RECONSTRUCTION OF EXTINCT PONDS USING OLD MAPS, HISTORICAL CADASTRES AND THE DIGITAL TERRAIN MODEL OF THE CZECH REPUBLIC OF THE 5TH GENERATION

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Abstract
Research of ponds in the Czech environment has a long tradition. In the past, nearly 76,000 ponds were scattered in the Czech landscape, with an area of approximately 160,000 hectares, two thirds of which were drained during the 18th and 19th century. This study compares possibilities to reconstruct location of extinct ponds that were drained before the creation of maps based on precise geodetic base and whose spatial form (position, size, shape of the shoreline) has so far remained unclear. Individual methods of reconstruction are statisticaly tested on 12 extinct ponds in the upper reaches of the Klejnárka river and use a combination of historical maps, historical aerial photographs and digital terrain model in the environment of geoinformation system as well as archived data of the Josephinian Cadastre (1787).

Key words: historical landscape, ponds, old maps, airborne scanner, Josephinian Cadastre, Klejnárka river.

INTRODUCTION

Fishponds are an interesting phenomenon of the landscape and history of the Czech lands. Ponds, water constructional works built by the hand of man, carried out functions that meet the demands of society as a source of potable and non-potable water (Čurda 2006), source of energy for the drive of production facilities (Wood and Barker 2000), fish breeding (Šusta 1995), component of the fortification (Čermák 2004) etc. They have become an important part of the ecological landscape (Biggs et al. 2005), where they perform the functions of an important biotope, of regional bio-centres, as water reservoirs and participate in shaping the character of the landscape. Fishpond systems (e.g. those of South Bohemia) have become an important European example of cultural landscape, which requires comprehensive care and protection (Vorel 2000). Ponds are a unique mix of valuable natural components of the landscape and at the same time of its strong anthropogenic influence (Waldon 2012). These artificial water reservoirs have become a natural part of the Czech countryside. Currently there are approximately 24,000 small reservoirs in the Czech Republic. But this is a mere fragment of the estimated 75,000 ponds situated in our country yet in the beginning of the 17th century (Vrána and Beran 2002). Two thirds of them were drained in the 18th and 19th centuries and never renewed (Frajer and Pavelková Chmelová 2010). They were replaced by expanding urban areas, arable land and wet meadows. The existence and location of these ponds can often be traced only through archival sources, old maps or relics of dams in the terrain (Dohnal M. 2008; Frajer and Pavelková Chmelová 2009; Havlíček et al. 2009; Šantrůčková et al. 2009; Chrudina 2010). Reconstruction of extinct ponds in terms of their location in the landscape, area and shape of the shoreline can be quite successful when

using maps of the Stable Cadastre (from the years 1826–1843), of the 2nd Military Survey (1836–1852) and eventually of the 3rd Military Survey (1877–1880). Rectification and subsequent vectorization of these historical maps in GIS environment allows relatively precise plotting of forms of extinct ponds and of their former position in the current landscape (e.g. based on orthophoto) with tolerable distortion. Errors in the accuracy of rectification in the 2nd Military Survey are generally up to 50 m (Pešťák and Zimová 2006; Veverka et al. 2007; Frajer and Geletič 2011), in the 3rd Military Survey up to 30 m (Cajthaml and Krejčí 2008; Frajer and Geletič 2011). Errors of the Stable Cadastre are within several metres. Most of the ponds in our area ceased to exist at the turn of the 18th and 19th century, in the period before the emergence of more accurate mapping sources, which makes reconstructive possibilities more difficult. That is why we are often referred to written archival sources of the 1st Military Survey (1764–1768), whose accuracy is problematic. Errors in the positional accuracy reach hundreds of metres. Completely new possibilities of reconstruction open with the combination of historical sources and accurate digital terrain models, in which we can identify relics of the dams or former pond basins.

Determination of the exact location and area of the extinct pond may contribute not only to a more detailed knowledge of the appearance of historic landscapes, but can also serve as a basis for further research of former ponds in terms of pedology, sedimentology and agriculture (farming on former pond areas). Spatial information about extinct ponds can become the basis for their eventual recovery (Pokorný and Hauser 2002) or other revitalization or flood control measures in the river landscape (Lhotský 2010).

AREA OF INTEREST

Our study focuses on the extinct ponds and their systems in the upper reaches of the Klejnárka river basin, a left tributary of the Elbe river, with a length of 40.26 km and a catchment area of 350.08 km^2 (DIBAVOD 2010). Klejnárka rises at an altitude of 516.53 m a.s.l. near the village Dobrovítov (central

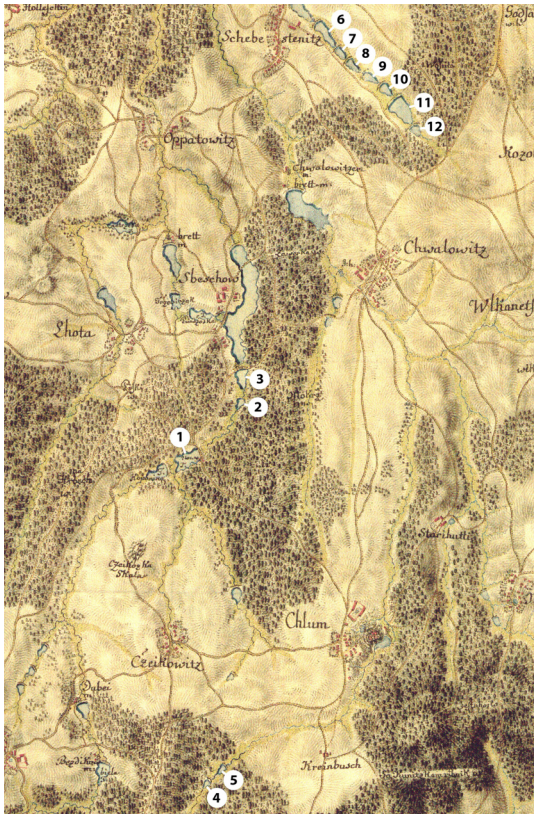

Figure 1 Localisation of the extinct ponds of interest (1st Military Survey map 1764–1768). Source: Geoinformatics Laboratory, University of J. E. Purkyně / Austrian State Archive / Military Archive, Vienna: 1st Military Survey, section no. 164 (original, not georeferenced).

Bohemia). Researched extinct ponds are situated in the upper reaches of the Klejnárka river near the village Zbýšov (3 ponds) and on its tributaries Šebestěnický potok (7 ponds) and Chlumský potok (2 ponds). These are small streams with a length of 6.29 km (Chlumský potok) and 3.28 km (Šebestěnický potok), flowing through municipalities Šebestěnice and Chlum. Selected ponds or their systems are typical representatives of extinct ponds that are displayed on the 1st Military Survey maps, but no longer present in later cartographic sources. From the system of the original eight ponds on Šebestěnický potok, only Návesní pond with an area of 1.04 ha has preserved up to the present (DIBAVOD 2010), while of the three ponds on Chlumský potok only Mlýnský pond remains with an area of

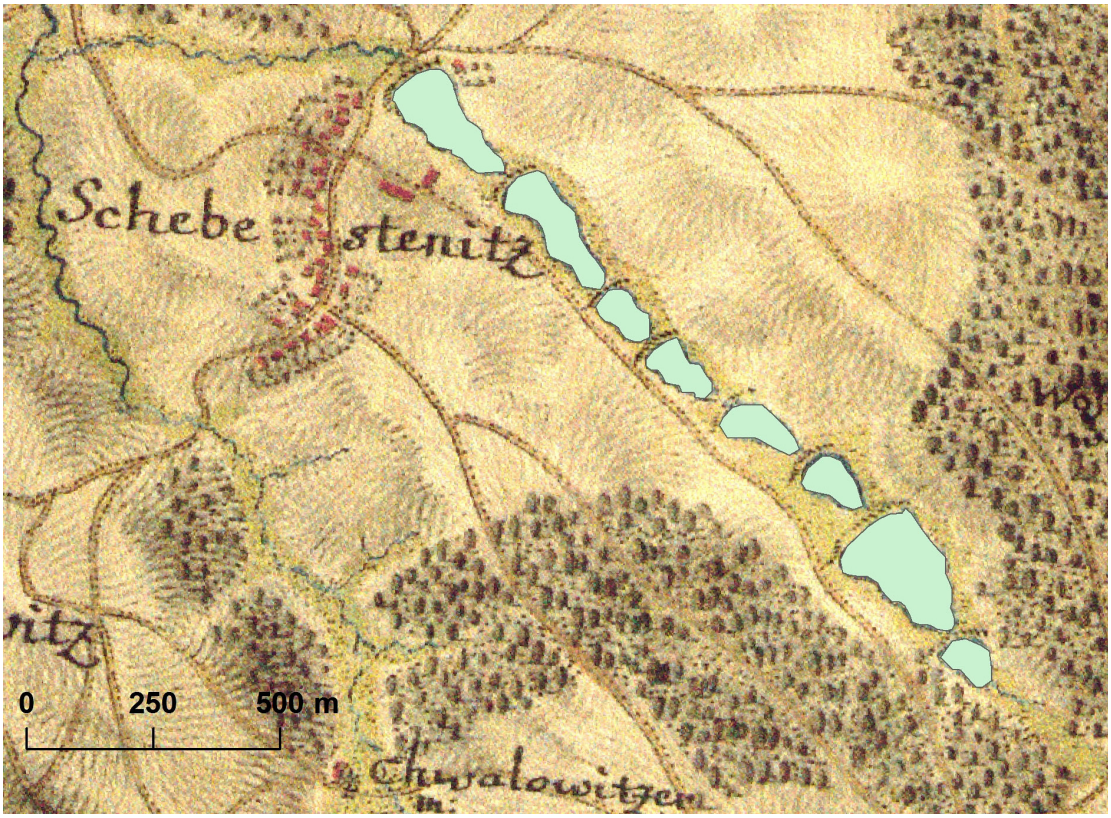

Figure 2 Example of pond reconstruction in ArcGIS 10.1 on the basis of a 1st Military Survey map. Map source: Geoinformatics Laboratory, University of J. E. Purkyně / Austrian State Archive / Military Archive, Vienna: 1st Military Survey, section no. 164.

8.269 ha. From the original eight reservoirs in the upper reaches of the Klejnárka river at Zbýšov one half of their former area still exists (a current total of 14.62 ha; DIBAVOD 2010). The emergence of ponds as well as their functions are not yet known (Dohnal M. 2008; Frajer 2008). We can only assume whether the ponds were either used as a source of water for processing silver ore that was mined in the area of Šebestěnice (Bílek 2000) or they were built for fish breeding for the Sedlec monastery, to which the villages Zbýšov and Šebestěnice belonged for several centuries. In the case of ponds of the Chlumský potok we can presume their possible link to the historic glassworks. Relics of extinct ponds are in all cases clearly visible in the field, although a number of dams were levelled or plowed in the mid-20th century. The studied ponds are indicated on the 1st Military Survey map in Figure 1.

METHODS AND SOURCES OF RECONSTRUCTION

Rectification and vectorization of the 1st Military Survey (1MS)

One of the ways to reconstruct extinct ponds is rectification and subsequent vectorization of old maps in the GIS environment. In this case study it cannot be used conclusively because the only map source showing the ponds is the 1st Military Survey. This mapping is a completely unique evidence of the state of landscape of the Czech lands before the beginning of the industrial revolution. Mapping was carried out on the whole territory of the Habsburg monarchy in the years 1763–1785, at a scale of 1:28,800. Due to time constraints and economic cost, however, it was made without precise

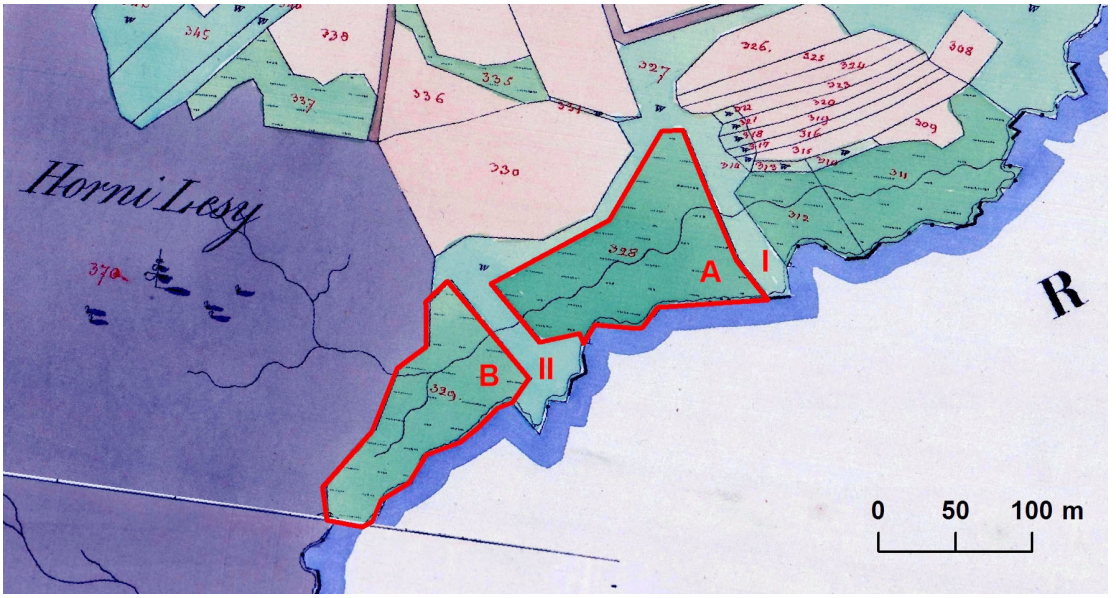

Figure 3 Example of pond reconstruction from the Stable Cadastre. Former ponds (A, B) as new meadow plots and their dams as pasture plots (I, II) – Horní Trubný and Dolní Trubný ponds. Map source: Czech Office for Surveying, Mapping and Cadastre (2012a) – Stable Cadastre no. 2504-1 Chlum.

geodetic foundations. Mapping was handled by specially authorized military engineers, who captured the landscape "à la vue" (i.e. by eyesight) – recording spatial features of the landscape according to their observation from horseback. More detailed mapping was carried out only rarely and using the method of pacing (Mikšovský and Zimová 2006). Such a way of mapping affected the accuracy; positional errors reach hundreds of metres, in the mountainous terrain up to several kilometres. For the purpose of this study the map sheet no. 164 was rectified in ArcGIS 10.1. The average RMSE using affine transformation reached a high value of 593 m when choosing the maximum number of identical points (26). Subsequently ponds were vectorized (Figure 2) and their area was determined using ArcGIS.

Retrogressive reconstruction based on maps of the Stable Cadastre (SCrec)

Another possibility is the retrogressive method of reconstruction of extinct ponds, using newer sources to reconstruct older reality (Dohnal M. 2006). In this case, we used coloured maps of the Stable Cadastre (1826–1843), which were made at the scale of 1:2,880. Not only persisting ponds but also drained ponds are recorded there – although meadows are in the place of ponds, the pond dams are still noticeable on the maps in the form of narrow strips marked with the colour for grazing. We can expect that after draining of the pond new plots were created:

- *meadow*, whose area equals approximately to the area of the original pond;
- *pasture*, which covers the area of the dam.

The Stable Cadastre maps were georeferenced in a GIS environment and meadows established in the place of former ponds were vectorized and subsequently their area was determined. This method has its own limits. It is obvious that the shoreline of the pond could not exactly correspond with the borderline of the meadow, because surveyors captured only the bottom of the former ponds during the mapping and expanded space marked out by former water surface is therefore not represented (Figure 3). Moreover, without detailed archival research we cannot determine whether the land after draining of the pond was not already further partitioned in several places.

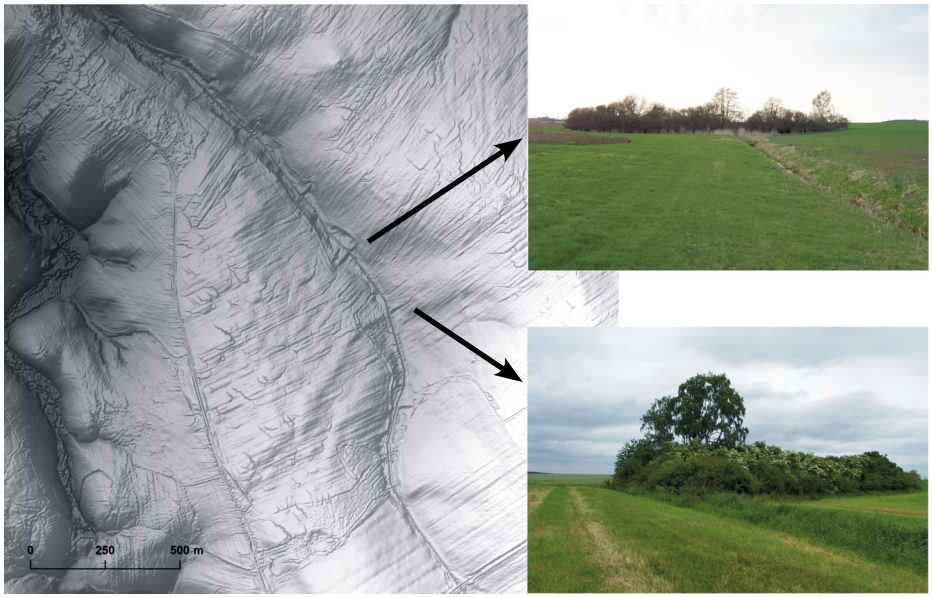

Figure 4 Digital Terrain Model of the Czech Republic of the 5th Generation. Identification of the relics of dams on the terrain model and in the field. Telecí and Velký Vosenický ponds. Data source: Czech Office for Surveying, Mapping and Cadastre. Photos: J. Frajer 2012.

Reconstruction using the Josephinian Cadastre (JC)

The Josephinian Cadastre was a forerunner of the Stable Cadastre. Its implementation was ordered by Joseph II by an edict from 1785 and its aim was reassessment of land in the Habsburg monarchy for fiscal purposes without distinction of manorial and serf land. Mapping was performed by using trivial methods without distinctive surveying equipment, but ponds together with forests were due to its atypical shape (unlike other categories of land) surveyed by experienced engineers (Roubík 1954). Representative maps were not made for the written cadastral records of the Josephinian Cadastre. Preserved field sketches ("brouillons") were so inaccurate that it was not possible to compile the map for one cadastral municipality. Reconstruction is therefore limited to indication of the area of ponds quoted in a declaration book ("Fassionsbuch") for each cadastral municipality (NAČR 2012). These books are handwritten in the Kurrent script. In search of ponds it is necessary to examine the lists of all the parcels, which is very difficult and time consuming. The area of ponds needs to be converted from historical measurement units into the metric system. This fact makes the Josephinian Cadastre generally less used as a source for understanding historical landscape (Lipský 2000; Maur 2010).

Reconstruction of extinct ponds using DMR 5G

The *Digital Terrain Model of the Czech Republic of the 5th Generation* (DMR 5G) was created by the Czech Office for Surveying, Mapping and Cadastre (2012b), based on aerial laser scanning performed by the Military Geographic and Hydrometeorological Office (VGHMÚř) in Dobruška. It is a result of the "Project of creating a new elevation of the Czech Republic" which started in 2008 and will be completed in 2015 (Brázdil 2009). The first outputs of this scanning were made available to the public in 2012, when scanning, georeferencing, robust filtering and interpolation of the central zone of the Czech Republic was finished. The result is a triangulated irregular network (TIN) with a total standard error 0.18 m of height in bare terrain and 0.3 m in the terrain with dense vegetation (Brázdil 2012). The test results of DMR 5G have already been used in studies of Uhlířová and Zbořil (2009) and

Figure 5 Results of the reconstruction by DMR 5G. Orthophotomap: Czech Office for Surveying, Mapping and Cadastre.

Uhlířová and Nováková (2011), which examined the possibility of its application in water management practice.

For the purpose of this study DMR 5G was processed using map sheet SM Ledeč nad Sázavou 1-0, 2-1 and 2-2. Based on the triangular irregular network and using the function TOPO to RASTER in ArcGIS 10.1, a hydrologically correct digital elevation model was created in which were subsequently detected relics of former dams and compared with the results of the field survey (Figure 4). Pond dams were in a few cases levelled or only partially preserved. In this case, the dam was reconstructed on the basis of rectified Stable Cadastre maps and also using military aerial photographs from 1938, when some of the dams were still preserved.

Subsequently, in simulation using the FILL algorithm of ArcGIS 10.1, the extinct ponds were "filled" with water up to the level of 90 cm below the dam crest. Contemporary fishpond literature (Dubravius 1953) recommended this height to be about two cubits, i.e. around 118 cm. The simulated scenario marks the maximum possible extent of submerged area of land. An example of such "filling" is shown in Figure 5 on the background of a current orthophotomap.

Statistics

The resulting values of the area of extinct ponds, obtained by different reconstruction methods, were statistically analyzed. Main focus was on the relative difference between results of each reconstruction method, with standard deviation (s) and variance (s^2). Furthermore, analysis of variance was performed using one-way ANOVA method in MS Excel. Statistical significance of differences between variances was found using that method. Partial calculations are shown in Figure 6 and Table 1.

The resulting critical region F was compared with the tabulated value F_{crit} at a confidence level of 95% with the appropriate degrees of freedom (alpha).

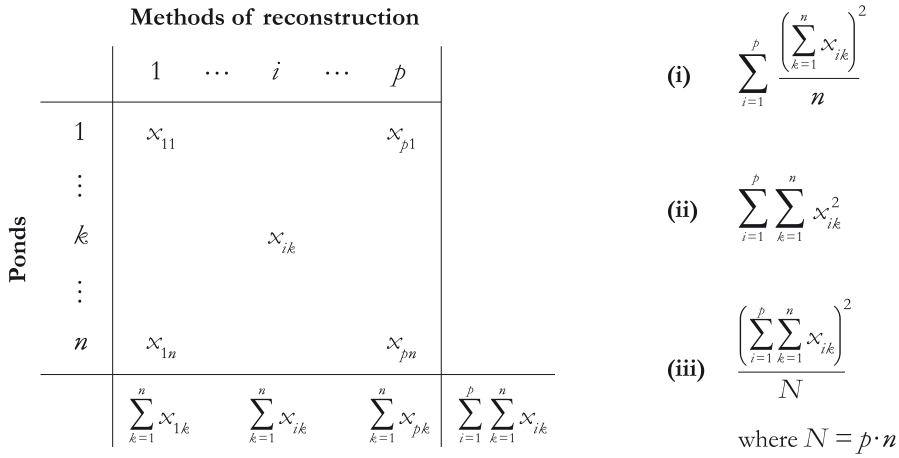

Figure 6 Matrix and polynoms for ANOVA statistics. Source: Dohnal L. (2008), modified by authors.

Table 1 ANOVA calculations. Source: Dohnal L. (2008).

Variability source	Sum of squares (SS)	Degrees of freedom (df)	Mean square (MS)	F-test
Between groups	S_1 = (i) − (iii)	$p - 1$	$M_1 = S_1 / (p - 1)$	M_1 / M_0
Within groups	S_0 = (ii) − (i)	$N - p$	$M_0 = S_0 / (N - p)$	
Total	$S_1 + S_0$ = (ii) − (iii)	$N - 1$		

RESULTS AND DISCUSSION

Reconstruction of extinct ponds by individual discussed methods shows a relatively high variability of results (Table 2). The smallest mutual deviations are within values of the Josephinian and Stable Cadastres (areas differ by 7%) and standard deviation also shows the lowest value (0.21) in this case. The largest differences are between the Josephinian Cadastre and the 1st Military Survey (areas differ by 32%) with standard deviation of 0.8 and between the 1st Military Survey and the Stable Cadastre with a high value of standard deviation (1.0). Reconstruction by DMR 5G results in large deviations from the other methods. It can be caused by the fact that this method reconstructs the real water level which involves the lower part of the dam and banks. On the contrary, the Stable Cadastre shows only the plot on the bottom of the former pond while the dam is represented by a different plot. We found a few extreme values at the extinct pond Kociánek with an area five times larger in the 1st Military Survey than in the Josephinian Cadastre. It is probably caused by inaccurate mapping. Another extreme case is the area of extinct pond Prostřední as reconstructed by the DMR 5G due to the fact that only a negligible part of the dam remains, which means that the reconstruction may be inaccurate.

Results of one-way ANOVA are presented in Table 3. The value of the computed critical region ($F = 0.42$) is smaller than tabulated values ($F_{crit} = 2.82$; Hendl 2012), which confirms the null hypothesis that there is no significant statistical difference between the results of the presented reconstruction methods.

CONCLUSION

Ponds extinct at the turn of the 18th and 19th century can be reconstructed in several ways. First, there is vectorization from rectified maps of the 1st Military Survey. Due to their positional inaccuracy such reconstruction is questionable. Nevertheless, the 1st Militay Survey is a bearer of irreplaceable

Table 2 Results of extinct pond reconstruction. Source: authors' calculations.

Pond	Reconstructed area (ha)				Relative area differences					
					JC/			1MS/		SCrec/
	JC	1MS	SCrec	DMR	1MS	SCrec	DMR	SCrec	DMR	DMR
(1) Nový	1.90	2.49	1.38	2.26	0.76	1.38	0.84	1.81	1.10	0.61
(2) Malý Komárovský	0.50	0.43	0.53	1.05	1.18	0.95	0.48	0.81	0.41	0.51
(3) Velký Komárovský	1.99	1.34	2.18	3.96	1.49	0.91	0.50	0.61	0.34	0.55
(4) Horní Trubný	0.95	0.29	0.83	1.40	3.26	1.14	0.68	0.35	0.21	0.60
(5) Dolní Trubný	0.91	0.36	1.13	1.09	2.56	0.81	0.83	0.32	0.33	1.03
(6) Kociánek	0.36	1.78	0.43	0.57	0.20	0.83	0.62	4.16	3.12	0.75
(7) Prostřední	0.66	0.69	1.00	0.26	0.96	0.66	2.59	0.69	2.69	3.92
(8) Kamenný	0.72	0.79	1.28	1.24	0.90	0.56	0.58	0.62	0.64	1.03
(9) Brodecký	0.70	0.86	0.76	1.20	0.81	0.92	0.58	1.13	0.72	0.64
(10) Telecí	1.08	0.74	1.05	0.97	1.47	1.02	1.11	0.70	0.76	1.09
(11) Velký Vosenický	3.77	3.04	3.55	3.57	1.24	1.06	1.06	0.86	0.85	1.00
(12) Malý Vosenický	0.60	0.61	0.68	0.79	0.97	0.88	0.75	0.90	0.78	0.86
Average relative area difference					1.32	0.93	0.89	1.08	0.99	1.05
Variance (s^2)					0.63	0.04	0.30	1.00	0.80	0.79
Standard deviation (s)					0.80	0.21	0.55	1.00	0.89	0.89

Note: JC – Josephinian Cadastre, 1MS – 1st Military Survey, SCrec – Stable Cadastre (retrogressive reconstruction), DMR – Digital Terrain Model of the Czech Republic of the 5th Generation (DMR 5G)

Table 3 One-way ANOVA results. Source: authors' calculations, Hendl (2012).

Variability source	Sum of squares (SS)	Degrees of freedom (df)	Mean square (MS)	F	F_{crit} (Hendl 2012)
Between groups	1.20	3.00	0.40	0.42	2.82
Within groups	41.55	44.00	0.94		
Total	42.76	47.00			

information about the very existence of ponds in a certain area. As a useful supplement it is possible to use data of the Josephinian Cadastre. For the reconstruction we can also use the retrogressive method in which the pond is reconstructed by using newer mapping sources such as the Stable Cadastre. However, there may also be inaccuracy due to the potential change in the land borders of the former ponds. New options for reconstruction of the historic landscape, especially ponds, offers the Digital Terrain Model of the Czech Republic of the 5th Generation in combination with other sources. It enables both to detect accurately relics of the former dams in otherwise inaccessible terrain, to determine their height with a declared precision of up to 18 cm (according to type of vegetation cover) and to reconstruct the shoreline or volume changes at different height levels. It is obvious that the reconstruction is dependent on changes in the height of the dam and of the pond basin itself due to erosion. With this confounding factor we must also count in case of the majority of extinct ponds

within the presented case study. The dams and bottoms of pond basins are covered with grassland vegetation or shrubs, but the surroundings of the former ponds are farmed intensively; that is why accumulation of material in the former pond basin by runoff of topsoil from the surrounding fields must be considered even at moderate slopes. The largest layer of sediments in the basin comes undoubtedly from the time when the pond existed, which itself formed a barrier to sediment transport. Another possible research topic in the field of reconstruction of extinct ponds and using DMR 5G is the determination of the extent of potential clogging of the bottom and its relation to the change of the former pond basin.

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Résumé

Rekonstrukce zaniklých rybníků pomocí starých map, historických katastrů a digitálního modelu reliéfu České republiky 5. generace

Příspěvek se zabývá možnostmi rekonstrukce zaniklých rybníků pomocí různých metod a zdrojů, které jsou vzájemně srovnávány. Důraz je kladen především na rybníky, které zanikly ještě před vytvořením přesnějších mapových děl, které by je dokumentovaly v reálných hranicích a rozlohách. Pro rekonstrukci takových rybníků (především jejich rozlohy a prostorové lokalizace) lze využít:

(a) map *1. vojenského mapování* z let 1764–1768 v měřítku 1 : 28 800, které jsou však díky způsobu, jakým byly zhotoveny, zatíženy velkou mírou nepřesnosti, která dosahuje až stovek metrů;
(b) mapového operátu *stabilního katastru* z roku 1838, pomocí tzv. retrogresivní metody za předpokladu, že po zaniklém rybníce vznikly nové pozemky – např. louka na dně bývalého rybníka a pastvina na hrázi;
(c) *josefského katastru* z roku 1787, který neobsahuje prostorovou informaci o rybnících v podobě map, ale ve svém písemném operátu má uvedeny rozlohy rybníků v jitrech a sázích; tyto údaje je však velmi pracné vyhledat, neboť rybníky jsou ve fasovních knihách josefského katastru zařazeny v přehledech mezi louky a je tedy nutné procházet jednotlivé pozemky a parcely v obcích;
(d) *digitálního modelu České republiky 5. generace* (DMR 5G) s vysokým rozlišením, na němž lze spolehlivě identifikovat relikty hrází a v prostředí GIS je rekonstruovat (například za pomoci starých map či historických leteckých snímků) a rybníky poté znovu „naplnit" (s akceptací potenciálních nepřesností vycházejících z faktu, že DMR 5G reflektuje současný terén a nikoliv historický).

Jednotlivé metody rekonstrukcí (ve smyslu určení rozlohy bývalých rybníků) byly testovány na dvanácti zaniklých rybnících v horní části povodí Klejnárky. Dílčí rekonstrukce vykazovaly poměrně velké odchylky. Problematické se ukázalo 1. vojenské mapování, které v několika případech vykázalo extrémní hodnoty rozlohy rybníků vůči ostatním metodám. Omezené možnosti DMR 5G se projevily u rybníků, jejichž hráze se zachovaly v minimálním rozsahu. Statistickým porovnáním bylo zjištěno, že nejmenší vzájemné odchylky vykazují josefský katastr a stabilní katastr, což naznačuje další možnosti jejich společného využití ve výzkumu historické krajiny. Jednoúrovňový ANOVA test však celkově potvrdil nulovou hypotézu, tj. mezi výměrami rekonstruovaných rybníků nejsou významné statistické rozdíly.

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