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ABOUT DEVELOPMENT OF AN INFORMATION ANALYTICAL SYSTEM FOR THE STUDY OF AQUATIC ECOSYSTEMS

Abstract. The water bodies under study are habitats for many species of living organisms that provide the most important property of aquatic ecosystems - the ability to self-clean. If the anthropogenic load does not exceed certain limits, the water body copes with it. If this limit is exceeded, the aquatic ecosystem degrades. At the same time, the ability to self-clean is also reduced. Taking care of the stability of the aquatic ecosystem, humans also satisfy their needs for a high-quality water resource.

Based on the quantitative characteristics of phytoplankton and phytobenthos, the bioproductivity of the aquatic ecosystem is calculated. Data on the quantity of algae and their biomass and other quantitative indicators (pigments, proteins, fats, carbohydrates, the number of nucleic acids, ash elements, respiratory rate, photosynthesis, etc.) are used for recalculation.

The development of an information-analytical system for studying aquatic ecosystems with a set of mathematical models makes it possible to carry out quantitative studies of fundamental environmental problems, including changes in the ecological state of aquatic ecosystems (by example of lakes in Kazakhstan). The results of model calculations allow estimating the impact of anthropogenic factors on the natural condition of aquatic ecosystems.

The development of mathematical methods of environmental forecasting is necessary both for the optimization of environmental management and for the serious scientific substantiation of programs in the field of environmental quality management and nature protection. Mathematical models of aquatic ecosystems allow us to describe non-equilibrium dynamic processes in hydrobiocenoses under various external influences, such as changes in water temperature, surface illumination, water or biogenic load, meteorological conditions. The construction of such models requires a large amount of information about the parameters of geophysical, geochemical, biological and other natural processes, the comprehension of which is impossible without the involvement of modern information technologies.

Key words: mathematical model, information-analytical system, aquatic ecosystem, database, phytoplankton, biomass.

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СУ ЭКОЖҮЙЕЛЕРІН ЗЕРТТЕУДІҢ АҚПАРАТТЫҚ ТАЛДАУ ЖҮЙЕСІН ӘЗІРЛЕУ

Аннотация. Зерттеу объектісі болып табылатын су объектілері су экожүйелерінің маңызды қасиеті – өзін-өзі тазарту қабілетін қамтамасыз ететін тірі организмдердің көптеген түрлерінің мекендейтін орны болып табылады. Егер антропогендік жүктеме белгілі бір шектерден аспаса, су объектісі онымен күресе алады. Егер бұл шектен асып кетсе, су экожүйесінің тозуы орын алады. Бір мезгілде

өздігінен тазару қабілеті төмендейді. Су экожүйесінің тұрақтылығына қамқорлық жасай отырып, адам сапалы су ресурсына деген қажеттіліктерін қанағаттандыруды қамтамасыз етеді.

Фитопланктон мен фитобентостың сандық сипаттамалары негізінде су экожүйесінің биологиялық өнімділігі есептеледі. Балдырлар саны және олардың биомассасы туралы деректер және басқа да сандық көрсеткіштер (пигменттер, ақуыздар, майлар, көмірсулар, нуклеин қышқылдарының саны, күл элементтері, тыныс алу жылдамдығы, фотосинтез және т.б.) қайта есептеу үшін пайдаланылады.

Математикалық модельдер кешенімен су экожүйелерін зерттеудің ақпараттық талдау жүйесін әзірлеу іргелі экологиялық проблемаларға, оның ішінде су экожүйелерінің экологиялық жай-күйінің өзгеруіне (Қазақстан көлдері мысалында) сандық зерттеулер жүргізуге мүмкіндік береді. Модельдер бойынша есептеу нәтижелері антропогендік факторлардың су экожүйелерінің табиғи жағдайына әсерін бағалауға мүмкіндік береді.

Экологиялықболжаудыңматематикалықәдістеріндамытутабиғатты пайдалануды оңтайландыру үшін де, қоршаған ортаның сапасын реттеу және табиғатты қорғау саласындағы бағдарламаларды маңызды ғылыми негіздеу үшін де қажет. Су экожүйелерінің математикалық модельдері әртүрлі сыртқы әсерлердегі гидробиоценоздардағы әркелкілігі динамикалық процестерді сипаттауға мүмкіндік береді, мысалы, су температурасының өзгеруі, оның бетінің жарықтандырылуы, су немесе биогендік жүктеме, метеорологиялық жағдайлар. Мұндай модельдерді құру геофизикалық, геохимиялық, биологиялық және басқа да табиғи процестердің параметрлері туралы ақпараттың үлкен көлемін қажет етеді, оларды қазіргі заманғы ақпараттық технологияларды тартпай түсіну мүмкін емес.

Түйін сөздер: математикалық модель, ақпараттық-аналитикалық жүйе, су экожүйесі, деректер қоры, фитопланктон, биомасса.

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К РАЗРАБОТКЕ ИНФОРМАЦИОННОЙ АНАЛИТИЧЕСКОЙ СИСТЕМЫ ИССЛЕДОВАНИЯ ВОДНЫХ ЭКОСИСТЕМ

Аннотация. Водные объекты, являющиеся объектом исследования, являются местообитанием множества видов живых организмов, которые обеспечивают важнейшее свойство водных экосистем - способность к самоочищению. Если антропогенная нагрузка не превышает определенных пределов, водный объект справляется с ней. Если этот предел превзойден, происходит деградация водной экосистемы. Одновременно снижается и способность к самоочищению. Заботясь об устойчивости водной экосистемы, человек обеспечивает и удовлетворение своих потребностей в качественном водном ресурсе.

На основе количественных характеристик фитопланктона и фитобентоса рассчитывается биопродуктивность водной экосистемы. Данные о количестве водорослей и их биомассе и другие количественные показатели (пигменты, белки, жиры, углеводы, количество нуклеиновых кислот, элементы золы, скорость дыхания, фотосинтез и др.) используются для пересчета.

Разработка информационно-аналитической системы исследования водных экосистем с комплексом математических моделей позволяет проводить количественные исследования фундаментальных экологических проблем, в том числе изменения экологического состояния водных экосистем (на примере озер Казахстана). Результаты вычислений по моделям позволяют оценивать влияние антропогенных факторов на естественное состояние водных экосистем.

Развитие математических методов экологического прогнозирования необходимо как для оптимизации природопользования, так и для

серьезного научного обоснования программ в области регулирования качества окружающей среды и охраны природы. Математические модели водных экосистем позволяют описывать неравновесные динамические процессы в гидробиоценозах при различных внешних воздействиях, например, таких как изменение температуры воды, освещенности ее поверхности, водной или биогенной нагрузки, метеорологических условий. Построение такого рода моделей требует большого объема информации о параметрах геофизических, геохимических, биологических и других природных процессов, осмысливание которых невозможно без привлечения современных информационных технологий.

Ключевые слова: математическая модель, информационно-аналитическая система, водная экосистема, база данных, фитопланктон, биомасса.

Introduction. Kazakhstan has the opportunity to overcome the shortage of water resources by 2040 through the upgrade and development of infrastructure at a reasonable cost of $18-20 billion, self-financing measures for the effective use of water resources, as well as the development of municipal infrastructure worth $35 billion. By rigorously implementing deficit-reduction measures, the country can prevent adverse effects and become one of the pioneers of responsible water management among the neighboring States of Central Asia and other countries of the world with limited water resources. Industrial wastewater quality standards were developed in the Soviet era without taking into account economic factors; in addition, they are difficult to comply with and are much more complicated than EU standards. In some cases, the standards contradict each other (Integrated Environmental Permit for Activities and MPC). The norms that set the standards for wastewater quality suggest to go from the local conditions, which is a good practice, but in fact it is difficult to implement, as it requires environmental, physical and chemical data for all discharge locations (river, lake, water reservoir, etc.) and a detailed monitoring scheme tailored to local conditions, as well as a clear methodology for determining the required quality of wastewater depending on local conditions. In addition, the system used in world practice for online monitoring of the quality of discharges from the largest enterprises in Kazakhstan is virtually absent (Naydenko et all, 2003: 186).

Research materials and methods. It is necessary to create a system for monitoring water bodies – a system for monitoring the state of water bodies and the sources of harmful effects on them. The task of environmental monitoring of reservoirs includes assessment of their current state, tracking of evolution, and forecasting as a result of anthropogenic impact (Fyodorov, 1975). It is important to preserve not just water, but the aquatic environment, with its flora and fauna, that is, aquatic ecosystems.

It was proposed to refer environmental monitoring to the system of repeated observations of one or more elements of the natural environment in space and time for certain purposes in accordance with a prearranged program.

The current system of environmental monitoring, carried out by both scientific institutions and republican regulatory bodies, is of low efficiency not only because of the poor technical resources but also, to a large extent, due to disregard of modern methods of data management and comprehensive mathematical processing of the results of multivariate observations. The wealthiest information in the hydrochemistry of natural water systems, the information on hydrobiological observations remains cast off and is lost every year. It is obvious that in addition to the traditional poorly informative reports on the part of indicators exceeding the MPC, these data could be successfully used to build both local models of seasonal and long-term dynamics of reservoirs, and generalized models of rational environmental and economic development of territorial complexes (Shitikov et all, 2003: 463).

According to the Water Code of the Republic of Kazakhstan (Art.60, paragraph 2): «State monitoring of water bodies is a system of regular observations of hydrological, hydrogeological, hydrogeochemical, sanitary-chemical, microbiological, parasitological, radiological and toxicological indicators of their state, collection, processing, and transmission of the obtained information in order to timely identify negative processes, assess and predict their development, develop recommendations for the prevention of harmful effects and determine the degree of effectiveness of water management measures».

Results. The specific nature of the tasks of monitoring complex objects imposes certain requirements, which, on the basis of the above considerations, can be expressed as follows:

- in the process of monitoring, knowledge of the monitored object should be ensured;

- the monitoring task should be solved on the basis of all available a priori information about the monitored object and its operating environment and information obtained during the measurement experiment;

- all the obtained intermediate and final monitoring results should have a metrological substantiation in the form of their quality indicators;

- to effectively solve the tasks of monitoring the monitoring objects (MO) and operational environment (OE) model, as well as methods, algorithms, and monitoring tools should reflect the main properties of complex objects, in particular, the properties of stability, self-development, and self-organization;

- monitoring results should be presented in the forms of parameter values, analytical expressions, conclusions and solutions in semantic form.

Environmental monitoring scheme is shown in Figure 1 (General, 1975: 471).

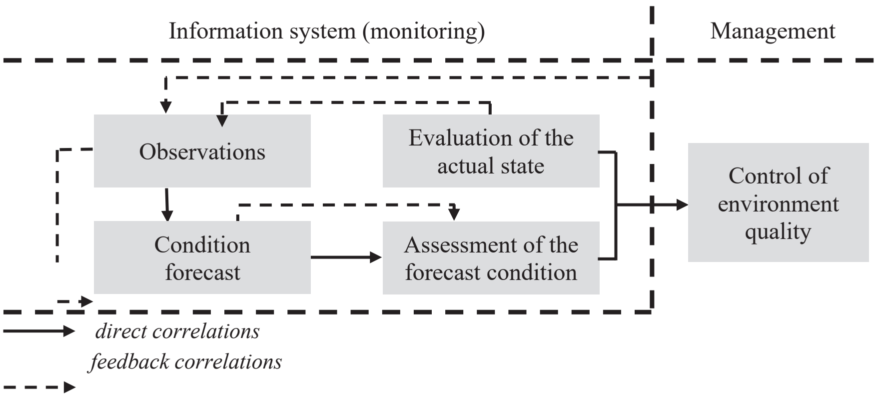

Figure 1 – Environmental monitoring flowchart

In monitoring aquatic ecosystems, the following activities should be identified:

- distinguishing of the observation object;
- survey of the distinguished observation object;
- building of an information model for the observation object;
- forecasting changes in the state of the observation object;
- presentation of information in a form convenient for the user to perceive.

In order to ensure the main objectives of environmental monitoring of aquatic ecosystems, within this work an information and analytical system for studying aquatic systems is developed. Information and analytical systems are a special class of information systems designed for analytical processing of data, their dynamic presentation, analysis of historical and current data, analysis of trends, modeling and forecasting of performance results. It is now generally accepted that the management of data from multidisciplinary environmental studies in large regions requires new approaches and the creation of new data flow management structures (Martin, 1980: 662). The planned research is aimed at solving these problems.

The main functions of the information-analytical system are:

- extracting data from various sources, converting them and uploading them to the repository;
- data storage;
- data analysis, including operational and intellectual ones;
- preparation of the results of operational and intellectual analysis for their effective perception by the consumers.

Currently, IAS is one of the most popular classes of software in the custom software market, this is due to the global process of automating the information activities of entire industries. At the same time, in addition to the general problems of organization and management of their arrangement, they have peculiarities, requirements and problems of a more specific nature, arising from the specific nature of the functional purpose of the IAS, as well as the conditions in which the IAS is created and used.

The most important task of unified environmental monitoring is not only the collection of information, but also its rational storage, processing and presentation. IAS for Aquatic Ecosystem Studies should process a large number of indicators that need to be monitored. First of all, it is the data of hydrochemical observations. The number of components for which MPC standards are established is about 2000 substances. Hydrobiological monitoring data should reflect information on aquatic organisms living in water bodies and characterizing their environmental state – more than a hundred species. Hydrological and hydrophysical monitoring data reflect water level information and a number of important parameters (temperature, water turbidity, pH, etc.) that directly affect the state of aquatic ecosystems.

The relevance of the IAS creation to study aquatic ecosystems is related to the need to regularly receive, integrate and use significant amounts of information on the state of aquatic ecosystems of Kazakhstan, which is distributed both in time (historical and current) and in space.

From a technical point of view, the IAS is a set of procedures, methods, and regulations that lead to the regular planned collection, storage, analysis, and provision of information used for making management decisions (Boyko et all, 1989: 351, Yakubaitis, 1996: 368, Singer et all, 1987: 208).

There are two fundamentally different approaches to the design of information and analytical systems (IAS) for environmental management and protection. In the first of them, the system is created on the basis of known types of territorial objects (rivers, lakes, air basin, anthropogenic environment) and the relations existing between them. The second approach is to solve specific problems of information management (Belov, 2005:111, Voronoi et all, 2007:194, Galliani, et all, 1982:737).

The general work plan for designing the Aquatic Ecosystem Study IAS is shown in Figure 2:

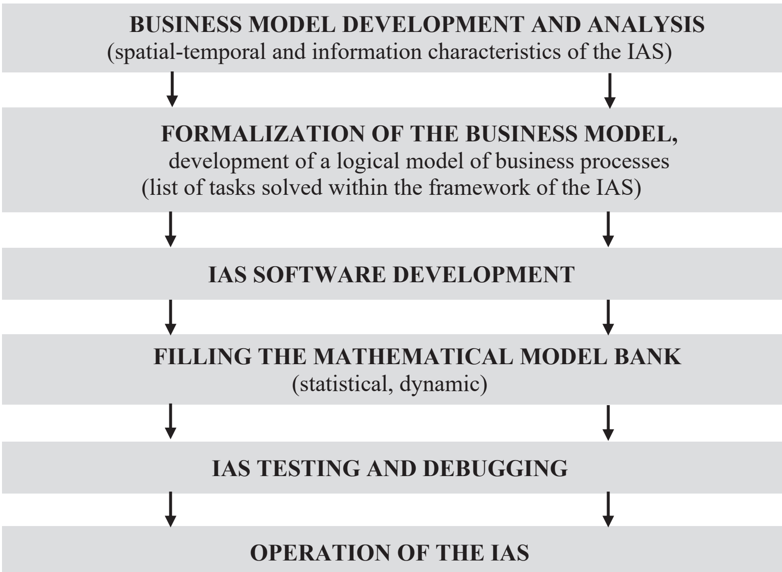

Figure 2 – IAS Designing Steps Sequence

Designing of the IAS should be aimed at solving the tasks of information management and research, for example, monitoring of aquatic ecosystems, all data should be oriented to the «problem» in focus.

The use of information systems in the field of environment (Environmental Informatics, geoinformatics) has been intensively developing in Europe, the USA, Japan in recent years, as evidenced by the large amounts of funding allocated to these studies, the huge flow of publications, regularly held scientific conferences, as well as the inclusion of environmental informatics in the curricula of various departments of universities. NSF (USA) included the creation of geographic information platforms and the development of information infrastructure for them in the list of priority funded R&D. To illustrate the magnitude of the costs, back in 1981, the United States spent about $500 million, or about 2-2.5

% of total environmental costs, on monitoring and monitoring-based water quality management (Matsyashek, 2002: 432).

The main purpose of creating an information-analytical system for studying aquatic ecosystems (IAS) (through the example of lakes in Kazakhstan) is to implement at a qualitatively new level a procedure for analytical processing and interpretation of the results of observations to forecast supposed changes in the aquatic environment, as well as the organization of centralized storage of heterogeneous (hydrochemical and hydrobiological, etc.) data.

The purpose of such a system is not only the accumulation and visualization of monitoring data, but also the creation of a single information space and the provision of extensive system analysis of information for effective environmental quality management and ensuring the safety of the population (State Program, 2014, Matveyev et all, 2005: 96). To do this, it is necessary to establish a relationship between different types of indicators, not only purely correlative, but also causal, formalized in the form of mathematical models, which, in turn, are used to form control scenarios.

Modeling of microbial communities of plant organisms. The functioning of aquatic ecosystems is largely determined by the lower trophic levels. The biological productivity of systems is based on the productivity of phytoplankton (Alekseyev et all, 1992: 366, Abrosov et all, 1988: 333). The study of phytoplankton is an important and interesting task. Communities of microorganisms and, in particular, phytoplankton, are studied quite intensively, including by means of mathematical modeling (Riznichenko et all, 1993: 301, Jorgensen et all, 2005: 20, Adamovich et all, 2005: 5).

Essential for phytoplankton is its spatial distribution, which has a high degree of heterogeneity (Riznichenko et all, 1993: 168, Shushkina et all, 1997: 278). This heterogeneity is determined both within and between species relations in phytoplankton and environmental conditions. Among the influencing factors, experts distinguish mineral nutrition, that is, those mineral substances used by the plant organism to create organic matter in the process of photosynthesis (Riznichenko et all, 1993: 186, Silkin et all, 1988: 230,). The list of such substances is extensive, but the main role is played by compounds based on carbon, nitrogen, phosphorus and silicon (Abrosov et all, 1988: 322, Adamovich et all, 2005: 8). Mathematical models of the dynamics of microorganism biomasses based on the study of the process of consumption of mineral substances have different nature (Riznichenko et all, 1993: 201, Alekseyev et all, 1992: 185, Abrosov et all, 1988: 142, Abakumov, 1994: 107). We address models of mineral nutrition of phytoplankton based on the concept of «cell quota» of M. Drupa (Droop, 1974: 198).

Discussion. When studying such large reservoirs as Lake Balkhash, satellite remote sensing data of the surface of the lake can be used (Shushkina et all, 1997: 102). A large part of the problems considered with the use of this material is related to the living component of the aquatic environment. Satellite information contains data on chlorophyll concentration and fluorescence, illumination and temperature, water turbidity, and a number of other characteristics of the surface layer of the reservoir (Silkin, 2011: 24, Barbini, 2004: 2095). These data are refined and supplemented by other remote and contact methods (Silkin, 2011: 122).

In mathematical models of the dynamics of biomass of microbiological communities, the properties of solutions are investigated. The model of a system with the internal flow is used to study the phytoplankton community in the aquatic ecosystem. The properties of solutions coincide with the dynamics of natural communities, demonstrating the dominance of individual species in the community.

Assessment of the biological productivity of ecosystems is important for studying the state of the natural environment and the possibilities of environmental management. For aquatic ecosystems, biological productivity can be evaluated based on phytoplankton productivity (Jorgensen, 1985: 160). The productivity of phytoplankton is largely determined by the process of consumption of mineral substances in the construction of a plant organism during photosynthesis (Riznichenko et all, 1993: 217). Remote sensing data from the surface of the seas and oceans are currently playing an important role in the study of the state and functioning of phytoplankton. In particular, artificial Earth satellites provide data on the content of minerals and chlorophyll in the surface layer. Data on chlorophyll (primarily chlorophyll «a») make it possible to assess the content of phytoplankton and give a rough estimate of primary production (Shushkina et all, 1997: 137). Data on mineral substances (based on nitrogen, phosphorus, silicon and other chemical elements), constituting the material basis for the construction of plant organisms in the process of photosynthesis, make it possible to assess the characteristics of the production processes of phytoplankton (Droop, 1974: 13). At this stage, mathematical models of the dynamics in the populations (biomass) of the main species of the phytoplankton community are useful (Riznichenko et all, 1993: 220).

Similar mathematical models are also used in describing the dynamics of microbial cultures in laboratory experiments. The paper presents groups of models of dynamics of biomass communities of microorganisms. The models are based on systems of differential equations. The qualitative properties of solutions at the structural level were investigated.

Models of functioning of phytoplankton communities describe the dynamics of the transformation of substances in the photosynthesis and construction of the plant organism. The models focus on biological species of phytoplankton and groups of mineral nutrients. Phytoplankton is represented by m species, their content in the medium is indicated by y_i for i type. Mineral nutrition of plant organisms is divided into n groups of similar substances (based on nitrogen, phosphorus, silicon, etc.). In the considered models, nutrients are assumed to be not interchangeable. The content of substances in the group j in the medium is denoted as z_j.

For a living organism, a strategy of activity is determined not only by the environment, but also by its state. The internal state of the body can be characterized in different ways. In our case, it is proposed to use the intracellular content of nutrients based on mineral compounds in the external environment as an indicator.

The content of nutrients in the group j in a cell of the i type is denoted as $q_{ij.}$ This value is called the cellular quota. The growth rate of a separate species is determined on the basis of the Libich principle (Jorgensen, 1985: 206): it is limited by the growth rate of the least productive mineral substance. The consumption of nutrients by microorganisms is carried out at a specific rate $\upsilon_{ij,}$ and the growth of plant biomass occurs at a specific rate μ_{ij} (q_{ij}) depending on the vector $z = (z_j)_j^n = 1$, the content of minerals in the external environment and the matrix $q = (q_{ij})_j^n = 1$ a content of nutrients in plant cells. The mass dynamics model of the system has the following shape (1) (Riznichenko et all, 1993: 207):

$$\frac{\partial y_i}{\partial t} = (\mu(q_i) - D)y_i$$

$$\frac{\partial z_j}{\partial t} = (D(z_{jo} - z_j) - \sum_{i=1}^{m} v_{ij}\,(z_j, q_{ij})y_i \text{ для } i = 1, \dots n. \qquad (1)$$

$$\frac{\partial q_{ij}}{\partial t} = v_{ij}(z_j, \mu_i(q_i) \cdot q_{ij})$$

q_i denotes the vector $q = \left(q_{ij}\right)_j^n = 1$ μ_i (q_i) the function is calculated by the formula $\mu_i(q_i)=\min \mu_{ij} (q_{ij})$. Parameter D indicates the flow rate of the substance in the system, by z_0 - the content of mineral nutrients in the incoming stream, by v_{ij} (z_j)- the specific rates of absorption of the substance of the group j by organisms of type i.

The model is used by us for calculations using hydrochemical data of the characteristics of the phytoplankton community in the reservoir.

Conclusion. In conclusion, it should be noted that the purpose of the paper was to justify the creation of an Information and Analytical System for the Study of Aquatic Ecosystems, as well as in the systematization and analysis of dynamic models of biological systems that are applied to aquatic plant microorganism communities. Such communities are represented by continuous cultures in the laboratory and phytoplankton communities in natural aquatic ecosystems. We gave examples of the application of these models and the properties of their solutions, an assessment of the effectiveness of their use and the prospects for expanding this research area.

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