Lakes and artificial water reservoirs –
natural processes and socio-economic importance
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NATURAL PROPERTIES OF KARST LAKES IN BELARUS

Abstract: Karst lakes of Belarus belong to the azonal type and are distributed in Polesje region in the area of superficial deposition of chalk rocks. Specific features of these type lakes include: small water surface, funneled form of a hollow, low water exchange rate and increased level of water mineralization; the lakes refer to mesotrophic or eutrophic types.

Key words: karst lakes, origin, hollow, hydrology, hydrochemistry, hydrobiology, bottom sediments.

The lakes of Belarus are confined to three geomorphologic regions: Belarusian Poozerje (Lake region) in the North; Belarusian Polesje, in the South; and Belarusian Ridge together with adjoining plainlands, in the central part. The geological structure and geomorphologic processes that took place on these territories have determined the character of distribution and the hollow genesis of the present day lakes. Lakes of glacial and residual origin comprising about 30% of the total are represented in Poozerje region and in the central part of Belarus in the basins of the river Zapadnaja (Western) Dvina, Vilija and Neman as well as along glaciation boundaries. In contrast, in the region of Polesje and in the central part of Belarus in floodlands and in the valleys of principal rivers of Dnieper and Pripiat' and their tributaries, flood plain lakes are predominant (more than 70% of the total), whose hollow genesis is linked to river-bed processes. Within Polesje region in the basins of Pripiat' and Dnieper and their tributaries so-called «lakes-floods» and lakes of the karst origin occur. The former (about 10%) were formed in flat lowlands as a consequence of the territory inundation occurring along with isostatic ground level sinking. Distribution of karst lakes is azonal and their number does not exceed 0.5% of the total number of lakes in the Republic of Belarus (Jakushko et al., 1992).

Karst lakes of Belarus are allocated to the lowland area of the Eastern European plain Polesje zone and form so-called «Polesje karst lake belt» that stretches from Poland up to the Middle Volga region and further eastward (Stupishin et al., 1980) (Fig. 1).

Their appearance in Polesje lowland is associated with the presence of the karst rocks of Cretaceous age covered with thin (less than 50 m thick) layer of quaternary sedimentary rocks (Fig. 2).

The most intensive karst processes at the Polesje lowland area took place in the late Oligocene. Favorable tectonic and climatic conditions promoted lixiviation of the carbonate chalk stratum that led to the appearance of paleokarst, to formation of craters, sometimes joined into chains, and hollows reaching significant depth (100 m and deeper) (Matveev, 2002). The most recent stage of karst formation and emergence of modern lakes hollows, in our opinion, were brought about by activation of upward movement of groundwater at the end of Pleistocene (AL). The age (C_{14}) of the peat at the base of karst lakes sediments is dated as Peschanoe – 11750; Bobrovichskoe – 11320±187 (GSB-884) (Zernitskaja, 2000).

Data analysis of the long-term complex studies allowed to classify 20 karst lakes according to their natural characteristics, i.e. morphometric and hydrological parameters, main watershed features, hydrophysical and hydrochemical properties of the water body, volume and composition of bottom sludge and sapropel, biological parameters.

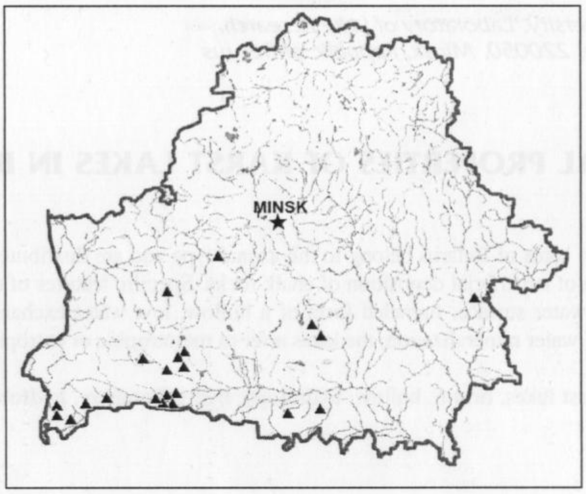

Fig. 1. Karst lakes distribution in Belarus.
Ryc. 1. Rozmieszczenie jezior krasowych na Białorusi.

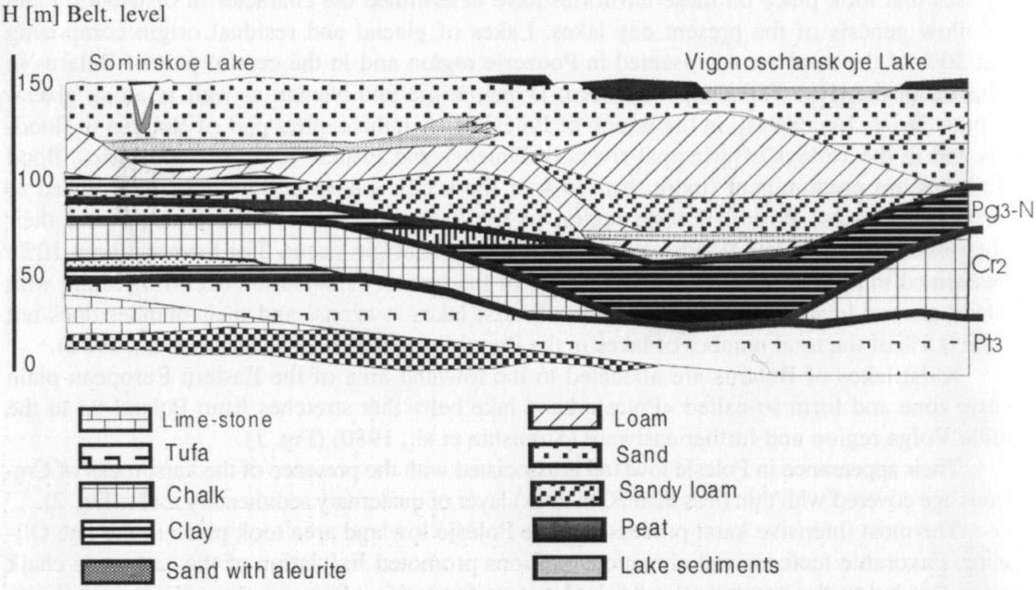

Fig. 2. Geological cut through the chain of lakes Sominskoe – Vygonoshchansoe.
Ryc. 2. Przekrój geologiczny przez zespół jezior Sominskoe – Vigonoschanskoje.

Karst lakes possess some distinctive limnologic features that are related to the history of their hollows. Depth of the hollow depression into the bedrock is 15–35 meters. The lakes are surrounded by flat area of the lowland type with absolute height of 120–150 m, low sandy hills and dunes comprised of sand and peat. Watersheds are covered with forests (average coverage – 44%) and wetlands (average – 13%).

The lakes' surface area ranges from 0.1 to 3.5 km^2, water capacity – from 0.14 to 12.19 mln. m^3 (Tab. 1). Lake hollows may have either of the two shapes: most common (70% of the surveyed lakes) is round-shaped or oval form with conic or parabolic in plan reservoir, sharp litoral and sublitoral zone and funnel-shaped profundal zone. Less often occurring type has lociniate or oval form in plan, flat litoral or sublitoral, and flat reservoir floor (2–4 m in depth) with one or several deep funnels. The maximal depth of the lakes ranges from 4.2 to 33.5 m, with prevailing average 3–6 m (Fig. 3).

Table 1. Morphometric characteristics of karst lakes.
Tabela 1. Charakterystyki morfometryczne jezior krasowych.

Lake	Area, km^2	Water volume, mln.m^3	Depth max., m	Depth mean., m	Length, km	Width max. km	Width mean, km	Index of depth	Index of open	Index of length	Index of capacity	Watershed area, km^2	Relative water-exchange	Specific water-exchange
Beloe – Brest	0.5	2.6	21.5	5.12	1.05	0.62	0.48	6.44	0.1	2.19	0.24	140	0	5.94
Beloe – Luninetc	0.23	1.75	17	7.6	0.60	0.40	0.36	12.34	0.03	1.81	0.45	0.31	0.02	44.80
Beloe – Ivan	0.17	0.51	5	3	1.78	0.7	0.3	5.4	0.05	2.91	0.6	0.63	0.15	6.58
Beloe – Drogich	5.69	45.02	13.2	7.9	3.46	2.63	1.64	4.42	0.72	2.11	0.60	–	–	–
Vulkovskoye	0.49	3.12	23.8	6.3	1.03	0.68	0.37	7.99	0.07	2.78	0.26	145.91	6.34	0.16
Gorodische	0.74	2.93	8.1	4	1.48	1.09	0.5	4.42	0.18	2.96	0.49	1.54	0.35	2.85
Dvorischanskoye	0.23	0.43	4.2	1.87	0.62	0.54	0.37	3.06	0.12	1.67	0.44	8.76	2.26	0.44
Zavischovskoye	1.32	7.05	10.7	5.3	1.61	1.02	0.82	4.83	0.24	1.96	0.49	33.76	0.6	1.65
Konchitskoye	0.53	1.79	8.3	3.4	1.19	0.69	0.44	4.2	0.15	2.7	0.41	146.9	10.35	0.1
Kroman	0.92	12.19	26.5	13.2	1.4	1.12	0.65	15.4	0.06	2.1	0.5	124.1	1.55	0.64
Lukovskoye	3.5	11.4	12.4	3.25	2.6	2	1.35	2.17	1.08	1.93	0.26	111.9	0	1.08
Lyuban	1.96	10.83	11.5	5.5	2.19	1.44	0.89	4.39	0.35	2.46	0.48	78.8	0.76	1.32
Mulnoye	0.42	3.06	21	7.3	0.8	0.68	0.52	9.75	0.05	1.54	0.35	0.38	0.01	61.2
Okunino	0.23	1.15	10.9	5.2	0.96	0.31	0.23	8.62	0.04	4.17	0.48	3.28	0.35	2.85
Peschanoe	2.09	6.75	5.7	3.2	2.37	1.72	0.88	2.5	0.64	2.69	0.56	48.9	0.8	1.25
Rogoznyanskoye	0.4	1.05	5.8	2.62	0.97	0.72	0.41	3.56	0.15	2.36	0.45	13.33	1.4	0.71
Svityaz	1.76	6.1	15.1	3.5	1.65	1.42	1.06	2.89	0.50	1.55	0.23	2.77	0.55	–
Svyatoye	0.07	0.14	9.3	5.27	0.2	0.17	0.13	–	0.01	1.48	0.6	1.01	1.02	0.98
Selyahi	0.48	1.88	8.6	3.91	1.03	0.65	0.46	5	0.12	2.24	0.45	11.02	0.65	1.54
Semihovichskoye	0.32	1.21	7.4	3.8	0.81	0.54	0.4	5.59	0.08	2.02	0.51	4.68	0.48	2.1
Sominskoye	0.46	2.94	33.5	6.4	0.92	0.65	0.5	8.31	0.07	1.84	0.19	4.79	0.22	4.52
Stradechskoye	0.14	0.43	6.6	3.07	0.6	0.33	0.23	5.92	0.04	2.61	0.46	8.57	2.21	0.45

The watershed area of lakes comprises 0.3 to 140 km^2, therefore the extent of interaction between certain lakes and corresponding hydrographic net may vary from low (areic lakes) high (high endoreic lakes). The lakes can be divided into two groups. 1). *Accumulative* and *running-off* lakes lack surface water inflow and receive their water from direct atmospheric precipitation and groundwater inflow; water turnover time is 5 – 61 yr. 2). *Transit, or drainaige-tributary* lakes both receive and discharge surface waters and demonstrate high water exchange rate (turnover time 0.1 – 2 yr).

According to the chemical composition of the water karst lakes are referred to as hydrocarbonate class of calcium group. The ionic structure can be expressed as follows: $HCO^{3-} > Ca^{2+} > SO_4^{2-} > Cl^- > Mg^{2+} > Na^+ > K^+$.

General mineralization of the lake water ranges between 29 mg/l and 420 mg/l. Low level of mineralization (below 100 mg/l) have running-off lakes that have no surface water inflow; 75% of the drainaige-tributary lakes have increased level of mineralization (200.0 – 270.0 mg/l) due to the ground water inflow; high mineralization (more than 300 mg/l) is characteristic of the high-flow lakes subjected to strong anthropogenic influence.

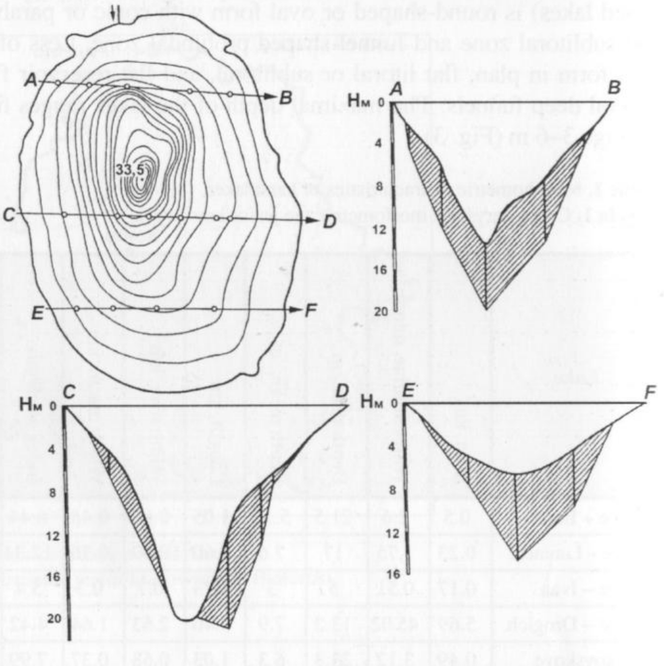

Fig. 3. Scheme of depths and cuts of bottom sediments of Sominskoe Lake.
Ryc. 3. Plan batymetryczny i przekroje osadów dennych jeziora Sominskoe.

Vertical distribution of ions across water body expresses clear stratification pattern with concentration gradient increasing from surface to bottom. Concentration of HCO_3^- ions fluctuates within limits 24–292 mg/l and in general it follows general mineralization pattern of the water. Percentage of Ca^{2+} ion in salt solution is 19–44% (31–85 mg/l), Mg^{2+} – 3–4.5% (0.4–12.4 mg/l), Cl^- – 3–11% (1.4–15.2 mg/l). About half of the lakes are characterized by an average value of ions' content. Percentage of SO_4^{2-} ion is 4–14% (2.1–19.2 mg/l, average – 9.2 mg/l) and its concentration is significantly higher in the running-off lakes with low mineralization level. Concentration of biogenic elements in the lake lake water varies widely, from low – in running-off lakes, to high – in the lakes with high level of anthropogenic eutrophication. The silicon content ranges from 0.07 mg/l up to 4.4 mg/l; ammonium nitrogen – 0.01–2.3 mg N/l; and PO_4^{3-} content in the summer varies from zero to 0.5 mgP/l.

Most important physical parameters that determine water quality in karst lakes are following: temperature, pH, transparency, and concentration of dissolved gases. The distinctive feature of the karst lake waters is the presence of a pronounced vertical temperature and gas stratification during summer and winter stagnation. The summer temperature of the water varies from 4–14 °C in benthic layers up to 18–28.8 °C – near the surface; oxygen saturation level varies from complete absence (in benthic layers) to over-saturation in the upper layers that takes place during algal blooms occurring in the highly eutrophic lakes. The pH value of the lake water ranges between 5.3

and 8.8. In 57% of surveyed lakes the pH value in the summer was in the range of 7.0–8.0. The water transparency value during summer is 0.7–4.5 m, with prevailing value being 1.5–2.5 m (64% of lakes). The parameter of chromaticity of waters fits in the range from 20° up to 150° on the scale Pl – Co° with half of the surveyed lakes showing chromaticity below 50^0. The content of organic compounds in water quantified using permanganate- and dichromate oxidizability tests comprised 3.6–15.7 mgO/l and 10.0–114.0 mgO/l, respectively (Tab. 2).

Table 2. Hydrochemical indices of karst lakes.
Tabela 2. Wskaźniki hydrochemiczne wód jezior krasowych.

Lake	Depth of water, m	pH	Transparence, m	Color, Cr-Co degree.	HCO_3	Ca^{2+}	SO_4^{2}	Cl^-	Mg^{2+}	Fe_{sum}	PO_4^{3-}	NH_4	Σ of ions
					mg/dm³								
Beloe – Brest	0.5 / 21.0	7.78 / 7.2	1.5	90 / 80	164.7 / 134.2	49.9 / 42.2	2.06 / 7.4	2.88 / 1.44	6.81 / 6.2	0.091 / 0.048	0.001 / 0.002	0.019 / 0.012	226.1 / 192
Beloe – Luninetc	0.5 / 17.0	6.5 / 6.5	3.8	15 / 15	18.3 / 24.4	6.01 / 4.21	0.7 / 1.6	6.38 / 7.02	0 / 1.09	-- / --	-- / --	0.09 / 0.00	35.9 / 42.4
Beloe – Ivan	0.5 / 4.0	5.42 / 5.42	2.0	20 / 20	12.2 / 15.2	5.67 / 5.67	8.8 / 9.03	4.73 / 5.07	0.49 / 0.49	0 / 0.5	0 / 0.012	0.43 / 0.365	31.9 / 35.5
Beloe – Drogich	0.5 / 11.0	6.06 / 5.82	2.0	70 / 75	219.6 / 219.6	78.8 / 78.8	17.5 / 18.8	14.9 / 15.6	3.89 / 3.40	0.11 / 2.60	0.01 / 0.124	0.43 / 0.75	334.7 / 336.0
Vulkovskoye	0.5 / 12.0	8.46 / 7.63	0.7	50 / 60	262.3 / 298.9	80.2 / 85.0	9.4 / 6.7	6.0 / 6.6	5.8 / 6.8	0.04 / 2.2	0.003 / 0.031	0.17 / 0.73	375.2 / 418.5
Gorodische	0.5 / 6.0	5.95 / 5.75	1.7	80 / 80	170.8 / 179.9	55.9 / 56.9	14.5 / 14.7	13.5 / 13.6	5.0 / 4.9	0.20 / 0.24	0.011 / 0.017	0.57 / 0.54	259.7 / 270.1
Zavischovskoye	0.5 / 9.0	8.7 / 7.5	2.6	20 / 70	128.1 / 146.4	44.2 / 47.4	11.1 / 10.8	5.0 / 5.4	1.4 / 2.8	0.01 / 0.1	0.001 / 0.008	0.1 / 0.64	195.2 / 221.3
Konchitskoye	0.5 / 8.0	8.88 / 7.6	1.5	30 / 60	115.9 / 122	39.3 / 42.4	13.1 / 11.3	8.2 / 8.2	2.9 / 1.4	0.17 / 0.34	0.004 / 0.04	0.09 / 0.5	187.5 / 196
Kroman	0.5 / 25.0	8.06 / 7.29	2.0	70 / 80	189.1 / 213.5	57.1 / 59.5	-- / --	7.7 / 9.2	11.6 / 12.4	0.06 / 1.2	0 / 0	0.11 / 0.65	269.8 / 302..0
Lukovskoye	0.5 / 5.0	8.12 / 7.15	2.2	40 / 40	170.8 / 195.2	63.5 / 65.9	7.7 / 6.9	12.2 / 12.5	0.9 / 1.8	0.01 / 2.5	0.00 / 0.01	0.14 / 0.59	265.7 / 304.2
Lyuban	0.5 / 11.0	8.5 / 7.65	2.1	25 / 70	134.2 / 158.6	51.1 / 53.5	17.3 / 13.8	14.2 / 14.2	2.3 / 3.8	0.11 / 2.25	0.000 / 0.158	0.58 / 0.58	228.4 / 256.4
Mulnoye	0.5 / 19.0	8.44 / 7.3	2.0	25 / 25	103.1 / 128.1	31.2 / 35.3	6.53 / 6.1	6.9 / 7.3	3.0 / 4.0	0 / 0.16	0.004 / 0.029	0.03 / 0.14	160.1 / 191.2
Okunino	0.5 / 8.0	8.6 / 7.5	3.0	25 / 120	146.4 / 291.6	42.1 / 59.1	8.5 / 3.8	5.5 / 6.9	1.95 / 3.89	0.08 / 4.6	0.0 / 0.5	0.0 / 2.9	213.1 / 303.5
Peschanoe	0.5 / 5.0	8.6 / 8.0	0.7	50 / 60	183 / 189.1	69.9 / 70.7	19.2 / 15.4	10.4 / 10.7	2.4 / 2.9	0.05 / 0.86	0.008 / 0.033	0.14 / 0.00	294.1 / 297.9
Rogoznyanskoye	0.5 / 5.0	7.85 / 6.8	1.1	40 / 150	109.8 / 140.3	38.8 / 40.4	9.6 / 8.7	7.5 / 7.2	0.4 / 2.9	0.099 / 5.5	0 / 0.35	0.12 / 0.33	172.7 / 214.1
Svityaz	0.3 / 15.0	6.88 / 5.63	4.0	15 / 15	10.4 / 15.9	5.0 / 5.2	8.6 / 8.2	2.5 / 2.5	1.6 / 1.4	0.06 / 0.14	0.012 / 0.012	0.19 / 1.76	29.4 / 36
Svyatoye	0.5 / 8.5	6.1 / 6.8	–	-- / --	3.0 / 10.2	4.4 / 3.6	4.8 / 5.3	4.6 / 5.0	0 / 0.7	-- / --	0.006 / 0.013	0.60 / 2.47	18.2 / 30.9
Selyahi	0.5 / 6.5	8.0 / 7.09	1.8	40 / 120	91.5 / 110	34.8 / 34.4	8.5 / 7.3	8.9 / 8.9	0.4 / 4.3	0.01 / 2.22	0 / 0.361	0.12 / 0.8	150.5 / 186.5
Semihovichskoye	0.5 / 6.0	8.4 / 7.65	0.9	20 / 30	103.7 / 146.4	31.3 / 38.9	5.8 / 5.8	16.2 / 16.6	3.0 / 3.0	0 / 0.13	0.00 / 0.068	0.00 / 1.02	171.3 / 230.1
Sominskoye	0.5 / 30.0	8.08 / 7.66	2.9	25 / 25	134.2 / 152.5	40.1 / 42.5	11.5 / 10.4	5.7 / 6.0	3.4 / 4.9	0.08 / 0.19	0.024 / 0.105	0.14 / 0.15	201.8 / 226.2
Stradechskoye	0.5 / 6.4	8.0 / 6.65	1.5	40 / 30	82.4 / 134.2	29.9 / 34.0	11.5 / 11.0	8.0 / 8	1.9 / 5.8	0.05 / 0.9	0.000 / 0.098	0.1 / 0.3	140.6 / 200.7

According to the species composition and population density of hydrobiota of karst lakes two biolymnologic types can be distinguished: mesotrophic and eutrophic. Running-off water bodies belong to the first group (e. g. lake Svitiaz); the majority of the surveyed lakes (68%) refer to the second type. The value of summer phytoplankton biomass lays in the limits of 0.5–25 g/m^3, with cyanobacteria (80–95%; e. g. lakes Mulnoe, Vulkovskoe) and diatomeae (30–65%; e. g. lakes Dvorishanskoe, Rogoznianskoe, Lukovskoe) being predomonant. The zooplankton biomass changes within the limits of 0.69–6.2 g/m^3, where Cladocera (up to 63%) and Copepoda (up to 34%) dominate. In the zoobenthos species composition prevail Chironomidae (total biomass 2–33.4 g/m^2), dominate Mollusca (up to 42%) and Hirudinea (up to 30%), and Chironomidae (up to 20%).

Ichthyofauna of lakes is rather poor, of perch-roach type, potential fishery resources are below 100.0 kg/ha. In the species structure prevail *Rutilus rutilus* (L)., *Scardinius erythrophthalmus* (L), *Tinca tinca* (L), *Carassius auratus gibelio* (Bloch), *Gobio gobio* (L), *Perca fluviatilis* (L), *Gymnocephalus cernuus* (L), *Esox lucius* (L).

The water vegetation is developed poorly. Helophyte plants *Phragmites australis* (Cav.) Trin. ex Steud., *Schoenoplectus lacustris* (L). *Palla*, *Acorus calamus* L., *Typha angustifolia* L., *Glyceria maxima* (Hartm.) Holmb., *Echium vulgare* L., *Sagittaria sagittifolia* L., and *Equisetum* species grow as narrow stretches (30–50 m. wide, sometimes up to 200 m). Hydrophytic plants (growing in 10–100 m. wide stretches, sometimes up to 500 m) are represented by *Potamogeton lucens* L., *Potamogeton pectinatus* L., *Potamogeton gramineus* L., *Potamogeton crispus* L., *Potamogeton pusillus* L., *Potamogeton perfoliatus* L., *Ceratophyllum demersum* L., *Myriophyllum spicatum* L., *Elodea canadensis* Michx., *Stratiotes aloides* L., and Characeae species. Plant species with floating leaves are seldom (*Nuphar lutea* L., *Potamogeton natans* L., *Persicaria amphibia* (L.) S.F. Gray, *Nymphaea candida* Presl., *Hydrocharis morsus-ranae* L., *Lemna minor* L.) and grow in the shadow cast by the shore vegetation and in gulfs.

In the mesotrophic lakes with low mineralization (e. g. Svitiaz and Beloie lake in Luninets region) grow rare and protected plant species (*Caulinia flexilis* Willd., *Lobelia dortmanna* L., *Isoetes lacustris* L., *Litorella uniflora* (L.) Aschers., *Nitella gracilis* (G.M. Smith). Bottom sediments of the lakes are distinguishable by the depth-wise differentiation and concentric character of distribution of various types (phases) of deposits at the bottom. Two types of the lakes can be distinguished based on the quality of the bottom sediments: those accumulating organic sapropels (ash content – up to 76.6%, C organic – up to 36.5%, Al_2O_3 – up to 8.1%, SiO_2 – up to 20.2%, SO_3 up to 2.1%) and another accumulating organic-mineral sapropels (ash content – up to 60%, C organic up to 20%, Al_2O_3 – up to 4%, SiO_2 – up to 48%, SO_3- up to 3.5%). Some lakes have an increased content of CaO in sediments (9–12% – Peschanoe, Svitiaz') and Fe_2O_3 (up to 10% – Luban', Okunino, Sominskoe). The maximal capacity of the lake sediments is 10–15 m. (average 6–7 m.). In stratigraphic cuts the sediments are represented as (from bottom to the top): coarse- to fine-grained sand in a mixture, occasionally – interbeds of peat (Sviatoe, Peschanoe), interbeds of humus rich clay or silt, overlapped with a layer of fine-grained detrital or siliceous sapropel.

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STRESZCZENIE

PRZYRODNICZE CHARAKTERYSTYKI JEZIOR KRASOWYCH BIAŁORUSI

Słowa kluczowe: jeziora krasowe, geneza, zapadlisko, hydrologia, hydrochemia, hydrobiologia, osady denne.

Jeziora krasowe na Białorusi należą do typu jezior astrefowych i występują na obszarze Polesia, gdzie na powierzchni zalegają utwory wapieni. Do charakterystycznych właściwości tych jezior należą: mała powierzchnia, lejkowata forma misy jeziornej, mały wskaźnik wymiany wody i podwyższony poziom jej mineralizacji. Są to jeziora typu mezotroficznego lub eutroficznego.