SECTION III

METHODOLOGICAL APPROACHES TO THE CREATIONS OF LPS

MODELLING OF IMPACT OF REGIONAL ECONOMY ON THE STATE OF THE WATER BODIES[1]

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This article analyzes the possible negative anthropogenic impact on the state of surface waters in the region and the choice of ways to prevent it. For this purpose an attempt is made to include the general problem of optimization of spatial structure of the economy of the region block of conditions for protection of water resources. The author gives the economic and mathematical notation of appropriate conditions. The interpretation of these conditions is given and the possibility of their use for the analysis of influence of anthropogenic activities on water environment is evaluated. Special attention is paid to the Lower Angara region. The paper describes the specific features of the Lower Angara region from the standpoint of the impact of the prospects for the development of production on water environment. The characteristic of the present stage of its development is given and the strategic aspects of its further formation are considered. Shown are the basic shortcomings of the investment project «Integrated Development of the Lower Angara» with an emphasis on environmental matters. It is concluded that the development of the region under conditions of observance of the environmental requirements is possible only if using the advanced technology.

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PROTECTION OF WATER RESOURCES AS ONE OF THE IMPORTANT DIRECTIONS OF ENVIRONMENTAL ACTIVITIES IN THE DEVELOPMENT OF A REGIONAL ENVIRONMENTAL STRATEGY

The growth of limitation of water resources, deterioration of their quality make necessary inclusion problems of rational use and protection of water resources in a number of strategic priorities for regional environmental policy. This problem is of particular relevance in regions which are experiencing shortage of surface water resources and undergoing significant anthropogenic pressures on water bodies. Thus, the use and protection of water resources serves as one of the important directions of environmental activities in the development of a regional conservation strategy.

In order to identify the possible negative anthropogenic impact on state of surface waters in the region and the choice of ways to prevent it we have attempted to include in the model of choice of economic decisions in the region taking into account their environmental effects the block of conditions for the protection of water resources [1, 3]. The goals, objectives and tools of analysis the impact of human activities on the water environment are shown in Figure 1.

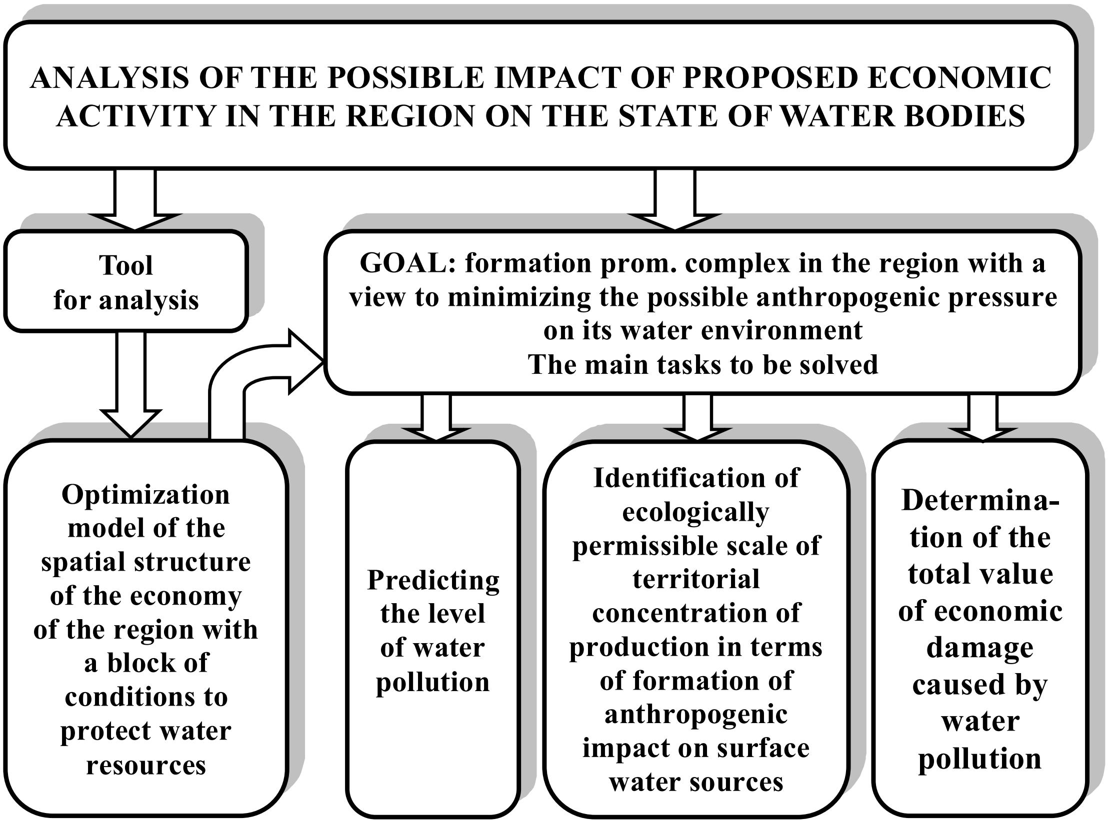
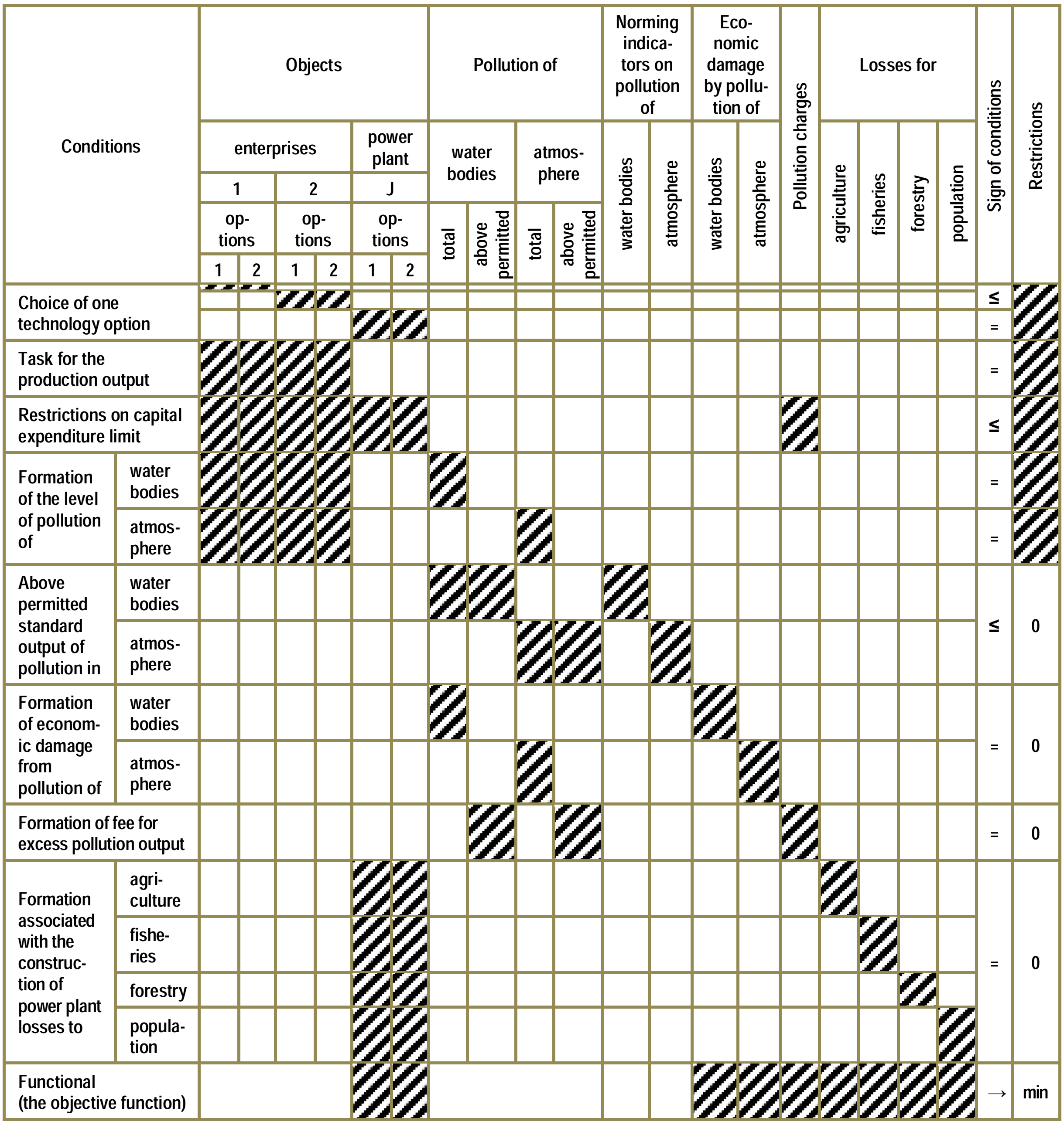


Fig. 1. The goals, objectives and tools of analysis of the impact of human activities on the water environment

Block diagram of the initial model is shown in Figure 2. It lists the basic conditions of the model and the study objects under consideration, presents the nature of constraints and objective function coefficients, nonzero elements of communication are shown. For simplicity, the block diagram model reflects the conditions corresponding to the same areal (or industrial node) and one time period.



Note: shaded blocks containing nonzero elements

Fig. 2. Block diagram of the model of choice of variants of economic decisions based on their environmental impact

The main problem to be solved by using this block for the protection of water resources, provide for:

- predicting the level of water pollution;
- identification of ecologically acceptable scale territorial concentration of production from the standpoint of the formation of anthropogenic load on surface water sources;
- determining the total value of economic damage caused by pollution of water bodies and others.

Such a block is designed specifically for the conditions of the Lower Angara region and western part of Kansk-Achinsk fuel and energy complex (KAFEC) [1, 2, 3].

Conditions of water block are united into the following groups (Figure 3):

1. Conditions of formation of water pollution balances for certain types of hazardous substances in each of the areas (or industrial centers) in a given period of time.

2. Restrictions on the discharge of pollutants into surface water sources.

3. Conditions of non-worsening environmental situation (quality of the aquatic environment) in each area over time, taking into account the possible accumulation of harmful substances in water and transport of pollution along the rivers.

4. The requirement to minimize economic damage caused by water pollution.

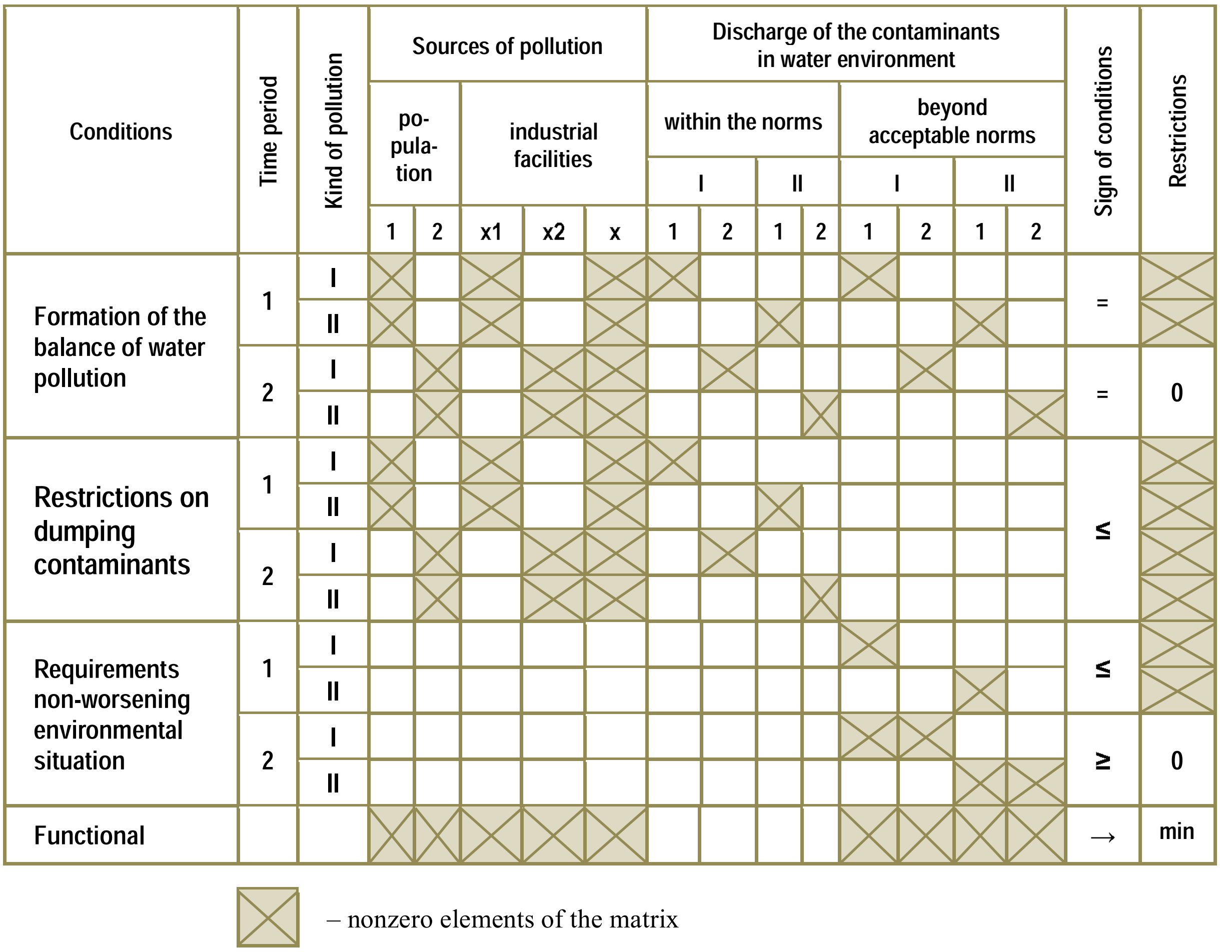


Fig. 3. Block conditions for the protection of water resources

Figure 3 shows a block diagram of a model fragment with block conditions for the protection of water resources. For example, a block diagram is constructed for one area, the two time periods and for the two types of pollution in the wastewater. Let us dwell on the characteristics of the economic-mathematical notation selected conditions and consider what range of issues can be resolved with their use.

Economic-mathematical notation above conditions has the following form [1, 3].

ECONOMIC-MATHEMATICAL NOTATION OF CONDITIONS OF THE WATER BLOCK

1) Formation of the balance of water pollution:

$$P_{qk}^{t} + \Delta P_{qk}^{t} = \Phi_{qk}^{t(t-1)} + \Phi_{qk^{'}k}^{t} - \Phi_{qkk^{"}}^{t} + \sum_{j} E_{qj}^{t} x_{jk} + \sum_{j} E_{qj} x_{jk}^{t} + E_{q} z_{k}^{t} \qquad \forall q, k, k^{"}, t, \tag{1}$$

where

P_{qk}^{t} – volume of discharge with sewage within the permissible limits of the substances q into the aquatic environment of the area (or industrial node) k in the period t;

ΔP_{qk}^{t} – volume of discharge with sewage beyond acceptable norms substances into the aquatic environment q of the area k in period t;

$\Phi_{qk}^{t(t-1)}$ – volume of the accumulation of the contamination by the time t pollution type q, released to the water environment of the area of k in period t–1;

$$\Phi_{qk}^{t(t-1)} = (1-\beta_{qk})^{\tau_t} \Delta P_{qk}^{t}. \tag{2}$$

Here β_{qk} – the rate of natural decomposition of the pollution of kind q p in aqueous medium of the area k during the year; τ_t – the length of time t;

$\Phi_{qk^{'}k}^{t} (\Phi_{qkk^{"}}^{t})$ – the amount of income (removal) of pollution q in the area k (from the area k) from the area k' (to the area k'') as a result of the natural transfer of substances.

Volumes of pollutant transport between neighboring industrial nodes determined in accordance with the model of Phelps–Streeter:

$$\Phi_{qk'k}^{t} = \alpha_{qk'k} (P_{qk'}^{t} + \Delta P_{qk^{'}}^{t}) \;\; \Phi_{qkk''}^{t} = \alpha_{qkk''} (P_{qk}^{t} + \Delta P_{qk}^{t}), \tag{3}$$

where $\alpha_{qk'k}$ $(\alpha_{qkk''})$ – the degree of decomposition of the substance q as a result of transit on the section of the river from the area k' to k (from k to k'').

Thus: $\alpha_{qk'k} = 10^{-k_q \rho_{k'k}}$. Here k_q – rate constant of the oxidizing substances q ($k_q > 0$ – for non-conservative organic substances); $\rho_{k'k}$ – oxidation time of a substance in the area from k' up to k (or the movement of river water from the from the section k' of the river to the section k); $\rho_{k'k} = R_{k'k} / V$, where $R_{k'k}$ – distance between k' and k; V – average velocity of flow of the river.

Further, in the condition (1):

x_{jk} – the intensity of the variant of operation of the facility j in the area k;

x_{jk}^{t} – capacity of the facility j in the area k at end of period t;

E_q – the volume of output of pollution q form domestic wastewater;

z_k^t – population of the area k at end of period t;

E_{qj}^{t} (E_{qj}) – the amount of pollution type q, discharged into the waters with sewage generated at facilities j with a fixed (unreserved) intensity at the end of period t.

Volumes of output of harmful substances from industrial and municipal wastewater are defined as: $E_{qj}^{t} = e_{qj} v_{j}^{t}$; $E_{qj} = e_{qj} v_{j}$; $E_{q} = e_{q} v$, where e_{qj} (e_q) – the final concentration of the substance q in the effluent of the object j (in household wastewater);

In this case: $e_{qj} = c_{qj}^{нач} - c_{qj}$; $e_q = c_q^{нач} - c_q$.

Here $c_{qj}^{нач}$ $(c_q^{нач})$ – initial concentration of the substance q in the effluent of the object j (in household wastewater);

c_{qj} (c_q) – the amount on which the concentration of the substance q are reduced in the effluent of the object j (household effluent) as a result of neutralization in wastewater treatment plants;

v_j^t – volume of wastewater of the object j at the end of period t;

v_j – specific volume of wastewater of the object j with the desired intensity;

v – specific volume of waste water (for 1 thousand people).

Substituting equalities (2) and (3) in condition (1), we obtain:

$$(1-\alpha_{qkk''})(P_{qk}^t + \Delta P_{qk}^t) - \sum_{k'} \alpha_{qk'k}(P_{qk}^t + \Delta P_{qk}^t) - (1-\beta_{qk})\Delta P_{qk}^{t-1} -$$

$$-\sum_j E_{qj}^t x_{jk} - \sum_j E_{qj} x_{qk}^t - E_q z_k^t = 0 \qquad (\forall q, k, k', t) \tag{1a}$$

Thus, according to condition (1a) forming the level of water pollution by this or that ingredient in every industrial node is performed for each time period with taking into account the following factors:

- discharge of harmful substances with industrial and domestic waste waters;
- the degree of neutralization of contaminants in wastewater treatment plants depending on the cleaning methods;
- magnitude of accumulation of pollution over time taking into account the background contamination;
- volumes of natural transfer of harmful substances between neighboring industrial hubs.

As a result of such representation of the volume of harmful substances in waste water pollution dynamics in each period reflected by the amount of pollution released to the aquatic environment in the previous period, in view of its possible accumulation during this period, and in accordance with the dynamics of the development and production of household activity in every industrial junction.

2) Restrictions on dumping contaminants in surface water sources:

$$P_{qk}^t \le \frac{G_q^l}{K^l}(R_k^t - \sum_j d_j^t x_{jk} - \sum_j d_j x_{jk}^t - dz_k^t) \qquad (\forall q, l, k, t) \tag{4}$$

where G_q^l – the maximum permissible concentration (MPC) of the substance q, belonging to a limiting attribute of hazards (LAH) l;

K^l – the number of harmful substances belonging to one LAH l;

R_k^t – the water flow at the source on a plot k during the period t.

$$R_k^t = R_k - W_k - \sum_{k'} W_{k'}^t \tag{5}$$

R_k – the average multiyear water flow in the source on the plot k;

W_k – volumes of water consumption by existing industrial units in the area k;

$W^t_{k'}$ – water withdrawals at the end of period t by consumers in areas k', which are located up the river;

d^t_j, d_j, d – volume of withdrawal of flow for irrevocable water consumption and dilution of the wastewater of the objects j and for domestic water supply and domestic sewage dilution.

$$d^t_j = (\kappa_j - 1)v^t_j + w^t_j;\; d_j = (\kappa_j - 1)v_j + w_j;\; d = (\kappa_j - 1)v + w \tag{6}$$

Here κ_j (κ) – the multiplicity of dilution of the wastewater discharged by the object j (domestic waste water);

w^t_j – volumes of water consumption the object j in period t;

w_j – specific volume of water consumption the object j with the sought intensity;

w – specific volume of water consumption by the population (for 1000 people).

Condition (4) taking into account of the conditions (5) and (6) can be rewritten as follows (a more convenient for inclusion in a model of the task):

$$\frac{\kappa^l}{G^l_q} P^t_{qk} + \sum_j d^t_j x_{jk} + \sum_j d_j x^t_{jk} + dz^t_k \le R^t_k \quad (\forall q, l, k, t) \tag{4a}$$

Thus, in the described water block the restrictions on wastewater discharges of contaminants in the aquatic environment – the conditions (4) or (4a) – are built taking into account:

- MPC indicators of harmful substances in water reservoirs;
- summation effect of action of various substances belonging to one of LAH;
- water flow at the source;
- irrevocable water consumption volumes;
- desired degree of dilution discharged into surface water bodies treated wastewater.

3) Conditions of non-worsening environmental situation in each industrial nodes over time:

$$\Delta P^t_{qk} < \Delta P^{t-1}_{qk} \quad (\forall q, k, t) \tag{7}$$

Condition (7) means that the amount of pollution, released into the aquatic environment of a particular industrial bodes in a given period of time in excess of allowable limits, shall not exceed the corresponding pollution released to the aquatic environment at the end of the previous period, i.e. qualitative state of the aquatic environment in each area over time should not deteriorate. Specifying the conditions (7), we are able to manipulate in certain limits with pollution, allocated beyond acceptable norms, limiting its output with period t=1 or later periods, when as the formation of regional economy and enhance its production capacity increases and discharge of harmful substances from sewage.

All above conditions of the introduced block, are constructed, firstly, for all considered in the task of pollutants contained in industrial and domestic wastewater; secondly, for each of the selected within the limits of a region the territorial units, which are accepted as industrial nodes; and, thirdly, for each of the calculated time intervals into which the whole analyzed in the task period of forecasting is partitioned.

As follows from condition (1), the entire volume of the produced pollution is divided into two parts – the pollution generated within the limits of the acceptable health standards, and pollution from the resulting sewage over the permissible level. This division allows the discharge of pollutants in water bodies over environmental standards adopted in the absence of technical capacity to provide the desired degree of neutralization of wastewater. In this case the discharge of harmful substances into the water environment of the region (beyond acceptable limits) will be accompanied by damage to the natural environment. This fact is reflected in the formation of the objective function, which represents the minimum, firstly, calculated expenditures for establishment and functioning of all elements of the regional economy (including of the discounting), and secondly , the magnitude of the economic damage caused by water pollution.

The last element is calculated as the sum of products of specific damages from water pollution under consideration ingredients wastewater volumes and pollution coming into the aquatic environment beyond accepted norms (see below).

4) The requirement to minimize economic damage from water pollution:

$$\sum_k \sum_t U_k^t \to \min \text{,where } \quad U_k^t = \sum_q \sum_k \sum_t g^t u_{qk} \Delta P_{qk}^t \quad (\forall t) \tag{8}$$

Here U_k^t – the value of the total economic damage from water pollution in the area k at the end of period t;

g^t – the discount factor;

u_{qk} – Indicators of specific economic damages from water pollution in the area k of substance q[1].

Dividing the volume of pollution into two parts (of pollutants discharged into water bodies within the limits of standards and beyond permissible limits) allows:

- to determine the limiting capabilities defined by conditions of the task systems of wastewater treatment;
- to determine the amount of economic damage from water pollution and minimize this value in the process of solving the problem, depending on the current production and the spatial structure of economic complex;
- to implement the accounting of the accumulation of pollution entering the water environment beyond the limits;
- to provide for the possibility of solving the problem in case of impossibility of exit onto set environmental standards.

If as a result decision generated pollution does not keep within the specified restrictions, it can serve as an alarming signal that the economic activity in a particular industrial junction goes beyond environmentally acceptable limits and to avoid this, you need to take some additional measures, such as:

- to introduce new conditions of the task (more environmentally friendly) technologies of the main productions at production facilities;
- to introduce into the conditions of the task (more environmentally friendly) technologies of the main productions at production facilities;
- supplement or replace by a more advanced by predetermined wastewater treatment systems;
- to propose other variants of production location for the purpose of the deconcetration of production over the territory to make better use of adaptive mechanisms of the aquatic environment;
- to abandon the creation of certain objects in the industrial hubs with the most intense environmental situation, or go the way outs of production on the individual enterprises to environmentally acceptable scale, etc.

[1] Indicators of specific economic damages from pollution of surface water sources in the discharge of hazardous substances in excess of the permissible limits, calculated in accordance with the «Temporary technique for determining of prevented environmental damage» (approved by Goskomekologiya 09.03.1999).

In general, the inclusion of characterized conditions in the model of the task allows us to solve the following issues:

– to identify environmentally acceptable in terms of impact on the aquatic environment scale of the development of economic activities in the region;
– to identify opportunities of the defined by conditions of the task systems of neutralization of industrial and domestic waste water;
– to analyze the impact factors of the accumulation and natural transport of hazardous substances by the rivers on the formation of the overall level of pollution in water bodies within the considered territory;
– to estimate the economic damage that may be caused the region's economy and public health by water pollution in case the discharge of harmful substances in excess of the permissible norms;
– to verify to what changes in the choice of allocation scheme the investigated production in the region could cause accounting requirements of protection of water resources.

By using characterized block model, we have made calculations, in particular, on the materials of the Lower Angara region in the Krasnoyarsk krai. Before proceeding to the presentation of some results of realization of described model with the inclusion of water block, let us consider in more detail the characteristics of specific conditions of the Lower Angara region, influencing the development of the environmental situation of the water basin.

LOWER ANGARA REGION AS EXAMPLE OF THE AREA OF THE NEW ECONOMIC DEVELOPMENT: PROBLEMS AND PROSPECTS

The Lower Angara Region[1] in the Krasnoyarsk krai is a typical example of the region of the new economic development, which has become the subject of a major investment in Russia in the post-Soviet period. At present there the investment project «Integrated Development of the Lower Angara area» [4, 5] is being realized, investment project «Angara-Yenisei cluster» was proposed [6, 7]. In the region as a result of implementation of the 1st stage of the investment project «Integrated Development of the Lower Angara area» (IP IDLA) is established supporting basis for further intensive and large-scale economic development. The main reason for the investment attractiveness of the region is the presence on its territory of diverse and often unique in quality and scale of energy and raw materials, including ferrous, non-ferrous and precious metals, hydrocarbon feedstock varied nonmetallic raw materials, forest, and water and hydropower resources. An important role is played by the Boguchan power plant, which is currently being constructed (close to being operational), as well as some infrastructural developments. In particular, two railway connections to the region (Achinsk–Lesosibirsk and Reshoty–Karabula); the Karabula–Yarki railroad, an automobile bridge across the Angara River and several highways, including the Kansk–Kodinsk highway, are being built. One can also name other ongoing projects, such as the connection of Ust-Ilimsk to Lesosibirsk as part of the North Siberian railway.

No doubt, the creation of large infrastructure facilities has a great potential for the development of the region at the initial stage. If at the first stage production gravitates

[1] Lower Angara region is generally understood as a region located in the basin of the lower course of the Angara and the middle cource of the Yenisei River and covering the five areas in the Krasnoyarsk krai (Boguchansky, Kezhemsky, Motyginsky, Yeniseisky, North Yeniseisky). Total area ≈ 260 km^2, population – about 230 thousand people.

mainly to Boguchany industrial node (Boguchany power plant, aluminum plant and pulp and paper mill), then in the longer term (by the year 2020), it is foreseen to build new enterprises in the Kodinsk (the Tagara mining and dressing plant and a cement plant) and Boguchany (gas processing and gas chemical plants) industrial hubs. New production is also envisaged in the Motyginsk area (the Gorevsky mining and dressing plant and the Motyginsk hydro power plant). The second phase of the development of the Lower Angara region is mainly associated with the development of oil and gas deposits for the East Siberian oil and gas industry (the southern part of Evenkia). Therefore, in addition to the construction of several industrial facilities, as well as transport and energy infrastructure, the second phase of development goes beyond the Lower Angara region in terms of its territorial coverage. The financial needs of the second phase are estimated at 540 billion rubles. One should note that the current state of the region is characterized by a low pace of economic development, the economy's orientation towards the forest industry, a high share of the grey economy, as well as a stable population outflow and unemployment.

The investment project «Integrated Development of the Lower Angara» is the largest Russian project implemented in the post Soviet period. Its implementation is based on the principle of public-private partnership. Public financial support is allocated on the basis of cofinancing from the Investment Fund of the Russian Federation and is aimed at creating major transport and energy infrastructure facilities that can propel the industrial development of the region. At the same time, 55.2% of the funds required for the project are provided by Vneshekonombank [8].

In spite of the exerted attention to the region and all the pluses of the mentioned projects the last are characterized in general by lack of comprehensive and balanced development of the territory, mainly focusing on the development of the lower of energy production cycles, ignoring the environmental and social problems. This is manifested, in particular, in the absence of:

- complex approach to the development of the area in terms of the development and operation of basic sectors of the economy in relation to social issues and the environment;
- coordinating the establishment and operation of all facilities on the territory, including infrastructure;
- the intention to build an innovative model of development in view of the continuous adaptation to the requirements of the scientific and technological progress;
- formation of the infrastructure of local importance;
- consideration of the requirements of environmental protection and restoration of natural resources;
- approaches to solving a complicated tangle of social problems, ultimately aimed at improving living standards of people;
- the ability to use the available natural resources in the interests of the entire population living in the region rather than a number of large companies (and, generally, in the context of sustainable development, i.e., in the interest of the present and future generations), and so on.

Let us briefly discuss the problems of possible impact of the planned economic activity in the study region on the state of its water bodies.

Issues of water pollution in the lower reaches of the Angara River can not be considered without a comprehensive analysis of all the Angara river basin. This is due to the fact that even now the state of water quality in the Lower Angara region, where the existing anthropogenic pressures are still very insignificant, to a large extent determined by the effect of pollution, which is formed in the upper and middle current of the river. Therefore, solution to the problem of improving and maintaining the required water quality in the lower reaches of the Angara largely depends not only on the current and future scope of economic activity within the Lower Angara region and most of the corresponding system of environmental and other events, but also on the environmental situation in the upper and middle sections of the Angara river.

Taking into account quite a high level of background contamination of the upper and middle current of the river, Angara has a negative impact on the modern quality condition of the lower portion of the river. It seems necessary to implement water conservation measures first of all in the upper and middle part of the Angara River, receiving a significant amount of polluted industrial and domestic wastewater from industrial facilities and settlements within the Irkutsk region (primarily the cities of Irkutsk, Angarsk, Usolye-Siberian, Bratsk, Ust-Ilimsk). To regulate the problems of control and transit of pollution throughout the river Angara would be useful to have a special administrative body.

If we consider the Angara River basin as a whole, then, it is estimated that almost all of the wastewater entering the Angara and its tributaries, is reset to the territory of the Irkutsk region (over 98%), while the share of the Krasnoyarsk Krai in total contamination is negligible (less than 2%) [9]. At the same time decisive influence on pollution of the Angara River within the Lower Angara region have wastewater of industrial enterprises of Bratsk and Ust-Ilimsk. So, below of discharges of the Ust-Ilimsk timber industry complex the concentration of phenols in Angara reaches 25 MPC (maximum permissible concentration), oil – 10 MPC, the magnitude of the BOD (biological oxygen demand) is about 5 mg O_2 / liter.

In the context of the branches main part of contaminated wastewater entering the Angara-Yenisei basin from industrial enterprises is accounted for objects of pulp and paper industry and hydrolysis (31.1%), as well as petrochemical and chemical industry (27.6%).

An important role is played the problem of forecasting quality of water resources of the Angara River in conditions of possible hydropower construction. Operating experience of existing water reservoirs of the Angara cascade and water quality analysis in them enables (let us) to suggest that the envisaged new reservoirs on the lower Angara will (by analogy with the existing water reservoirs) serve as the sedimentation tanks of pollution. In the case of the continuation of wastewater discharge in the middle and upper reaches of the Angara River it is probably the sharp deterioration of water quality in the reservoirs in the Low Angara and at the outputs of them. Also, necessary to consider that reservoir in the lower reaches of the Angara will be trailing in the cascade for which the general trend is consistent deterioration of water quality in reservoirs from the top down. Thus, the forecasting of economic activity within the Lower Angara region should be carried out first of all taking into account the quite a high background of water pollution.

Considering the Lower Angara region through the prism is currently implemented investment project «Integrated Development of the Lower Angara area», it should be noted that this region, first, is being developed predominantly on the resource scenario and, second, the territorial concentration of production within it is uneven: the development is limited only two industrial nodes – Boguchany and in the longer term – Kodinsk. This means that the question of the uniform development of its territory is not put, production expected to focus in large individual nodes. It will entail and increase of the territorial concentration of production within these nodes and, consequently, increase of the load on the environment at the corresponding nodes and possibly in connection with this the complication in this environmental situation.

In the future, the water environment in the Lower Angara region will be determined, at least the following factors:

- features of local natural and climatic conditions of the region (unfavorable adaptable possibilities of the environment) and low stability of natural systems in relation to anthropogenic impact;

- choice of options for possible technological solutions on prospective production facilities of the region;
- low quality water conditions in the upper and middle reaches of the Angara River and the need to conduct an appropriate system of protection measures for existing industrial enterprises of the Irkutsk region in the Angara River basin;
- impact on the status of water bodies in the region of the reservoir Boguchanskaya HPP, as well as possible future water reservoirs, intended to establish in connection with the construction of new power plants in the lower reaches of the Angara River;
- choice of possible allocation scheme for future productions in the region and as a whole character of the production structure of the individual areas and the scale of concentration of production in them.

Specificity of local conditions affecting the development of the environmental situation of the water bodies in the Lower Angara region necessitates access to the region with technologically advanced industries. So, the Lower Angara region is characterized by a low assimilative capacity, which is due, firstly, to its high potential for atmospheric contamination (the worst conditions can be observed in the settlements of Lesosibirsk and Kodinsk) and, secondly, to a low self-purification capacity of surface water and, thus, unfavorable conditions for the oxidation of organic matter, as well as levels of water pollution (by suspended materials, phenols, oil, and other organic substances). The quality of water does not satisfy the adopted standards, which in turn puts forward special requirements for basic and nature conservation technologies applied by industrial facilities that are being set up in the region.

This is compounded by the building of reservoirs and the violation of the natural hydrological regime of the river. The self-cleaning ability of the Angara River has thus far largely been exhausted and for a number of pollutants (such as suspended solids, phenols, petroleum products, etc.), the water quality does not meet the required standards which in turn imposes special requirements for basic and environmental technology planned in the region of production. In addition, one should note a fairly high level of background contamination of the aquatic environment in the settlements of Boguchany and Kodinsk, which will bear the major anthropogenic burden following the implementation of the investment project [1, 10, 11].

The choice of capacities for future industrial facilities in the region is equally important. Thus, the planned annual capacity of the Boguchany aluminum plant is 600 thousand tons, which does not comply with international standards: the ultimate power of aluminum smelters worldwide is 200–250 thousand tons per year. At present, it is close to 190 thousand tons per year [12, 13]. Furthermore, the environmental incompatibility of aluminum production with the processes of pulp and paper production entails the risk that Boguchany can repeat the sad fate of Bratsk, where the creation of similar super industries resulted in the extinction of coniferous forests and more frequent occurrence of cancer among children.

Crisis situations in the state of the environment in the Lower Angara can be avoided by preventing adverse changes in ecological character, adherence to the accepted environmental requirements, obligatory environmental impact assessments of any of new economic projects, the application of advanced technical and technological solutions. It is necessary to create conditions, not only to guarantee the protection of the environment, but also to stimulate environmental measures and to involve in economic circulation of natural resources in the region.

In general, the lower regeneration capacity of the natural environment of Lower Angara underpins the need for stringent requirements for production technology, including both technological (core production technology) and environmental (environmental protection measures, etc.) innovation. One can only consider the establishment of complex economic facilities in the region in general and, more specifically, the foreseen combination of plants and their respective capacities, if the above conditions are met. At the same time, it is not only necessary to give a priority to advanced low-waste technologies for the core production of the planned facilities but also to implement a range of environmental activities, which comprehensively cover all aspects of the anthropogenic impact on the environment, including the possibilities of rational placement and territorial organization of productive forces, waste disposal, selection of various technological options providing a response to the disposal of pollutants and their combinations, etc.

LOWER ANGARA REGION AS OBJECT OF THE APPLICATION OF THE PROPOSED APPARATUS OF ANALYSIS OF ENVIRONMENTAL AND ECONOMIC INTERACTION AND FEATURES

In IEIE SB RAS some experience has been accumulated in the field of research on account of influence of environmental factors on the formation of the spatial structure of the economy in the Lower Angara region [1, 2, 3, 10, 11]. One of the directions of this research is to analyze the impact of the p forecasted economic activity within the region on the environment, including water basin, as well as the possibility of the creation of reservoirs on the Angara River and their contribution to the change processes of accumulation of pollution in surface waters and natural transfer of pollutants[1].

As already mentioned, using conditions of characterized block of the model, a series of experimental calculations on materials of the Lower Angara Region in Krasnoyarsk Krai was carried out. Analysis performed calculations allowed us to determine the influence of the factors included in the task on the choice of the environmentally friendly solutions taking into account possible negative consequences of the environmental pollution and putting into exploitation large-scale Boguchanskaya hydro power plant (BoHPP) in the lower reaches of the river Angara.

For calculations with using the supposed model was used software package LP-system, which allows solving optimization tasks of linear programming based on a modified simplex method. As a result of solution was clarified possible production structure considered industrial nodes in the Lower Angara region, within which is planned the main concentration of the objects of timber and metallurgical complexes.

According to the task conditions on the territory of the Lower Angara region were considered:

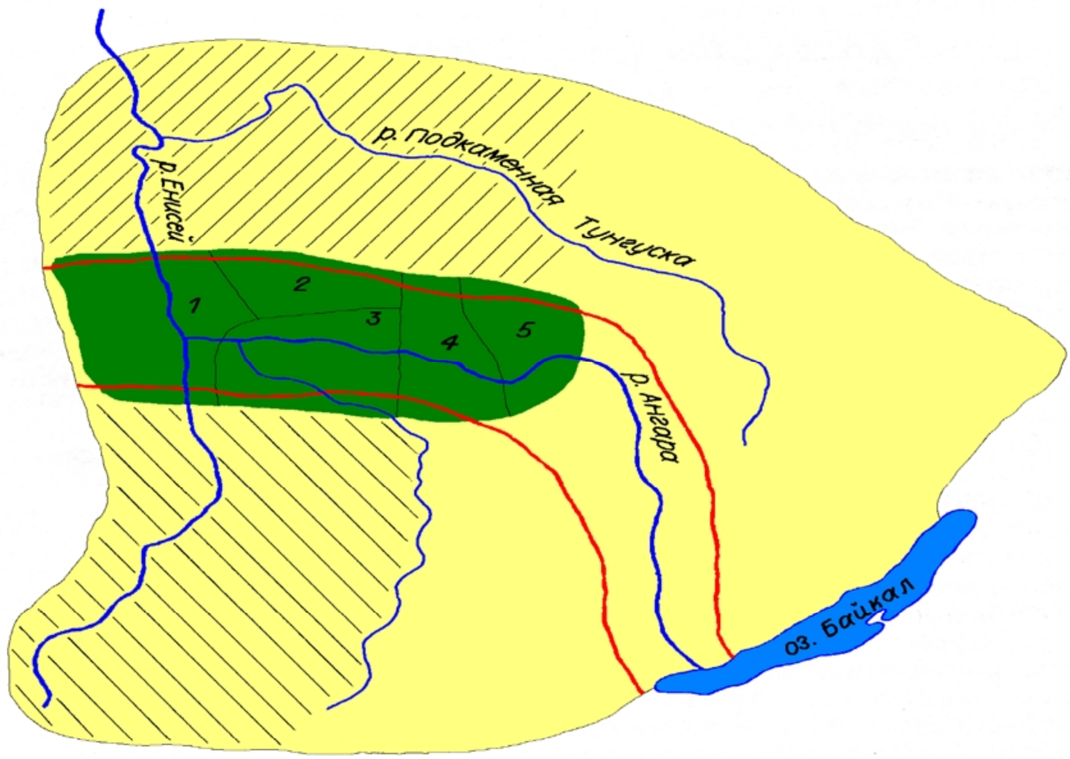
1) 5 industrial nodes: Kodinsk (as part of the administrative district Kezhma), Boguchany, Motygino and – on the Angara River, and Abalakovo and Lesosibirsk (as part of the administrative district of the Yeniseisk) – on the Yenisei River (Figure 4).

2) about 20 industrial objects, including timber industry (4 Pulp and paper mills (PPM), 2 Hydrolysis Yeast Plants (HYP), 4 Timber processing complexes (TPC)), mining and metallurgical combines (Tagara Iron Ore and Gorevsky Lead-Zinc Mining and Processing Plant), metallurgical plants (aluminum, lead, zinc, etc.), enterprises of chemical industry and energy (Table 1).

3) 5 types of pollution: suspended solids, phenols and chlorides, oil and Biological oxygen demand in full (BODf).

4) 3 time periods, each of 5 years.

[1] In general, studies on optimization of the formation of the Lower Angara region aimed at identifying possible location scheme of the supposed for the creation of the study area of new industrial enterprises, industrial production structure nodes, scale and pace of development of the main elements of the production and social infrastructure, options for the use of local natural resources, the scope of possible contamination of water and air, the magnitude economic damage from water pollution and atmospheric under conditions of fulfillment of a given production program and providing the required living conditions of the population.



– the Angara-Yenisei region
– the Angara-Tunguska area
– the Krasnoyarsk area
– the boundary of Angara area
– the Lower Angara area

***1–5* – Administrative regions of the Lower Angara Region:**
1 – Yeniseisk
2 – North-Yeniseisk
3 – Motygino
4 – Boguchany
5 – Kezhma

Fig. 4. The areals of research

Table 1

Possible variants of distribution of the objects in the Lower Angara region on areals (under the terms of the problem)

Objects	Areals (industrial nodes)				
	Kodinsk	**Boguchany**	**Motygino**	**Lesosibirsk**	**Abalakovo**
Pulp and paper mill – PPM 1:	**X**		**X**		
PPM 2		**X**			
PPM 3				**X**	**X**
PPM 4				**X**	**X**
Hydrolysis Yeast Plant – HYP 1:				**X**	
HYP 2	**X**				
Timber processing complex – TPC 1:				**X**	
TPC 2	**X**				
TPC 3		**X**			
TPC 4				**X**	

Objects	Areals (industrial nodes)				
	Kodinsk	Boguchany	Motygino	Lesosibirsk	Abalakovo
Tagara Iron Ore Mining and Processing Plant (MPP)	X				
Gorevsky Lead-Zinc MPP			X		
Ferroalloy Plant (FP)	X	X		X	X
Lead-Zinc Plant (LZP)	X	X	X		X
Alumina Refinery (AR)		X	X		
Aluminum Plant (AP)	X	X			
Copper-Chemical Plant (CCP)	X	X			
Petrochemical combine (PCC)	X	X		X	X
Plant for the production of synthetic liquid fuels (SLF)		X			X

The time factor is taken into account first of all when determining the possible level of discharges and emissions of contaminants in the environment of Kodinsk and Boguchany industrial nodes. Formation of such level for every ingredient in each reporting period shall be based on taking into account of the following three factors:

- discharges and emissions of harmful substances with industrial and household waste;
- the level of emissions purification depending on the technology used on the object-pollutant;
- accumulation of contamination over time, taking into account background pollution.

Thus, the dynamics of contaminants in each of the periods is reflected through the output of harmful substances in the previous period of time, taking into account its possible accumulation during this period, and furthermore also the dynamics of economic and domestic activities is taken into account.

Information on emissions and discharges of pollutants has been taken, particularly, from industry handbooks on best available techniques (BAT Reference Documents (BREFs)) [14, 15].[1]

Let us consider characterize the results obtained solutions.

FORMATION OF THE PRODUCTION STRUCTURE OF THE REGION TAKING INTO ACCOUNT THE POTENTIAL IMPACT ON THE WATER ENVIRONMENT

During the research was carried out a series of the variant calculations; the main content of the individual variants are shown in Table. 2.

The choice of possible schemes of locating productions being considered on the territory the Lower Angara region, is characterized by following features for the different variants of the calculations.

[1] Development of handbooks is carried by the European Bureau on Complex Pollution Prevention and Control at the Institute for Prospective Technological Studies (Seville, Spain). All the reference books are publicly available on the website of the Bureau at the address: http://eippcb.jrc.es/reference/. At present there are 26 sectoral («vertical») and 7 «horizontal» (revealing common to several branches of questions) reference documents, 18 of them were approved by the European Commission [14, 15].

Table 2

Variants of solutions of the task

Variants of the solutions	Content of the Variants of the solutions
I	Without taking into account conditions to protect water bodies
II	Conditions of variant I plus block of conditions to protect water bodies
III	Conditions of variant II plus account of requirements of non-worsening environmental situation in each areal with a certain time period
IV	Conditions of variant III plus: • decreasing dynamics of water flow in the springs located on the Angara River, • the conditions of a possible deterioration of the initial conditions of wastewater discharged into surface water sources
V	Conditions of variant IV plus the requirements of the non-worsening environmental situation
VI	Conditions of variant V plus taking into account of possibilities to reduce the flow of water on four of the five reviewed sections of the river (near Boguchany, Motygino, Lesosibirsk and Abalakovo)

From the point of view of the formation prescribed by the conditions of the task possible production structure of the selected areas (industrial nodes) in the region and crea-ted by them a corresponding pressure on water bodies according to the results solv-ing the most stressful situation develops in Lesosibirsk and Motygino industrial nodes. In that case production structure of the Lesosibirsk industrial hub from the standpoint of the possibility of pollution discharge with sewage into surface water sources on the results of solutions is limited by considered here objects of timber industry, including pulp and pa-per mills, hydrolysis yeast plants and some timber processing complexes. Along with this under defined by the task conditions of the location variants of the objects in Lesosibirsk industrial hab, their facilities and wastewater treatment systems it requires further unload-ing of this industrial hub to get closer to the permissible levels of pollutants discharge into the aquatic environment.

The same applies to Motygino industrial node, where on the results of calculations situation with the water pollution is primarily determined by the choice here PPM. This enterprise is the largest of all the considered in the task pulp and paper mills and its con-tribution to the total water pollution is much greater than the contribution of other of en-terprises that are included on the results of the solutions in the Motygino node (including Gorevsky mining and processing plant, alumina and lead-zinc plants).

Within the framework of the proposed formulation of the task (in addition to these options in Table 1) was carried out a series of solutions of variant calculations, aimed at investigation of the influence on the formation of the spatial structure of the Lower Anga-ra region of possible changes in the individual conditions of the task and given the levels of several indicators. In compressed form characteristics implemented in the calculations directions of variations of conditions of the model and the level of the values of individual indicators, as well as a short description of the results of variant calculations are summa-rized in Table 3.

Table 3

Characteristics of variant calculations

Conditions of model	Indicators to be subjected to variation	The obtained results
I. The formation of a balance of pollution of water bodies	1. Indicators of output of finite pollution in wastewater of the individual enterprises: PPM, HYP, PCC and SLF (variation was carried out in the direction of deterioration of initial conditions wastewater)	There are changes in an allocation scheme of the production envisaged, related to the increase of the content of pollutants in discharged wastewater. These changes can be considered negligible, mainly because of the limited set of location options for investigated enterprises. Increase in the discharge of pollution from sewage accompanied by an increase the total amount of economic damage caused by pollution of water bodies.
	2. Indicators of the degree of decomposition of nonconservative organic matters	Reducing the degree of decomposition of pollutants (in particular Kodinsk areal) associated with the construction of the reservoir of the Boguchanskaya HPP causes, on the one hand, the reduction in the removal of contaminants from this areal and, on the other hand, the strengthening of the processes of accumulation of harmful substances into the aquatic environment of the corresponding area. The ratio of these two processes, as well as the initial pollution in areals, between which there is transit of pollutants (eg, from Kodinsk to Boguchany), and determines the final level of contamination in each of the areals. In the Kodinsky areal pollution discharge into the water increases slightly. The same is true for the other pairs of neighboring areas, among which may be created by water reservoir (Boguchany and Motygino).
	3. Calculations taking into account (and without taking into account) the factor of the accumulation pollution	There is a slight increase in the overall level of water pollution in the area of Kodinsk and Boguchany in connection with the creation of Buguchany reservoir and in the future – Nizhneangarsk HPP reservoir.
	4. Calculations taking into account (and without taking into account) the factor of the natural pollution transport	Ecological situation with water pollution in the Lesosibirsk industrial node escalates and, accordingly, increases the value of economic damage in the site water pollution. In other areals significant increase in the overall level of water pollution does not occur.
II. Restrictions on the discharge of pollutants to surface waters	Variation of any indication was not carried out	
III. Conditions non-worsening environmental situation in each of the industrial nodes over time	1. Calculations without the inclusion of these conditions in the model of the task	During the optimization of the spatial structure of the economy of the Lower Angara region actively participate indicators of economic damage from water pollution, affecting: a) the choice of the location variants of the objects (the result is strengthening of deconcentration of production on the territory of the region) and b) the choice of their variants construction (preference have options with later start dates for construction and operation of individual businesses).

Conditions of model	Indicators to be subjected to variation	The obtained results
	2. Inclusion of appropriate parameters from the first period of time (t=1)	In this case, the above permitted standard of pollutants discharge must not exceed the level of initial background contamination. It is impossible requirement (under the conditions of the task), because produced amount of pollution does not keep within the specified standards.
	3. Inclusion of appropriate indicators from the period of time when major objects-polluters shall enter into operation	There is a choice of options for the construction of a number of objects (ferroalloy, lead and zinc plants, Gorevsky MPP and plant for the production of synthetic liquid fuels, for which the establishment and functioning of the relevant objects begins as early as possible. This provides by the second half of the forecast period the maximum possible discharge of pollution. Thus there is almost a twofold increase in the amount of economic damage caused by water pollution.
IV. Objective function	Calculations based on indicators of economic damage caused by water pollution separately for each kind of using water bodies (household-drinking and fishery purposes, as well as in the aggregate)	There are changes in the choice of options for the timing of construction of individual objects (ferroalloy, alumina and aluminum plants, Gorevsky Lead-Zinc MPP, Plant for the production of synthetic liquid fuels) in the direction of displacement of the beginning their construction near the end of the forecast period

RECOMMENDATIONS AND CONCLUSIONS BASED ON ANALYSIS OF THE PERFORMED CALCULATIONS

Analysis of the conducted calculations using the proposed model allows to draw the following conclusions and to make some recommendations.

1. Decision showed the need for the deconcentration of production in the region (by refusing to the creation of large industrial nodes and super-large objects, by considering the deconcentration of production in the territory for a better using the adaptive mechanisms of the aquatic environment). In this case, the predicted environmental situation in the selected part of the Lower Angara region is characterized by a satisfactory level of water pollution, although there is some excess of established norms, which is accompanied by the appropriate application of economic damage.

2. In perspective the main load in the aquatic environment of the Lower Angara region should expect first of all from the objects of timber industry complex (pulp and paper, and hydrolysis of yeast plants). Share of these objects in the total wastewater pollution for all considered enterprises in the region is the predominant: more than 90% of suspended solids and about 98% – phenols and chlorides.

3. Under given conditions of the task (first of all production technologies) joint solution of the issues of aquatic environmental protection and placing objects-giants is problematic, due to which reduction in individual production capacities of a number of enterprises under consideration, first of all pulp and paper mills is required. According to our calculations, the optimum size of the unit capacity of PPM in the Lower Angara region in order to maintain the specified quality of water resources must not exceed 300–400 thousand tons. This is confirmed by data from the world practice the establishment and operation of such facilities (despite the existence of certain exceptions).

4. Results of the solution showed that even in such rivers as the Angara and Yenisei, which are characterized by high rates of water flow, this factor does not provide by dilu-

tion of conditions bringing the initial sewage discharged to the established standards (for given conditions of the problem scale, composition, production technologies and options for placement of the objects). That is the possibility of using water resources in the region to dilute wastewater as additional steps to make the initial condition up to established standards are limited.

In conditions of high background levels of water pollution its qualitative state is currently for a number of indicators (oil products, phenols, suspended solids, copper, etc.) does not satisfy the sanitary standards. This in turn leads to increased demands on technologies for the production and technologies for wastewater treatment facilities of placed in the region and requires the implementation of environmental measures in the cities located in the upper and middle reaches of the Angara River to reduce effluent discharge existing enterprises.

5. Taking into account of accumulation of pollution, implemented in Kodinsky industrial node due to the creation of the reservoir of Boguchanskaya HPP and Boguchany industrial node in connection with the possible construction of HPP Motygino (after 2020), showed that the contribution of accumulation of dirt in the formation of the overall level of water pollution in the relevant habitats while insignificant. This is explained by the fact that according to the task conditions the basic tasks objects-pollutants (PPM, etc.) come into operation at full capacity by the end of the 2nd and 3rd periods. As a result of the accumulation of pollution occurs substantially within just the last period of time and its share in the total pollution is negligible.

6. Taking into account of natural pollution transfer between the neighboring industrial nodes testifies to its influence on the formation of balances of water pollution in the industrial node Lesosibirsk where to pollution from upstream and Abalakovo and Motygino nodes are tolerated. Since in the Lesosibirsk industrial node already develops stressful environmental situation (especially with pollution of chlorides and phenols contamination) the additional flow of pollution from natural migration exacerbates the situation that due to the limited capacity of unloading Lesosibirsk node leads to an increase in value caused by this pollution economic damage. In other industrial sites factor natural transfer of harmful substances has no appreciable effect on the overall level of water pollution, as because of the high speed of movement of water pollutants largely transit the downstream considered rivers.

Factors accumulation and transfer of pollution are of particular importance in predic-ting water quality in the lower reaches of the Angara River. At present the load on the aqua-tic environment in the Kodinsk and Boguchany areals is negligible. It is formed mainly due to the discharge of untreated sewage in small volumes, as well as navigation and timber floating and to a greater extent falls on the upper and middle reaches of the river. However, creating a reservoir accompanied by stagnation of river water, resulting in contamination transferred from higher situated areas, together with pollution, formed directly in the Kodinsk industrial node will accumulate, and this will lead to a significant reduction in water quality.

7. Implementation of the production program, given conditions of the problem, accompanied by pollution of surface water bodies in the region beyond acceptable norms. This fact makes application of certain economic damage, the value of which is estimated on the options solutions from 3.6 to 22.0 billion rubles per year (depending on the options for placing objects-polluters, production structure of selected areals and other factors). In this case the requirement under the terms of the task is minimizing the damage works as one of the main tools of choice layout of objects location. Under the influence of this requirement, there are some changes in the choice of options for the timing of construction of individual objects-polluters (there is a shift the start of their construction ahead).

In general, the formation of the economy in the Lower Angara area provided strict compliance with applicable environmental standards makes it necessary:

a) entering new ecological oriented production technology;

b) revision of the scale of being placed and future facilities towards decrease the unit capacities of individual enterprises taking into account the nature and extent of their impact on the environment;

c) more thorough substantiation of the number anticipated for placement within the region of industrial enterprises and their possible concentration to the Industrial sites.

The development of the Low Angara requires a thoughtful approach based on the interlinked economic, social, and environmental priorities of development by means of high-tech production and creation of energy-efficient and environmentally friendly enterprises. The long-term development of the area will depend on whether it will be mostly based on resource extraction (limited to the lower levels of the energy-production cycle) or whether an emphasis will be put both on the integrated development of the territory according to the logic of «a hydro power plant – aluminium plant» or «forest, water – pulp, and a paper mill» and the economy's diversification in general which will create preconditions for long-term sustainable development in the region. In this case, the focus should not be on mining. Rather, the emphasis should be on the development of processing industries, building the upper levels of the energy production cycle, high added value production, and the competitiveness in the domestic and global markets. One should locate such production facilities in more southern parts of Krasnoyarsk Krai rather than in Lower Angara. From the above perspective, the Lower Angara region could become a model region for testing the approach to innovation-based exploration and development.

Therefore, the specific situation in the region dictates the need for the development of an adequate innovation policy for exploration, as well as the development of production and a spatial structure of the economy. Such a policy should be both bottom-up (initiated at the level of individual facilities) and top-down (initiated at the level of the federal government and the government of Krasnoyarsk Krai) [16, 17]. In the first case, one can refer among environmental innovations to the creation and use of environmentally friendly technologies (including the organization of waste management), the introduction of environmental management systems at industrial plants, environmental certification, environmental marketing, etc.

In the second case, it involves the consideration of long-term structural interests and opportunities of the regional economy (which requires the abandoning of the exclusive natural resources development scenario); the elaboration of tools for environmentally innovative activity, encouraging the introduction of environmentally friendly technologies, the creation of environmental requirements for the development and continuous improvement of technology; development of licensing systems for all types of activities negatively affecting the environmental situation; the restoration of the practice of environmental expertise; the implementation of environmental audits, etc. The transformation of the investment project into a federal target program could provide a solution to many of these problems.

Question about this transformation naturally put on the basis of long-term interests of the region, since it is the state regional programs (as one of the most effective tools to control the formation and organization of production on site) allow purposefully linked into a single system all implemented and planned activities in the region in cooperation with the requirements of building an innovative model of development, as well as the maintenance of environmental security and achieving desired social goals. In our opinion, the Investment Project «Integrated Development of the Lower Angara region», transformed into a regional program would fit in well with the methodology and structure of the existing system of government strategic planning and management in Russia, under which regional programs are recognized as the primary (spanning the country's interests and region) strategic planning tool. This does not contradict the established order and the funding of regional projects from the Investment Fund. Seem possible, at least two ways to transform the investment project in the regional program. First, it can be considered an appropriate adjustment of investment projects under the Strategy for socio-economic development of the Krasnoyarsk Krai. Secondly, it is possible to initiate the authorities of Krasnoyarsk Krai to development of a specific target program with the federal status.

In any case, the Program on the Lower Angara region, in our view, should consist of at least two interconnected basic blocks:

1) investment projects (this is what we have at present);
2) the objectives and priorities of socio-economic development of the region in the long term (more than 20 years, preferably 30), including environmental and social spheres.

It is known that to obtain the status of the Federal target program is not easy. There are strict criteria and defined procedure for the selection of territories to get this status. Also a serious justification of the corresponding claims is required. In this case the initiative must come from the regional authorities and from them in this regard significant efforts are required. At the same time it's worth it, because the program allows us to pose the problem more broadly than the investment project. So, if the investment project is being developed with the aim of attracting investments into separate objects, on condition of subsequent getting profit (usually developed at the first stage of the project lifecycle, providing for concept development), then the regional program is coordinated by the resources, time, implementing a set of measures to ensure the achievement of goals and objectives, and from the standpoint of the interests of the country and the region, rather than individual objects.

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