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NORMALIZATION OF THE ULTIMATE ALLOWABLE LOAD IN THE DRAINAGE BASIN OF THE KARATAL RIVER BASIN

Abstract. Based on the equation of hydro-chemical balance of the water of river basins and iodine factor dependence, which characterizes the relative productivity of semi-submersible water vegetation from river flow and the content of pollutants, a mathematical model has been developed to determine the environmentally acceptable maximum load in the catchments of the river basin, including predicting the concentration of water pollutants in the river, and an acceptable level of non-returnable water consumption and ecological runoff, which are realized for determination of the maximum permissible level of natural-technogenic load in the basin of the river Karatal.

Key words: catchment of the river basin, ecology, water, substance, pollution, norm, productivity, hydro-chemical balance equation, load, model.

Introduction. The progressive pollution of the basins of small rivers as a result of the anthropogenic activities of urban and industrial facilities is one of the most actual problems of modern ecology science. The actuality of the problem is related to the fact that the channels of these rivers take the main technogenic load from agricultural and industrial enterprises - the nature of users who are sometimes at a sufficiently large distance from each other and belong to different administrative-territorial units in the catchment areas of river basins.At the same time, streams perform a transport function and transfer toxic pollutants from some territories located in the upper reaches of the river, on which they were formed and entered into a streams, and on others - adjacent areas located downstream, which are forced to take on this toxic and polluted stream for induced recharge. Thus, the transfer of pollutants is polluting in nature and causes a number of problems not only ecologically, but also regulatory and economic, which requires the need to develop methodological support for determining the ecologically acceptable maximum load in the catchment areas of river basins.

The purpose of the study is to assess the allowable impact level in the catchments of the Karatal river basin and, on the basis of them, to develop a mathematical model to determine the ecological flow, allowable limits for irrevocable water consumption and pollution, ensuring the sustainability of the aquatic ecosystem.

Materials and research methods. Based on the equation of hydrochemical balance of substances in the catchments of river basins and the relative productivity of vegetation from river runoff and the content of pollutants, as a function system allowing to describe the behavior of the aquatic system in a state of stable equilibrium, taking into account the influence of natural and anthropogenic factors, a mathematical model is obtained that characterizes the equation balance of substances, relative to concentration (C_p) [1; 2]:

$$C_p = \frac{g_б \cdot C_б \cdot}{(A \cdot g_б + g_{bon})} + \frac{g_{bon} \cdot (K_b \cdot C_б + K_{пз} \cdot C_б)}{(A \cdot g_б + g_{bon})} - \frac{b_{\max} \cdot S(w) \cdot S(c)}{(A \cdot g_б + g_{bon})},$$

here A - is a dimensionless indicator, characterizing the ratio of the natural flow of the river (flow rate) (Wr) to the volume of river flow ($W_б$); $g_б$ - water flow module from catchment area, l /s·km^2; g_{bon} - module of water demand in thecatchment of the river basin; $C_б$ - specific removal of substance from a unit of catchment area; $b_{\max}$ - the specific maximum volume of substances absorbed by aquatic vegetation per unit volume of water, kg / m3; K_b - ratio of return water; $K_{пз}$ - coefficient of groundwater; $S(w)$ - indicator that takes into account the effect of the volume water in the river on the vegetation productivity; $S(c)$ - indicator that takes into account the effect of pollution in river water by the substance under consideration.

The function $S(w)$ and $S(c)$ characterizing the relative productivity of aquatic vegetation from river flow (W_i) and the content of pollutants (C_i) are one-factor dependencies, having the form of dome-shaped curves, well described by formula V. V. Shabanov [3]:

$$S(\varphi)=\left(\frac{\varphi_i}{\varphi_{opt}}\right)^{\gamma\cdot\varphi_{opt}}\cdot\left[\frac{(1-\varphi_i)}{(1-\varphi_{opt})}\right]^{\gamma\cdot(1-\varphi_{opt})},$$

here $S(\varphi)$ - is a relative productivity of water semi-submersible vegetation; φ_i - the actual value of the considered environmental factor; φ_{opt} - optimal value of the considered environmental factor; γ - parameter of self-regulation of semi-submersible aquatic vegetation.

Thus, the mathematical module characterizing the substance balance equation with respect to concentration (C_p) makes it possible to determine the ecological allowable exposure limits based on the Le Chatelier-Brown principle, which states that «an external influence that brings the system out of balance stimulates processes that tend to weaken the results of this influence».

Results of the study. Based on the developed mathematical model for assessing the ecological allowable limit of natural and man-made impact on the environment of small rivers, a numerical experiment was conducted to determine the maximum allowable level of water use of the Karatal river taking into account not only the volume or discharge of polluted wastewater from cities and industrial facilities, as well as incoming collector-drainage waters from from the territory of irrigated arrays.

In this case, the dependence function of the relative productivity of water semi-submersible vegetation on river flow ($S(w)$) and the content of pollutants ($S(c)$) will be represented as a product of the function ($S(w,c)$): $S(w,c)=S(w)\cdot S(c)$.

Assessment of the relative productivity of semi-submersible aquatic vegetation in the watersheds of the Karatal river basin was estimated at the following values: $\gamma = 5.0$ - the parameter of self-regulation of semi-submersible water vegetation [4]; $\varphi_{opt}^{w} = 0.70$ is the relative optimal value of the permissible limit of the irretrievable water intake; $\varphi_{opt}^{c} = 0.30$ is the relative optimal value of the content of pollutants in the waters of the river basin; $\varphi_i = 0\text{-}1$ is the range of variation of the considered environmental factors (table 1 and figure 1).

Table 1 – Relative productivity of semi-submersible aquatic vegetation in the Karatal river basin

Range of change of the considered environmental factors (φ_i)	Indicators of relative productivity of water semi-submersible vegetation		
	$S(w)$	$S(c)$	$S(w)\cdot S(c)$
0,0	0,000	0,000	0,000
0,1	0,005	0,464	0,002
0,2	0,052	0,864	0,045
0,3	0,185	1,000	0,185
0,4	0,396	0,897	0,355
0,5	0,665	0,630	0,418
0,6	0,896	0,399	0,358
0,7	1,000	0,182	0,182
0,8	0,867	0,054	0,047
0,9	0,463	0,005	0,002
1,0	0,000	0,000	0,000

As can be seen from figure 1, the relative productivity of semi-submersible aquatic vegetation ($S(\varphi)$) depending on the range of variation of the considered environmental factors (φ_i), having the form of dome-shaped curves, shows that their maximum values are located in the zone of optimal values of the environmental factors (φ_{opt}).

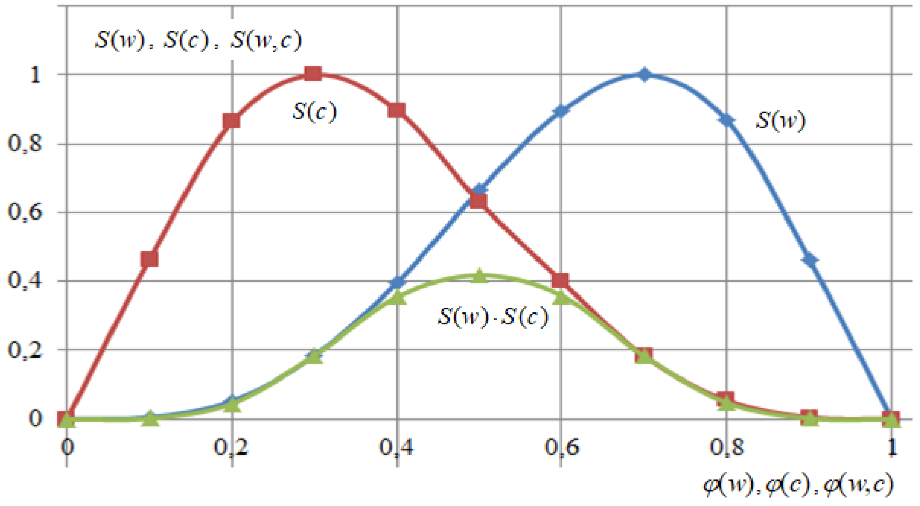

Figure 1 – Relative productivity of semi-submersible aquatic vegetation ($S(\varphi)$) of the Karatal river basin depending on the range of variation of the considered environmental factors (φ_i)

Herewith, the maximum value of the dome-shaped curves of the product of the function ($S(w,c)$), taking into account the combined effect of the volume of water in the river ($S(w)$) and pollution of the river water to certain substances ($S(c)$) is within 0.40, which characterizes the lower limit of the maximum possible value of ecological flow, ensuring the environmental sustainability of natural systems in the watersheds of the river basin.

Based on the use of the hydrochemical balance equation of a river flow substance, that is, the first two terms can be used to assess the external impact on the river ecological system, denoting them as a certain concentration (C_{pm}), characterizing the effects of natural and man-made activities that have formed intrawater processes where water self-purification occurs river basins [1]:

$$C_{pm} = \frac{g_{\text{б}} \cdot C_{\text{б}}}{(A \cdot g_{\text{б}} + g_{bon})} + \frac{g_{bon} \cdot (K_b \cdot C_{\text{б}} + K_{\text{пз}} \cdot C_{\text{б}})}{(A \cdot g_{\text{б}} + g_{bon})},$$

here C_{pm} - concentration of river water formed under the influence of natural and man-made activities.

Herewith, the volume of the substance absorbed by water semi-submersible vegetation is determined using the third term equation of the hydrochemical balance of the substance of river runoff [1]:

$$C_{pb} = \frac{b_{\max} \cdot S(w) \cdot S(c)}{(A \cdot g_{\text{б}} + g_{bon})} = C_b \cdot S(w) \cdot S(c),$$

here C_{pb} is the indicator of self-cleaning ability of semi-submersible water vegetation, i.e. $C_b = b_{\max} / (A \cdot g_{\text{б}} + g_{bon})$.

If river water concentration is known (C_{pm}), which are formed under the influence of natural and man-made activities, then taking into account the self-purification ability of semi-submersible aquatic vegetation (C_{pb}), substance balance equation, relative to concentration (C_p), has the following form [1]:

$$C_p = C_{pm} - \frac{b_{\max} \cdot S(w) \cdot S(c)}{(A \cdot g_{\text{б}} + g_{bon})} = C_{pm} - C_b \cdot S(w) \cdot S(c) \cdot$$

The analysis of mathematical models characterizing the substance balance equation with relative to concentration (C_p) shows that the derivative of the function describing the change in the stationary state of the system according to the factors under consideration, that is W_i и C_i, must be increasing: $dC_p / dw > 0$, $dC_p / dc > 0$.

It should be noted, firstly, the function adequately meets the condition when, for the normal development of aquatic semi-submersible vegetation, according to the law of Y. Liebig, a number of circumstances are required at the same time so that it loses biological stability, enough critical situation for one of the considered factors, secondly, one-factor dependences $S(w)$ and $S(c)$ are determined by concentration $C_б$, but not C_p, since the latter is the result of the action of self-purification of the ability of water semi-submersible vegetation (C_{pb}), thirdly, to determine the maximum allowable impact of the natural-man-made system C_p, the derivative of the function is taken only according to the variable parameters of the state of the river (W_i, C_i); fourthly, the maximum allowable concentration of river water is determined at a fixed value of the river flow of water and vice versa fixed level of river pollution.

For determining the maximum allowable impact of the natural and man-made system in the watersheds of the Karatal river basin, the following value of the aquatic ecosystem is used: A = 0,35 - dimensionless indicator characterizing the ratio of the natural flow of the river (the rate of flow or environmental flow) (W_p или $W_э$) to the volume of river flow ($W_б$); $b_{\max}$=0,20 - the specific maximum volume of substances absorbed by aquatic vegetation per unit volume of water, kg / m3;drain module from the catchment (l / s·km^2); $g_б$ = 3,55 drain module from the catchment (l / s·km^2); K_b=0.50 is the return water coefficient; $K_{пз}$ = 0,25-groundwater ratio; C_p^{opt} =0,30 - the concentration of a substance in a river that is optimal for water semi-submersible vegetation (g / l); $C_p^{\max}$=1,00 –maximum concentration of a substance in a river for water semi-submersible vegetation (g / l) (table 2 and figure 2).

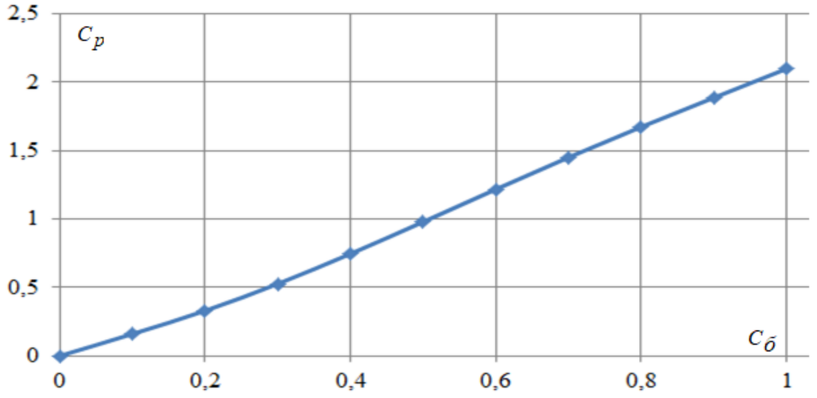

Figure 2 – Dependence of water concentration (C_{pm}) in the catchments of the river basin, which is formed as a result of natural and man-made activities from the specific removal of the substance from a catchment area unit ($C_б$)

Thus, as can be seen from figure 2, which was built on the basis of data from table 2, the change in water concentration (C_{pm}) in the catchments of the Karatal river basin as a result of natural and man-made activities, the concentration of water in the river (C_{pm}) increases with an increase in the specific removal of matter from a unit of the catchment area ($C_б$).

For a system analysis of the behavior of a function $У(C_p) = f(\varphi)$, it is necessary to consider its derivative with respect to the considered environmental factors, that is $У'(C_p) = f'(\varphi)$, then the derivative of these functions can be represented as follows:

$$У'(C_p) = \lim_{\Delta\phi \to \infty} \frac{f(\phi + \Delta\phi) - f(\phi)}{\Delta\phi} \approx \frac{f(\phi + \Delta\phi) - f(\varphi)}{\Delta\phi}.$$

Thus, depending on the concentration of pollutants in the river ($C_б$), the determination of its production from the concentration of pollutants in the river $dC_p / dC_б$, without taking into account the self-purification ability of semi-submersible aquatic vegetation, is made in a tabular form (table 3) and is presented in figure 3.

Table 2 – Determination of the maximum allowable range of the impact of the factors under consideration in the catchments of the Karatal river basin

Indicators	The range of impact of the considered environmental factors ($C_б$)										
	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
A	0.350	0.350	0.350	0.350	0.350	0.350	0,350	0,350	0,350	0,350	0,350
$g_б$	3.550	3.550	3.550	3.550	3.550	3.550	3.550	3.550	3.550	3.550	3.550
$A \cdot g_б$	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242	1,242
g_{bon}	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700
$A \cdot g_б + g_{bon}$	1,942	1,942	1,942	1,942	1,942	1,942	1,942	1,942	1,942	1,942	1,942
$g_б \cdot C_б$	0,000	0,355	0,710	1,065	1,420	1,775	2,130	2,485	2,840	3,195	3,550
$\frac{g_б \cdot C_б}{(A \cdot g_б + g_{bon})}$	0,000	0,183	0,365	0,548	0,731	0,914	1,097	1,280	1,463	1,646	1,829
$K_b + K_{пз}$	0,750	0,750	0,750	0,750	0,750	0,750	0,750	0,750	0,750	0,750	0,750
$(K_b + K_{пз}) \cdot C_б$	0,000	0,075	0,150	0,225	0,300	0,375	0,450	0,525	0,600	0,675	0,750
$(K_b + K_{пз}) \cdot C_б \cdot g_{bon}$	0.000	0.053	0.105	0.158	0.210	0.263	0.315	0.368	0.420	0.473	0.525
$\frac{g_{bon} \cdot C_б (K_b + K_{пз})}{(A \cdot g_б + g_{bon})}$	0,000	0,027	0,054	0,081	0,108	0,135	0,162	0,189	0,216	0,243	0,270
C_{pm}, g / l	0,000	0,210	0,419	0,629	0,839	1,049	1,259	1,469	1,679	1,889	2,099
$S(c)$	0.000	0.464	0.864	1.000	0.897	0.670	0.399	0.182	0.054	0.005	0.000
$S(c) \cdot b_{\max}$	0.000	0.097	0.173	0.200	0.179	0.134	0.080	0.036	0.011	0.001	0.000
$\frac{b_{\max} \cdot S(c)}{A \cdot g_б + g_{bб}}$	0.000	0.050	0.089	0.102	0.092	0.069	0.041	0.018	0.005	0.001	0.000
C_p, g / l	0.000	0.160	0.333	0.527	0.747	0.980	1.218	1.451	1.674	1.888	2.099

Table 3 – Determination of the driving function $dC_p / dC_б$ from the concentration of pollutants in the river, without taking into account the self-purification ability of semi-submersible aquatic vegetation depending on the concentration of pollutants in the riverKaratal ($C_б$)

$C_б$	C_p	$dC_p / dC_б$
0,0	0.000	1,00
0,1	0.160	1,60
0,2	0.333	1,73
0,3	0.527	2,39
0,4	0.747	2,20
0,5	0.980	2,33
0,6	1.218	2,38
0,7	1.451	2,33
0,8	1.674	2,23
0,9	1.888	2,14
1,0	2.099	2,11

The graph shows the derivative (figure 3), the range of concentration ($C_б$) in the waters of the Karatal river basin, within which the Le Chatelier-Brown principle is fulfilled, that is, the minimum concentration value ($C_б^{\min}$) is 0.30 g / l and the maximum concentration value ($C_б^{\max}$) -0.60 g / l in non-returnable water consumption $(1 - A)$=0,75.

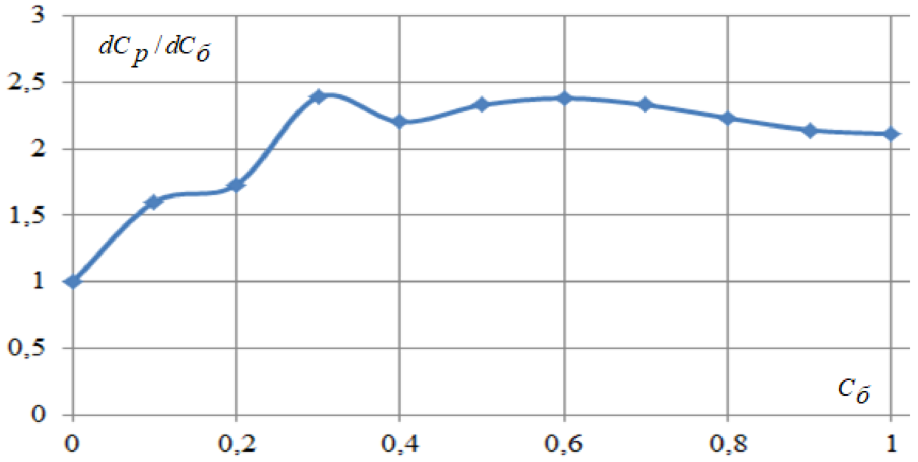

Figure 3 – Graph of dependence of the driving function $dC_p / dC_б$ from the concentration of pollutants in a river, without taking into account the self-purification capacity of semi-submersible aquatic vegetation depending on the concentration of pollutants in the river ($C_б$) Karatal

As, it can be seen from figure 3, the concentration of pollutants from the flow of water of the river Karatal, formed as a result of natural and man-made activity ($C_б$) and its $dC_p / dC_б$ derivative of the concentration of pollutants in the river comparing with the relative productivity curve of water semi-submersible vegetation ($S(\varphi)$) depending on the range of variation of the considered environmental factors (φ_i),it can be seen that the maximum value of the function is observed within the range of 0.40-0.60, which shows the possibility of using them to estimate the maximum allowable value of river flow, ensuring the environmental sustainability of the natural system of river basins.

On the basis of these principal positions, it can be determined the maximudm permissible level of use of the volume or flow of water in river basins, that is, it can be determined the maximum permissible level of anthropogenic load on the ecological system using the following formulas:

$$W_n = W_p \cdot S(w) \cdot S(c),$$

$$Q_n = Q_p \cdot S(w) \cdot S(c),$$

here W_n, Q_n - the maximum permissible level of use of the volume or flow of water flows in river basins, km^3 or m^3 / s; W_p, Q_p - the volume or flow of water formed in river basins, km^3 or m^3 / s.

Therefore, based on the use of the equation, for determining the maximum allowable level of use of the volume or flow of water in river basins, it is possible to determine the volume ($W_э$) and consumption of environmental flow ($Q_э$), ensuring the environmental sustainability of the natural system of river basins:

$$W_э = W_p \cdot [1 - S(w) \cdot S(c)],$$

$$Q_э = Q_p \cdot [1 - S(w) \cdot S(c)].$$

On the basis of mathematical models, for determining the ecological flow and maximum allowable level of water use of river basins and the average annual water consumption in various facilities of the Karatal river in the period 1932-2009, a forecast was calculated to determine the ecological flow and non-returnable water consumption in the regional economy (table 3).

When building a forecast calculation to determine the ecological flow and non-returnable water consumption in economic sectors in the catchments of the Karatal river basin, the following provisions were taken into account, that is, first, the calculation period was considered within the past (1932-1986) and the present (1987-2009) which show changes in water consumption in rivers on a time scale, and secondly, information and analytical materials were used to assess changes in the flow of water in rivers on a spatial scale.

Table 3 – Forecast calculation on the use of water resources in the catchments of the Karatal river basin

Settlement period	Indicators	Q_o, m^3/s	W, million m^3	C_v	C_S	River water flow at various sufficiency, m^3 / s						
						5%	10%	25%	50%	75%	90%	95%
Hydrological station - the village of Karatal, located at the exit of the foothills of the Zhetisu Alatau												
1932-1986	Q_p, m^3/s	25,0	789	0,23	0,69	35,50	32,70	29,60	24,30	20,90	18,20	16,80
	Q_n, m^3/s					21,30	19,62	17,76	14,58	12,54	10,92	10,08
	$Q_э$, m^3/s					14,20	13,08	11,84	9,72	8,36	7,28	6,72
1987-2009	Q_p, m^3/s	34,9	1100	0,24	0,72	50,10	46,00	41,50	33,90	28,80	25,00	23,10
	Q_n, m^3/s					30,06	27,60	24,90	20,34	17,28	15,00	13,86
	$Q_э$, m^3/s					20,04	18,40	16,60	13,56	11,52	10,00	9,24
Hydrological station - the village Naimensuk, located on the flat territory of the basin of Lake Balkhash												
1932-1986	Q_p, m^3/s	71,9	2269	0,33	0,89	115,00	103,00	89,70	68,00	54,30	44,30	39,60
	Q_n, m^3/s					69,00	61,80	53,82	40,80	32,58	26,58	23,76
	$Q_э$, m^3/s					46,00	41,20	35,88	27,20	21,72	17,72	15,84
1987-2009	Q_p, m^3/s	77,4	2443	0,29	0,78	119,00	107,00	94,90	74,60	61,10	51,10	46,20
	Q_n, m^3/s					71,40	64,20	56,94	44,76	36,66	30,66	27,72
	$Q_э$, m^3/s					47,60	42,80	37,96	29,84	24,44	20,44	18,48

Hydrological posts - Karatal village, located at the exit of the foothills of the ZhetisuAlatau and Naimensuk, located on the flatland basin of Lake Balkhash, which allow developing a management system and regulation of water resources, ensuring rational and effective use for the development of industries in the regions.

Conclusions. Based on the equation of hydrochemical water balance of river basins and iodine factor dependencies characterizing the relative productivity of semi-submersible water vegetation from river flow and the content of pollutants, a mathematical model has been developed to determine the environmentally acceptable load in watersheds of the river basin, including predicting the concentration of pollutants in the river water, a acceptable level of non-returnable water consumption and ecological runoff, which are realized us to determine the maximum permissible level of natural and technogenic load Karatau Basin, showing the possibilities of their use for the planning, management and regulation of river basin water resources to ensure the sustainability of the natural system of the region.

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ҚАРАТАЛ ӨЗЕНІНІҢ СУЖИНАУ АЛАБЫНЫҢ ШЕКТЕЛГЕН-МҮМКІНШІЛІК ЖҮКТЕМЕСІН МӨЛШЕРЛЕУ

Аннотация. Өзен алабының гидрохимиялық теңгермесінің теңдеуінің және өзеннің ағынының және ондағы ластаушы заттардың құрамына байланысты суға жартылай батқан су өсімдігінің өнімділігінің қатынасын сипаттайтын бір дәлелдемелі теңдеудің негізінде, өзеннің сужинау алабының экологиялық тұрғыдан шектелген-мүмкіншілік жүктемесін анықтауға арналған математикалық үлгі құрылған, ал ол өзеннің ағынының тұтынудан қайтарылмайтыншектелген-мүмкіншілік деңгейін және экологиялық ағынын жобалауға пайдалануға болады және ол Қаратал өзенінің алабының шектелген-мүмкіншілік жүктемесін дәрежесін анықтау үшін қолданылған.

Түйін сөздер: өзеннің сужинау алабы,экология, су, заттар, ластану, мөлшер, өнімділік, гидрохимиялық теңгерменінің теңдеуі, жүктеме, үлгі.

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НОРМИРОВАНИЕ ПРЕДЕЛЬНО-ДОПУСТИМОЙ НАГРУЗКИ В ВОДОСБОРАХ БАССЕЙНА РЕКИ КАРАТАЛ

Аннотация. На основе уравнения гидрохимического баланса вод речных бассейнов иоднофакторной зависимости, характеризующей относительную продуктивность водной полупогружной растительности от речного стока и содержания загрязающих веществ, разработана математическая модель для определения экологически предельно-допустимой нагрузки в водосборах бассейна реки, включающих прогнозирование концентрации загрязняющих веществ воды в реке, предельно-допустимого уровня безвозвратного водопотребления и экологического стока, которые реализованы, для определения предельно-допустимого уровня природно-техногенной нагрузки в бассейне реки Каратал.

Ключевые слова: водосбор речного бассейна, экология, вода, вещество, загрязнение, норма, продуктивность, уравнение гидрохимического баланса, нагрузка, модель.

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