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DYNAMIC PROCESSES IN THE ECONOMIC AND ECOLOGICAL SYSTEMS OF WATER BASINS OF UKRAINE: METHODOLOGY AND PRACTICE OF THE USE OF ECONOMIC-MATHEMATICAL METHODS OF ANALYSIS

ДИНАМИЧЕСКИЕ ПРОЦЕССЫ В ЭКОНОМИКО-ЭКОЛОГИЧЕСКИХ СИСТЕМАХ ВОДНЫХ БАССЕЙНОВ УКРАИНЫ: МЕТОДОЛОГИЯ И ПРАКТИКА ПРИМЕНЕНИЯ ЭКОНОМИКО-МАТЕМАТИЧЕСКИХ МЕТОДОВ АНАЛИЗА

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Abstract. *In the present work, freshwater resources of water basins of Ukraine are the object of research. The purpose of this study was to develop methodological approaches to the application of economic and mathematical methods of analysis in assessing the development of dynamic processes in the use of freshwater resources.*

To achieve this goal, the work analyzes the sources of delay in the reaction of the freshwater system, and analyzes the types of delay taking into account the influence of external and internal factors of influence.

A methodological algorithm for solving the problem of optimization of dynamic processes in solving economic and environmental problems arising from the economic use of water basin resources has been developed. The methodological approach presented in the work is a fairly flexible tool with a free choice of elements of analysis depending on the goals and objects of management.

Keywords*: economic-ecological systems, water basins, dynamic processes*

Introduction. The urgency of the problem related to the sustainable and balanced development of the economic, ecological and social conditions of the economic and ecological systems of water bodies in Ukraine is caused by the considerable degradation of the environment, leading to the emergence of complex and negative situations of socioeconomic and ecological origin.

The development of dynamic processes in the economic and ecological systems of water basins in a number of cases leads to a dual result, which on the one hand contributes to the emergence of water management problems, and on the other hand has a negative impact that causes these problems to grow into crisis phenomena.

One of the factors contributing to obtaining such a dual in quality is the presence of a temporary lag in the reaction of the freshwater basin system for the practical use of science and technology achievements in promising water protection technologies and methods of production activity.

Time lag has a negative impact on the stability of all subsystems of the ecological and economic system of the water basin, since they all represent a single whole of a multifactorial dynamic system with a whole complex of acting factors of mutual influence. This influence affects, first of all, the balance and stability in the development of subsystems and the entire freshwater system as a whole.

Purpose and objectives of the study. The purpose of this study is to develop methodological approaches to the application of economic and mathematical methods of analysis in assessing the development of dynamic processes in the economic use of freshwater resources in Ukraine.

To achieve this goal of the research, it is necessary to perform the following tasks:

1. To conduct a study of the sources of delay in the reaction of the freshwater system for any effects.
2. To assess the types of delay in the reaction of the freshwater system while ensuring its safe and balanced development.
3. Assess the impact of external and internal factors of lag.
4. Describe methodological approaches to the application of economic-mathematical methods of analysis in the description of dynamic processes in water basins.
5. Develop a methodological algorithm for solving the problem of optimizing dynamic processes in solving economic and environmental problems in water basins.

Examine existing solutions to the problem. In recent years, the spectrum has expanded significantly, and various scientific studies have significantly intensified in the issues of sustainable development of freshwater systems associated with solving urgent problems of optimizing the use of natural resources, protecting and improving the natural environment.

Hydroecological problems of Ukraine today have acquired not only national, but also international significance. The water factor has become not only one of the main indicators that limit the development of the production and household spheres of individual regions, but also an unconditional paradigm for the country's national security.

The methodological foundations of this line of scientific research for the territory of Ukraine were laid in the works of a number of scientists [9,11-13, 15,17]. Particular attention in these studies has always been given to the analysis and assessment of freshwater resources as one of the main natural factors that determine not only the level of industrial and economic development of the region, but also the social and everyday component of public life.

Among the main directions of the solution of the problem in question, defined in the resources of the world scientific periodicals, it is possible to single out:

- in the development of conceptual directions of economic assessment of the potential of natural resources in terms of sustainable development of the territory [2,5,15];
- evaluation of economic aspects of the theory of sustainable and balanced regional development [6,20,21];
- in works [12,13,24], along with the economic and financial aspects of solving the problems under consideration, the resolution of institutional issues, as well as the solution of environmental policy problems at various levels, is being considered;

An alternative option was proposed in works [14,16,22,23], which assumes that the main focus in solving the problem should be directed to environmental activities in the economic and ecological systems of Ukraine's water basins, the development of modern low-waste and resource-saving technologies. The authors [9, 10] draw on a special role in investing in the protection of the environment of freshwater resources in Ukraine.

The authors of [3,18,24] suggest a different approach to solving the problem under investigation, when sustainable and balanced development of the territory is carried out in the context of the development of integrated water basin management schemes.

Despite a significant amount of scientific research, it can be argued that the issues of methodological justification for an overall strategy in terms of the sustainable and safe development of economic and environmental systems at the regional level - the level of the water basin - remain insufficiently studied.

Material and methods. To solve the tasks set in the work, methods of analysis and synthesis, comparative comparison, logical generalization and analogies were used, in combination with monographic and graphoanalytical studies.

Assessment of the possibility of loss of stability of the economic-ecological freshwater system requires the development of special methods for analyzing the state and management of this system using methods of multidimensional mathematical modeling.

The studies carried out in [5,7,8] show the presence of two sources of lag in the reaction of freshwater systems to the conduct of any actions, including environmental ones, on their development:

- the volume of the system, as a result of which there is an inertia and a false impression of the ineffectiveness of the impact on the current situation;
- a temporary delay in the implementation of science and technology achievements in the implementation of environmental programs, which may arise if the administration of environmental and regulatory acts is poorly managed, and if there is insufficient funding.

According to [9,18], the following four types of delay in the reaction of freshwater systems can be identified while ensuring safety and balance in their development:

- the delay of the beginning of the reaction in relation to the moment of the beginning of the impact on the economic and ecological system from the achievements of science and technology in the implementation of environmental activities;
- strategic delay, as a result of which the reaction of the economic and ecological system comes only after the introduction of all the proposed options for the achievements of science and technology in improving environmental activities to ensure the safe development of economic and environmental systems;
- lag caused by the threat of changing the status of this system of providing the resource, which requires the appearance of additional regulatory and legislative acts, as well as organizational measures to use these achievements of science and technology;
- the delay caused by inertia of the performers' thinking, their psychological unpreparedness to introduce such innovations and, consequently, to the appearance of false estimates in the economic and environmental effectiveness of the implemented achievements of science and technology.

This or that kind of time lag is manifested depending on the presence of external and internal factors: the current economic and environmental situation; Availability of investors willing to provide investment in the required volumes; availability of appropriate equipment, professionally trained personnel; availability of techniques that ensure the introduction of practical scientific and technological achievements in science and technology; availability of legislative and regulatory acts ensuring the legality of the use of relevant achievements of science and technology in programs to ensure the safe development of economic and environmental freshwater systems.

One of the main improvements in the direction of dynamic systems for risk prevention should be the application of a systematic and integrated approach to the use of science and technology achievements in environmental activities to ensure the safe development of the above systems, which should include not only the economic, environmental and technical preparation of these systems for the use of relevant achievements science and technology in their practical activities, but also the relevant educational and psychologists training.

When studying the dynamic model of qualitative aspects of water management problems for the development of an optimal time schedule for the distribution of costs in planning the development of certain areas of scientific and technological progress, it is advisable to take the dependence as the objective function:

$$Q_{CH}^{C} = \int_{t_0}^{t} Q_{CH}(t)dt \to \min, \quad (1)$$

where Q_{CH}^{C} - is the functional dependence on time of the above normative discharge of pollutants into the reservoir with the sewage waters of the enterprise after their treatment at the treatment facilities, t; $(t - t_0)$ - time interval in which the optimization of the distribution of costs for the development of scientific and technological progress, units of time [4,24].

When modeling the dynamic processes occurring in the quantitative and qualitative aspects of the water management problems in the given region, it is necessary to take into account that practically in all the cause-effect chains participating in the construction of the dynamic model, there is a temporary lag. This lag characterizes the inertia in changing a given indicator under the influence of disturbing factors, the action of which is taken into account in this model. The presence of the indicated delay in the change in the parameters introduces the corresponding nonlinearity into the mathematical description of the cause-effect chain [1].

The delay in the changes in the indicators over time in the cause-effect chain can be taken into account by introducing special links in it that are described by equations of the form:

$$V_{ji}(t-\tau) * L_{ji}(t-\tau) = Q_{ji}(t), \quad (2)$$

where $V_{ji}(t-\tau)$ - the value of the ji-th indicator at the entrance to the lagging link of the given cause-effect chain at the time $(t-\tau)$, unit of measurement of the indicator; τ - delay time, unit of time; $L_{ji}(t-\tau)$ - the functional operator of this link of the cause-effect chain; $Q_{ji}(t)$ - the value of the ji-th indicator at the output of the delay link, the units of measurement of this indicator.

In the study of the dynamic models described above, it is also necessary to take into account that the physical essence of most of the studied indicators requires the positivity of their values, while the values of the changes of these same indicators can be either greater or less than zero [1,5].

Dynamic models that take into account the quantitative and qualitative aspects of the existing water management problems, built on the basis of the principles outlined above, can be used not only for the optimal allocation of costs for improving water management activities, taking into account the technologies and economic operations at individual sites, but also for planning scientific and technical progress in its separate branches of management.

The importance of optimizing dynamic processes in solving problems of sustainable and safe development of freshwater systems is obvious, as they unfold in time. The effectiveness of the use of funds, material and labor resources, directed by society to solve emerging problems in the use of freshwater resources, largely depends on how fully the time factors are taken into account.

The objective function of the problem of optimizing the dynamic processes that arise when solving the problems posed will be:

$$\Phi = \int_{t_0}^{t_1} F_1(x_1; x_2; x_3 \ldots x_n; t)dt \rightarrow extremum \tag{3}$$

At the same time, the imposed restrictions on energy, material, labor and financial resources used to solve the above-mentioned economic and environmental problems can be presented in the form of:

$$Y_1 = \int_{t_0}^{t_1} f_j(x_1; x_2; x_3 \ldots x_n; t)dt \geq Y_{зад.}, \tag{4}$$

where the intervals of change in indicators $j = 1,2,\ldots k;\ i = 1,2,\ldots n;\ (x_i)_{\min} \leq x_i \leq (x_i)_{\max}$.

In the functional dependencies x_1; x_2; …, x_n - the parameters of the freshwater problems that occur over time, under the influence of organizational and technical measures aimed at their solution through the accelerated introduction of the corresponding achievements of scientific and technological progress in the household and production and economic activities of economic entities.

A dynamic problem, formed on the basis of an objective function of the form (3) and constraints (4), is a multi-step problem, in solving which it is required to find a certain number of consecutive solutions. At the same time, it is obvious that each decision taken depends on all past decisions and, in turn, influences all future decisions. The optimality principle in this case can be formulated as: "The optimal strategy has the property that, whatever the initial state and the initial decision taken, subsequent decisions should constitute an optimal strategy for the state that arose as a result of the initial decision" [18,19].

Using the notation used in the theory of dynamic programming, we define the decision taken by the vector q. The previous state of freshwater problems is characterized by a vector p. Then a new state of economic and environmental problems $(p^{"})$, in which they are transferred as a result of the implementation of the adopted decision, can be presented, as $p = T(p_1 q)$. Values of the objective function for one stage can be represented as $\Phi(p,q)$, i.e. as its value obtained during the transition from state p to state p''. As mentioned above, the goal of organizing a N step-by-step process for solving the problem of optimizing the dynamic processes that arise when solving freshwater problems is to obtain the extreme value of the objective function when the constraints are fulfilled, i.e. obtaining an extreme value of the sum of the values of the specified objective function for all stages [8].

Taking into account all the above, and also using the principle of optimality, we obtain in the end the following recurrence formula ensuring the finding of the optimal solution for the entire multistage task:

$$\hat{Q}_{n+1}(p) = \max[R(p,q) + f_n(T_n(p,q))], \quad (5)$$

where $R(p,q)$ - is the value of the objective function at one stage, which can be obtained if the initial state of economic and environmental problems p takes on value q; $f_n(T_n(p,q)$ - the extreme value of the objective function over the h stages, which functionally depends only on the initial state of the economic and environmental problem p and the number of stages h.

It is obvious that for $h = 0$

$$\hat{Q}_1(p) = \max R(p,q). \quad (6)$$

When using the recurrence relation for solving the above problem, constraints can be represented as:

$$Y_1 = \sum_{n=1}^{N} (Y_i)_h \geq (Y_{зад}). \quad (7)$$

When developing the economic and ecological systems of freshwater basins, it is necessary to take into account that the results of the introduction of the achievements of science and technology are manifested through a certain time interval. It is also necessary to take into account that this time interval for different components of this economic-ecological system will be different in magnitude. In Fig. 1 shows the general characteristic of the time lag factor.

Conclusions. On the basis of the conducted research it can be concluded that the algorithm for solving the problem of optimizing dynamic processes in solving economic and environmental problems using the recurrence relation and constraints can be represented from the sequence of the following operations:

1. Formation of a task with objective function and limitations as a multi-stage: determination of the number of stages, their duration in time; Determine the values of the constraints for each of the steps and for the entire task as a whole.

2. Determination of optimal conditions for the objective function for each of the 3. Formation of restrictions for each of the stages.

3. Determining the values of the control parameters that provide the optimal value of the objective function on the basis of using the recurrence relation formed

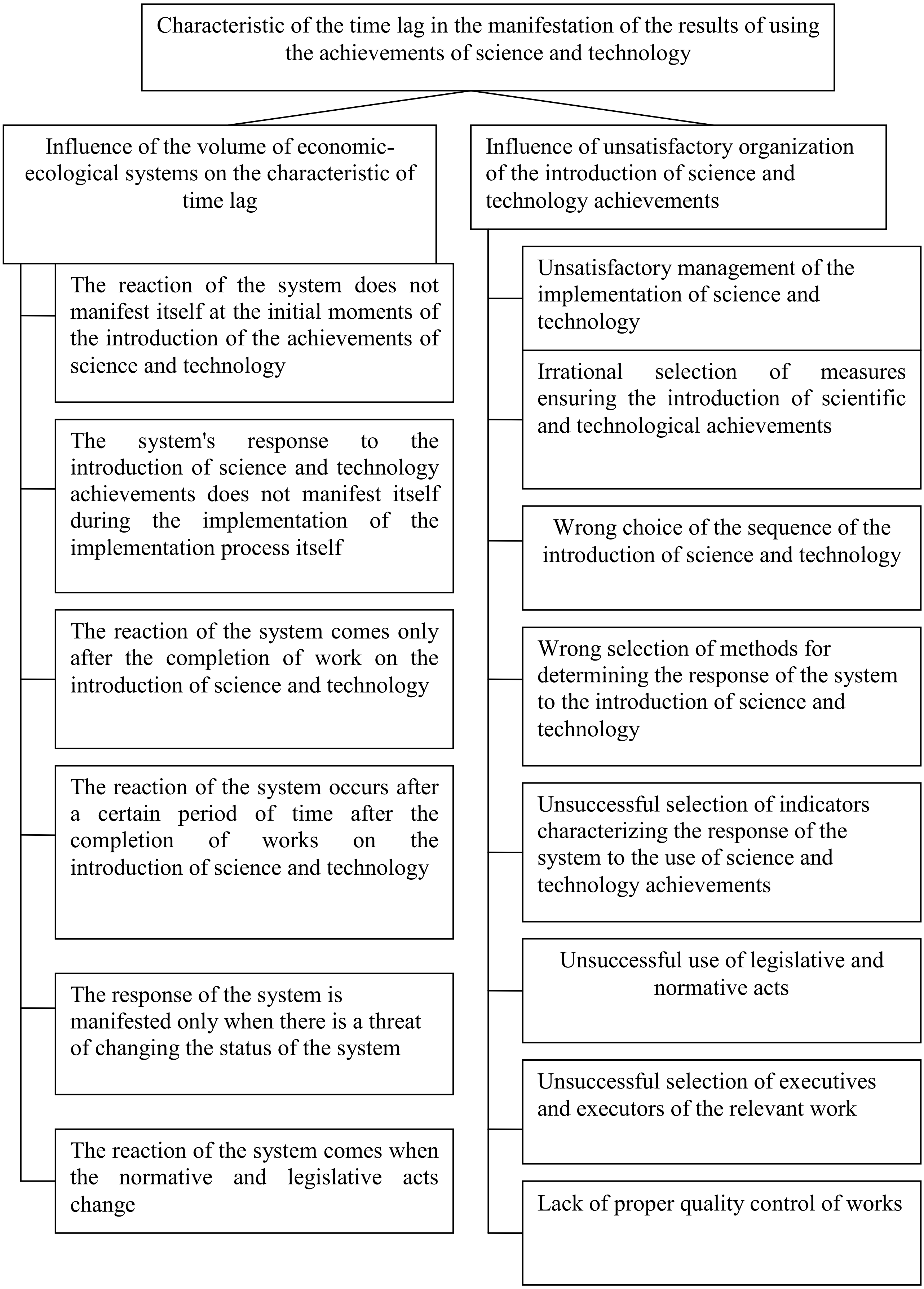

Fig. 1. - Characteristic of the time lag in the manifestation of the results of using the achievements of science and technology [19]

above, taking into account the created constraints.

4. Creation of a schedule for changing the management parameters that will ensure the solution of these economic and environmental problems, when the limiting value of the objective function and observance of constraints is reached.

5. Formation of the results of solving the problem of optimization of dynamic processes in solving economic and environmental problems in a form convenient for practical application.

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Аннотация. *В настоящей работе объектом исследования являются пресноводные ресурсы водных бассейнов Украины. Целью исследования явилась разработка методологических подходов применения экономико-математических методов анализа в оценке развития динамических процессов при использовании пресноводных ресурсов.*

Для достижения поставленной задачи в работе проведен анализ источников запаздывания в реакции пресноводной системы, выполнено исследование видов запаздывания с учетом влияния внешних и внутренних факторов влияния.

Разработан методологический алгоритм решения задачи оптимизации динамических процессов при решении экономико-экологических проблем, возникающих при хозяйственном использовании ресурсов водных бассейнов. Представленный в работе методологический подход является достаточно гибким инструментом со свободным выбором элементов анализа в зависимости от поставленных целей и объектов хозяйствования.

Ключевые слова: *экономико-экологические системы, водные бассейны, динамические процессы*

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