et al., 2009), in the Hodonín district (Havlíček et al., 2012), and in the Trkmanka River Basin (Kilianová et al., 2008). A gradual growth of areas covered by forests was documented both in the regional studies of the surrounding areas (Demek et al., 2011; Skokanová et al., 2012; Havlíček et al., 2012; Mackovčin et al., 2012), and in studies covering the whole Czech Republic (Bičík et al., 2001; Štych, 2011). Changes in vineyards and orchards correspond with results of studies from the Hodonín District (Havlíček et al., 2012).

4.3 Processes of land use change and driving forces in the Kyjovka and Trkmanka River Basins

The dominant land use change processes in the Kyjovka and Trkmanka River Basins between 1836–1841 and 1876 included the transition into arable land that occurred on 15.3% and 9.9% of the study areas, respectively (Fig. 6). These processes were concentrated mainly in the close vicinity of the Kyjovka and Trkmanka Rivers and other water streams. In most cases, they occurred at the expense of permanent grassland and water areas or were part of the usual crop rotation (arable land – vineyard – orchard). In the Kyjovka River Basin, the transition into forest (2.0%) as well as into permanent grassland (1.6%)

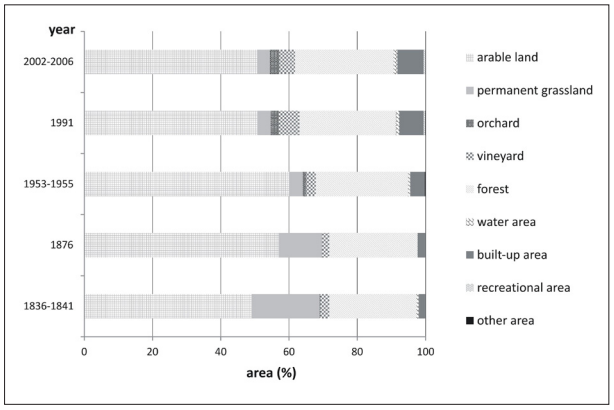

Fig. 4: Land use development in the Kyjovka River Basin: 1836–2006 (%)

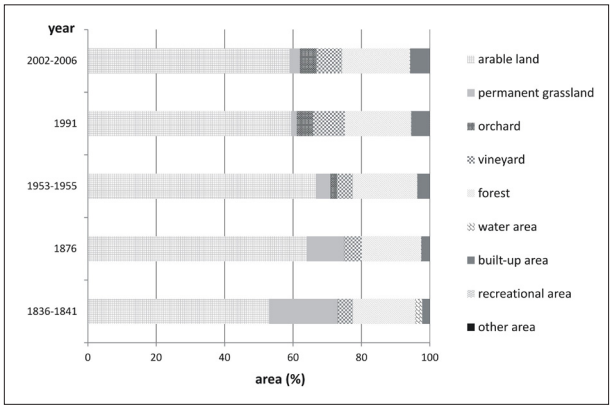

Fig. 5: Land use development in the Trkmanka River Basin: 1836–2006 (%)

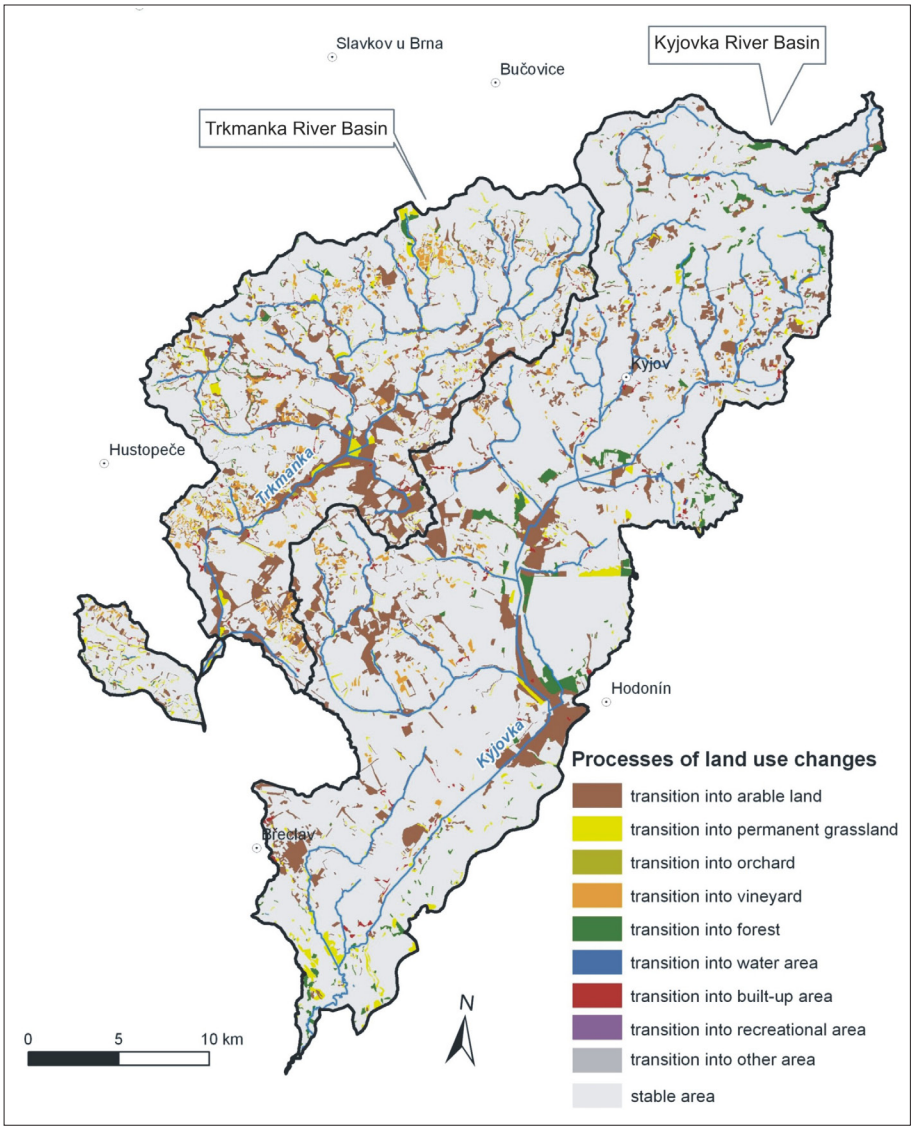

Fig. 6: Processes of land use change in the Kyjovka and Trkmanka River Basins between 1836–1841 and 1876
Source: The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, v. v. i.

was also significant, whereas the transition into permanent grassland (2.7%) and vineyards (2.4%) dominated in the Trkmanka River Basin. The principal driving forces of land use change between these two periods were related to the agrarian revolution leading to a higher consumption of food and to changes in animal farming (Bičík et al., 2001). The strong effect of sugar industry development was also significant in the region (Havlíček et al., 2012).

Between 1876 and 1953–1955, dominant processes in the two river basins were again the transition into arable land (8.5% of the Kyjovka River Basin and 8.2% of the Trkmanka River Basin), mainly due to the ploughing of permanent grassland and partly as a result of the already-mentioned rotation (Fig. 7). Other significant processes in the Kyjovka River Basin included the transition into forest (2.4%), built-up areas (2.0%) and vineyards (1.7%). A significant proportion of newly-created water bodies in this basin (1.0%) should also be mentioned, with more details described above. Other significant processes in the Trkmanka River Basin included the transition into vineyards (2.2%), orchards (1.9%) and forest (1.7%). The conversion to socialist large-scale farming (Bičík et al., 2001) and the development of industrial and residential complexes due to industrialisation and urbanisation, can be considered as generally applicable driving forces between 1876 and 1953–1955. The economic activity of the Fishery Hodonín, leading to a restoration of water bodies on the Kyjovka River, can be considered as a special driving force affecting land use change processes between these two periods.

The land use change processes in the Kyjovka and Trkmanka River Basins between 1953–1955 and 1991 were much different from the previous periods (Fig. 8). In both basins, the transition into vineyards predominated (4.5% and 6.1%, respectively), resulting especially from newly-planted large-scale vineyards during the period of socialist agriculture. The second most significant process was the transition into arable land (3.0% and 5.4%, respectively). This was followed by the transition into built-up areas (2.9%) in the Kyjovka River Basin and by the transition into orchards in the Trkmanka River Basin. The processes of agriculture intensification or urbanisation therefore continued in both river basins.

The notably lower proportions of changed areas between 1991 and 2002–2006 are influenced by the shorter interval in comparison with the previous periods (Fig. 9). Particularly the transition of vineyards and orchards into arable land predominated (3.9% in both basins). Processes of transition into permanent grassland, orchards and vineyards occurred on an area larger than 1% as well. Driving forces

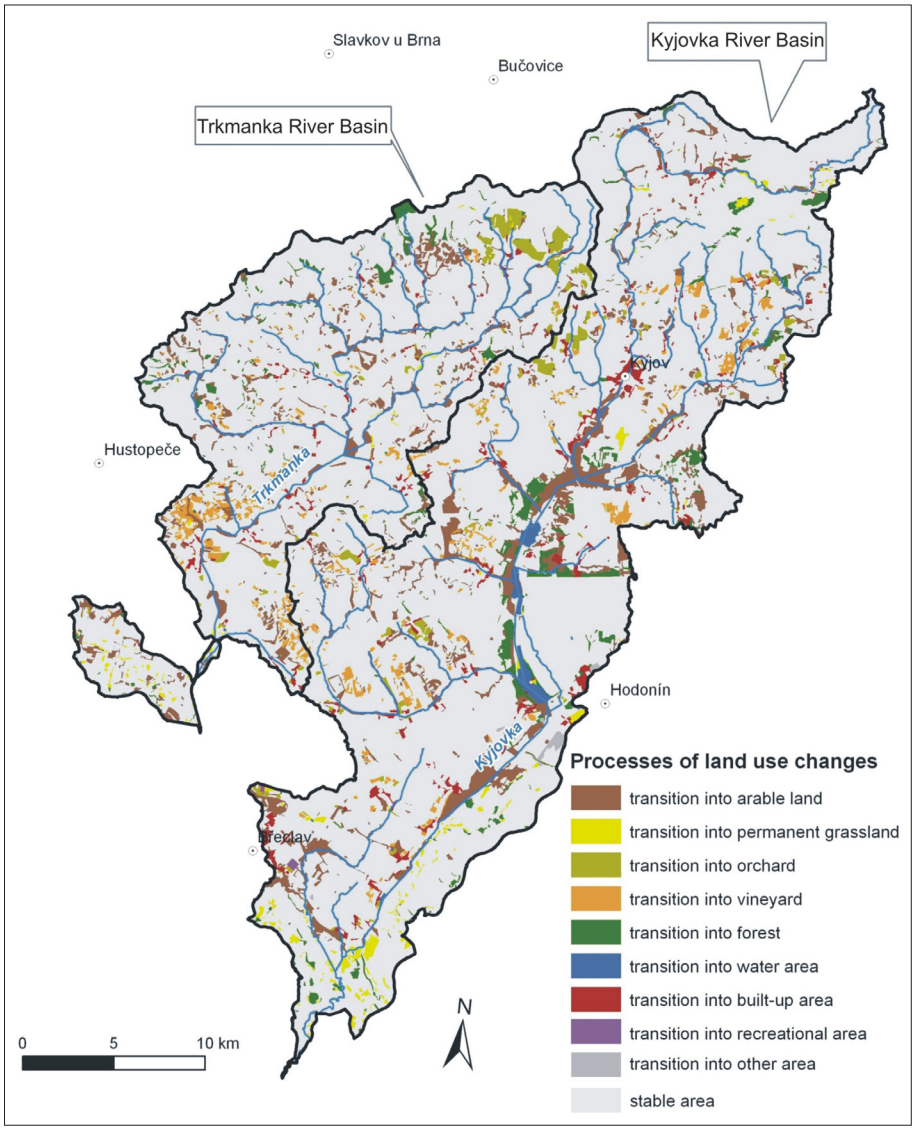

Fig. 7: Processes of land use change in the Kyjovka and Trkmanka River Basins between 1876 and 1953–1955
Source: The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, v. v. i.

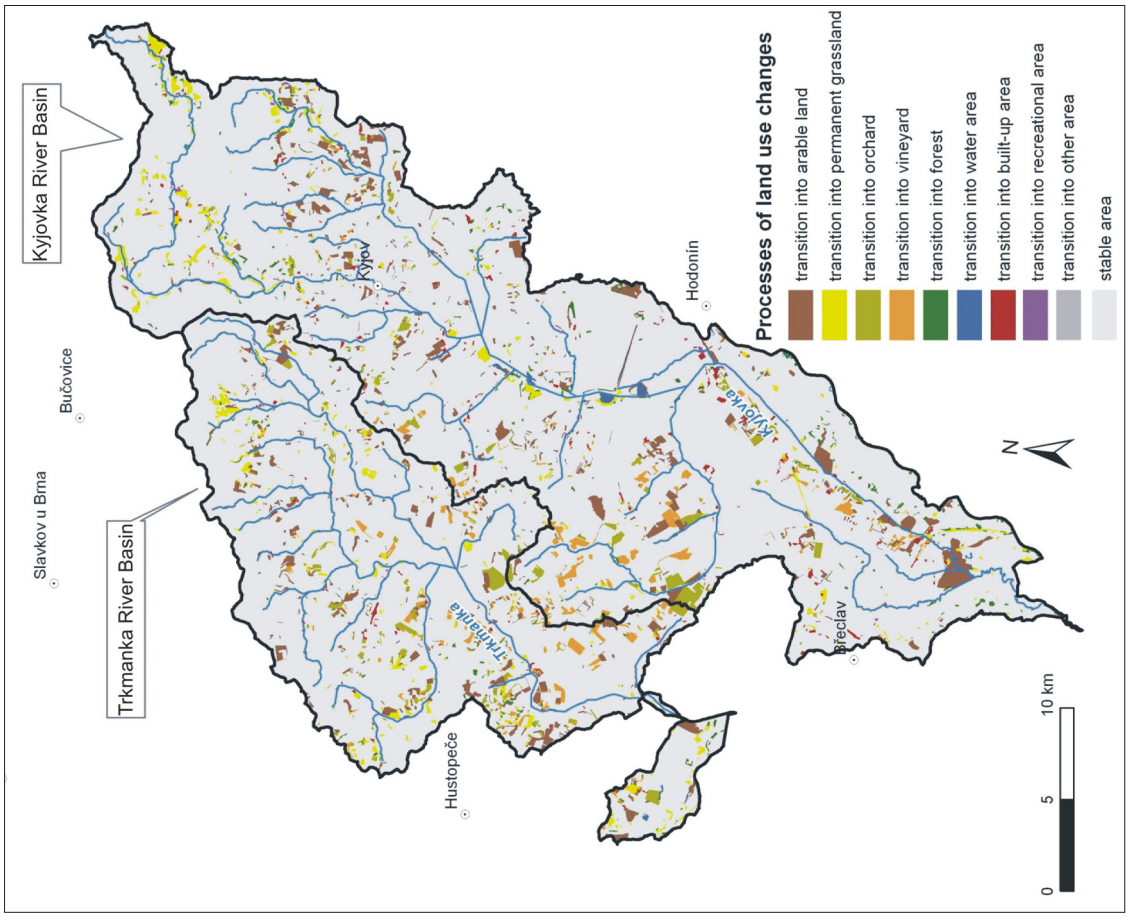

Fig. 9: Processes of land use change in the Kyjovka and Trkmanka River Basins between 1991 and 2002–2006. Source: The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, v. v. i.

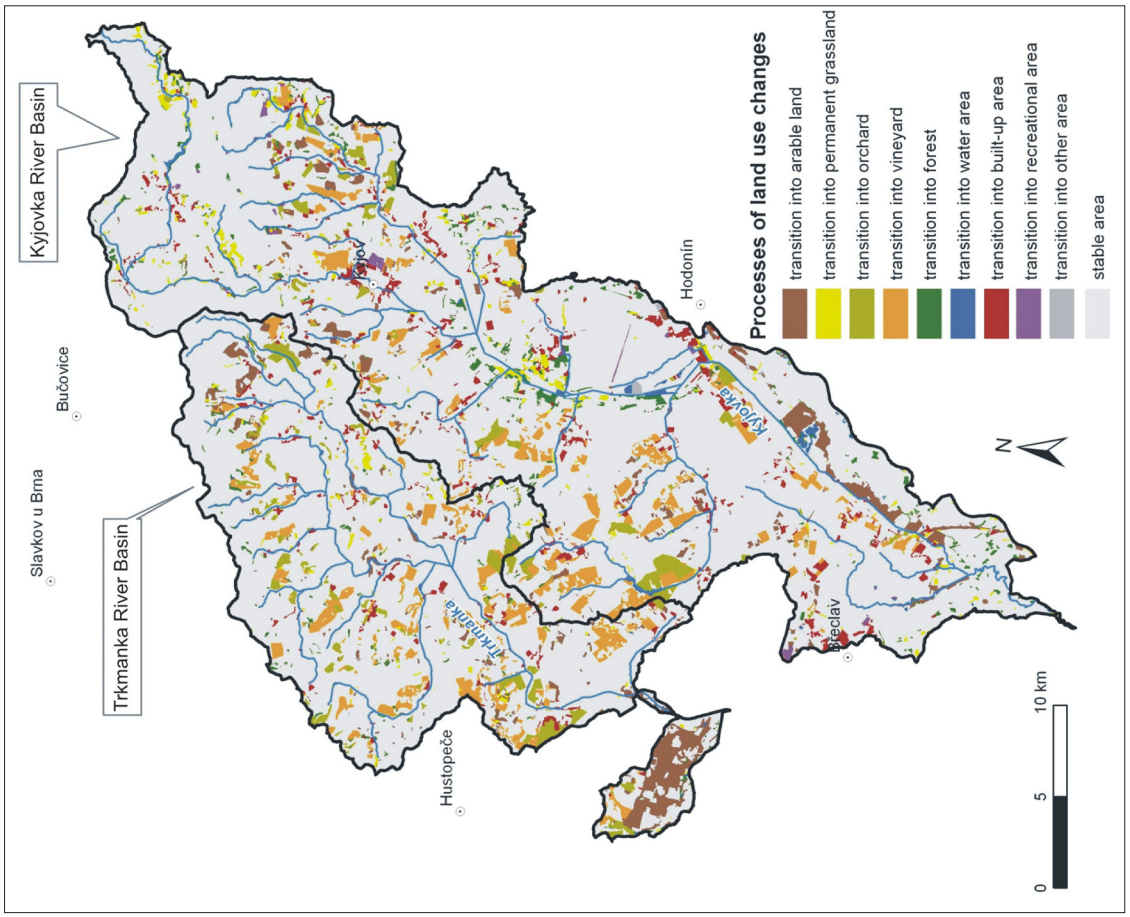

Fig. 8: Processes of land use change in the Kyjovka and Trkmanka River Basins between 1953–1955 and 1991. Source: The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, v. v. i.

leading to the decline of some agricultural areas predominantly included agricultural transformation, transition to the market economy and restitution of agricultural land (Bičík et al., 2001). The restoration of permanent grassland was also caused by changes in agriculture and by the subsidised conversion of arable land into meadows and pastures in less favourable agricultural regions (in this case mainly in the Chřiby and Ždánický les Highlands).

4.4 Types of land use change in water bodies

This overview of the types of land use change clearly documents fundamental differences in the development of water bodies in the Kyjovka and Trkmanka River Basins (Tab. 5). In the Kyjovka River Basin, the type 61666 predominated, i.e. the disappearance of water bodies between 1836–1841 and 1876 and their restoration in the following period (1953–1955). This relates to the restoration of the fishpond system on the Kyjovka River indicated above. A large area of newly-created water bodies was formed from the original permanent grasslands (types 22666 and 22266). Restoration of fishpond systems in this basin is also documented by the high proportion of restored water bodies – see types 61666, 62666, 61166, 61266 and 61566. On the other hand, the very low proportion of water bodies steadily used is rather surprising (type 66666). Only three ponds were documented on all five map sets in the Kyjovka River Basin – the Milotický rybník Pond, the Hovoranský rybník Pond and the Žižkovský rybník Pond.

Types of land use change leading to the disappearance of water bodies without their restoration predominated in the Trkmanka River Basin. The most frequent type of land use change was their direct conversion into arable land (types 61111 and 66111) or their gradual transition through permanent grassland into arable land (types 62111 and 62211). Types of land use change leading to the disappearance of water bodies through their conversion into arable land and later into built-up areas (types 61117, 61177 and 61777) also occur in abundance. Water bodies steadily used (type 66666) cover only 2.5 ha in the Trkmanka River Basin, which is even less than in the Kyjovka River Basin. They are represented by a small pond in the village of Brumovice and by an oxbow lake of the Dyje River in the southern part of the basin.

4.5 Changes in the elevation of water bodies

Data about the elevation of water bodies also show interesting results and contribute to information about their spatial distribution in the two studied basins. To increase the accuracy of the comparison and analysis of the distribution of water bodies in the selected elevation intervals, only periods represented by medium-scale maps (1:28 800 and 1:25 000) were chosen.

The average elevation of water bodies in the Kyjovka River Basin showed the highest elevation at the beginning of the studied period (Tab. 6), when the water bodies were uniformly distributed across the whole basin, i.e. concurrently at the lowest, medium and highest elevations. A decline of the average elevation in the Kyjovka River Basin between 1953–1955 and 1991 was caused by the disappearance of water bodies in the higher parts of the river basin and by the construction of ponds in the lower parts.

Kyjovka River Basin		Trkmanka River Basin	
Type of land use change	Area in ha	Type of land use change	Area in ha
61666	212.8	61111	524.3
22666	84.2	62111	199.1
22266	73.6	62211	21.9
61111	42.0	66111	11.9
22166	27.9	22166	6.2
55566	25.8	22216	5.9
22226	24.6	61211	5.6
21166	23.4	61117	5.3
62666	22.9	61177	4.8
61166	21.0	61777	4.3
22126	20.6	62212	3.7
11166	16.9	26111	3.3
61266	16.8	21166	3.2
55565	14.7	61112	2.9
21666	14.6	66666	2.5
61122	13.9	61131	2.5
55506	13.1	61115	2.4
22566	12.6	67777	2.3
61566	11.0	22116	2.3
66666	9.9	22226	2.0

Tab. 5: Overview of the twenty most significant types of land use change in the Kyjovka and Trkmanka River Basins (Legend: 1 – arable land, 2 – permanent grassland, 3 – garden and orchard, 4 – vineyard and hop-field, 5 – forest, 6 – water area, 7 – built-up area, 8 – recreational area, 0 – other area)

Period	1763	1836–1841	1876	1953–1955	1991
Kyjovka River Basin	204	193	197	182	185
Trkmanka River Basin	200	199	200	189	203

Tab. 6: Average elevation of water bodies in the Kyjovka and Trkmanka River Basins (m a. s. l.)

Table 6 shows a higher average elevation of water bodies in the Trkmanka River Basin than in the Kyjovka River Basin. The lower proportion of lowlands (Tab. 1) can explain this finding. Fluctuations of the average elevation in this basin are not so strong (Tab. 6), except for the period 1953–1955, with the lowest number of water bodies in the river basin and with the preserved water bodies located in the lower part of the river basin.

The numbers of water bodies according to elevation intervals (Tabs. 7 and 8) show a crucial difference in the development of water bodies in the two basins. Restored and newly-founded ponds in the lower part of the Kyjovka River Basin (around the town of Hodonín) gradually increased the number of water bodies in the lowest parts of the basin. In the Trkmanka River Basin, the decline of water bodies in the elevation interval 190.0–209.0 m a.s.l. is very notable. This was, among other things, due to the fact that ponds with watermills concentrated in the central part of the Trkmanka River between 1763 and 1836–1841 ceased to exist, and have never been restored in later periods.

5. Conclusions

The Kyjovka and Trkmanka River Basins are typical agricultural areas of South Moravia. From the perspective of long-term land use development, it is clear that the category of permanent grassland has undergone the greatest changes. Agricultural intensification and gradual urbanisation have led to the disappearance of a majority of meadows and pastures. In both basins, the proportion of arable land, vineyard and orchard has increased. The proportion of forests, originally covering about a quarter of the Kyjovka River Basin and about a fifth of the Trkmanka River Basin, has slowly increased. The proportion of built-up areas has been increasing systematically; it has quadrupled in the Kyjovka River Basin and doubled in the Trkmanka River Basin over the period under study.

The largest area covered by water bodies in both basins was observed in 1736: 1,256 ha in the Kyjovka River Basin and 996 ha in the Trkmanka River Basin. These values are very likely overestimated due to the inaccuracy of the source map.

In the second half of the 19th century, the principal driving forces leading to the disappearance of an absolute majority of water bodies in both basins dominated. Unprofitable fish breeding, the development of the sugar industry in the region and higher demands for food and technical crops for industrial production, were the main driving forces for the disappearance. While numerous water bodies were gradually restored in the Kyjovka River Basin, their restoration in the Trkmanka River Basin was negligible. This fact might be explained by higher slopes occurring in the basin and by flat areas being predominantly used as arable land. The restoration of water bodies in the Kyjovka River Basin after World War II was connected with the development of fish farming on the Kyjovka River; some water bodies were also newly re-managed as sources for drinking water or irrigation. Some water bodies were not restored at all. In total, 723 ha of water bodies are currently present in the Kyjovka River Basin and only 75 ha in the Trkmanka River Basin. The marked decline of water bodies in the Trkmanka River Basin has led to a decrease of ecological functions and impaired the overall biodiversity in the region. By contrast, despite the predominant production function of the restored pond systems in the Kyjovka River Basin, we can see their positive ecological impact on the landscapes, such as maintaining the diversity of aquatic birds, positive impacts on microclimate, water retention, etc.

The present situation shows efforts to restore water bodies in the region as a means of flood protection and water retention, and this is also supported by individual investors, landowners and municipality authorities in the

Elevation interval (m a.s.l.)	1763	1836–1841	1876	1953–1955	1991
150.0–169.9	3	12	8	24	41
170.0–189.9	23	5	22	27	28
190.0–209.9	13	16	21	11	11
210.0–229.9	4	4	4	4	4
230.0 and more	12	4	6	3	10

Tab. 7: The number of water bodies according to elevation intervals in the Kyjovka River Basin

Elevation interval (m a.s.l.)	1763	1836–1841	1876	1953–1955	1991
150.0–169.9	1	3	3	3	4
170.0–189.9	17	8	12	12	9
190.0–209.9	20	9	4	1	4
210.0–229.9	10	2	7	4	4
230.0 and more	7	5	10	3	6

Tab. 8: The number of water bodies according to elevation intervals in the Trkmanka River Basin

region. While many ponds in the Trkmanka River Basin were restored in places of the former ponds, ponds in the Kyjovka River Basin were largely constructed in places with no former pond occurrence. Therefore, this study can contribute in the identification of the most suitable localities for the restoration of ponds.

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