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Data concerning the color and chemical composition of
the water of the upper Volga

By V. F. Roshchupko

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Material on the Chromaticity* and Chemical
 Composition of the Water in the Upper Volga
 Reservoir

By V.F. Roshchupko

The waters of the upper reaches of the Volga play a fundamental role in the water supply of Moscow, and increased chromaticity and oxidizability represent a major shortcoming of Volga water from the viewpoint of its drinking qualities (Ozerov, 1927). The study of the chromaticity and chemical composition of this water is therefore of practical value.

The colouration of the waters in the upper reaches of the Volga and the Upper Volga Reservoir was studied simultaneously with other chemical and physical features of the water - temperature, transparency, electric conductivity, permanganate oxidizability, total iron content, content of hydrocarbonates, calcium, magnesium, and, in individual samples, sodium and potassium. These studies were carried out on expeditions organized by the Institute of the Biology of Inland Waters of the Academy of Sciences of the USSR from 1964 to 1966.

*, ** See next page.

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In order to determine the chromaticity of the water we used a chrome-cobalt scale; the colour tone of the water was determined from the Forel'-Ule scale. The total salt content was ascertained from the specific electric conductivity on an R-38 rheochord bridge.*** The other components were determined by generally accepted methods (Alekin, 1954). Some research has been devoted to the chemical mechanism of the waters of this region (Ozerov, 1927; Abrosov, 1961). Data of the Hydrometeorological Service of the Central Regions, in addition to our own observations, were used in this report.

The basin of the upper reaches of the Volga River is a complex lake and river region. A large number of hollows, sinkholes and small lakes, and the presence of extensive forests that regulate surface runoff, retard the development of erosion processes, and the increased moisture leads to the formation of swamps over large areas. A predominance of snow feeding, which represents 50% (Zagorskii, 1960), and the considerable extent to which the sandy and sandy-loam soils are washed, cause the water to be poor in mineral salts, while the extensive occurrence of swamps, and the heavy forest cover of the region, increase the content of coloured organic matter and maintain the high oxidizability of the water.

* Translator's note.

"Chromaticity" is a translation of the Russian tsvetnost'. Another translation is "colour index", but a comparison of the definitions of the two terms as given in Webster's Third New International Dictionary, seemed to favour the former in the present context.

** Numbers in the right margin indicate the corresponding pages in the original.

*** Translator's note. "Rheochord bridge" is taken directly from the Russian reokhordynyi mostik, for which no other suitable equivalent is available.

The water at the source of the Volga is of swamp origin and is characterized by a weakly acid reaction, a high chromaticity and oxidizability, and a low content of dissolved salts. The chromaticity of the water at the source, to judge from single observations made in May, July, August and September 1950 and ^{1964 to} 1966, varies within wide limits. In July 1950, a rainy year, V.N. Abrosova (1961) determined a chromaticity of 488°; in the dry summer of 1966, a chromaticity of 240° was determined (our data). The permanganate oxidizability of the water at the source was of the order of 50 to 60 mg O₂/l. The specific electric conductivity was low (40 to 65 micromho/cm); the total iron content ranged from 0.6 to 0.74 mg/l, and the overall hardness did not exceed 0.77 microgram-equivalents/l Ca⁺⁺ + Mg⁺⁺.

When Volga Creek empties into Lake Malyi Verkhit (about 1.5 /121 to 2 km from the source) the chromaticity of the water in the former decreases by 2.5 to 4 times. In [Lake] Malyi Verkhit during our observations the chromaticity of the water ranged from 90 to 170°. The oxidizability too, drops to less than half; its values in this lake do not exceed 20 to 25 mg O₂/l. The total iron content decreases depending upon the season and the precipitation* during the year.

The chromaticity of the water in Lake Bol'shoi Verkhit in summer and autumn is 20 to 30° higher than in Lake Malyi Verkhit.

* Translator's note. "Precipitation" is a translation of the Russian vodnost', meaning literally "water content".

This is explained by the entry of heavily coloured water from the swamps located downstream from the latter.

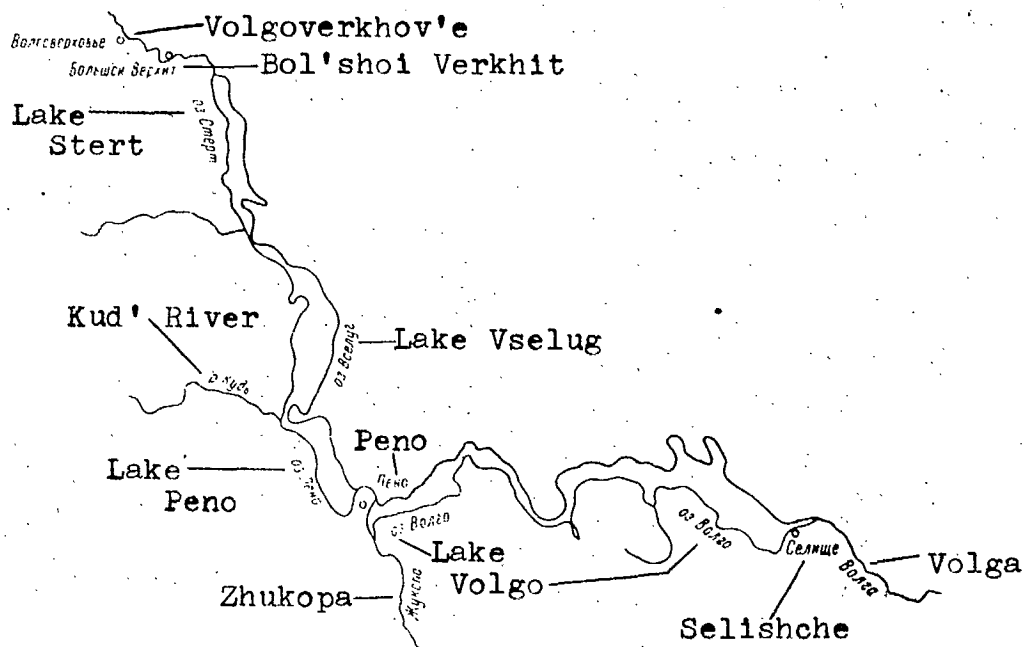


Diagram of the upper reaches of the Volga and the Upper Volga Reservoir

Individual observations showed that in July and August 1964 and 1966 the colouration of the water fluctuated from 100 to 120°.

The Upper Volga Reservoir is an unusual body of water that includes four controlled lakes (see illustration): Sterzh, Vselug, Peno and Volgo. When the reservoir is normally filled, its surface area reaches 181 km², and its volume, 805.1 million m³. Before the Moscow Canal was dug and the Volga Cascade created, water was accumulated in the Upper Volga Reservoir in order to provide guaranteed depths for navigation in the upper pool of the Volga as far as Rybinsk. Water is now discharged in order to increase the flow rates of water in the Moscow Canal. Water is

discharged through the aperture** twice a year: in spring (May and June) and in autumn (September and October). The annual discharge of water from the Upper Volga Reservoir averages 866 million m³.

Lake Sterzh, the uppermost pool of the reservoir along the Volga, undergoes least the effect of the hydrostatic head. The water of Lake Sterzh is fairly uniform in its hydrochemical properties throughout the entire ice-free period. Its electric conductivity increases in comparison with the source of the Volga and reaches 110 to 130 micromho/cm, and its hardness increases to 1.3 to 1.5 milligram-equivalents/l Ca⁺⁺ + Mg⁺⁺. The water volume of Volga Creek is in this case less than that of the other numerous tributaries feeding the lake. In the course of a year the chromaticity of the water varies within wide limits. Its values fluctuate from 22 to 124° depending upon the season and the precipitation during the year. In July and September the coloured waters at the source of the Volga have no significant effect on the colouration of the waters of Lake Sterzh. Thus a chromaticity of 60° was determined in July where the Volga empties into Lake Sterzh. During the year, the chromatic tone of the lake water varies within the limits of XVI to XXI on the Forel'-Ule scale.

The Runa River, 28 km long, which carries the waters of the basins of Lakes Khvoshchnya and Istoshchnya, discharges into

**Translator's Note- "Aperture" is only a suggested rendition of the Russian beishlot, for which no other suitable equivalent is available. Beishlot appears to be of German derivation; the translation suggested above is based on an approximate German meaning.

the channel between Lakes Sterzh and Vselug. At flood time it brings in more water than all the small rivers and creeks emptying into Lake Sterzh together, including the small river conventionally taken as the source of the Volga. The Runa often causes a counterflow in the direction of Lake Sterzh. The annual runoff of the Runa during the period from 1897 to 1898 was 116.2 million m^3 (Bushmakin, 1904). Flowing through swampy forest terrain and receiving about 30 tributaries with a total length of 73 km, the Runa carries dark-coloured waters whose chromaticity usually exceeds 100° and increases the chromaticity of the waters in the upper area of Lake Vselug by 15 to 20° .

The second widened pool of the Upper Volga Reservoir is Lake Vselug. In the north it is joined by a narrow channel to Lake Sterzh, and in the southern area to Lake Peno, located below. The water of Lake Vselug differs little in its characteristics from the water of Lake Sterzh. According to data from the Rybinsk Hydrometeorological Observatory, the transparency decreases from winter to summer, falling to a minimum during the mass development of phytoplankton. The chromaticity also decreases from the spring and summer period to the winter, fluctuating within the limits of 96 to 21° . The chromatic tone of the water in winter corresponds to XVI, as in Lake Sterzh during this period. Hydrocarbonates and calcium predominate in the ion composition. The relative content of ions of strong acids increases in the late water towards autumn owing to HCO_3' .

Lake Peno is the third in the system of the Upper Volga Reservoir. In its upper area, Lake Peno is separated from the pool of Lake Vselug by a dike which spans the flood plain of the Kud' River a short distance above the point at which this river empties into the lake. The length of the pool is 9.0 km; its surface area when it is filled to the normal level is 21.2 km²; its average depth is 4.2 metres, and its maximum depth is 8.4 metres.

The transparency of the water in the Lake Peno pool ranges from .05 / ^{to} 2.2 metres in summer (Table 1) and reaches its highest values in winter. In the summer months the chromatic tone ranges from XVIII to XIX and in winter corresponds to XVI.

It may be seen from the data given in Table 1 that the seasonal variations in the colouration of the water differ widely in individual years. The colouration indices in the winter months are determined mainly by the hydrometeorological situation at the end of the autumn of the preceding year, i.e., in the period when water accumulates in the reservoir with the aperture* closed. The active reaction of the water in Lake Peno is for the most part neutral or weakly alkaline. The pH rises to 8.2 during the intensive development of blue-green algae at the end of summer and the beginning of autumn. The content of hydrocarbonate ion [s] during the winter months ranges from 73 to 95 mg/l (Table 2) and in spring decreases to 58 mg/l. In July and August the content of hydrocarbonate ion [s] again increases, reaching more than 80 mg/l in individual samples. Among cations the most important is

* See Translator's Note, p.5.

calcium, whose content ranges from 21 to 26 mg/l in winter, 17 to 19 mg/l in summer, and 16 to 24 mg/l in autumn, i.e., within the limits typical of the region being studied.

The Kud' River empties into the upper area of the lake from the west; in the upper reaches of this river a reservoir has been built for the purpose of maintaining timber floating along the river during the low-water period. The annual flow of the Kud' River during 1897-1898 was 140.8 million m³ (Bushmakin, 1904).

The water of the Kud" is poor in dissolved salts and its chromaticity ranges from 45 to 80° (in July and September). The Orekhovnya River, emptying from the west into one of the bays of the lake, significantly influences the colouration of the southwest part of the pool of Lake Peno during flood time. /127

Table 1

Physical and Chemical Properties of the
Water of Lake Peno

1. Сезон, дата	2. Место отбора проб	3. Прозрач- ность, м	4. Цветность град.	pH	Удельная электропро- водность, $\frac{\text{С}}{\text{КСМ}} \cdot \frac{\text{СМ}}{\text{СМ}}$	6 Общее же- лезо мг/л	7 Окисляе- мость (пер- ман.) мг $\text{O}_2/\text{л}$	8. Источник данных	
9. Весна									
20 V 1950	13 Волжская протока	2.0	48	7.6	—	—	—	20. Абросов	
23 V 1965	14 Середина расширенной части	—	100	—	—	—	18.62	1. Фоткев	
10. Лето									
4 VIII 1950	13 Волжская протока	—	66	—	—	—	—	20. Абросов	
6 VII 1961	15 Изведово	—	51	7.40	—	0.22	15.6	22. Пост ГМС	
29 VIII 1963	»	—	34	7.40	—	0.36	11.7		
20 VIII 1964	»	1.0	40	7.60	—	—	—	23. Чиркова Пост 22. ГМС	
30 VII 1964	»	—	31	7.80	—	0.05	12.6		
16 VII 1965	17 ст. 23	2.0	55	< 7.59	100.0	0.36	11.0	24. Наши данные	
18 VII 1966		ст. 18-а	2.2	35	8.20	97.9	—		10.9
23 VII 1966		ст. 22	0.8	60	7.17	110.6	—		14.0
		ст. 21	1.5	40	8.20	95.1	—		10.6
		ст. 20	0.5	55	7.60	108.9	—		13.2
	ст. 23	1.3	45	7.60	99.3	—	11.5		
11. Осень									
9 IX 1962	15 Изведово	—	76	7.20	—	0.22	15.1	22. Пост ГМС	
22 X 1964		»	—	32	7.60	—	0.42		10.5
15 IX 1965	17 Ст. 23	1.5	40	8.20	120.0	0.17	8.1	24. Наши данные	
17 XI 1965	15 Изведово	1.0	48	7.60	—	0.28	11.9	22. Пост ГМС	
12. Зима									
28 III 1950	13 Волжская протока	1.5	80	—	—	—	—	20. Абросов	
20 III 1961	15 Изведово	—	118	6.65	—	0.30	24.0	22. Пост ГМС	
19 III 1962		»	—	53	7.20	—	0.42		13.0
26 III 1963		»	—	80	7.00	—	0.32		22.8
11 III 1964		»	—	40	7.40	—	0.14		10.1
12 III 1965		»	1.9	24	7.15	—	0.20		8.2
10 III 1966	18 пос. Пено:							25. Рыбин- ская ГМО	
	19. глубина 0.5 м	2.4	XVI	7.00	—	—	—		
	19. глубина 2.2 м	—	XVI	6.80	—	—	—		

Key: Table 1

1. Season and date;
2. Place where samples taken;
3. Transparency, in metres;
4. Chromaticity, in degrees;
5. Specific electric conductivity, in micromho/cm;
6. Total iron, in mg Fe/l;
7. Oxidizability (permanganate), in mg O₂/l;
8. Source of data;
9. Spring;
10. Summer;
11. Autumn;
12. Winter;
13. Volga channel;
14. Middle of widened area;
15. Izvedovo;
16. Peno settlement;
17. Station;
18. Peno settlement;
19. Depth;
20. Abrosov;
21. Fotiev;
22. Station of Hydrometeorological Service;
23. Chirkova;
24. Our data;
25. Rybinskaya dead volume level.

Note: The Roman numerals indicate the colour tone on the Forel'-Ule Scale.

Ton Composition of the Water of Lake Peno

Table 2

Season & date Сезон, дата	Place where samples taken Место отбора проб	Ca ⁺⁺	Mg ⁺⁺	Na ⁺ + K ⁺	HCO ₃	SO ₄ ⁼⁼	Cl ⁻	Ion total Сумма ионов	Source of data Источник данных
Spring Весна 20 V 1950	Volga Channel Волжская протока	19.1	1.10	0.26 *	58.0	4.5	0.40	83.5	Abrosov Абросов Station of Hydro-meteorological Пост ГМС Service
		0.95	0.09	0.01	0.95	0.09	0.01	1.05	
	Izvedovo Изведово	45.2	4.30	0.5	45.2	4.3	0.5	—	
		17.2	3.50	1.82	58.6	8.00	3.20	92.2	
Summer Лето 4 VIII 1950	Volga Channel Волжская протока	0.86	0.29	0.07	0.96	0.17	0.09	1.22	Abrosov Абросов Пост ГМС
		35.2	11.9	2.9	39.3	7.0	3.7	—	
	Izvedovo Изведово	59.2	—	—	0.97	4.80	0.00	1.07	
		45.3	—	—	4.7	4.7	0.0	—	
6 VII 1961	Izvedovo Изведово	16.5	3.40	2.68	58.6	8.60	2.20	92.0	Our data Наши данные
		0.82	0.28	0.10	0.96	0.18	0.06	1.20	
	Station ст. 23	34.2	11.6	4.2	40.0	7.4	2.6	—	
		22.3	4.00	2.60	83.6	4.90	2.50	120.0	
29 VIII 1963	Station ст. 23	1.11	0.33	0.10	1.37	0.10	0.07	1.54	Our data Наши данные
		36.0	10.7	3.3	44.4	3.3	2.3	—	
	Station ст. 23	22.0	3.50	2.20	76.9	6.20	3.10	113.9	
		1.41	0.29	0.08	1.26	0.13	0.09	1.48	
30 VII 1964	Station ст. 23	37.2	9.8	3.0	42.6	4.4	3.0	—	Our data Наши данные
		25.8	2.30 **	1.15	70.2	—	—	—	
	1.29	0.10	0.03	1.15	0.27 **	—	1.42		
	45.0	—	5.0	40.5	9.5	—	—		

Table 2 - cont'd.

Season & date Сезон, дата	Place where samples taken Место отбора проб	Ca ⁺⁺	Mg ⁺⁺	Na ⁺ K ⁺	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	Ion Summa ионов total	Source Источник данных of data	
26 VII 1965	Изведово Izvedovo	23.4 1.17 41.8	2.80 0.23 8.2	-- -- --	-- -- --	70.8 1.16 41.7	7.20 0.15 5.4	2.90 0.08 2.9	-- 1.39 --	Station of Hydromet. Пост ГМС Service
3 VIII 1965	"	23.0 1.14 40.8	2.70 0.22 7.6	2.10 0.08 2.4	-- -- --	72.6 1.19 41.3	7.90 0.16 5.6	3.10 0.09 3.1	114.4 1.44 --	
18 VII 1966	Station ст. 18-a	20.3 1.01 35.5	3.8 0.31 11.0	1.70 0.07 3.5	1.08 0.03 --	70.8 1.16 40.8	19.6 0.20 *** 7.0	2.20 0.06 2.2	119.5 1.42 --	
23 VII 1966	ст. 22	22.8 1.14 35.0	4.90 0.40 12.1	2.10 0.09 2.9	0.78 0.02 --	83.6 1.37 41.5	10.6 0.22 *** 6.7	2.10 0.06 1.8	126.9 1.65 --	
23 VII 1966	ст. 21	21.2 1.06 32.0	5.80 0.48 14.5	2.00 0.09 3.5	1.05 0.03 --	73.8 1.21 36.5	18.7 0.39 *** 11.7	2.10 0.06 1.8	124.7 1.66 --	Our data Наши данные
23 VII 1966	Ст. 20	23.8 1.19 38.4	3.20 0.26 8.4	1.80 0.08 --	0.76 0.02 3.2	83.6 1.37 44.2	5.8 0.12 *** 3.8	2.10 0.06 2.0	121.1 1.55 --	
23 VII 1966	ст. 23	20.6 1.03 35.3	3.80 0.31 10.3	2.00 0.09 4.4	1.12 0.03 --	72.0 1.18 40.5	10.6 0.22 *** 7.0	2.20 0.06 2.5	112.3 1.46 --	
Осень 9 IX 1962	Изведово Изведово			-- -- --	-- -- --	61.0 1.00 43.2	4.90 0.10 4.40	2.00 0.06 2.4	-- 1.16**** --	Station of Hydromet. Service Пост ГМС
18 IX 1965	Station ст. 23	22.0 1.10 38.0	2.88 0.24 8.0	1.95 0.08 4.0	0.90 0.02 --	70.2 1.15 39.0	-- 0.29 *** 11.0	-- -- --	-- 1.44 --	Our data Наши данные

Season & date Сезон, дата	Place where samples taken Место отбора проб	Ca ⁺⁺	Mg ⁺⁺	Na ⁺ + K ⁺		HCO ₃ [']	SO ₄ ^{''}	Cl [']	Ion summa Сумма ионов total	Source Источник данных of data
17 XI 1965	Изведово	—	—	—	—	81.2	6.90	3.20	—	} Пост ГМС Station of Hydromet. Service
Winter	Izvedovo	—	—	—	—	1.33	0.14	0.09	1.56****	
Зима		—	—	—	—	42.6	4.50	2.90	—	
28 III 1950	Волжская протока	25.1	4.00	7.00		93.4	15.2	1.10	145.8	} Абросов Abrosov
	Volga channel	1.28	0.33	0.28		1.53	0.32	0.03	1.89	
		33.9	8.7	7.4		40.7	8.5	0.8	—	
20 III 1961	Изведово	13.1	3.20	4.70		36.0	18.4	3.90	79.3	} Абросов Abrosov
	Izvedovo	0.65	0.26	0.17		0.59	0.39	0.10	1.08	
		30.1	11.4	8.5		27.0	18.0	5.0	—	
19 III 1962	»	22.7	4.30	5.36		90.3	7.00	1.70	131.4	} Пост ГМС Station of Hydromet. Service
		1.13	0.35	0.20		1.48	0.15	0.05	1.68	
		33.6	10.6	5.8		44.2	4.4	1.4	—	
26 III 1963	»	21.4	3.30	1.07		73.2	4.90	2.90	106.8	} Пост ГМС Station of Hydromet. Service
		1.07	0.27	0.04		1.20	0.10	0.08	1.38	
		38.3	9.8	1.9		43.8	3.8	2.9	—	
11 III 1964		23.0	5.00	3.22		87.8	7.30	3.20	129.5	} Абросов Abrosov
		1.15	0.41	0.12		1.44	0.15	0.09	1.68	
		33.8	12.1	4.10		4.29	4.40	2.70	—	
12 III 1965	Изведово	25.8	4.6	2.41		95.2	7.00	1.90	137.0	} Абросов Abrosov
		1.29	0.38	0.09		1.56	0.15	0.05	1.76	
		36.6	10.8	2.6		44.3	4.3	1.4	—	

Note: For each sample: first line is mg/l; second line is mg-equivalents/l, third line is percentage equivalent.

* Na⁺ and K⁺ were calculated from [their] difference.

** Na⁺ and K⁺ were determined on a flame photometer.

*** SO₄^{''} and SO₄^{''} + Cl['] were calculated from [their] difference.

**** Analysis does not balance.

The transparency of the water in the section of the Upper Volga Reservoir between the Peno and Volgo Pools, ranges from 0.8 to 1.0 metres in summer and increases towards winter. According to our observations, the chromaticity of the water in this region was of the same order as in the upper pools. In autumn higher chromaticity values were noted below the mouth of the Zhukopa River.

The Zhukopa River empties into the Reservoir from the south below the settlement of Peno; flood time on this river begins somewhat sooner than in the basin formed by the northern pools of the Reservoir, and its water flow exceeds the total flow volume of rivers emptying into the Reservoir above the settlement of Peno. The annual flow of the Zhukopa River is 380.3 m^3 (Kalinin Oblast' Atlas, 1964). Flowing through forested terrain that is swampy in places, the Zhukopa River brings into the Reservoir water that is more coloured than that of the Kud' and Runa Rivers. The Zhukopa carries a large quantity of crushed wood bark, which is not only an important component of bottom deposits, but is also a possible factor increasing the chromaticity and oxidizability of the water in the Reservoir. The chromaticity values of Zhukopa water in May, July, and September are high (150 to 225°). The amount of mineral matter is higher than in the Runa or the Kud'.

The level, depth and surface area of the pool at Lake Volgo - the lower pool in the system of the Upper Volga Reservoir - fluctuate within wider limits than in the upper pools. According to observations made in summer, the greatest transparency (1.3 metres) has

been found in the deep, widened area of the pool. The transparency increases at the beginning of autumn and reaches its highest values in winter. During the year, the degree of colouration of the water in the Lake Volgo Pool ranges from 21 to 156°. A sharp drop in colouration and oxidizability in winter, together with a simultaneous increase in the total content of ions, indicates an increase in the role of ground [water] feeding. Colouration indices reaching 150° and more were noted by V.N. Abrosov (1961) in May and August of 1950, a year in which water was abundant in the upper reaches of the Volga. In July and August 1965 and 1966 the chromaticity of the water in Lake Volgo ranged from 50 to 90°.

The permanganate oxidizability of the water of Lake Volgo ranges from 9 to 23 mg O_2 /l. During the greater part of the year the active reaction of the water is close to neutral. The highest pH indices - 7.9 to 8.4 - are characteristic of the summer months and the beginning of autumn.

The quantity of mineral components dissolved in the water is small. Even in July, the water of Lake Volgo contains fewer dissolved salts than the upper pools, which is explained by the greater dilution of winter waters by the waters at flood time. The content of salts increases in autumn and in winter.

The rivers emptying into Lake Volgo carry waters that are more coloured and richer in dissolved salts than the water of the lake itself.

Conclusion

The colouration of the waters in the upper reaches of the Volgo is, as a rule, above average and is high in places. According to

the classification of water colouration proposed by M.A. Fortunatov (1959), waters of medium and increased colouration predominate in the Upper Volga Reservoir. No waters virtually free of colouration have been found either in the Reservoir or in the rivers flowing in the basin formed by the upper reaches of the Volga. Highly coloured and dark-coloured waters are found in open pools of the Reservoir, mainly in years with a heavy runoff, in the second /128 phase of high water, or in years with heavy summer precipitation. Very darkly coloured waters, and those that are exceptionally darkly coloured whose chromaticity is above 150° , are found in creeks and rivers flowing out of swamps. The swamp from which flows the creek conventionally called the source of the Volga, is characterized by a very high water colouration (from 200 to 488°). When the upper and lower pools are compared, it may be seen that the water of Lakes Sterzh, Vselug, and Peno is less coloured than that of the Lake Volgo Pool located below. This is related to the greater flow volume of coloured water in the Zhukopa River as compared to the other tributaries emptying into the Reservoir above the settlement of Peno.

The high chromaticity indices of the water in the Upper Volga Reservoir are caused by the presence of organic matter carried in by rivers and creeks, which is confirmed by their high permanganate oxidizability. The influence of ferric salts on the value of the chromaticity is negligible, since the total iron content does not exceed 1 mg/l.

The quantity of dissolved salts increases from the source to the aperture*. Tributaries carry into the Reservoir waters that are richer in dissolved salts than the water of the lakes. In the Reservoir itself and in its tributaries the water must be assigned to the hydrocarbonate class, calcium group (Alekin, 1954).

* See Translator's note p. 5

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