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NEW APPROACH TO ESTIMATION OF PERMISSIBLE DISCHARGE OF BIOGENIC MATTER INTO WATER BODIES (EXAMPLE OF THE NEVA ESTUARY OF THE BALTIC SEA)

The calculation of the assimilating capacity (or ecological capacity) of water body is considered to be a new method for assessing ecological quality of coastal and marine ecosystems. It can also serve as the foundation for the system approach to surface water protection, prevention of eutrophication as well as for the management and the choice of ecologically efficient and economically profitable water protection measures.

1. INTRODUCTION

Establishing the balance between economy and ecology as well as the coordinated solution of economic and environmental problems are considered to be the main postulates of sustainable development model. Ecologically permissible levels of anthropogenic impacts on environment constitute the measure which ensures the combination of ecological and economical interests. Excessive impacts create danger to both nature and people. The paper deals with the assessment of the assimilating capacity of water body (ecological capacity) which allows matching it with the impact levels.

The method of calculating ecological capacity [1] of the Neva estuary in terms of phosphorous and nitrogen and the effect of wastewater from Saint Petersburg agglomeration on eutrophication of this estuary belonging to the Baltic Sea were presented. In the calculations, any sanitary-hygienic standards of permissible discharges were not used. They are based on ecologically permissible concentrations obtained in our earlier research.

The calculations of the assimilating capacity of a water body can be considered to be a the new method of assessing ecological quality of coastal and marine ecosystems and may serve as scientific foundation of a system approach to surface water protec-

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tion, prevention of eutrophication as well as management and choice of ecologically efficient and economically profitable water protection measures.

2. DISCUSSION OF THE RESULTS

At present there is a lack of methods allowing us to assess the ecological capacity of water body and the corresponding ecologically permissible loads of pollutants. In practice, for example, the allowable concentrations (*AC*) of pollutants in treated wastewater ("end of pipe approach") are calculated on the basis of their maximum permissible concentration (*MPC*) in a control section of water body according to the following equation [4]:

$$AC_i = (MPC_i - C_{bi})n + C_{bi}, \tag{1}$$

where:

AC_i – an allowable concentration of pollutant in wastewater,

MPC_i – a maximum permissible concentration of pollutant in a control section of water body,

C_{bi} – a background concentration of pollutant in water,

n – the degree of dilution.

The degree of dilution (n) is a quantitative characteristic of the rate of the concentration decrease in water reservoirs and rivers as the result of water and wastewater mixing. It allows us to establish the value of n as the ratio of an excess concentration of pollutants in the site of discharge to their concentration in the examined section of water body:

$$n = \frac{AC - C_b}{C_m - C_b}, \tag{2}$$

or as the ratio of wastewater and water mixture flow to wastewater flow:

$$n = \frac{Q + Q_0}{Q_0}, \tag{3}$$

where:

$C_{m.}$ – the concentration of pollutant in a control section after mixing,

Q – the part of water flow participating in mixing process,

Q_0 – the wasterwater flow.

The distribution of pollutant concentration along water flow cross-section is characterised by definite unevenness; a minimum dilution is found at the point of maximum pollutant concentration. Defining this point and estimating the concentration value it is possible to calculate the minimum degree of dilution:

$$n_{\min} = \frac{C_0 - C_m}{C_{\max} - C_m} \quad \text{or} \quad n_{\min} = \frac{AC - C_b}{C_{\max} - C_b}. \tag{4}$$

In calculations, the value of $n_{\min}$ is usually considered to be estimated on the basis of equation (4).

Maximum permissible discharge (*MPD*) of pollutants is calculated in the following way:

$$MPD = AC \cdot Q_0. \tag{5}$$

The value of *AC* estimated by means of calculation is understood as a control value and becomes the basis for a permissible discharge limit into a water body.

When defining the conditions of wastewater discharge it is necessary to consider the water quality of the recipient (background concentration) as the main condition preventing the accumulation of harmful substances. For non-regulated rivers, the parameters of the qualitative characteristics of water must be calculated on the basis of the flow of 95% water volume.

So, the determination of the conditions of wastewater discharge into water bodies on the basis of the existing calculation methods is connected with an obligatory consideration of the following parameters [4]:

- a maximum permissible concentration (*MPC*) of the substances discharged in the area of water usage as an initial indicator of sanitary assessment of water body,
- a maximum reliable degree of wastewater dilution at a minimum monthly water flow of 95% volume, taking account of hydrological regime and hydrodynamic processes.

Under these conditions the existing calculation methods are not only considered to be basic when dealing with wastewater discharge into water recipient in spite of their approximate character but also connected only with the conditions of wastewater dilution.

Transformation of polluting substances which can lead to secondary pollution of water is not taken into account in the above mentioned methods. The existing sanitary-hygienic *MPC* does not characterise the abilities of water ecosystem to compensate for anthropogenic impacts. The most spectacular example is the discharge of nutrients which are responsible for eutrophication and secondary pollution of surface waters.

There are also other approaches as, for example, the assessment of allowable concentrations (*AC*) on the basis of *BAT* (the best available technology). According to this approach Helcom estimated the rate of phosphorus discharge (1.5 mg P/dm^3) and the rate of nitrogen discharge (10 mg N/dm^3) with wastewater into the Baltic Sea. But in some cases, these concentrations do not prevent eutrophication, in other cases – these rates are too strict. This can be explained by the fact that eutrophication is controlled not only by biogenic loads but also by the complex of hydrodynamic and anthropogenic factors [1].

Let us try to calculate the ecological capacity (*EC*) of the Neva estuary of the Baltic Sea in terms of phosphorous and nitrogen and to define the role of wastewater from Saint Petersburg agglomeration in eutrophication of the Neva estuary, taking into account all sources of nutrients. In calculations, we did not use any sanitary-hygienic *MPC*, but ecologically permissible concentrations (*EPC*) obtained in our earlier research [3], [5].

Evidently, when calculating the ecologically permissible loads, it is necessary to proceed according to the assumption that ecological capacity of water body must not be exceeded by the loads originating from different sources [2]:

$$EC \geq J_1 + J_2 + J_3 + J_4 + J_5 + J_6 + J_7 + J_8, \quad (6)$$

where J_1, J_2, J_3, J_4, J_5, J_6, J_7, J_8 are the loads of pollutants from wastewaters, diffused sources, surface flow, recreation sources, from roads, atmosphere, rivers and other.

Assuming that $dC/dt = 0$ (where C stands for the nutrients' concentration in water) we can arrive at the following equation representing the ecological capacity of water body in terms of nutrients:

$$EC = (C_{EPC} - C_m)Q \cdot 10^{-6}, \quad (7)$$

where:

EC – an ecological capacity of water body, t/day,
C_{EPC} – an ecologically permissible concentration of phosphorous or nitrogen, g/m^3,
C_m – the concentration of nutrient in water, g/m^3,
Q – a summary water flow, m^3/day.

Ecological capacity of the Neva estuary can be calculated as follows:

$$EC_{NE} = k_1 J_1 + k_2 J_3 + k_3 J_7 + k_4 J_4 + k_5 J_8, \quad (8)$$

where:

J_1, J_3, J_7, J_4, J_8 – the loads from wastewaters, surface flow, river flow, from recreation and other sources,

k_1, k_2, k_3, k_4, k_5 – the coefficients characterising the quotas of discharge from every source.

From equation (8) it is possible to calculate EC_{NE} in terms of mineral phosphorous P_m, total phosphorous P_{tot}, mineral nitrogen N_m in a whole water object under actual conditions:

$$EC_{NE\,(Pm)} = (C_{EPC\,(Pm)} - C_{m\,(Pm)}) \cdot Q_{NE} \cdot 10^{-6} = (0.057 - 0.016) \cdot 218.5 \cdot 10^{6} \cdot 10^{-6} = 8.96 \text{ t/day},$$

$$EC_{NE(P\text{tot})} = (C_{EPC\,(P\text{tot})} - C_{m(P\text{tot})}) \cdot Q_{NE} \cdot 10^{-6} = (0.062 - 0.02) \cdot 218.5 \cdot 10^{6} \cdot 10^{-6} = 9.18 \text{ t/day},$$

$$EC_{NE\,(Nm)} = (C_{EPC\,(Nm)} - C_{m\,(Nm)}) \cdot Q_{NE} \cdot 10^{-6} = (10.9 - 0.66) \cdot 218.5 \cdot 10^{6} \cdot 10^{-6} = 2237 \text{ t/day}.$$

On the basis of literature data the proportion of every source of nutrients was estimated. Then equation (8) for the Neva estuary can be written as follows:

$$EC_{NE\,(P)} = 0.60\,J_1 + 0.15\,J_3 + 0.20\,J_7 + 0.01\,J_4 + 0.04\,J_8, \tag{9}$$

$$EC_{NE\,(N)} = 0.21\,J_1 + 0.34\,J_3 + 0.38\,J_7 + 0.01\,J_4 + 0.04\,J_8. \tag{10}$$

Therefore, ecologically permissible discharge (*EPD*) of nutrients with wastewaters must not exceed the proportion for wastewaters (EC_{ww}), i.e., $EPD \leq EC_{ww}$.

Nowadays with treated and untreated wastewaters 5.37 t of phosphorous daily is discharged into the Neva estuary. This constitutes 97% of the ecological capacity of water body. Load of nitrogen discharged with wastewaters is only 39.5 t daily, i.e., 8.5% of the ecological capacity of this water ecosystem. Proceeding from EC_{ww} it is possible to calculate the permissible concentration of phosphorous and nitrogen C_{per} in wastewater being discharged into the Neva estuary:

$$C_{\text{per}} = \frac{EC}{Q_0} \ (\text{mg/dm}^3), \tag{11}$$

where:

EC – an ecological capacity of water body, g/day;

Q_0 – the wastewater flow, m^3/day.

The comparison of the permissible nutrient concentrations in wastewaters (*AC*) and their maximum permissible discharge (*MPD*) calculated in a traditional way (on the basis of balance equation) and of the Helcom standards with the values of C_{per} and ecologically permissible discharge (*EPD*) calculated on the basis of *EC* is presented in table 1.

Table 1

Comparison of the values of C_{per} and *EPD* for nutrients with *AC*, *MPD* and the Helcom standards

Nutrient	C_{per} mg/dm^3	*AC* mg/dm^3*	Helcom standard mg/dm^3	*EPD* t/day	*MPD* t/day
Phosphorous	2.2	1.6	1.5	5.5	3.8
Nitrogen	188.0	70.0	20.0	470.0	172.4

**AC* – a permissible concentration of nutrient in wastewater calculated on the basis of balance equation with dilution taken into account.

The calculations presented are approximate and first of all depend on the reliability of initial data. Nevertheless the method proposed shows that the ability of water body to compensate for the ecological misbalance is greater than the demands accepted in national and international standard regulations.

Therefore the problem is the following: although the ecological capacity of the Neva estuary in general exceeds the load of nutrients discharged there, the sites of wastewater discharge, i.e., Northern Station of Aeration (*NSA*), Krasnoselskaja Station of Aeration (*KSA*) of the city of Petrodvoretz and other, are located in coastal zone whose ecological capacity is significantly lower than general capacity of the Neva estuary because of hydrodynamic, morphometric and other natural differences. Hence, the ecological capacity of water body in terms of phosphorous was calculated in the places of wastewater discharge from the main wastewater treatment plants of Saint Petersburg (table 2).

Table 2

Ecological capacity (*EC*) of water body, actual nutrient discharge from main wastewater treatment plants of Saint Petersburg and the required level of additional treatment of wastewater

Place of wastewater discharge	Phosphorous t/day		Nitrogen t/day		Concentration in purified wastewater				Post-purification level	
					C_P mg/dm^3		C_N mg/dm^3			
	EC	Actual discharge	*EC*	Actual discharge	C_{al}	*C* actual	C_{al}	*C* actual	Phosphorous	Nitrogen
Northern Station of Aeration (NSA)	0.02	0.41	5.89	5.20	0.032	0.67	9.33	9.3	95%	not required
Central Station of Aeration (CSA)	7.92	1.85	2023.0	12.60	5.26	1.23	13.45,0	9.4	not required	not required
Krasnoselskaja Station of Aeration (KSA)	lack	0.14	lack	0.82	0.0	2.0	0.0	39.0	100%	100%

Thus the gross discharge of phosphorous and nitrogen with wastewaters into the Neva estuary does not exceed the ecological capacity of this water body. But the discharge of nutrients into the coastal areas exceeds the compensation abilities of these areas, whose ecological capacity has been already exceeded by nutrients discharged from other sources. This fact explains why coastal waters are threatened with eutrophication. If wastewater is discharged directly into the transition zone of the estuary (Ship Navigating Channel or Galley Navigating Channel), the additional removal of nutrients from wastewaters is not required.

To prevent the Neva estuary from eutrophication it is necessary to adopt the system of complex measures that allow us to reduce the discharge of nutrients not only with wastewaters, but also from other sources. Additional removal of nitrogen from wastewater under the Neva estuary conditions is not economically profitable and not ecologically efficient. The approach proposed can be used for the estimation of ecological capacity *EC* relative to other pollutants.

3. CONCLUSIONS

Establishing the balance between economy and ecology as well as the coordinated solution of economic and environmental problems are among the main postulates of sustainable development model. Ecologically permissible levels of anthropogenic impacts on environment constitute the measure which ensures the combination of ecological and economic interests. Excessive impacts create danger to nature and people. The paper deals with the assessment of ecological quality of surface waters as well as the assimilating capacity of water bodies.

At present there is a lack of methods allowing us to assess the assimilating (ecological) capacity of water body and the corresponding ecologically permissible loads of pollutants. The transformation of pollutants which can lead to a secondary pollution of water is not taken into account in the existing methods. The paper presents the method of both calculation of the assimilating (ecological) capacity of the Neva estuary in terms of phosphorous and nitrogen and estimation of the role of wastewater from Saint Petersburg agglomeration in eutrophication of this estuary of the Baltic Sea. The above-mentioned calculations are not based on sanitary-hygienic standards of permissible discharges, but on **ecologically permissible** concentrations obtained in our earlier research.

Evidently, when calculating the ecologically permissible loads, it is necessary to proceed according to the assumption that ecological capacity of water body must not be exceeded by the loads originating from different sources.

The calculation of the assimilating capacity (or ecological capacity) of water body is a new method of ecological quality assessment of coastal and marine ecosystems and can serve as the foundation for the system approach to surface water protection, prevention of eutrophication as well as for management and the choice of ecologically efficient and economically profitable water protection measures.

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Obliczanie pojemności ekologicznej wód powierzchniowych, w tym przybrzeżnych wód morskich, stanowi nową metodę oceny ich stanu ekologicznego. Opracowana metoda może służyć za naukową podstawę systemowego podejścia w rozwiązywaniu problemów ochrony wód powierzchniowych i zapobieganiu procesom eutrofizacji. Może być także stosowana do zarządzania zasobami wodnymi oraz do wyboru ekologicznie efektywnych i ekonomicznie uzasadnionych rozwiązań w zakresie ochrony wód.