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RIVERS' HYDROLOGICAL CHARACTERISTICS OF THE NATIONAL PARK «BIALOWIEZA FOREST»

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Abstract
The article presents analysis of modern hydrological characteristics of the of Bialowieza Forest rivers' during the period of instrumental observations and provides a water regime's forecast assessment of the research territory. The database of Bialowieza Forest rivers' hydrological characteristics was updated with the help of GIS.

Keywords: river, flow, hydrology, database, Bialowieza Forest.

ГИДРОЛОГИЧЕСКИЕ ХАРАКТЕРИСТИКИ РЕК НАЦИОНАЛЬНОГО ПАРКА «БЕЛОВЕЖСКАЯ ПУЩА»

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Реферат
В статье представлен анализ современных гидрологических характеристик рек Беловежской пущи за период инструментальных наблюдений и дана прогнозная оценка водного режима исследуемой территории. База данных гидрологических характеристик рек Беловежской пущи была обновлена с помощью ГИС.

Ключевые слова: река, сток, гидрология, база данных, Беловежская пуща.

Introduction

The National park «Bialowieza Forest» is located in the eastern part of the Visla's river basin, on the catchment area of the rivers Narev and Lesnaya (Left and Right). The divide between the Baltic and Black Seas runs near park's northern and northeastern borders. The tributaries of the river Neman – rivers Svisloch and Ross – originate not far from the northern vicinity of the forest; the source of Yaselda, a tributary of the river Pripyat that flows into the river Dnieper, is located at the north-eastern forest's vicinity. There is a watershed between the basins of two tributaries of the river Bug – the Left Lesnaya and the Mukhavets – in the south-eastern limits of the forest [1, 2].

The river Narev that originates in the swamps of the tract «Dikoe» plays an extremely important role in regulating of the hydrological regime in the northern part of the forest. In the southern part of the National park, the main waterways are the rivers Right Lesnaya and Left Lesnaya. The river Right Lesnaya originates in Poland, flows in a south-easterly direction through the southern part of the National park and merges with the river Left Lesnaya on its' border, forming the Lesnaya River, which flows into the river Zapadny Bug north of city Brest. The source of the river Left Lesnaya is located on the territory of the National park («Shereshevskoe forestry»). The river Left Lesnaya flows in a south-easterly direction, then turns to the southwest and represents the south-eastern border of the National park by itself. The remaining rivers originate mainly in the territory of the National park and flow into the rivers Narev, Left Lesnaya and Right Lesnaya.

There are no natural lakes on the territory of the National park. As a result of hydro-reclamation works carried out in the second half of the twentieth century, several fairly large artificial reservoirs were created: Lyadskoe, Khmelevskoe, Sipurka, Pererovnitsa and Colonna.

Water landscapes significantly affect the functioning of the geosystem of Bialowieza Forest, as well as the maintenance of the natural water and energy balance depends on them. Water landscapes include swampy massifs, swampy forests and meadows, which affect the formation of runoff of water objects located on the forest's territory.

Rational management of water resources can be implemented only in case of existence of complete, unified, reliable and timely information about conditionы and trends of changes in water ecosystems or their individual components. Geographic information systems (GIS) are the systems that provide all levels of water resources management for determining the strategy of environmental management and making operational decisions [3, 4].

The purpose of current research is to determine the main hydrological characteristics of the rivers on the territory of National park «Bialowieza Forest» within the borders of the Republic of Belarus.

Materials and methods

The methodological basis of the research was the scientific provisions on the stochastic nature of river flow, which made it possible to apply statistical methods of time series analysis. The methods of water and heat energy balance, mathematical modeling were used. A system analysis of the accumulated information and a comparative geographical method made it possible to synthesize and objectively evaluate the patterns of spatial and temporal fluctuations of the water resources on the territory of the National park «Bialowieza Forest».

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A large number of small rivers and streams flow through the territory of Bialowieza Forest, but regular hydrological observations are not enough for an objective assessment of water resources. Therefore, we used the data of hydrological observations not only on rivers, located on the territory of the National park, but also in the immediate vicinity, on which hydrometric observations are conducted or were conducted, such as: the river Zelvyanka in the observation point of the village Peski, the river Yaselda in the observation point of the village Horev, the river Rudavka in the observation point of the village Rudnya, the river Ross in the observation point of the village Studenets, the river Narev in the observation point of the village Nemerzha, the river Lesnaya in the observation point of the village Zamosty. The following hydrological data on water consumption were used for research: average annual, average monthly, maximum spring floods, maximum rain floods, summer-autumn and winter low water by observation points for the period from 1946 to 2018 inclusive.

The missing data in the series of observations were restored using the observation data of analog observation points, taking into account the presence of synchronicity in the fluctuations of the observation point and of the point-analog using the software package «Hydrologist – 2» [5, 6].

For these rivers, according to TCP 45-3.04-168-2009, calculated hydrological characteristics were determined using analytical distribution functions of annual exceedance probabilities, in particular the three-parameter gamma distribution. At the initial stage, the homogeneity of the series of hydrological observations was assessed on the basis of genetic and statistical analyses of the initial observation data [7, 8].

According to the series of hydrological observations, the following estimates of the parameters of the analytical distribution curves were determined by the highest likelihood method: the average long-term value $\bar{Q}$, the variation factor C_v and the ratio of the asymmetry factor to the variation factor C_s/C_v. Mathematical models in the form of linear trends were used to assess trends in flow fluctuations. The quantitative indicators of these changes were estimated by a gradient that is numerically equal to the regression coefficient (a) multiplied by 10 years, i.e. α=a×10 years [9].

For rivers were no hydrological observations, regional methods for calculating hydrological characteristics were used, based on the results of generalization of hydrometeorological observations in the research area, taking into account the influence of local factors [7, 8].

The use of regional methods for determining the main hydrological characteristics provides for the determination of a number of hydrographic characteristics of catchments: catchment area, km^2; length of the river, km; average height of the catchment, m; average slope of the riverbed, %; lake cover, forest cover and swampiness of the catchment, %, which were determined using GIS technologies.

One of the regulatory documents when creating a GIS hydrographic network is the Directive of the European Parliament and of the Council establishing a framework for Community action in the field of water policy, which was adopted in 2000. This document regulates approaches in the policy of protection, use and management of water resources and is intended to harmonize and unify the approaches of the EU and other European countries to water resources management and protection. The main objects of any GIS are maps, geographical data and tables.

The framework requires European countries to provide a significant amount of information in the form of maps (more than 13 layers and 49 data tables). The best form of providing most of the required information is the form of thematic GIS layers. This is due to the fact that most of the data should be presented in a spatial context. The implementation of the framework requires the comparison of geographical data (coordinates of locations) both for the purpose of preparing water management plans in the basins, and for the purpose of preparing reports of Basin administrations. In the first case, GIS technology is necessary for the development of various information layers (for example, the characteristics of basins, the chemical and ecological state of surface and groundwater).

The GIS of the hydrographic network of the territory of the National park «Bialowieza Forest» is based on existing cartographic materials. All digital data was recorded in the GIS database in geographical coordinates. The geodetic mapping system was used by Pulkovo 1942. This method of recording made it possible to easily transform data into a new system of plane coordinates, which was necessary for spatial analysis. The flat coordinates of Pulkovo 1942 GK Zona 5N were used with the purpose to form a general map of the entire natural-territorial complex Bialowieza Forest.

GIS of the hydrographic network of the natural-territorial complex Bialowieza Forest was created as a result of processing graphic materials, and GIS contains the following main layers:

- linear layer of rivers;
- linear channel layer;
- polygonal layer of reservoirs;
- polygonal layer of catchments.

As additional layers, GIS contains:

- polygonal and raster layers of swamps;
- polygonal layer and raster layers of forest cover;
- raster layer of reservoirs;
- linear layer of the border of the National park «Bialowieza Forest»;
- chiseled layers of the location of the points of the sources and estuaries;
- rasters of digital terrain models, topographic plans and satellite images;
- tables.

The linear layer of rivers includes 117 objects with a total length of more than 942 km, of which 53 objects are represented by rivers, and the rest are tributaries, meanders and other objects. As attribute information, this layer contains information about the name of the water body, its encoding, and geometric parameters. Additional connected attribute information contains information about the average slope along the length of the object.

The linear channel layer contains 2,270 objects with a total length of 2,168 km. The channel layer contains information about the encoding of objects, as well as information about geometric parameters.

The polygonal layer of reservoirs is represented by 49 objects with a total area of 11.6 km^2. The layer contains information about the type of water body, its encoding and geometric parameters. Of the 49 objects, 46 objects are encoded. As an addition, the polygon layer is duplicated as a bitmap image.

The polygonal layer of catchments includes 49 objects. As attribute information, there are names of catchments, their geometric dimensions, information about the degree of lake cover, forest cover and swampiness of the catchment. As a connected additional information, the layer contains information about the areas of forests, reservoirs and swamps for each catchment.

Polygonal and raster layers of swamps and forest vegetation provide visual information about the degree of forest cover and swampiness of the National park «Bialowieza Forest» and adjacent territories.

The linear layer of the border of the National park «Bialowieza Forest» is demonstrative and contains only information about its length, which is 568 km.

The point layers of the sources and estuaries of rivers display, respectively, the location of the sources and estuaries of 53 and 49 rivers. The layers contain information about belonging to the river and coordinates in the form of latitude and longitude. The river source layer contains information about the height of the river source point as additional connected information.

The raster of the digital relief model presents visual and digital information about the heights of the territory of the National park «Bialowieza Forest» and adjacent territories for 2006 – 2008 in the form of a set of pixels with a dimension of 12.5x12.5 m.

Topographic plans and satellite images carry only visual information about the territory of the National park «Bialowieza Forest» and adjacent territories.

The tables are presented with attribute information about the height of the sources of rivers, the average slope of rivers, the areas occupied by forest vegetation, swamps and reservoirs. These tables act as additional connected information for some layers.

The ArcGIS tools are used to calculate the proportions of forested, watered, and swampy catchments. The calculation algorithm is common for all 3 parameters and is shown in Figure 1.

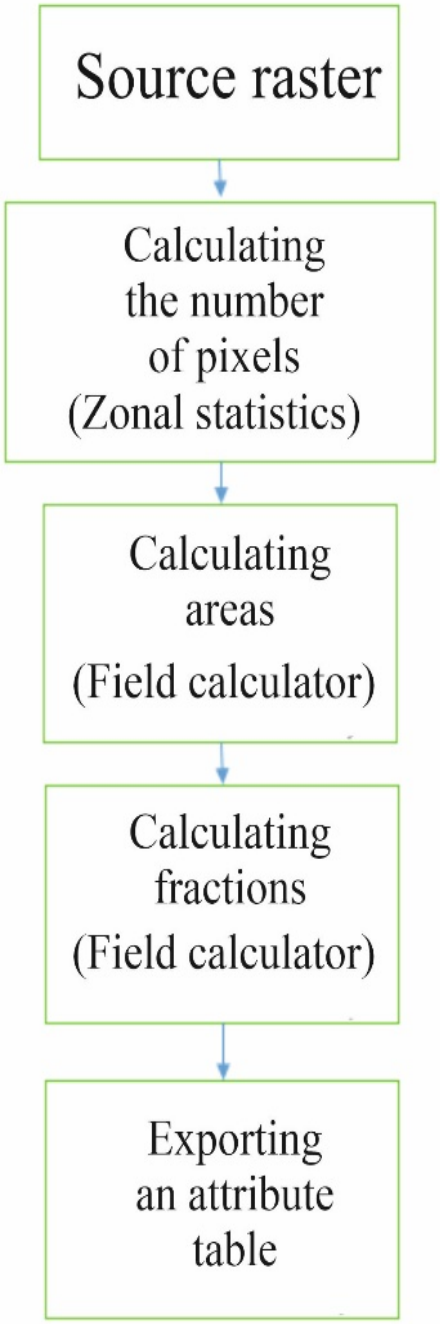

Figure 1 – Algorithm for calculating the proportions of forest cover, waterlogging and waterlogging of catchments

As initial rasters, previously created rasters of forest vegetation, reservoirs and swamps within the catchments of rivers of the National park «Bialowieza Forest» are used (Figure 2).

The *Zonal Statistics as a Table* tool was used to calculate the number of pixels of forests, swamps and reservoirs within catchments. River catchments act as a working area.

After creating tables with the calculated number of pixels of swamps, reservoirs and forests, the areas within the catchments were calculated. Knowing the pixel size – 5x5 m using the *Field Calculator tool*, the areas occupied by these parameters were calculated.

Knowing the size of the catchment areas, using the *Field Calculator tool*, the degrees of forest cover, waterlogging and swampiness of the catchment areas of water objects were calculated.

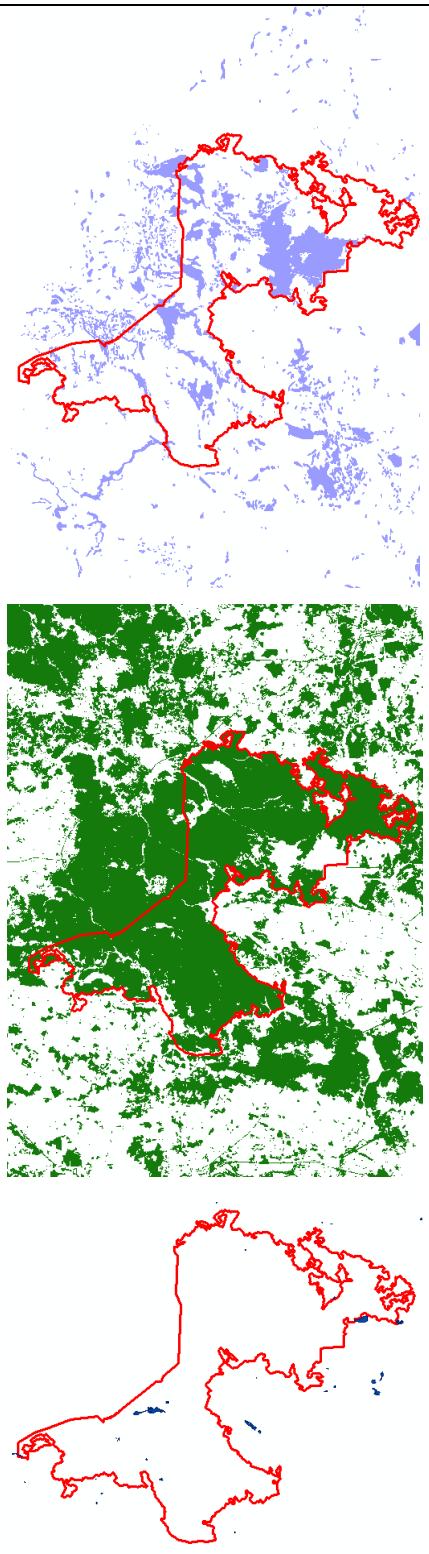

Figure 2 – Rasters of swamps, forest vegetation and reservoirs of the National park «Bialowieza Forest»

Results and discussion

The chronological course of maximum spring flood runoff, maximum rain flood runoff, minimum summer-autumn runoff, minimum winter runoff for the rivers Yaselda, Rudovka, Ross, Narev, Lesnaya, Zelvyanka, where regular hydrological observations are conducted, as well as their trends are presented in Figure 3.

The chronological course of annual runoff is represented in Figure 4.

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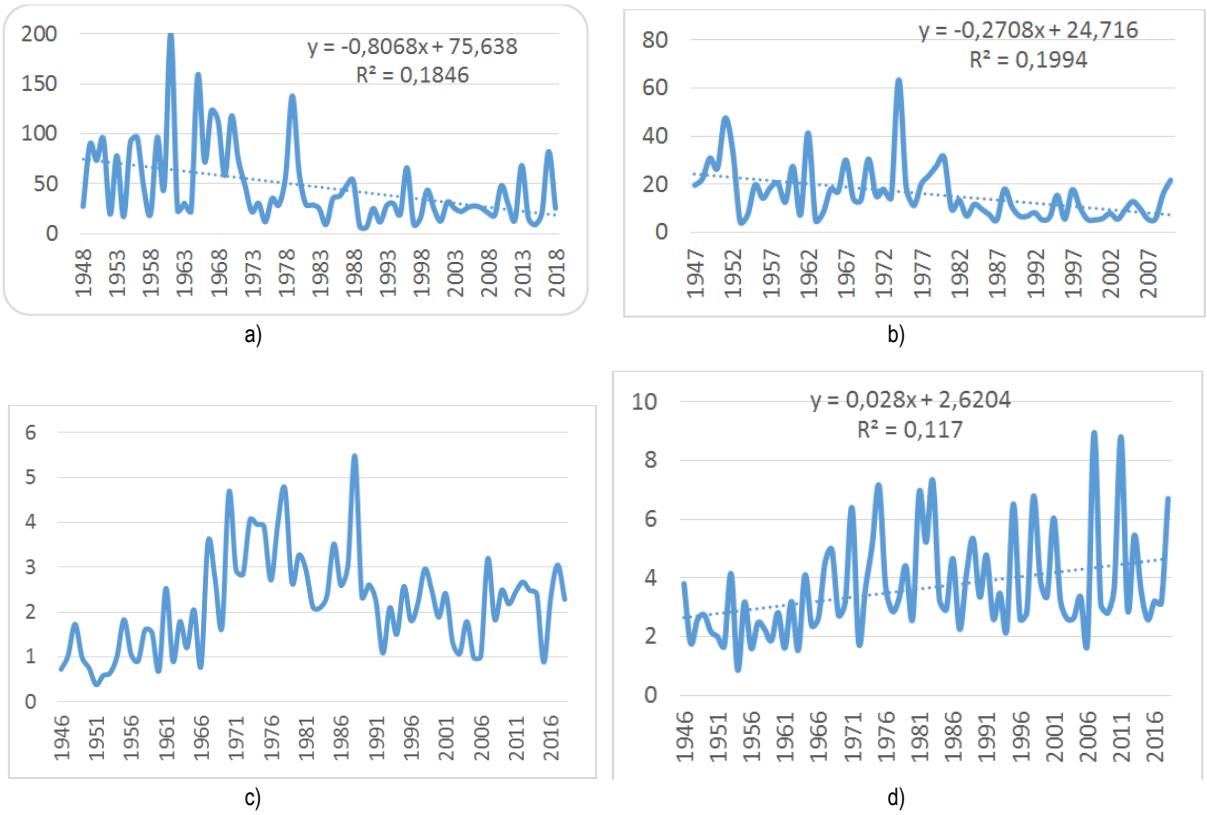

a) maximum spring flood runoff; b) maximum runoff of rain floods; c) minimum summer-autumn runoff; d) minimum winter runoff

Figure 3 – Chronological course of various types of runoff of the Lesnaya river in the observation point of the village Zamosty

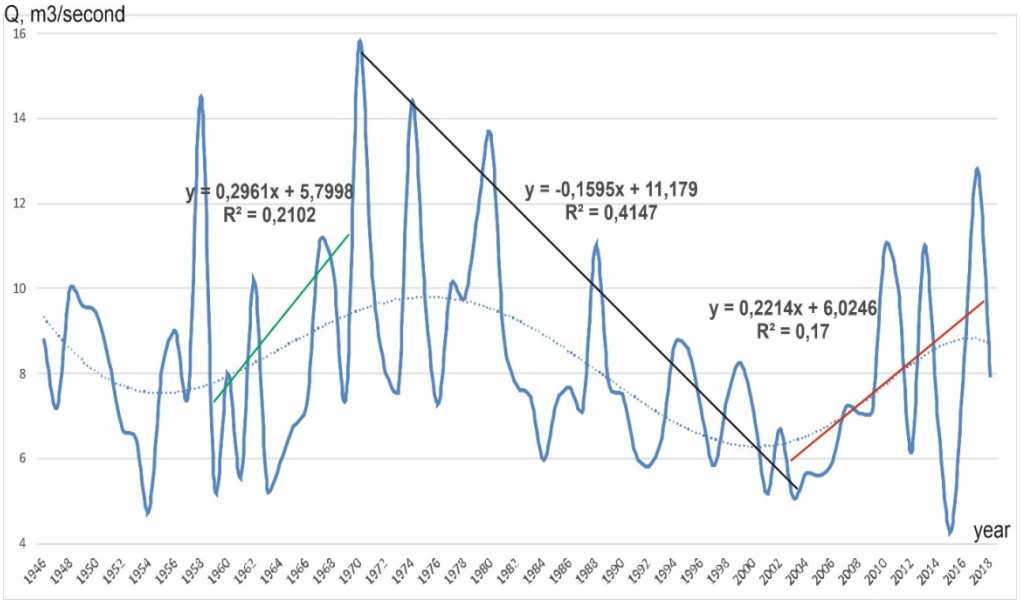

Figure 4 – Chronological course of annual runoff of the Lesnaya river in the observation point of the village Zamosty

The analysis of the obtained results showed that for all rivers, there isa decrease in the flow of maximum spring flood runoff (power trend – 19,5%) and maximum runoff of rain floods (power trend – 20,8%) and an increase in the flow of minimum winter runoff (power trend – 12,2%). Minimum summer-autumn runoff has the behavior of a time series the same as annual runoff.

The consumption in winter has increased, due to milder winters, the presence of frequent thaws and sufficient humidification of the territory. Firstly, it increased due to a decrease in the accumulation of groundwater in the ice in the aeration zone during the migration of unfrozen moisture to the freezing front. Secondly, the losses of underground river supply to the formation of ice formations have decreased: river ice, ice, seasonal underground ice. Thirdly, with a decrease in the thickness of the ice in the rivers, the carrying capacity of the channels increases. Fourth, with a decrease in soil freezing, their air permeability increases. With a freer penetration of air into the aeration zone over groundwater in winter, a lower pressure is not created than in the atmosphere, and groundwater is freely discharged into rivers.

Table 1 shows the average long-term values of annual runoff water consumption, maximum spring flood runoff, maximum rain flood runoff, minimum summer-autumn runoff, minimum winter runoff for the rivers Yaselda, Rudavka, Ross, Narev, Lesnaya, Zelvyanka for the estimated

period from 1946 to 2018, as well as factors of variation and parameters of linear trends of flow changes.

Using the three-parameter gamma distribution method, the annual water consumption characteristic of a very high-water year (5% security) and a very low-water year (95% security), as well as for the maximum water consumption of the spring flood, the maximum water consumption of rain floods, the minimum expenses of summer-autumn and winter autumn were determined (Table 2).

The calculation of the average monthly water consumption of the Bialowieza Forest's rivers on which regular hydrometric observations of a very high-water year (P=5%), an average water content year (P=50%) and a very low-water year (P=95%) are conducted is presented in Table 3.

For rivers where regular hydrological observations are not conducted, distribution parameters and calculated values were determined using a set of methods, namely: water balance; hydrological analogy; averaging in a homogeneous area; construction of contour maps, etc. [7, 8].

The calculation of the average annual water consumption of the rivers of the National park «Bialowieza Forest», as well as the annual expenses of very high-water and very low-water years are presented in Table 4.

The calculation of the average monthly water consumption of the rivers of Belovezhskaya Pushcha on which there are no regular hydrometric observations for the security of 5, 50, 95% is presented in Table 5.

Table 1 – Main hydrological characteristics of the rivers of the National park «Bialowieza Forest»

River	Observation point	Runoff type	Norm, m^3/sec	Factor		Gradient, m^3/sec 10 years
				variation	correlation	
Zelvyanka	Peski	Annual	9.18	0.23	0.01	-0.09
		Spring flood	62.5	0.90	0.02	-12.83
		Rain flood	14.3	0.52	0.16	-0.31
		Summer-autumn	3.28	0.44	0.33	0.01
		Winter	4.26	0.33	0.22	0.21
Lesnaya	Zamosty	Annual	8.16	0.29	0.20	-0.17
		Spring flood	48.4	0.82	0.20	-8.85
		Rain flood	15.7	0.72	0.24	-2.42
		Summer-autumn	2.18	0.50	0.49	0.13
		Winter	3.66	0.47	-0.02	0.28
Narev	Nemerzha	Annual	1.33	0.51	0.14	-0.04
		Spring flood	12.4	1.02	-0.04	-2.60
		Rain flood	2.64	0.64	0.23	-0.08
		Summer-autumn	0.17	0.83	0.11	-0.02
		Winter	0.33	0.72	0.07	0.02
Ross	Studenets	Annual	4.91	0.18	0.09	-0.06
		Spring flood	36.9	1.20	-0.13	-9.79
		Rain flood	6.00	0.40	0.13	0.10
		Summer-autumn	2.82	0.23	0.38	-0.05
		Winter	3.22	0.27	0.25	0.13
Rudavka	Rudnya	Annual	0.645	0.35	0.18	-0.01
		Spring flood	4.53	0.49	0.18	-0.55
		Rain flood	2.07	0.73	0.12	-0.25
		Summer-autumn	0.100	0.87	0.10	0.01
		Winter	0.174	0.70	-0.01	0.02
Yaselda	Horev	Annual	3.15	0.34	0.12	-0.10
		Spring flood	11.8	0.53	0.13	-1.47
		Rain flood	5.23	0.28	0.19	-0.06
		Summer-autumn	0.755	0.52	0.48	-0.01
		Winter	1.75	0.50	0.53	0.27

Table 2 – Water consumption of rivers of the National park «Bialowieza Forest» in very high and very low-water years, m^3/sec

Year dryness	Runoff type				
	Annual	Spring flood	Summer-autumn	Winter	Rain flood
river Zelvyanka – Peski					
P=5 %	13.3	187	6.06	7.27	33.6
P=95 %	7.06	21.3	1.31	1.98	7.87
river Lesnaya – Zamosty					
P=5 %	12.8	127	3.9	7.18	37.3
P=95 %	5.21	10.5	0.663	1.53	4.63
river Narev – Nemerzha					
P=5 %	2.52	23.9	0.522	0.98	7.74
P=95 %	0.716	1.98	0.011	0.088	0.613
river Ross – Studenets					
P=5 %	5.95	74.4	3.79	4.97	8.7
P=95 %	4.10	2.92	1.83	2.65	4.65
river Rudavka – Rudnya					
P=5 %	1.35	9.69	0.37	0.599	6.54
P=95 %	0.37	2.57	0.00	0.024	0.623
river Yaselda – Horev					
P=5 %	4.74	20.8	2.02	3.64	10.5
P=95 %	2.35	6.27	0.481	1.00	3.31

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Table 3 – Annual distribution of the runoff of the Bialowieza Forest's rivers for years of different security (in % of the annual runoff)

Year dryness, %	Spring				Summer-autumn							Winter			
	III	IV	V	Σ	VI	VII	VIII	IX	X	XI	Σ	XII	I	II	Σ
river Zelvyanka – Peski															
5	5.78	24.9	9.25	40	5.59	7.46	4.45	5.48	6.58	8.16	37.7	6.56	5.36	10.4	22.3
50	20.2	12.1	7.43	39.8	7.13	5.7	4.7	5.75	6.46	7.88	37.6	7.39	9.21	5.99	22.6
95	18.1	13.2	10.1	41.4	6.94	5.76	4.92	5.26	6.58	7.81	37.3	9.12	6.54	5.7	21.4
river Lesnaya – Zamosty															
5	18.7	8.95	5.39	33.1	8.43	5.65	3.89	4.77	8.43	11.1	42.3	5.31	7.32	12	24.7
50	20	14.4	8.29	42.7	7.67	5.07	3.32	3.87	5.01	6.25	31.2	8.48	11.6	6.04	26.1
95	23.3	16.3	10.9	50.5	4.89	3.32	2.46	2.8	4.11	6.03	23.6	10.4	7.11	8.35	25.9
river Narev – Nemerzha															
5	10.6	20	4.02	34.6	2.77	6.9	4.53	4.48	11.1	15	44.7	3.55	10.6	6.52	20.7
50	26.8	19.7	9	55.5	4.33	2.9	1.51	1.56	2.73	4.73	17.8	8.26	13.6	4.82	26.7
95	36.2	24.6	11.6	72.4	1.6	0.75	0.42	0.46	0.81	1.35	5.4	4.9	10.1	7.19	22.2
river Ross – Studenets															
5	14.2	9.3	6.76	30.2	6.69	7.9	5.83	8.09	7.04	7.53	43.1	8.82	7.85	10	26.7
50	12.4	10.2	8.23	30.8	7.68	6.96	5.91	6.71	7.58	8.34	43.2	8.68	7.62	9.7	26
95	11.8	9.83	8.3	29.9	7.36	5.51	6.25	6.04	7.98	9.59	42.7	10.5	8.81	8.04	27.3
river Rudavka – Rudnya															
5	12.7	6.97	3.81	23.4	3.08	6.32	10.7	4.93	9.24	15.9	50.2	7.58	14.1	4.7	26.4
50	8.33	32.7	18.4	59.4	6.81	2.39	1.41	2.2	3.59	5.72	22.1	5.47	9.76	3.19	18.4
95	24.4	49.3	11.3	85	1.36	0.59	0.28	0.26	0.59	1.22	4.29	5.83	2.7	2.18	10.7
river Yaselda – Horev															
5	4.99	7.05	3.53	15.6	10.5	8.42	6.17	7.33	10.1	12	54.5	9.65	12.7	7.48	29.9
50	8.78	17.1	12.1	38.1	6.9	5.24	4.37	4.99	6.22	7.32	35	8.61	11.5	6.8	26.9
95	21.5	14.9	11.8	48.2	5.46	3.52	2.82	3.26	4.75	6.02	25.9	8.52	10.7	6.72	25.9

Table 4 – Characteristics of the Bialowieza Forest's rivers

River	Catchment			Runoff norm, м³/с	Water runoff dryness, %	
	square, km²	degree of forest cover, %	swampiness, %		P=5 %	P=95 %
Belaya	273.3	23.1	2.1	1.10	1.91	0.507
Berezovka	24.7	21.2	–	0.077	0.126	0.039
Vishnya	43.4	77.7	3.0	0.126	0.231	0.051
Gvozna	94.0	93.1	24.1	0.384	0.647	0.185
Gitka	13.3	99.5	1.8	0.038	0.065	0.018
Guricinka	9.6	56.3	2.7	0.039	0.061	0.021
Drunyuvka	40.4	69.1	14.8	0.143	0.241	0.069
Yelenka	12.3	95.3	14.6	0.042	0.071	0.021
Zlota	6.4	40.3	4.0	0.018	0.031	0.009
Zubrica	14.6	91.5	10.3	0.044	0.076	0.021
Kalinovets	7.2	99.3	5.3	0.021	0.037	0.009
Kolonna	93.8	52.0	15.4	0.478	0.771	0.247
Krapivnica	39.1	43.4	2.8	0.137	0.227	0.068
Kulevka	9.9	96.6	18.8	0.034	0.058	0.017
Left Lesnaya	435.0	54.3	6.0	1.48	2.61	0.646
Right Lesnaya	409.6	63.2	8.0	1.57	2.74	0.705
Lomovka	17.3	57.8	1.6	0.061	0.099	0.031
Loshanka	35.9	19.4	0.0	0.126	0,207	0,064
Luzhaika	47,4	19,4	17,1	0,113	0,206	0,046
Lutovka	82,5	92,0	7,3	0,316	0,542	0,147
Medyanka	57,8	60,1	17,6	0,276	0,469	0,130
Muravka	5,8	31,9	4,3	0,018	0,031	0,008
Narevka	468,5	60,1	8,7	1,98	3,33	0,959
Nemerzhanka	34,8	98,2	25,3	0,116	0,198	0,055
Ol'hovka	16,6	30,1	77,3	0,068	0,114	0,033
Orluvka	18,7	98,8	24,2	0,066	0,110	0,033
Perevoloka	33,2	96,6	17,0	0,098	0,167	0,047
Peredelka	17,8	17,8		0,056	0,093	0,028
Pesec	9,0	95,7	4,4	0,035	0,059	0,017
Plyuskovka	96,8	97,2	22,1	0,332	0,595	0,137
Poboika	13,5	91,4	11,4	0,047	0,079	0,023
Polichna	126,7	66,9	4,0	0,528	0,898	0,249
Poperechnaya	57,1	8,8	0,4	0,186	0,332	0,078
Pchelka	37,9	64,9	15,8	0,152	0,247	0,076
Sipurka	67,3	27,9	2,0	0,193	0,327	0,091
Solomenka	84,8	91,9	23,2	0,193	0,327	0,091
Stanock	19,2	94,3	5,4	0,056	0,098	0,025
Tochnica	38,3	20,5	0,2	0,133	0,240	0,056
Tushemlyanka	26,8	64,9	27,9	0,095	0,159	0,046
Horovka	21,0	50,9	1,0	0,074	0,116	0,039
Schiba	124,7	44,3	2,9	0,652	1,03	0,353
Yamenka	40,3	98,4	16,0	0,119	0,203	0,056
Yatvez'	55,0	29,1		0,186	0,305	0,098

Table 5 – Annual distribution of the runoff of the Bialowieza Forest's rivers for years of different dryness (in % of the annual runoff)

Year dryness. %	Spring				Summer-autumn							Winter			
	III	IV	V	Σ	VI	VII	VIII	IX	X	XI	Σ	XII	I	II	Σ
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
river Guricinka															
5	23.4	7.4	4.2	35	8.7	4.9	6.1	3.7	8.4	12.8	44.6	11	5.5	3.9	20.4
50	30.5	9.7	5.5	45.7	6.6	3.8	4.7	2.8	6.5	9.8	34.2	10.8	5.4	3.9	20.1
95	39.5	12.5	7.1	59.1	4.3	2.4	3	1.8	4.2	6.3	22	10.2	5.1	3.6	18.9
river Pesec															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	35.5	14.4	6.1	56	5.4	3.2	1.9	0.8	3.3	6.4	21	14	5.7	3.3	23
river Schiba															
5	23	7.9	4.2	35.1	8.72	4.88	6.07	3.7	8.38	12.8	44.5	11	5.5	3.91	20.4
50	30	10.2	5.5	45.7	6.63	3.82	4.72	2.83	6.46	9.76	34.2	10.8	5.42	3.92	20.1
95	38.8	12.9	7.2	58.9	4.33	2.44	3.03	1.84	4.2	6.29	22.1	10.2	5.14	3.65	19
river Medyanka															
5	42	10.7	3.7	56.4	2.59	1.86	5.45	6.71	4.79	6.8	28.2	4.96	2.34	8.11	15.4
50	40.3	20.1	8.84	69.3	3.92	2.32	1.7	1.99	3.2	5.29	18.4	5.42	3.11	3.77	12.3
95	49.8	27.6	8.59	86	1.61	0.91	0.70	0.79	1.11	1.81	6.94	3.9	1.91	1.3	7.11
river Perevoloka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Solomenka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Tochnica															
5	22.2	9.37	4.1	34	10.5	6.2	3.83	1.8	6.53	12.5	41.4	13.6	5.83	3.55	22.9
50	30.5	12.9	5.56	49	6.9	4.07	2.52	1.23	4.3	8.25	27.3	14	6.07	3.63	23.7
95	41.1	17.3	7.43	65.9	3.17	1.93	1.2	0.58	1.97	3.85	12.7	12.7	5.45	3.28	21.5
river Polichna															
5	22.5	9.24	3.94	35.3	10.7	6.28	3.73	1.64	6.59	12.6	41.5	13.8	5.73	3.35	22.8
50	31	12.7	5.36	49.1	6.98	4.09	2.42	1.13	4.3	8.21	27.1	14.3	6.01	3.45	23.8
95	41.8	17.1	7.17	66.1	3.11	1.91	1.12	0.52	1.91	3.73	12.3	13	5.41	3.14	21.6
river Sipurka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Right Lesnaya															
5	21.8	9.55	4.32	32.2	10.2	6.09	3.98	2.02	6.46	12.4	41.2	13.3	5.98	3.82	23.1
50	29.9	13.1	5.85	48.9	6.79	4.03	2.64	1.38	4.3	8.3	27.4	13.6	6.14	3.89	23.7
95	40.2	17.5	7.79	65.5	3.24	1.97	1.31	0.67	2.04	4.01	13.2	12.3	5.5	3.48	21.3
river Belaya															
5	22.2	9.4	4.14	33.7	10.4	6.18	3.86	1.84	6.52	12.5	41.3	13.5	5.86	3.6	23
50	30.4	12.9	5.63	49	6.88	4.06	2.54	1.26	4.3	8.26	27.3	14	6.08	3.68	23.7
95	40.9	17.3	7.51	65.8	3.18	1.94	1.22	0.60	1.98	3.88	12.8	12.6	5.46	3.32	21.4
river Left Lesnaya															
5	21.9	9.53	4.29	32.4	10.2	6.1	3.96	1.99	6.47	12.4	41.2	13.3	5.96	3.79	23.1
50	30	13.1	5.82	48.9	6.8	4.03	2.63	1.36	4.3	8.3	27.4	13.7	6.13	3.86	23.7
95	40.3	17.5	7.75	65.5	3.23	1.97	1.3	0.66	2.03	3.99	13.2	12.4	5.5	3.46	21.3
river Krapivnica															
5	23.4	7.4	4.2	35	8.7	4.9	6.1	3.7	8.4	12.8	44.6	11	5.5	3.9	20.4
50	30.5	9.7	5.5	45.7	6.6	3.8	4.7	2.8	6.5	9.8	34.2	10.8	5.4	3.9	20.1
95	39.5	12.5	7.1	59.1	4.3	2.4	3	1.8	4.2	6.3	22	10.2	5.1	3.6	18.9
river Kolonna															
5	22.5	9.24	3.95	35.3	10.6	6.27	3.74	1.65	6.58	12.6	41.5	13.7	5.74	3.37	22.8
50	30.9	12.8	5.37	49.1	6.97	4.09	2.43	1.14	4.3	8.21	27.1	14.3	6.02	3.46	23.8
95	41.8	17.2	7.19	66.1	3.12	1.91	1.13	0.52	1.92	3.74	12.3	13	5.41	3.15	21.6
river Poboika															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Pchelka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Lomovka															
5	23.4	7.4	4.2	35	8.7	4.9	6.1	3.7	8.4	12.8	44.6	11	5.5	3.9	20.4
50	30.5	9.7	5.5	45.7	6.6	3.8	4.7	2.8	6.5	9.8	34.2	10.8	5.4	3.9	20.1
95	39.5	12.5	7.1	59.1	4.3	2.4	3	1.8	4.2	6.3	22	10.2	5.1	3.6	18.9

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
river Kulevka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Drunyuvka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Horovka															
5	23.4	7.4	4.2	35	8.7	4.9	6.1	3.7	8.4	12.8	44.6	11	5.5	3.9	20.4
50	30.5	9.7	5.5	45.7	6.6	3.8	4.7	2.8	6.5	9.8	34.2	10.8	5.4	3.9	20.1
95	39.5	12.5	7.1	59.1	4.3	2.4	3	1.8	4.2	6.3	22	10.2	5.1	3.6	18.9
river Tushemlyanka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Nemerzhanka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Orluvka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Gvozna															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Zlota															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Lutovka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Yelenka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Poperechnaya															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Narevka															
5	22.2	9.38	4.12	33.9	10.4	6.19	3.85	1.82	6.53	12.5	41.3	13.5	5.85	3.57	23
50	30.5	12.9	5.59	49	6.89	4.06	2.53	1.25	4.3	8.25	27.3	14	6.07	3.66	23.7
95	41	17.3	7.46	65.8	3.17	1.94	1.21	0.59	1.97	3.86	12.7	12.7	5.45	3.3	21.4
river Yamenka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Poperechnaya															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Muravka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Zubrica															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Gitka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Luzhaika															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
river Kalinovets															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Plyuskovka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Stanock															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Vishnya															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Yatvez'															
5	23.4	7.4	4.2	35	8.7	4.9	6.1	3.7	8.4	12.8	44.6	11	5.5	3.9	20.4
50	30.5	9.7	5.5	45.7	6.6	3.8	4.7	2.8	6.5	9.8	34.2	10.8	5.4	3.9	20.1
95	39.5	12.5	7.1	59.1	4.3	2.4	3	1.8	4.2	6.3	22	10.2	5.1	3.6	18.9
river Loshanka															
5	23.4	7.4	4.2	35	8.7	4.9	6.1	3.7	8.4	12.8	44.6	11	5.5	3.9	20.4
50	30.5	9.7	5.5	45.7	6.6	3.8	4.7	2.8	6.5	9.8	34.2	10.8	5.4	3.9	20.1
95	39.5	12.5	7.1	59.1	4.3	2.4	3	1.8	4.2	6.3	22	10.2	5.1	3.6	18.9
river Berezovka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6
river Peredelka															
5	22.6	9.2	3.9	35.7	10.7	6.3	3.7	1.6	6.6	12.6	41.5	13.8	5.7	3.3	22.8
50	31.1	12.7	5.3	49.1	7	4.1	2.4	1.1	4.3	8.2	27.1	14.4	6	3.4	23.8
95	42	17.1	7.1	66.2	3.1	1.9	1.1	0.5	1.9	3.7	12.2	13.1	5.4	3.1	21.6

Conclusion

The analysis of the database of hydrological observations of the flow of the Bialowieza Forest's rivers for various types (average annual, average monthly, spring floods, rain floods, summer-autumn and winter low water) for the current closed hydrometric posts for the period of instrumental observations up to and including 2018. In the course of the conducted studies, the missed water flow rates were restored, the series of observations were brought to a single calculation period from 1946 to 2018, and an assessment for uniformity was performed. The formed hydrological base allows solving a number of hydrological, ecological and water management tasks for the rivers of the National park «Bialowieza Forest».

During the research, hydrographic information on the rivers of the National park «Bialowieza Forest» was updated using GIS technologies, including the catchment area, river length, catchment slope, forest cover and swampiness of the territory in absolute and relative terms, and other parameters. This made it possible to estimate the flow of rivers for different water years.

The analysis of river flow fluctuations during the period of instrumental observations showed a slight change in the decrease in the average annual river flow. At the same time, there is a decrease in spring flood runoff and an increase in winter runoff on all rivers. The average long-term runoff of rain floods tends to some slight decrease, and the runoff of the summer–autumn fall, on the contrary, to a slight increase for most of the rivers studied.

Gratitudes

This research was completed within the scope of the task ZT.2.5. «Development of analyze and forecast changes in the water regime of the territory of National park «Bialowieza Forest» and recommendations for its maintenance» of the State Scientific and Technical Program «Green technologies of resource management and environmental safety» Subprogram «Sustainable nature management and innovative technologies for processing, protection and reproduction of natural resources».

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