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ASSESSMENT OF THE KRASNAYA SLOBODA FISH FARM IMPACT ON THE MOROCH RIVER RUNOFF

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Abstract

A comprehensive assessment of the impact of the Krasnaya Sloboda fish farm on the hydrological regime of the Moroch River in the calculated areas was carried out. The following methods were used in the work: field research, desk data processing, geographical analysis, statistical analysis, regression analysis, water balance calculations. The analysis of the hydrological regime of the calculated sections of the river used for the needs of the fish farm made it possible to determine the minimum average monthly water consumption of 95% probability of excess and ecological runoff, taking into account the intra-annual distribution of runoff. For the central section of the Krasnaya Sloboda fish farm, the permissible volume of withdrawal of water resources from the Moroch River has been determined.

Keywords: fish farm, reconnaissance survey, ecological runoff, water consumption, mathematical model, water content of the year.

ОЦЕНКА ВЛИЯНИЯ РЫБХОЗА «КРАСНАЯ СЛОБОДА» НА СТОК РЕКИ МОРОЧЬ

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Реферат

Выполнена комплексная оценка воздействия рыбхоза «Красная Слобода» на гидрологический режим р. Морочь в расчетных участках. В работе использовались следующие методы: полевые исследования, камеральная обработка данных, географический анализ, статистический анализ, регрессионный анализ, водобалансовые расчеты. Проведенный анализ гидрологического режима расчетных участков реки, используемых для нужд рыбхоза, позволил определить минимальный среднемесячный расход воды 95 % вероятности превышения и экологический сток с учетом внутригодового распределения стока. Для центрального участка рыбхоза «Красная Слобода» определен допустимый объем изъятия водных ресурсов из р. Морочь.

Ключевые слова: рыбоводное хозяйство, рекогносцировочное обследование, экологический сток, расход воды, математическая модель, водность года.

Introduction

Fishing is a unique type of production and plays an important role in the food complex of the Republic of Belarus, which provides the population with high-quality food. It is directly related to the use of water resources and places very high demands on their regime, quantitative and qualitative state. For the successful reproduction and normal development of fish, clean water with a sufficient amount of dissolved oxygen and the absence of harmful impurities, appropriate temperature and provision of feed are necessary. Water quality standards for fishery facilities are stricter than for drinking water sources.

For fish, the most important conditions are temperature, transparency, gas regime, content of nutrients. The connection of hydrobionts with the elements of the external environment is interdependent, and a change in one system of connections inevitably causes a change in the other. Therefore, considering the influence of individual components of the hydrochemical regime on the vital activity of hydrobionts, it is necessary to bear in mind the conditionality of such separation, because in nature all the relations of the organism and the environment are interconnected. The most favorable value for most fish is the hydrogen index (pH), which is close to neutral. With significant shifts to the acidic or alkaline side, the oxygen threshold increases, the intensity of fish respiration weakens, and the water itself can become toxic to fish [1, 2].

The purpose of this work is to assess the impact of the Krasnaya Sloboda fish farm on the Moroch River runoff.

Materials and methods

The Moroch is a 150 km long river in the Minsk region, a right tributary of the Sluch River. The catchment area is 2030 km^2. The average annual water consumption at the mouth is 8.7 m^3/s. The average slope of the water surface is 0.5%. The forest cover of the catchment area is 29%. The spring flood period accounts for 63% of the annual runoff. The maximum flood level is at the end of March, the average height above the mean level is 2.4 m. It freezes in mid-December, opens in mid-March. The spring ice drift lasts 5 days.

In this work, the data of hydrometric observations on the Moroch River for the period from 1954 to 2018, i.e. 65 years, which is sufficient to obtain objective statistical hydrological characteristics, are used. The missing data in the series of observations were restored with the use of data from observations of analogous points, taking into account the presence of synchronicity in the fluctuations of the river flow of the calculated gate and the lines of analogs, as well as taking into account the methods of bringing the series of hydrological characteristics to a multiyear period in the presence of hydrological observations for 6 years or more.

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To determine the water flow rates of different availability in a separate alignment, it is necessary to solve two separate tasks:

- arrange a temporary water measuring post and measure the main characteristics of the flow;
- determine the water content of the year of the studied watercourse at the current time.

According to the results of standard hydrometric work, the marks of the characteristic points of the channel are determined, on the basis of which the transverse profile of the channel is constructed, and the cross-sectional areas (ω), wetted perimeter (χ) and hydraulic radius (R) for different filling depths are calculated according to the following formulas:

$$\omega = \frac{1}{2}\sum_{i=1}^{n}\left(x_i\left(y_{i+1}-y_{i-1}\right)\right), \quad (1)$$

$$\chi = \sum_{i=1}^{n-1}\sqrt{\left(x_i - x_{i+1}\right)^2 + \left(y_i - y_{i+1}\right)^2} \quad (2)$$

where x_i and y_i – the coordinates of the i–th point of the polygon in question (Fig. 1), m;

n – the number of points of the polygon.

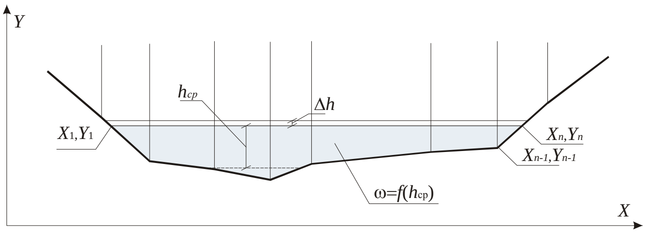


Figure 1 – Algorithm for calculating the proportions of forest cover, waterlogging and waterlogging of catchments

Thus, given the increment of depth Δh, the dependence of the cross-sectional area ω and the average depth h_{cp} is constructed. The increment of depth is taken depending on the severity of the relief of the bottom of the watercourse, but it is recommended to take the number of iterations $\tau > 25$, then $\Delta h = \frac{Y_{max} - Y_{min}}{\tau}$. Similarly the dependence of the wetted perimeter χ and the hydraulic radius R is determined.

Using the obtained arrays $\left[\omega, h_{cp}\right]$ and $\left[R, h_{cp}\right]$, the parameters of the regression model of the form [3] are evaluated

$$z = \alpha \cdot {h_{cp}}^2 + \beta \cdot h_{cp} + \varphi, \quad (3)$$

where z – the predicted geometric parameter of the channel;

α, β, φ – the constants of the regression equation.

To determine the water content of the current year, an analog river is selected, which has a long series of observations of the hydrological regime. As the preliminary analysis showed, the water content of the year with a high accuracy of approximation (r> 0.75) is determined by the months preceding the calculated one. When determining the parameters of the distribution function (three-parameter gamma distribution), the maximum likelihood method is used, for which there is a system of equations.

The method of determination developed by us is described in detail in [4, 5]. Ecological runoff is the amount of water that must remain in the river to ensure the conditions for the existence of hydrobionts while maintaining its necessary quality. In this case, floodplain ecosystems are preserved, and the river remains an element of the landscape. Thus, the ecological runoff ensures the quantitative and qualitative condition of the water body in the most low-water period of the year.

In general, environmental (minimum permissible) the drain should take into account the following factors [6]:

- the volume necessary for the normal development of hydrobionts. In this case, it is required to maintain water flow rates in the range of 0.25 – 0.6 m / s (0.25 m / s is the lower limit of the speed regime at which the rapid development of phytoplankton begins), with a flow depth of at least 0.1 – 3 m. An important period from the point of view of environmental functions is the inter–temperate periods of summer and winter. However, with an average thickness of ice formation from 17 to 45 cm, the death of ichthyofauna can be observed;
- the river performs its natural functions. The river network transports substances and energy, thus redistributing them in time and space;
- intra-annual variability of runoff. The presence of the variability of the river flow during the year supports the natural cyclicity in the development of various biological species;
- variability of runoff by year. As well as intra-annual variability, fluctuations in the volume of runoff over the years make it possible to enrich the floodplain part of the watercourse with nutrients. At the same time, flooding destroys hydrophobic plants inhabiting the floodplain during a low-water period.

In Belarus, the amount of ecological runoff is taken as 75% of the minimum monthly runoff of 95% security. But this approach does not fully meet the above requirements, namely: it does not provide intra-annual variability of runoff, does not take into account long-term cycles of water content and in most cases the minimum water flow velocity is not achieved.

The method of increasing security implies the allocation of the lower and upper limits of the flow change, which is practically found on a real river [7]. The essence of the method is to establish a lower limit of the environmentally acceptable runoff at the level of monthly expenses for a year of 99% security, since these conditions are marginal from the point of view of environmental management.

The consumption of 50% of security is accepted as the upper limit. Under these conditions, a normal mode of exchange of matter and energy is formed within the river-floodplain geosystem. The greatest productivity of river and floodplain ecosystems is observed with a security in the range of 40...60%.

The determination of the parameters of the ecological runoff distribution function is based on the transfer of the security of the average annual runoff to the predetermined security of the ecological runoff. Namely, it is assumed that the ecological runoff of 95% security corresponds to the average annual runoff of 99% security, and the ecological runoff of 25% security is assumed to be equal to the runoff of 50% security. Having two points of the curve of the distribution function of a random variable, you can select its parameters. However, the application of this approach limits the range of applied theoretical distribution curves (only two parametric distribution functions are applicable). In addition, the application of the transition is seen as quite subjective and cannot always be used as a project or directive. The application of this approach is most effective for large rivers. In the conditions of Belarus, where the compilation of the water balance is mainly aimed at small or medium-sized rivers, the use of this method is not always effective and reasonable [6].

The existing approaches to determining the ecological flow regulate only the minimum value of the river flow. At the same time, there is no definition of ecological runoff for various security conditions. The most effective way to determine the ecological runoff, taking into account the intra-annual distribution, is a way to increase security. Therefore, it is used in this work.

Results and discussion

To quantify the impact of the Krasnaya Sloboda fish farm on the flow of the Moroch River in June 2021, we performed hydrometric measurements of water flow in the channels located above and below the fish farm. The upper section is located on the northern outskirts of the agricultural town of Semezhevo, which is located in the south of the Kopylsky district of the Minsk region (Fig. 2).

Throughout the considered section of the river, the riverbed has a relatively rectilinear shape. Its width on the section of the target was 18 meters. The left and right banks with a height of about 1 m have a significant slope. The coastline is represented by sandstone, overlain by dense grassy vegetation with places of bushes. The bottom within the target is sandy-gravelly. The trunk is completely covered with aquatic vegetation (Fig. 3).

Figure 2 – Map-layout of the upper section

Based on the results of depth measurements in the upper alignment, a transverse profile of the Moroch river was constructed (Fig. 4) and the main characteristics were determined at the time of the survey: water flow Q = 1.08 m^3/s; cross-sectional area F = 13.83 m^2; river width along the water edge B = 17.4 m; average flow depth h_{cp} = 0.79 m; average water flow velocity V_{cp} = 0.78 m/s; maximum velocity V_{max} = 0.142 m/s.

The lower section is located near the intersection of the Moroch River and the H-9601 road on the stretch of road between the villages of Bolshoy and Maly Rozhan, which are located in the north-western part of the Soligorsky district of the Minsk region (Fig. 5).

The riverbed has a rectilinear character. Despite the width of 16 meters, the river in this place is quite shallow. The coast is low (does not exceed 1 m) in places steep sandy. The coastline and floodplain are covered with grassy vegetation. The bottom of the river is sandy. Near the shores, at some distance from the target, aquatic vegetation was present on the right bank, creating stagnant areas near the shores (Fig.6).

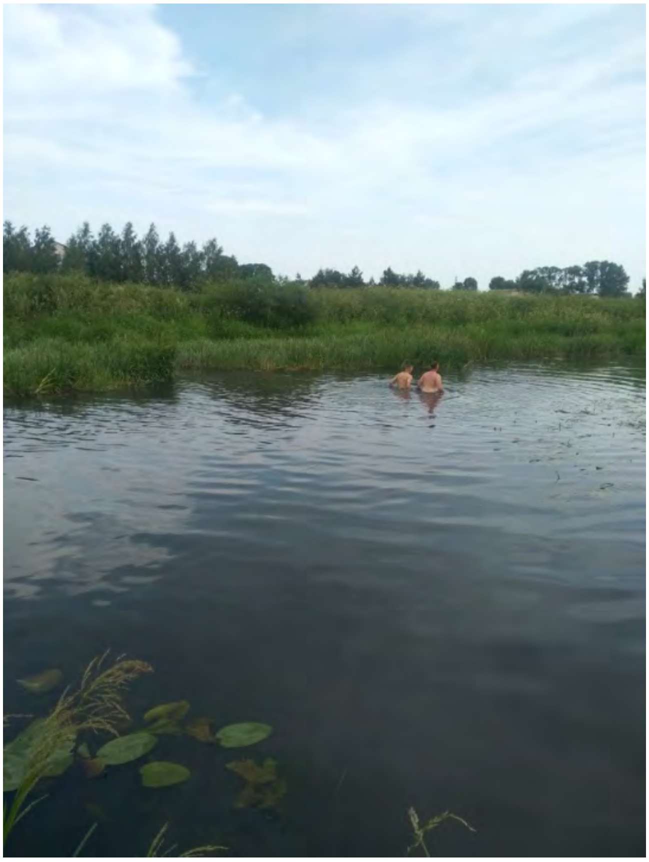
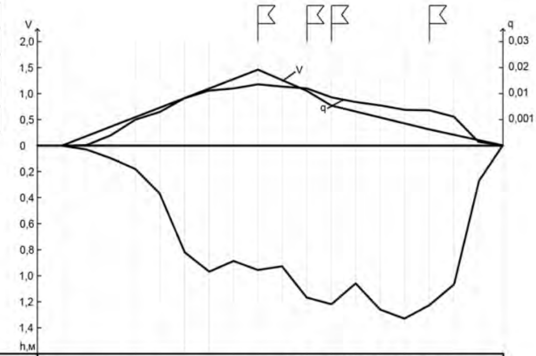


Figure 3 – Research area in the upper section

Q,m^3/s	1,08
F,m^2	13,83
B,m	17,4
hcp,m	0,79
Vcp,m/s	0,78
Vmax, m/s	0,142



No. of verticals		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Distance from the constant start, m	0,5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	17,9
Depth, m	0	0,02	0,1	0,16	0,38	0,83	0,97	0,91	0,96	0,94	1,18	1,2	1,13	1,22	1,26	1,21	1,08	0,3	0
Velocity, m/s	0	0,02	0,04	0,06	0,08	0,1	0,115	0,13	0,142	0,135	0,101	0,072	0,06	0,045	0,03	0,0298	0,01	0,005	0
Elementary water consumption, m^2/s	0	0,0002	0,004	0,0096	0,03	0,083	0,112	0,12	0,136	0,127	0,12	0,086	0,068	0,055	0,038	0,036	0,011	0,0015	0

Figure 4 – Transverse profile of the Moroch River in the upper section

Figure 5 – Map-layout of the lower section

Figure 6 – Research area in the lower section

Based on the results of depth measurements in the upper alignment, a transverse profile of the Moroch river was constructed (Fig. 7) and the main characteristics were determined at the time of the survey: water flow Q = 1.42 m³/s; cross-sectional area F = 8.685 m²; river width along the water edge B=16.4 m; average flow depth h_{cp}= 0.53 m; average water flow velocity V_{cp}=0.16 m/s; maximum velocity V_{max}= 0.234 m/s.

A comparative analysis of the studied sections showed their significant difference. So the section of the river in the lower alignment requires cleaning of the riverbed. Of the quantitative characteristics, attention is drawn to the increase in water runoff in the lower alignment ΔQ = 0.34 m³/s. This is caused by additional discharge of water from the surface of fish ponds.

Based on the results of processing hydrometric measurement data according to the method described above, mathematical models (flow rates/levels/velocities) and curves of the relationship between the velocity/flow rate and the water level in the formation of the Moroch River were obtained according to the method [8, 9]. As a feature, it should be noted that the use of communication curves is permissible only within the established range. The use of extrapolation is acceptable, but it can lead to significant deviations and errors.

For the upper section:

$$V = -0{,}0618 h_{\text{cp}}{}^3 + 0{,}1111 h_{\text{cp}}{}^2 + 0{,}0484 h_{\text{cp}}$$
$$Q = 2{,}1764 h_{\text{cp}}{}^3 - 0{,}4465 h_{\text{cp}}{}^2 + 0{,}1859 h_{\text{cp}}$$

For the lower section:

$$V = 0{,}0561 h_{\text{cp}}{}^3 - 0{,}1163 h_{\text{cp}}{}^2 + 0{,}3547 h_{\text{cp}}$$
$$Q = 0{,}6323 h_{\text{cp}}{}^3 + 4{,}6266 h_{\text{cp}}{}^2 - 0{,}0510 h_{\text{cp}}$$

The data obtained during the calculation of the ecological flow of rivers allowed us to determine the values of the permissible withdrawal of surface water from the river, taking into account evaporation losses from the water mirror and filtration from reservoirs. The results of calculations, provided that the ecological runoff is preserved in the rivers under consideration, taking into account the intra-annual distribution for various probabilities of excess (security), are given below.

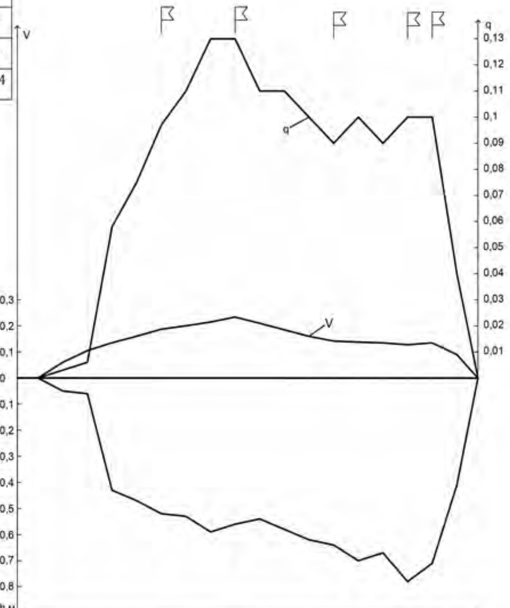
The analysis of the hydrological characteristics of the Moroch River was carried out on the estimated section of the river below the Krasnaya Sloboda fish farm. Data on the quantitative characteristics of the flow of the Moracha River by month and by year are presented in Table 1.

The characteristics of the minimum flow are calculated for the hydrological justification of various water management and water protection projects, namely: the design of hydroelectric power plants for energy generation, water supply of cities, rural settlements, water transport, fisheries. In the practice of water management design, the main application is found in the values of the minimum runoff of security in the range of 75–99%, characterizing years with low−water intervals of relatively rare repeatability. When assessing the worst conditions for the formation of water quality, a minimum flow of 95% security is usually used (average repeatability 1 time in 20 years), which is a rather arbitrary condition requiring differentiation depending on the severity of negative environmental and sanitary consequences. Table 2 shows the results of calculating the minimum average monthly water consumption of 95% of the probability of excess (security), taking into account the intra-annual distribution of runoff.

Taking into account the results of field studies and using the security transfer method, we carried out hydrological calculations to determine the ecological flow of the Moroch River, taking into account the intra–annual distribution of runoff for various probabilities of excess (security), the results of which are shown in Tables 3-4.

The results of calculations for the Moroch River showed the possibility of permissible withdrawal of surface water per year from 20.26 million m³ for ecological runoff 95% probability of excess to 83.12 million m³ for ecological runoff 5% probability of excess. The maximum allowable withdrawal of surface water from the river, taking into account the preservation of the lowest critical value of ecological runoff, cannot exceed 93.60 million m³. The largest withdrawal from the Moroch River is permissible in the spring months – in total from 14.86 million m³ (95% security) to 50.64 million m³ (5% of security), and the smallest – in summer (from June to August) – from 0.38 to 7.17 million m³, respectively. At the same time, in low-water years (in July there is a 95% probability of excess for runoff and in August there is a 75% probability of excess for runoff), withdrawal is not allowed, since the runoff in the river during these months corresponds to ecological runoff.

Q, m³/s	1.42
F, m²	8.685
B, m	16,4
hcp, m	0.53
Vcp, m/s	0.16
Vmax, m/s	0.234



No. of verticals		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Distance from the constant start, m	0	0.9	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	16.4
Depth, m	0	0.05	0.06	0.43	0.47	0.52	0.53	0.59	0.56	0.54	0.58	0.62	0.64	0.7	0.67	0.78	0.71	0.41	0
Velocity, m/s	0	0.06	0.105	0.135	0.16	0.187	0.2	0.215	0.234	0.21	0.185	0.16	0.142	0.138	0.135	0.128	0.135	0.09	0
Elementary water consumption, m²/s	0	0.003	0.006	0.058	0.075	0.097	0.11	0.13	0.13	0.11	0.11	0.1	0.09	0.1	0.09	0.1	0.1	0.04	0

Figure 7 – Transverse profile of the Moroch River in the lower section

Table 1 – Intra-annual distribution of the flow of the Moroch River in the average water content year

Interval												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Runoff, m^3/c												
3.36	4.70	17.2	22.7	4.75	3.07	2.59	2.53	2.68	3.33	5.10	4.81	6.42
Coefficient of variation, Cv												
0.71	1.02	0.75	0.95	0.63	0.70	0.68	1.07	0.82	0.53	0.61	0.60	0.30
Coefficient of asymmetry, Cs												
1.44	1.42	0.52	1.57	1.78	2.31	2.17	4.93	2.19	1.17	1.52	1.47	0.87
Autocorrelation coefficient, $r(1)$												
0.01	0.14	0.09	0.20	0.05	0.01	-0.16	-0.20	0.06	-0.15	0.00	0.03	0.25

Table 2 – Minimum average monthly water consumption of 95% security, taking into account the intra-annual distribution of the flow of the Moroch River, million m^3

Interval												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
4.78	3.46	28.9	41.53	10.01	4.89	2.72	3.59	3.02	4.12	6.88	7.52	121.4

Table 3 – Ecological runoff taking into account intra-annual distribution, million m^3

Interval												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
95 % probability of excess (security)												
3.86	2.79	23.3	33.50	8.07	3.95	2.19	2.90	2.44	3.32	5.55	6.06	97.97
75 % probability of excess (security)												
6.41	3.82	35.0	38.34	8.51	7.31	4.21	3.01	3.70	6.07	9.28	12.27	137.9
50% probability of excess (security)												
7.45	4.44	40.7	44.54	9.89	8.49	4.89	3.49	4.29	7.05	10.78	14.26	160.3
5% probability of excess (security))												
11.31	6.74	61.8	67.62	15.01	12.89	7.42	5.30	6.52	10.70	16.37	21.65	243.3

Table 4 – The values of permissible withdrawal of surface water from the Moroch River, taking into account the conservation of ecological runoff, million m^3

Interval												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
95 % probability of excess (security)												
0.91	0.65	5.56	7.85	1.45	0.30	0.00	0.08	0.19	0.59	1.25	1.43	20.26
75% probability of excess (security)												
1.27	0.75	7.01	7.52	1.22	0.82	0.17	0.00	0.35	1.01	1.78	2.45	24.35
50% probability of excess (security)												
1.55	0.92	8.54	9.19	1.59	1.14	0.35	0.12	0.51	1.28	2.19	2.98	30.35
5% probability of excess (security)												
4.00	2.38	21.9	23.85	4.85	3.94	1.96	1.27	1.92	3.60	5.74	7.68	83.12

Conclusion

A comprehensive assessment of the impact of the Krasnaya Sloboda fish farm, located in the Moroch River basin, on the hydrological regime of the river was carried out to improve the efficiency of water resources management, taking into account the ecological functioning of water bodies, during which the following tasks were solved:

– an analysis of the hydrological regime of the calculated sections of rivers used for the needs of fish farms located in the Moroch River basin, consisting of an analysis of available hydrological information, a representative period for calculating hydrological characteristics was established, which is 65 years and was adopted from 1954 to 2018, the main hydrological characteristics were determined, including the average annual values of runoff, coefficients of variation, asymmetries, autocorrelations;
– full-scale studies of river sections were carried out, during which the gates were laid above and below the water intake area for the needs of the fish farm. Transverse profiles are constructed. Hydrological characteristics have been calculated for the gates, which include the distribution of local longitudinal averaged water flow velocities and water flow rates in the cross sections of watercourses. The conducted field studies made it possible to determine the water consumption in the studied areas above and below the fish farms during the research period;

– hydrological calculations were performed to determine the minimum average monthly water consumption of 95% probability of excess (security) and ecological runoff, taking into account the intra-annual distribution of runoff of various security;
– mathematical models have been developed for the areas located below and above the fish farm in the form of mathematical models that allow, depending on the average depth of water in the alignment, to determine the flow rates and water flow rates;
– operational hydraulic calculations in order to assess the impact of water intakes by the fish farm on changes in the hydrological regime of water bodies (water depths, flow rates and water flow rates) are carried out on the basis of developed mathematical models as the difference in design parameters for the laid lines below and above the fish farms;
– the mathematical dependences for the depth, flow velocity and water flow rates in the studied areas below the fish farms corresponding to the ecological runoff were determined using the results of hydrological calculations and mathematical models of water bodies;
– the values of permissible withdrawal of surface water from the river used for the needs of fish farms have been determined, taking into account evaporation losses from the water mirror and filtration from reservoirs and ponds, while ensuring the conditions for preserving ecological runoff in rivers, which will allow determining the most effective filling regime for fish ponds.

The results obtained are relevant for the near future (10 years), however, they may require some adjustments in the future due to projected climate changes. Forecast estimates of changes in the flow of the Moroch River for the period up to 2035 are characterized by a slight change in the flow on average per year, but there is a high probability of its unevenness and multidirection in seasons and months. The runoff can change especially significantly in the summer months. The increase in the unevenness of the intra-annual distribution of runoff and the increase in flood risks caused by sharp thaws in winter, the earlier onset of spring floods and an increase in the intensity of rain floods can lead to an increase in the risks of extreme events, including the occurrence of low-water periods, the likelihood of long low-water periods increases. During low-water periods, there may be a significant decrease in the flow of small rivers, deterioration of the ecological state and recreational potential of rivers and adjacent territories, changes in the hydrogeological regime of groundwater, depletion of soil cover in the floodplain, etc.

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