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Research Article

Assessment of Environmental Risks of a Shallow Water Body during Dredging Works

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Abstract

Introduction. The increasing anthropogenic impact on water bodies necessitates integrated solutions to assess environmental risks. Literature describes the stages of risk assessment, the possibilities of environmental management, and expert analysis, while risk modeling in this field is being investigated. However, the potential for predicting risks to water quality and biodiversity during frequently performed hydraulic engineering works such as dredging has not been fully explored. The relevance and practical significance of such an approach are evident. This study aims to develop a mathematical model and software package that can assess risks to species diversity of the ecosystem of a shallow reservoir ecosystem during work in its water area.

Materials and Methods. The starting point for the simulation was a description of the movement of water masses based on the Navier-Stokes equations and the continuity equation at variable density. We used the diffusion-convection equation to predict the transfer of suspended and dissolved particles, as well as to assess the impact of impurities during eutrophication. To create the algorithm, we utilized the terms and definitions defined by the state standard for risk management in emergency situations.

Results. To test the solution, we took data on hydro-mechanical work in the port area of Arkhangelsk. We visualized the concentration fields of suspended particles 0, 15, 30 and 45 minutes after the soil was unloaded. It was found that during the settling of the suspension, the area of its distribution expanded significantly, and this was fully consistent with the data of field experiments during dredging. We calculated and tabulated the volumes of contaminated water at soil dumps in three sites (with a single discharge and in total). To assess the risks to the Sea of Azov, we used the maximum concentrations of pollutant (copper) obtained through measurements, modeling and remote sensing of the Earth. In tests to determine the potential danger of the substance, we assumed that its concentration caused a reaction in 50% of organisms. For fish, the potentially dangerous concentration was 4 mg/l with a duration of 96 hours of exposure. For zooplankton — 50 mg/l and 48 hours. For microalgae, 20 mg/l and 72 hours. The normalized risk value $R_n \approx 0.52$ was obtained. The risk of copper concentration of 80 µg/l in the waters of the Azov Sea was recognized as significant. A tendency towards increasing salinity and stratification of water masses in terms of oxygen content has been identified, consistent with the findings of expeditionary research.

Discussion and Conclusion. The developed approach has allowed us to assess the change in the quality of the waters of the Azov Sea and describe some transformations of the water area. Specifically, we are talking about the distribution of suspended particles and areas of their deposition. These processes can lead to changes in the bottom topography, which in turn can reduce the species diversity of the ecosystem.

Keywords: hydrochemical parameters of the water area, forecasting the spread and deposition of suspended particles, modeling the spread of pollutants, reducing the species diversity of the aquatic ecosystem

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Научная статья

Оценка экологических рисков мелководного водоема при проведении дноуглубительных работ

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Аннотация
Введение. Усиление антропогенного воздействия на водные объекты требует комплексных решений для оценки экологических рисков. В литературе описаны этапы оценки, возможности экологического менеджмента и экспертного анализа. Исследуется моделирование рисков в данной сфере. При этом не изучен потенциал прогнозирования рисков для состояния воды и биоразнообразия в ходе часто выполняемых гидротехнических работ, например дноуглубления. Очевидны актуальность и важное прикладное значение такого подхода. Цель исследования — описание математической модели и программного комплекса, которые позволят оценивать риски для видового разнообразия экосистемы мелководного водоема при проведении работ в акватории.
Материалы и методы. Исходной точкой моделирования было описание процесса движения водных масс по уравнениям Навье — Стокса и неразрывности при переменной плотности. Уравнение диффузии-конвекции использовали для прогнозирования переноса взвешенных и растворенных частиц и оценки влияния примесей при эвтрофикации. Создавая алгоритм, задействовали термины и определения, принятые Росстандартом для управления рисками в чрезвычайной ситуации.
Результаты исследования. Для тестирования решения взяли данные о гидромеханических работах в районе порта Архангельска. Визуализировали поля концентрации взвешенных частиц, через 0, 15, 30 и 45 минут после выгрузки грунта. Установлено, что в процессе оседания взвеси область ее распространения значительно расширяется, и это полностью согласуется с данными натурных экспериментов при проведении дноуглубительных работ. Рассчитали и свели в таблицу объемы загрязненной воды при отвалах грунта на трех участках (при однократном сбросе и в сумме). Для оценки рисков Азовского моря брали максимальные концентрации загрязняющего вещества (меди), полученные в ходе замеров, моделирования и дистанционного зондирования Земли. В тестах для определения потенциальной опасности вещества исходили из того, что его концентрация вызывает реакцию у 50 % организмов. Для рыб потенциально опасная концентрация — 4 мг/л при длительности влияния 96 ч. Для зоопланктона — 50 мг/л и 48 ч. Для микроводорослей 20 мг/л и 72 ч. Получено значение нормализованного риска — $R_n \approx 0{,}52$. Признан значимым риск концентрации меди 80 мкг/л в водах Азовского моря. Выявлена тенденция увеличения солености Азовского моря и стратификация водных масс по содержанию кислорода, что согласуется с результатами экспедиционных исследований.
Обсуждение и заключение. Разработанный подход позволил оценить изменение качества вод Азовского моря и описать некоторые трансформации акватории. Речь идет, в частности, о распространении взвешенных частиц и о районах их оседания. Указанные процессы обусловливают изменение рельефа дна, которое, в свою очередь, может привести к сокращению видового состава водоема.

Ключевые слова: гидрохимические параметры акватории, прогноз распространения и осаждения взвешенных частиц, моделирование распространения загрязняющих веществ, сокращение видового разнообразия водной экосистемы

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Introduction. The development of the economy is accompanied by large-scale works on the territory of water bodies. The examples include the construction of the Golden, Russian and Crimean bridges, dredging in order to expand water areas for navigation, laying underwater gas and oil pipelines, and much more. Fundamental part of such projects is the assessment of potential environmental impacts and risk forecasting. In Russia, these issues are regulated by the Requirements for Environmental Impact Assessment Materials[1]. Additionally, GOST R ISO 14001–2016, which is the official translation of the international standard ISO 14001:2015, is used to define the activities of enterprises and their environmental management systems when forming applications and implementing projects. It is worth noting that the current version of the standard is focused on preventing emergency situations, rather than eliminating their consequences.

The authors of [1] identify three stages of environmental risk assessment, while work [2] describes five stages. Paper [3] focuses on the risks of oil and gas companies. It also discusses positive aspects of the implementation of an environmental management system.

A significant part of the materials is devoted to the development of corporate environmental management systems to ensure international or national security in the field of ecology [4]. In [5], the correlation of the company's environmental responsibility and the value of its shares on the stock market are studied. A similar problem is considered in [6]. The point is that the environmental responsibility of the French company has affected the growth of its market value. The impact on the capitalization of the Green Company Awards was assessed, which recognizes the best facilities and enterprises from the point of view of ecology [7]. In many cases, an expert approach to assessing environmental risks of companies is taken into account [8]. However, it has significant drawbacks related to the subjectivity of conclusions and the complexity of processing a large amount of information in conditions of uncertainty [9]. Therefore, mathematical methods of risk assessment are more preferable.

Paper [10] describes popular approaches to risk assessment with an emphasis on the index approach. In [11], the authors consider a model for assessing environmental risks using the Dempster-Schafer evidence theory, which has proven itself well in solving problems under conditions of uncertainty. Nevertheless, its practical application is complicated by the need for many complex calculations, including combined ones. Article [12] describes a mathematical model based on a probabilistic approach and the determination of the integral value of risk assessment. The literature does not consider the possibility of predicting a set of risks for the state of water and biodiversity when performing hydraulic engineering works. However, it is precisely this approach that should be recognized as relevant, having obvious practical significance at the present stage of economic development.

The aim of the presented study was to describe a mathematical model and a software package that allowed assessing vulnerabilities and risks for the hydrochemical parameters of water area and species diversity of the ecosystem of a reservoir when deepening the bottom of a shallow reservoir. First of all, it concerned forecasting the propagation and deposition of suspended particles. These processes significantly affect the relief of the bottom surface. In addition, zones of distribution of pollutants were modeled. Their toxicity can become a factor in reducing the species diversity of aquatic ecosystems.

Materials and Methods. To predict the results of anthropogenic impact on a reservoir ecosystem (for example, during dredging), a comprehensive mathematical model of suspended particles movement in the water environment was proposed. It took into account wind currents, the movement of the aquatic environment and river flows, water body geometry, turbulent exchange, and variable density of the aquatic environment, which could be influenced by factors such as salinity or suspended matter. The model also considered the deposition rate of each particle fraction, determined by its size and shape. In addition, it could be supplemented by a model for reservoir eutrophication, which would take into account nutrient levels and their impact on processes within the reservoir.

Problem statement

A model of water movement. To describe the movement of water masses in a water body, we used a hydrodynamic model [13]. This model included the following expressions:

1. Navier—Stokes equations of motion:

$$
\begin{aligned}
&\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu\frac{\partial u}{\partial z}\right),\\
&\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu\frac{\partial v}{\partial z}\right),\\
&\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+\frac{\partial}{\partial x}\left(\mu\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu\frac{\partial w}{\partial z}\right)+g.
\end{aligned}
\tag{1}
$$

[1] *On approval of requirements for environmental impact assessment materials.* Order of the Ministry of Natural Resources and Ecology of the Russian Federation. URL: https://docs.cntd.ru/document/573339130 (accessed: 26.02.2024). (In Russ.).

Here $V = \{u, v, w\}$ — velocity vector of the water medium [m/s]; P — pressure [Pa]; ρ — density [kg/m^3]; μ, ν — horizontal and vertical components of turbulent exchange coefficient [m^2/s]; g — acceleration of gravity [m/s^2].

2. Continuity equation in the of variable density:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0. \tag{2}$$

The initial and boundary conditions for the system of equations (1) and (2) were described in detail in [13].

A model for suspended particles propagation. To predict the transport of both suspended and dissolved particles, we used a diffusion-convection equation [14]:

$$\frac{\partial c_r}{\partial t} + \frac{\partial (u c_r)}{\partial x} + \frac{\partial (v c_r)}{\partial y} + \frac{\partial \left((w + w_{s,r}) c_r \right)}{\partial z} = \frac{\partial}{\partial x}\left(\mu \frac{\partial c_r}{\partial x} \right) + \frac{\partial}{\partial y}\left(\mu \frac{\partial c_r}{\partial y} \right) + \frac{\partial}{\partial z}\left(\nu \frac{\partial c_r}{\partial z} \right) + F_r, \tag{3}$$

where c_r — concentration of the r-th fraction of suspension [mg/l]; $w_{s,r}$ — rate of gravitational deposition of the r-th fraction of suspension [m/s]; F_r — intensity function of the sources of the r-th fraction of suspension [mg/(l·s)].

System of equations (3) was considered under the initial and boundary conditions described in detail in [14].

Based on system (1)–(3), it was possible to simulate the processes of movement and deposition of suspended particles during dredging, as well as consider the possibility of optimizing the areas of soil dumps. It was advisable to use these models to reduce harm to the ecosystem of a reservoir.

An eutrophication model. To assess the effect of impurities, let us consider a model of eutrophication of waters based on diffusion-convection equation [15]:

$$\frac{\partial S_r}{\partial t} + \frac{\partial (u S_r)}{\partial x} + \frac{\partial (v S_r)}{\partial y} + \frac{\partial \left((w + w_{s,r}) S_r \right)}{\partial z} = \frac{\partial}{\partial x}\left(\mu \frac{\partial S_r}{\partial x} \right) + \frac{\partial}{\partial y}\left(\mu \frac{\partial S_r}{\partial y} \right) + \frac{\partial}{\partial z}\left(\nu \frac{\partial S_r}{\partial z} \right) + F_r, \tag{4}$$

where S_r — concentration of the r-th impurity [mg/l]; $w_{s,r}$ — rate of gravitational deposition of the r-th impurity [m/s]; F_r — function describing the intensity of a chemical-biological source of the r-th impurity [mg/(l·s)].

System of equations (4) was considered under the initial and boundary conditions, which were given in [15].

You can use (4), in particular, to describe:

– the influence of impurities entering the reservoir as a result of anthropogenic impact, for example, in an emergency situation or wastewater discharge;

– processes of oxidation and reduction of manganese;

– oxidation of hydrogen sulfide;

– calculation of the concentration of dissolved oxygen in water.

Data on the location of sources can be obtained using remote sensing of the Earth.

An algorithm for assessing the risk of anthropogenic impact. Known approaches to risk understanding were systematized in [16]. This paper used the definition of risk according to GOST R 55059-2012[2]. Risk is the probability of an emergency or the expected amount of damage associated with the realization of an adverse events. Let us consider an example when impurities enter the water that negatively affects the ecosystem:

$$R = Ef_S \cdot E_S. \tag{5}$$

Here R — risk factor; Ef_S — potential danger or toxicity of the impurity; E_S — exposure factor or the amount of impurity in terms of one biological target. For a reservoir, the exposure factor could be calculated using formula:

$$E_S = S \cdot P_S \cdot k_{BA}, \tag{6}$$

where S — impurity concentration specified or calculated based on model (4); P_S — hydrolysis rate index; k_{BA} — bioaccumulation[3] or accumulation factor (for example, heavy metals) [17].

In world practice, it is customary to use a set of standardized tests[4] to determine the potential danger of an impurity or a contaminant Ef_S. In the European Union countries, quantitative assessments of the toxicity of the substance described below are distinguished.

– *NOEC* — no observed effect concentration, the maximum inactive concentration of the substance. As a rule, this concentration, compared with the control one, does not cause a statistically significant negative effect (the probability of its occurrence does not exceed 0.05) during a given exposure time.

[2] *GOST R 55059–2012. Safety in emergencies. Emergency risk management. Terms and definitions*. Moscow: Standartinform, 2018. 8 P. (In Russ.)

[3] *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates*. Second edition. Washington: United States Environmental protection agency; 1994. 148 p.

[4] *Guidance on information requirements and chemical safety assessment. Appendix R10-2 Recommendations for nanomaterials applicable to Chapter R.10 Characterisation of dose [concentration] — response for environment*. European Chemicals Agency. URL: https://echa.europa.eu/guidance-documents/guidance-on-information-requirements-and-chemical-safety-assessment (accessed: 26.02.2024).

– *LOEC* — lowest observed effect concentration. Its action causes a response from the tested organisms. These can be metabolic disorders, as well as disorders of growth, development, reproduction, and even death. *LOEC* values are higher than *NOEC* values. If the effect (percentage of effect) of *LOEC* is known, you can roughly determine *NOEC*: $NOEC = LOEC / 2$ (at $10\% < LOEC < 20\%$). That is, if *LOEC* affects 10–20% of the study population, then the *NOEC* value can be roughly defined as half of *LOEC*.

– *MATC* — maximal acceptable toxicant concentration. This is a calculated parameter defined as the geometric mean of *NOEC* and *LOEC*;

– EC_x — effect concentration (concentration of the effect at which *x*% of the effect is observed compared to the control group). That is, it is the concentration of a substance at which a response is observed in *x*% of the tested organisms. For example, at EC_{50} concentration, 50% of organisms react. A statistical method (for example, regression analysis) is often used to calculate this criterion. At the same time, it is necessary to use a sufficient number of concentration groups (doses), since the accuracy of the assessment depends on the number and range of concentrations, and not on the sample size for each concentration. Along with the abbreviation EC_x abbreviations LC_x or $L(E)C_x$ are used.

Within the framework of this study, three sets of tests applicable to natural water bodies were considered.

Results. Based on the considered models and approaches to risk assessment, the five-step algorithm described below was formed.

Step 1. Study of the characteristics of the water area (geographical, climatic, hydrological). This step also meant considering potential sources of suspension and impurities, such as work on the expansion and cleaning of the water area, river runoff, industrial discharges, shipping, etc. It was also necessary to determine the volume of suspended material that could be present.

Step 2. Modeling scenarios for the propagation of suspensions and impurities based on equations (1)–(4).

Step 3. Assessment of toxic effect Ef_S according to three selected tests.

Step 4. Assessment of risk factor for each substance based on (5)–(6) and calculation of normalized risk factor $R_n \in [0, 1]$. For normalization, we used formula $(S - S_{\min})/(S_{\max} - S_{\min})$, where $S_{\min}$ and $S_{\max}$ — minimum and maximum concentrations of the substance in question.

Step 5. Formulation of preliminary conclusions. We considered the risk to be high at $R_n \geq 0.55$, significant at $0.3 \leq R_n \leq 0.55$ and absent at $R_n < 0.3$.

Steps 2–4 can be repeated if you need to determine the best way to carry out the work. For example, during dredging, it was possible to simulate the distribution of suspended solids for various soil discharge points and assess the damage caused to the ecosystem.

A software package in C++ has been developed for the numerical implementation of models (1)–(4) and the above-described risk assessment algorithm for anthropogenic impact. It combined four software modules. The purpose of each of them is described below.

1. Calculation of the three-dimensional velocity vector of the aqueous medium based on the system of equations (1)–(2). Complex geometry of the computational domain was taken into account.

2. Calculation based on the system of equations (3) of the transfer of suspended particles and their settling. In this case, we mean a multicomponent suspension.

3. Modeling of eutrophication of a reservoir based on system of equations (4). Phyto-, zooplankton, as well as 13 chemical elements and their compounds, which significantly affected the hydrobiological processes of the reservoir, were taken into account. These were dissolved oxygen, iron, sulfur, hydrogen sulfide, sulfates, sulfites, nitrogen, ammonium nitrogen, nitrites, nitrates, phosphates, silicates, silicic acid.

4. Assessment of risks of anthropogenic impact based on the algorithm described above.

Modeling of the processes of movement and sedimentation of suspension during soil dumping. The developed software package simulated siltation processes of navigable channels of the Don. In addition, it allowed us to study the transport of suspended particles and the reshaping of the bottom surface in the Azov Sea. Special attention was paid to the coastal and estuarine zones. In addition, the software was used to assess the environmental condition of water areas during dredging operations in the Dvina Bay of the White Sea.

As an example, let us consider modeling the processes of movement and deposition of suspended matter during work on expanding the water area [18]. To this end, we used data on work in the Arkhangelsk port area. To simulate the propagation and deposition of suspended particles, a 3 km long section along the flow direction was taken as the studied area of the reservoir. Its width was 1.4 km, its depth was 10 m.

Physical parameters of the aqueous medium and suspended matter:

– flow velocity — 0.2 m/s;

– suspended matter density — 1,600 kg/m^3;

– suspended matter deposition rate — 2.042 mm/s;

– content of particles with a diameter of less than 0.05 mm in the soil — 26.83%;
– volume of the discharged bulk material — 741 m^3.
Parameters of the calculated area:
– step along horizontal spatial coordinates — 20 m;
– height step — 1 m;
– estimated interval — 2 hours;
– time step — 1 minute.

Figure 1 shows the concentration fields of suspended particles (in mg/l) corresponding to different time intervals. A three-dimensional slice shows a section of the calculated area with a plane that passes through the discharge point and is formed by vectors directed vertically and along the flow (from left to right).

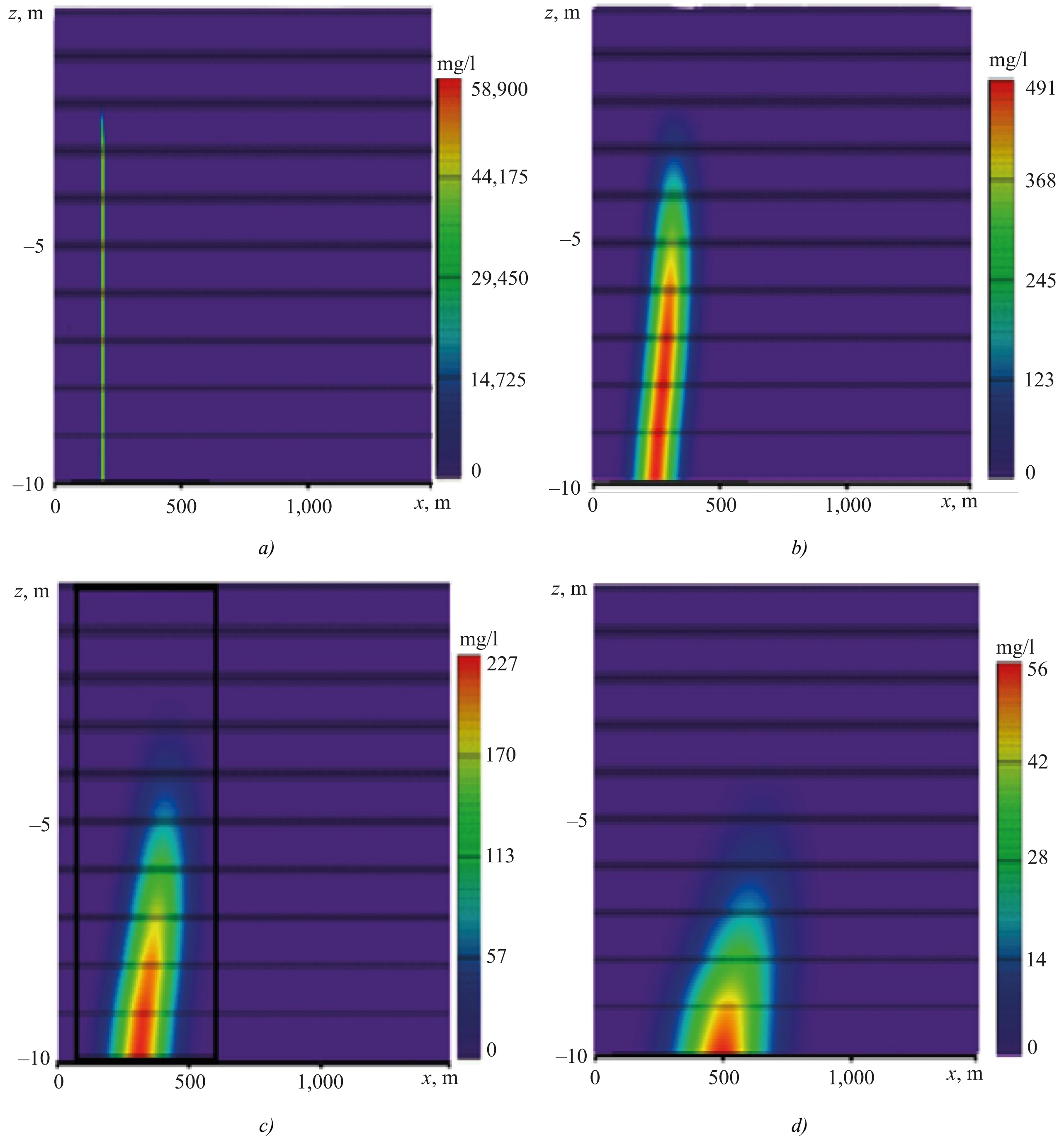

Fig. 1. Fields of concentration of suspended particles (in the "depth — width" section of the reservoir) at different time intervals from the moment of soil unloading: *a* — *T* = 0; *b* — *T* = 15 min; c — *T* = 30 min; *d* — T = 45 min.
The color scale indicates the concentration of the suspension. The horizontal axis represents data on the width of the reservoir, while the vertical axis represents data on depth

Based on the results obtained, the volume of polluted water was calculated at soil dumps at three discharge sites (Table 1).

Table 1

Volumes of polluted water during soil discharge at three sites, million m^3

Site	Volume of polluted water at one discharge, taking into account the concentration of suspended matter in water			Volume of discharges	Total volume of polluted water			
					taking into account the concentration of suspended matter in water			Total
	from 0.25 to 20 mg/l	from 20 to 100 mg/l	more than 100 mg/l		from 0.25 to 20 mg/l	from 20 to 100 mg/l	more than 100 mg/l	
1	0.890	0.245	0.150	124	110.36	30.38	18.6	159.34
2	0.813	0.202	0.105	50	40.65	10.10	5.25	56.00
3	0.889	0.240	0.150	45	40.01	10.80	6.75	57.56

It can be seen from the table that when the soil was discharged, a high concentration of suspension was fixed in a relatively small volume of water (this is, for example, part of the water that was mixed with the soil). A larger amount of water had a lower concentration (such as water in the immediate vicinity of dumped soil). Significant amounts of water were polluted with a lower concentration of suspension during the discharge of soil, its sedimentation and transfer by current.

The areas of soil discharge and the number of discharges were determined according to the terms of reference for work on deepening the port's water area. The areas of the reservoir in which the death of phyto- and zooplankton was possible were identified. The areas of these areas were calculated.

Assessment of the ecological state of the Azov Sea water area. The ecological state of a shallow water body, such as the Azov Sea, was assessed using two different approaches. The first approach involved analyzing databases containing constantly updated data, which were the results of expedition surveys conducted by the authors of this study in the Azov-Black Sea region. The second approach involved the use of software that simulated the hydrodynamics, hydrobiology, and transport of particles in a reservoir. Based on these comparisons, mathematical models were calibrated and validated in order to obtain more accurate risk assessments.

The software package allowed us to assess the risks associated with such phenomena as:

– exceeding the maximum permissible concentrations of dangerous pollutants;

– rapid growth in the process of eutrophication of harmful and toxic algae (also known as “water blooming”).

Thus, by using the new software, it was possible to reduce the costs of expeditions for water sampling.

It should also be noted that data from remote sensing of the Earth were used to monitor the ecological state of the studied water body.

Here is an example of how the measurement data from an expedition was processed. Let us take the process of copper discharge from metallurgical plants and its flow into the Azov Sea through the Don River. Copper is a heavy metal that can accumulate in living organisms to dangerous levels.

When assessing the risks associated with a shallow reservoir, such as the Azov Sea, maximum values of pollutant concentrations obtained from measurements, mathematical models, and remote sensing data were used. At a specific point in the reservoir, a measured or calculated concentration value of the pollutant was selected. Let us assume that the measurements revealed an actual concentration of suspended matter in the water to be 80 micrograms per liter. Depending on the location and depth of sampling, copper concentrations in the waters of the Azov Sea ranged from 0.001 to 100 micrograms per liter.

Hydrolysis rate index for copper was assumed to be equal $P_S = 1.5$, bioaccumulation factor (accumulation of matter) — $k_{BA} = 2$. Then according to (6) exposure factor $E_S = 240$ mcg/L.

As noted above, three tests were considered to determine the potential danger of substance Ef_S:

– LC_{50} for 96 hours for fish (sander) — 4 mg/l;

– LC_{50} for 48 hours for zooplankton (daphnia) — 50 mg/l;

– LC_{50} for 72 hours for inhibition of microalgae growth — 20 mg/l.

Let us take into account (5) and the algorithm described above. We get normalized risk value $R_n \approx 0.52$. Thus, the risk of the presence of copper at a concentration of 80 micrograms per liter in the waters of the Azov Sea can be characterized as potentially significant.

It is also worth noting that the model (1)–(4) made it possible to track the trend of increasing salinity of the Azov Sea and the stratification of water masses by oxygen content. This was consistent with the results of earlier expedition studies [19].

Let us focus on the implementation of the 4th step of the algorithm, that is, on the assessment of the risk factor for each pollutant. Using the system (5)–(6), the calculation of normalized risk factor $R_n \in [0, 1]$ and the developed software package, the maximum concentrations of the main pollutants characteristic of the Azov Sea were calculated.

The final risk analysis was carried out based on the results of processing the expedition data and the results of mathematical modeling. Judging by the water pollution index, the ecological condition of the Azov Sea was improving. Previously, water had been defined as "significantly polluted", then as "moderately polluted" [19].

Discussion and Conclusion. The proposed software solution allows us to predict the effects of human activity on the water quality of the Sea of Azov. The developed software package enables us to simulate the movement of suspended particles within the water body, and identify areas where they may settle. These processes can alter the bottom topography, potentially leading to a decrease in species diversity in the areas where sedimentation occurs. Based on the results of our simulations, we can take steps to reduce the area of soil dumped during dredging, thus limiting the damage to the reservoir's ecosystem. By analyzing the data generated by the software, we can assess the potential negative impacts associated with economic losses and risks to human health.

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