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BATHYMETRIC CHART OF LAKE DERANE AS THE BASIS FOR DEFINING THE HYDRO-ECOLOGICAL OPTIMUM OF THE DERANSKO WETLANDS

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ABSTRACT

Lake Derane is the largest water body in the area of the Deransko wetlands. Since the hydrological regime of the entire wetland area mostly depends on the water level oscillation of Lake Derane, it was necessary to determine the capacity of the latter before setting it as the basis for defining the hydro-ecological optimum for the period of most intensive biological activities. The preparation of a bathymetric chart of Lake Derane and the related free water surfaces involved bathymetric measurements of the lake basin using a predefined point route. The geographical coordinates for each of the bathymetric points were determined in advance, while the depth values were obtained by terrain bathymetric measurements. As these were taken during the hydro-ecological optimum, the results also represent the corresponding hydrological regime. The bathymetric chart of Lake Derane was obtained through the method of interpolation.

Key words: Derane lake, Derane wetlands, water level oscillation, bathymetric measurements, interpolation.

BATIMETRIA DEL LAGO DERANSKO QUALE BASE PER LA DETERMINAZIONE DELL'OPTIMUM IDRO-ECOLOGICO DELLA ZONA UMIDA DERANSKO

SINTESI

Il lago Deransko è il più grande specchio d'acqua nella zona umida Deransko. Poiché il regime idrico dell'intera area dipende dalle fluttuazioni del corpo idrico, è stato necessario determinarne la capacità volumetrica, quale base per la determinazione dei punti ottimali idro-ecologici nel periodo della massima attività biologica. La preparazione della batimetria del lago e delle superfici associate d'acqua libera è stata condotta con misurazioni batimetriche del lago lungo un percorso predeterminato. Le coordinate geografiche per ogni punto batimetrico sono state definite in precedenza, mentre le misurazioni batimetriche sono state eseguite sul campo nel maggio del 2014, durante l'optimum idro-ecologico. In tal modo i risultati rispecchiano l'attuale regime idrologico. La batimetria del lago Deransko è stata *condotta con il metodo d'interpolazione.*

Parole chiave: lago Deransko, zona umida Deransko, fluttuazioni nel livello d'acqua, misurazioni batimetriche, interpolazione.

INTRODUCTION

The Deransko wetlands are part of Hutovo Blato, a larger morphological depression created under the influence of primary tangential neotectonic movements. The land underwent a process of lowering, as karst processes caused further erosion and, as a result, the formation of a large number of sinkholes at the bottom of the depression. At the end of the last glacial period, the Neretva River poured into this morphological depression and under the influence of subtropical climate the area developed into subtropical marshes consisting of two entities: Svitavsko Blato and Deransko Blato. The recent construction of the hydropower plant Čapljina interfered significantly with the natural hydrological regime: Svitavsko Blato was transformed into a storage pool, and Deransko Blato was seriously affected, too, due to the lack of water, through it has preserved its wetland characteristics and remains to date a natural system. For this reason, it is necessary to define the eco-hydrological acceptable flow rates that would ensure the preservation and an optimal development of biodiversity in the area, especially among the birds.

To determine what an ecologically acceptable water flow for the Deransko wetlands would be, it is necessary to consider the volume of the water mass in the Lake Derane basin, as this is the largest lake in the wetlands and, as a result, its hydrological regime directly affects the hydro-ecological relations in the entire area. Understanding all the elements of the lake's hydrological regime, particularly its hydro-bathymetrical relations, is therefore of crucial importance for a more precise definition of ecologically acceptable water flows in the Deransko wetlands. The leverage factors are particularly significant during the May–July period, at the time of the most important ecological-biological cycles between the (hydrophilic) vegetation, the ichthyofauna and the avifauna inhabiting the marshes. Significant disturbances in natural inflows of water have been recorded during such periods in the past decades, resulting from intensive hydro-technical works in the wider area of the Hutovo Blato marsh. The primary negative effects of such actions involved, above all, the collection of natural underground and surface watercourses into artificial canals and basins, and manifested as:

- a decrease in minimal water flows during the season of hydrological minimums (May–September),
- more prominent high flows during the season of hydrological maximums (November–March),
- greater water level oscillation in the regimes of the entire Hutovo Blato hydrological system.

The complexity of the water level variations in the wider zone of the Deransko wetlands is manifested by the average Kolmogorov Complexity Index (as the measurement that can indicate the variability and irregularity of some natural processes in a given time series) of the lower course of the Neretva River, which is 0.506 (for the 1981-2010 period) (Hydrological Station Žitomislići) (Mihailović *et al.*, 2015). This value indicates there is a significant number of factors impacting the natural hydrological regime in various ways.

Another significant factor with a negative impact on the natural hydrological regime is the climate changes, resulting in an increased occurrence and duration of dry periods in the prominent vegetation season. Additionally, the broader investigated area of Lake Derane falls under the climate subtype Cfax"s – characterised by a moderate warm and moist climate, with hot summers and without the dry season (Drešković & Mirić, 2014). The air temperature in the Mediterranean climate zone reaches 12.1 °C, while in the broader investigated area it increases to 13 °C during the vegetation period (Drešković & Mirić, 2016).

Further to the above stated facts concerning the hydro-ecological optimum, one of the most important hydro-ecological parameters to determine would be the capacity of Lake Derane, since it holds the largest amount of the water mass of the entire area of the Deransko wetlands. This way it would be possible to define the ecologically optimal water flows for certain water-levels measured at the Boljun-Kuk and Karaotok hydrological stations (HS) during the period of intensive biological activities.

Defining the bathymetrical relations in the area of the Deransko wetlands is also problematic because of the marsh vegetation, woody as well as herbaceous, which covers most of the area (over 80%) and entails a more intensive deposition of sediments. Consequently, the larger part of the Deransko wetland basin is only a few tens of centimetres deep. One of the negative effects of the overgrown marsh vegetation is the decrease of the water mass storage capacity of the Deransko wetland basin and the consequent continuous decrease of its own natural hydro-regulation capacity. Adding to this the disturbances to the natural hydrological regime of water supply, it can be concluded that the existing trend indicates the third, final phase of the hydrological development of wetland, which could lead to the disappearance of this marsh hydro system.

In accordance with the research goal, this paper presents concrete bathymetric relations of the free water bodies, supplemented by the estimated values of certain (previously defined) marsh types of land cover with the aim to estimate the capacity of the entire Deransko wetlands.

MATERIALS AND METHODS

The bathymetric relations of Lake Derane have been determined through direct field measurements, performed at the beginning of May 2014, during the season of the hydro-ecological optimum. In this way, it was possible to form spatial conceptions of the hydrological characteristics of the Deransko wetlands based on different points of view, including:

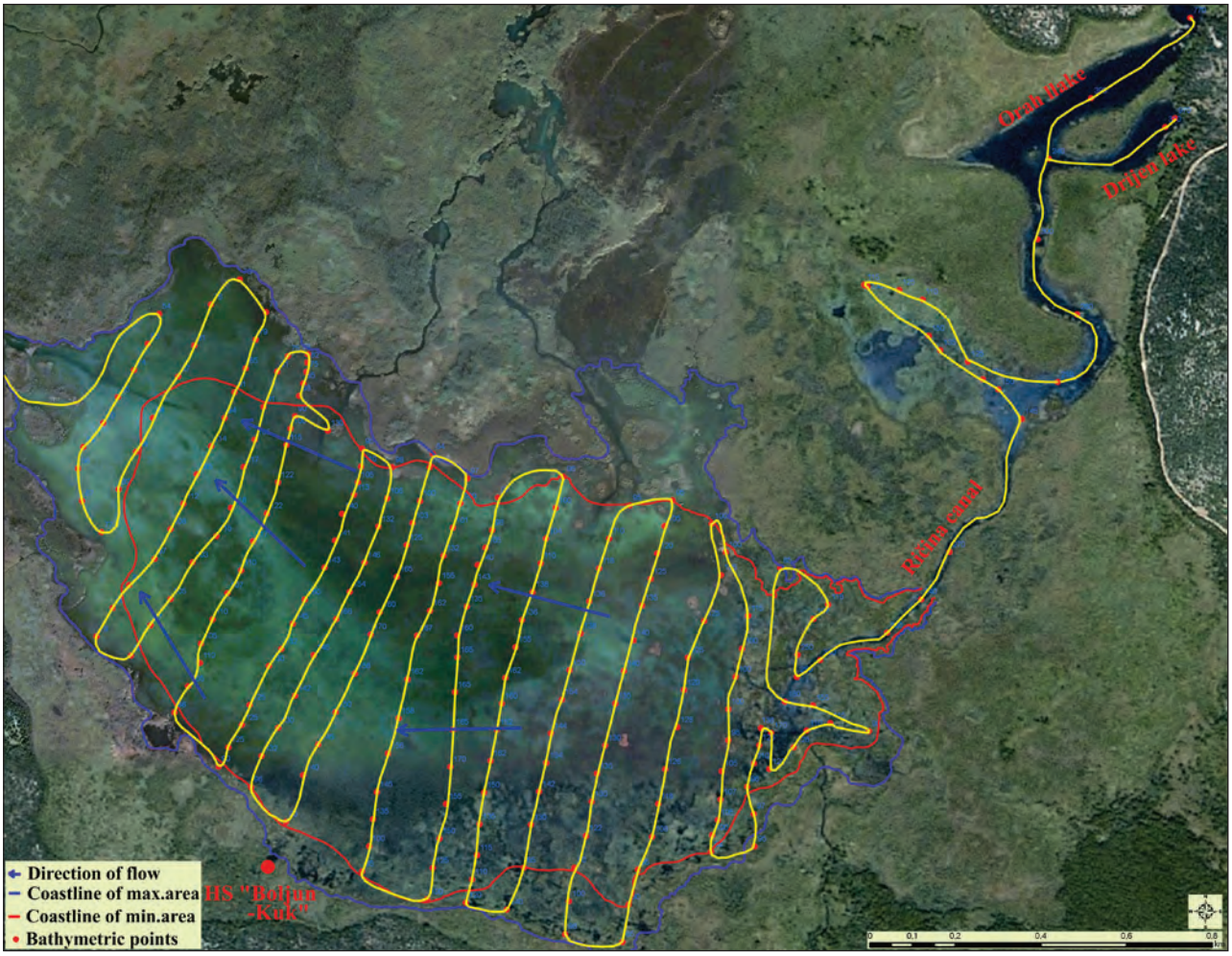

Fig. 1: Spatial position of bathymetric points with the movement route (Map background: Google Earth Imagery, Google, 2015).
Sl. 1: Zemljevid z batimetričnimi točkami in vzorčevalno potjo (Ozadje zemljevida: Google Earth Imagery, Google, 2015).

- the relative depth of Lake Derane and other directly related free water bodies,
- the water level of the flooded marsh vegetation during the season of the hydro-ecological optimum,
- the extent of flooded fields during the mentioned season.

The bathymetric measurements were performed using a digital echo sounder (Garmin fishfinder 250) and following a predefined route of bathymetrical points. The spatial position with geographical (φ, λ) and planar (x, y) coordinates had been previously determined for each of the points. Since the lakebed was significantly silted up, the investigation often combined echo sounder measurements with measurements employing a measuring rod in order to check the accuracy of the results. The average range between them decreased from 50 to 70 m (Fig. 1).

For the definition of the lake's banks and other elements on the bathymetric chart, additional sources were used: georeferenced Google Earth images of the area and orthophotographs of the Deransko wetland area, taken in two different seasons, spring and summer, at the scale of 1 : 5,000.

The bathymetric measurements were extended to free water bodies directly connected to Lake Derane: Ričina, Orah, and Drijen, as well as other neighbouring water bodies.

To find out the volume potentials of the water mass, a bathymetric chart with 10 cm contour intervals was prepared for Lake Derane (Hrelja, 2007).

The results of terrain measurements were then translated into the GIS data format, which above all implied the transformation of the position data from a geographical (WGS84) coordinate system into the national MGI-6 coordinate system. Each bathymetric point was assigned

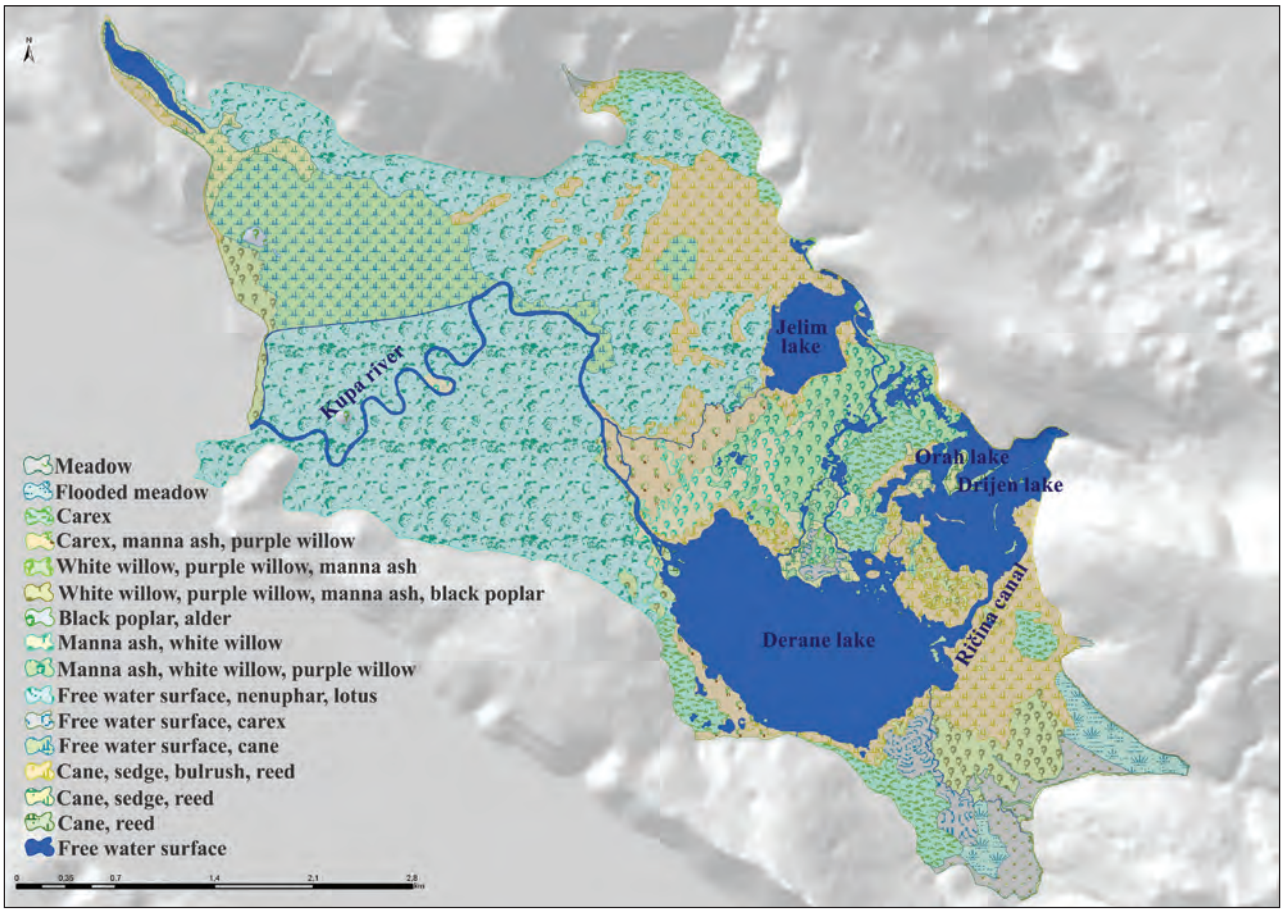

Fig. 2: Deransko wetlands land cover.
Sl. 2: Deransko mokrišče z vidika pokrovnosti.

the following characteristics: ordinal number, x, y, (position coordinates), h (relative depth).

Once the results had been processed, it was possible to apply the method of interpolation to the measured depths and prepare a bathymetric chart of Lake Derane and the neighbouring free water bodies. When analysed, the results obtained through measurement were combined with high resolution Google Earth images and orthophotographs thus providing the basis for determining the position of the banks of all continuous free water bodies.

However, since a comprehensive evaluation of water bodies and a clear image of the existing spatial relations in the lakeside environment would have to take into account the land cover types of the entire area of the Deransko wetlands, we first analysed those (Fig. 2).

The types of land cover were classified on the basis of the results of field work and an analysis of the orthophotographs. Sixteen different categories were determined, one denoting the free water bodies, and the remaining fifteen representing the dominant vegetation species and communities. The vegetation cover of the wider area of the Deransko wetlands was deduced from the plant communities featured in the hilly areas, in the flooded plains, in the marshes, and in the water areas.

In order to precisely determine the bathymetric chart of Lake Derane and the neighbouring free water bodies, depth measurements were made in 235 points, most of which (205) in the largest and most important water body of the Deransko wetlands in terms of capacity – Lake Derane.

RESULTS AND DISCUSSION

The GIS data analysis is summarised in Table 1. The most recent surface area of the natural, aquatic complex of the Deransko wetlands has been determined at around 1,933.4 ha. This value is the result of planimetric measurements of the surface based on a mean water level of 30 cm in the lakeshore zone during spring season.

The area of the foothills surrounding the depression is covered by thermophilic downy oak-oriental hornbeam woods (*Querco-Carpinetum orientalis*) featuring downy oak (*Quercus pubescens*), oriental hornbeam

Tab. 1: Land cover of the Deransko wetlands by categories.
Tab. 1: Pokrovnost Deranskega mokrišča z različnimi kategorijami.

No.	Category	P (ha)
1	Free water surface	349.60
2	Cane, reed	6.86
3	Cane, sedge, bulrush, reed	249.45
4	White willow, purple willow, manna ash, black poplar	80.63
5	Manna ash, white willow, purple willow	82.74
6	White willow, purple willow, manna ash	3.98
7	Manna ash, white willow	39.22
8	Free water surface, carex	25.27
9	Meadow	36.20
10	Flooded meadow	30.31
11	Free water surface, nenuphar, lotus	670.65
12	Cane, sedge, reed	33.93
13	*Carex*	95.01
14	Free water surface, cane	178.12
15	*Carex*, manna ash, purple willow	48.25
16	Black poplar, alder	3.13

(*Carpinus orientalis*), manna ash, pomegranate, European nettle tree etc. The vegetation of the flooded plains is comprised of white willow (*Salix alba*), purple willow, swamp ash, black poplar (*Populus nigra*), alder, fig tree, poplar tree etc. In the marshes of the Deransko wetland, the prevailing species are cane, sedge, bulrush and reed. The water areas are predominantly covered by the green leaves of nenuphar and lotus.

With regard to the mentioned indicators, it can be stated that the majority of the cover is represented by surfaces displaying a combined type of land cover, primarily water surfaces covered by communities of nenuphar, lotus and cane (around 34.7%), followed by surfaces covered with cane, sedge, bulrush, reed (around 13%) (Fig. 3). It is particularly important to emphasise that free water bodies make for a significant part of the land cover (around 350 ha or 18.1%), which is important in terms of survival of the entire natural-aquatic complex of Lake Derane.

The least represented land cover is that of flooded meadows, which extend over some 67 ha. Nevertheless, they are of great importance to the survival of the entire plant and animal life of the Deransko wetlands. In fact, further degradation and draining, as well as surface decrease of this land cover type in the Deransko wetlands is unacceptable, as it would additionally compromise and endanger the existing ecosystem.

One particular aspect in the interpretation of the mentioned land cover types is their water mass volume potential, especially in spring and summer, when water is of vital importance for eco-biological processes.

Tab. 2: Basic bathymetric indicators for Lake Derane.
Tab. 2: Temeljni batimetrični indikatorji za Deransko jezero.

D (cm)	O (m)	P (m²)	P (%)	D (cm)	O (m)	P (m²)	P (%)
up to 50	18224.98	199777.04	9.81	170-180	3836.41	6343.70	0.31
50-60	17651.47	119042.41	5.85	180-190	3326.24	4247.58	0.21
60-70	16866.30	154622.07	7.60	190-200	3123.72	4545.35	0.22
70-80	15647.65	151291.49	7.43	200-210	3097.56	4611.96	0.23
80-90	16430.55	166879.87	8.20	210-220	3080.00	3980.75	0.20
90-100	14843.44	229154.42	11.26	220-230	2953.49	4828.77	0.24
100-110	13049.04	185997.00	9.14	230-240	2365.12	5144.76	0.25
110-120	10966.49	189005.54	9.28	240-250	1638.59	2270.44	0.11
120-130	9505.70	174254.90	8.56	250-260	1314.40	1143.41	0.06
130-140	8370.86	171570.56	8.43	260-270	1010.55	913.04	0.04
140-150	7481.83	124730.53	6.13	270-280	766.97	353.50	0.02
150-160	6225.21	106644.49	5.24	280-290	751.50	376.35	0.02
160-170	4776.58	23495.33	1.15	290-300	371.21	411.64	0.02
					Total:	**39171.25**	**100.00**

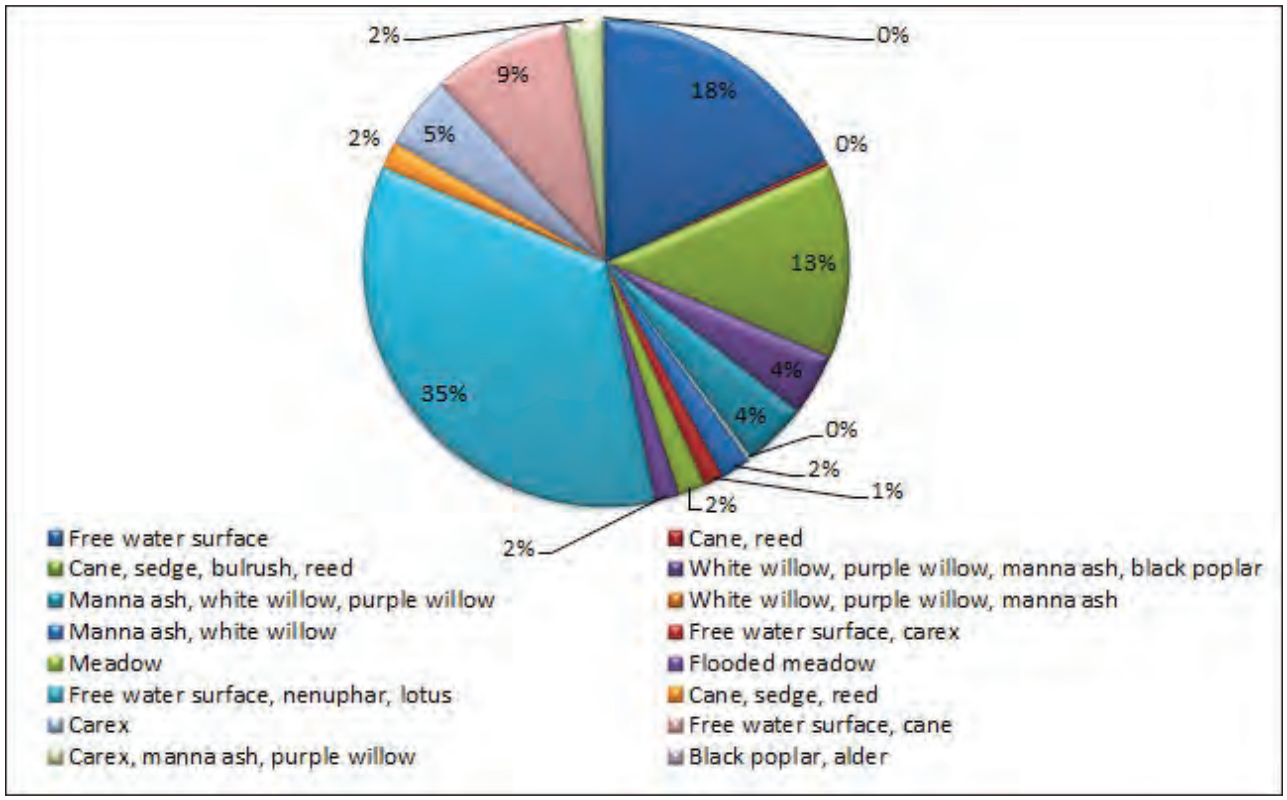

Fig. 3: Land cover of the Deransko wetlands by defined categories.
Sl. 3: Pokrovnost Deranskega mokrišča na podlagi določenih kategorij.

Bathymetric Plan of Derane Lake

The measurement have shown that with respect to the neighbouring marsh vegetation, the Lake Derane basin ends at the 50 cm isobath, with the average depth values in other flooded zones of the Deransko wetlands covered by different types of marsh vegetation varying between 50 and 0 cm (Fig. 4). The surface area of Lake Derane within the mentioned border isobath is 203.56 ha. Other basic bathymetric data concerning Lake Derane (depth of isobath (D), length of bathymetric line (O) and isobath percentage share in the total lake area) are given in Table 2.

It can be concluded from these data that the representation of isobath surfaces is significantly uneven, particularly in the eastern part of the lake, in the area around the Ričina River delta (Fig. 4). The lowest depths are registered in the zone of the lake isle (Krupa River) where, due to the low transportation power of the bottom and lateral lake currents, the most part of the pulled and suspended detritus is being deposited. A few smaller sandbanks (of several tens of m^2) have already formed here, inhabited by typical marsh vegetation – cane and reed, and in some places purple willow.

Similarly, a dozen of smaller sandbanks have formed across the northern borderline of the lake water body, also overgrown with cane and reed. From the mentioned zone towards the central part of the lake basin, the depth values gradually increase, reaching their maximum in the centre. The zones of greater depths (170 to 180 cm) are quite extensive, accounting for around 30% of the total lake basin area. The deepest areas are found in several smaller depressions and across the central part of the lake bed (in karst sinkholes). Further to the north, east, and south of the lake basin, towards the marsh vegetation margin the depth values gradually decrease to around 60 to 70 cm. The easternmost parts of the lake basin, at the crossover towards the Ričina River, are delimited by a 100 cm isobath running along a 50 m wide sand bank. Further away, closer to the area of the Ričina River delta, the depths suddenly increase to 300 cm, reaching the maximum value in the entire Lake Derane basin, as a result of increased erosion in the area of the mouth of the Ričine channel.

According to the depth relations defining the bathymetric chart of Lake Derane, it is possible to determine the water mass capacity of the lake's basin (Tab. 3). In the period of bathymetric measurements, the entire area of the Deransko wetlands registered an increased water inflow which was, in respect of the extent of flooded meadows and vegetation, still within the framework of optimal hydro-ecological conditions; the mean water level, measured at the Boljun-Kuk gauging station (May

Fig. 4: Bathymetric chart of Lake Derane (Map background: Google Earth Imagery, Google 2010).
Sl. 4: Batimetrija Deranskega jezera (ozadje zemljevida: Google Earth Imagery, Google 2010).

2, 2014), was 105 cm and in the range of the seasonal mean water level for Lake Derane.

According to the data calculated, the total capacity of Lake Derane, delimited by a 50 cm isobath at the mentioned water level, is 1,244,595 m^3 or approximately 0.0125 km^3. Isobaths with the greatest surfaces and largest capacity are areas of up to 100 cm of depth. More precisely, the largest amount of water is contained within the first isobath layer at 10 cm of depth (delimited by isobaths of a relative depth between 50 and 60 cm), which holds around 0.002 km^3 of water, followed by the second isobath layer (delimited by isobaths of a relative depth between 40 and 50 cm) with 0.0018 km^3 of water, and so on. Based on this, it can be concluded that the capacities of the lake basin are the lowest at the latter's greatest depths: the 25th isobath layer only holds around 15 m^3, the 24th around 60 m^3, and so on.

It can also be concluded that the zone of the Ričina River delta is also an area of increased capacity, where the values of the entire wet profile reach around 0.0015 km^3.

In addition to the mentioned bathymetric indicators, it is possible to determine other important bathymetric data for a lake water body, which enable a more detailed insight into its hydrological characteristics. Additional results of numerical analyses thus concern the following morphometric characteristics:

- Lake surface area (**F**) 203.56 ha
- Lake length (**L**) 1.97 km
- Lake mean width (**B**) 1.03 km
- Lake maximum width (**Bmax**) 1.515 km
- Bank length (**l**) 18.3 km
- Bank indentedness (**K**) 1.7
- Lake mean depth (**H**) 0.6 m
- Average lakebed gradient (α) 9^o-10^o

CONCLUSIONS

Based on a detailed analysis of the presented bathymetric indicators it can be concluded that Lake Derane is a small basin with polygenic traits originating from

Tab. 3: Volume (V) relations in Lake Derane (in m³).
Tab. 3: Prostorninski odnosi v Deranskem jezeru (v m³).

D (cm)	P (m²)	V (m³)
up to 50	2035636.90	193574.838
50-60	1835859.87	177633.866
60-70	1716817.46	163950.642
70-80	1562195.39	148654.964
80-90	1410903.90	132746.397
90-100	1244024.03	112944.682
100-110	1014869.61	92187.111
110-120	828872.61	73436.984
120-130	639867.07	55273.962
130-140	465612.16	37982.688
140-150	294041.61	23167.634
150-160	169311.07	11598.883
160-170	62666.58	5091.892
170-180	39171.25	3599.940
180-190	32827.55	3070.376
190-200	28579.97	2630.730
200-210	24034.62	2172.864
210-220	19422.66	1743.228
220-230	15441.91	1302.752
230-240	10613.13	804.075
240-250	5468.37	433.315
250-260	3197.93	262.623
260-270	2054.53	159.800
270-280	1141.48	96.473
280-290	787.98	59.981
290-300	411.64	13.721
Total:		**1244594.422**

tectonic activity and karst corrosion. This conclusion is corroborated by the shape of the lake basin – a deep plate – which represents the latter's primary morphological characteristic. The central part of the Lake Derane basin has the greatest area capacity and holds the largest amount of water.

In order to define an environmentally sound discharge, field research was carried out in the area of the greatest depth of water accumulation – Lake Derane. GIS software was employed to draft a model bathymetric chart of 10 cm isobaths. The bathymetric chart of the lake was produced according to the average water level during spring season, when the water levels are optimal for the development of a vibrant life in the Deransko wetlands. The mean water level is related to the measured water level at the Boljun-Kuk water gauge strip, located in the southern lakeshore area. Additional modelling at the level of individual 10-centimetre isobaths enabled the calculation of the volumetric capacity of Lake Derane and the correlated adequate water levels.

By applying these results to the measured water levels at the Boljun-Kuk hydrological station it would be possible to determine the amount of water in Lake Derane required during the growing season to allow for an optimal development of wildlife in the Deransko marshes.

BATIMETRIJA DERANSKEGA JEZERA KOT TEMELJ ZA DOLOČANJE HIDRO-EKOLOŠKEGA OPTIMUMA DERANSKEGA MOKRIŠČA

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POVZETEK

Deransko jezero je največje vodno telo na območju Deranskega mokrišča. Ker je hidrološki režim celotnega območja Deranskega mokrišča odvisen od nihanj vodnega telesa, je bilo potrebno določiti prostorninsko kapaciteto kot temelj za določevanje hidro-ekoloških optimumov v obdobju najintenzivnejših bioloških aktivnosti. Priprava batimetrije Deranskega jezera in povezanih prostih vodnih površin je bila opravljena z batimeričnimi meritvami jezera na predhodno določeni točkovni poti. Geografske koordinate za posamezne batimetrične točke so bile določene predhodno, medtem ko so bile batimetrične meritve opravljene na terenu. Le-te so bile opravljene v maju 2014, v času hidro-ekološkega optimuma, zato dobljeni rezultati kažejo dejanski hidrološki režim. Batimetrija Deranskega jezera je bila narejena z metodo interpolacije.

Ključne besede: Deransko jezero, Deransko mokrišče, nihanja vodne gladine, batimetrične meritve, interpolacija.

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