# Water quality management in the coastal zone of the sea

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**Abstract.** Sea resort areas are currently one of the most successful developing regions. At the same time, the ecological condition of such regions is important, especially those that specialize in the provision of recreational and tourist services. The quality of coastal water resources played an important role in the sustainable development of those coastal tourist areas. Analysis of physical factors of water exchange was carried out and assessment of water resources quality of the coastal zone of the sea was made, including in closed and semi-enclosed water areas. It has been shown that water exchange is the most important factor in the management of the quality of marine waters of partially enclosed coastal areas. The results of the studies made it possible to assess the circulation of coastal marine waters and the change in certain indicators of water quality, including in the presence of various coastal protection facilities, based on 0-dimensional and system-dynamic models. The results obtained can be used to predict the state of water resources in coastal territories.

## 1 Introduction

Sea water is the most important natural resource of the coastal zone of coastal tourist regions used in recreational activities.

The management of coastal zone resources is a complex problem, since the coastal zone is an area of interaction between various processes: economic, natural and anthropogenic. And these processes often lead to conflicts in areas related to the use of coastal zone resources. Most coastal ecosystems, including anthropogenic coastal zone systems, are associated with the use of coastal waters. Therefore, the different waters of the coastal region should be considered in the process of management.

Six coastal water systems are distinguished:

- land (fresh water),
- water (sea waters, currents, waves, tides, etc.),
- land and water (salted land water),
- anthropogenic (fishing, water supply, water transport, etc.),
- man-made marine (marine fisheries, navigation),
- anthropogenic land (coastal fisheries).

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Other systems, such as marine products, agriculture, sediment, etc., are included in the above.

The traditional approach, called Integrated Coastal Zone Management (ICZM), is based on meeting the needs of consumers while preserving and protecting natural ecosystems. Given the complexity of the coastal zone, ICZM can offer a principled approach and some basic principles. Users of onshore resources under this approach are motivated to implement sustainable consumption almost only by the need to pay environmental payments, as compensation for environmental damage.

International Environmental Management Standards (ISO 14000) /Environmental Management, 1999/ are being actively developed and implemented in recent years. These standards have also been approved as official Russian ISO 14000 standards [1, 2] and have been further developed. These standards define the internal environmental management system.

The damage-oriented life-cycle assessment method "Eco indicator 99 - EI 99" /The Eco-indicator 99... 1999/ forms an important part of standards ISO 14000 [3-5].

The following environmental damage models were introduced in method EI 99: damage to health, damage to ecosystems, and seizure of resources. At the same time, the latter model was being considered only for mineral resources, the first two categories were currently developed in more detail.

The general environmental management approach and the use of EI 99 may be recommended for the coastal area as well, including damage assessment [4].

The coastal zone of the sea is substantially and continuously polluted by anthropogenic activities in the coastal zone. The introduction of nitrogen and phosphorus compounds into the coastal zone of the sea leads to an increase in the number of seaweed near the shore, causes a decrease in fish stocks, reduces the concentration of oxygen dissolved in water in seawater near the coast. This worsens the use of the coastal zone of the sea for recreational and tourist purposes.

The main means of assessing damage to the aquatic environment and finding rational solutions is systematic and dynamic modeling of the corresponding physicochemical processes and impacts.

The ecological sustainability of any system is determined by the ability to resist impacts of a natural and anthropogenic nature, the ability to maintain its structure and functional properties.

Limited water exchange of partially enclosed sections of the coastal zone of the sea can lead to degradation of ecosystems in these areas. Therefore, it is considered as the most important factor in the management of the quality of marine waters of partially enclosed coastal areas.

The international standard ISO 9000-2000 defines seawater quality in the coastal zone of the sea as a characteristic of needs and expectations. To establish quality characteristics, first of all, it is necessary to determine who are the consumers or stakeholders. For the marine coastal zone, this is, first of all, the ecosystem itself, as well as water users and water users. It is also undoubtedly important that quality characteristics should be measurable [1-5].

The problem of water quality management in the coastal zone can be divided into three global ones. The first is to determine the qualitative characteristics of the water body. It should be understood that for such objects there can be characteristics common to all, but there can be characteristics inherent only to a given water object. The second is the formulation of the responsibility of water users and water users. The third is the management of processes by water users and water users themselves in such a way as to meet the established requirements. Currently, a very good tool is the implementation of ISO 14000 standards (ISO 14040-99. Environmental management, 1999) [4].

Existing scientific and practical experience shows that the control of mineral and organic substances, specific contaminants that enter the water environment, allows assessing the quality of surface water [6]. The following six groups of surface water indicators can be used for this monitoring [6]:

- mineral substances ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $Cl^{-}$, $SO_4^{2-}$, $HCO_3^{-}$);
- organic substances (total organic carbon, BOD, dissolved oxygen, CCE);
- eutrophication indicators (primary production and destruction or chlorophyll; dissolved oxygen; $NH_4^{+}$, $NO_3^{-}$, $NO_2^{-}$, $N_{total}$, $PO_4^{3-}$, $R_{total}$);
- toxicity indicators (specific biological tests (aquatic organisms, enzymatic reactions));
- specific contaminants (heavy metals (Hg, Pb, Cd, etc.), pesticides, petroleum products, phenols, CNs);
- general parameters (temperature, pH, electrical conductivity, redox potential, suspended substances).

The following common attributes of semi-enclosed water quality can be added to these indicators: oxygen content (BOD and COD), species diversity in the ecosystem, suspended substances and water exchange [7-10].

The tendency to increase the anthropogenic load on the coastal zone of the sea is pronounced in the modern world. This is due to a number of objective reasons, but the main ones are population growth, an increase in tourist flows to the sea coast and, as a result, an increase in environmental pollution. The specificity of the problem is to increase the recreational load on the coastal zone. At the same time, it should be noted that the peak use of coastal waters for recreation and tourism falls on the most difficult period in terms of ecosystem functioning (summer) and leads to their gradual destruction [7-12].

The problem is aggravated by the fact that for the protection of the sea coast, for the protection of recreational facilities located on the shore and for the protection and preservation of various types of beaches, the construction of coastal protection structures (boons, longitudinal long-range waves, artificial beaches, fencing moths, cove banks, etc.) is everywhere practiced. Hence the need to determine the quality of water in closed and partially closed coastal waters. These include lagoons, small bays, ports and beaches with coastal coweapons, i.e. coastal waters in which water exchange with the open sea is difficult. In naturally occurring closed and semi-closed water areas (lagoons, small bays, inter-tower compartments, etc.), established ecosystems are killed under the increasing flow of pollution. Those contaminants came, firstly, from overflow and precipitation; secondly, from recreants; and thirdly, from man-made accidents or disasters. In artificially created closed waters, the ecosystems that have developed there earlier are destroyed. As a result, the ability of the medium to self-clean decreases, and as a result, the concentration of pollutants of organic origin exceeds the maximum permissible standards (MPC) already at the beginning of the beach season.

Water quality is characterized by the concentration of suspended substances, which, in many ways, determine the hydro chemical and hygienic state of the waters of the coastal zone of the sea. They include a large share of the main pollutants: organic, heavy metals, pesticides, petroleum products, various types of bacteria, etc. There are good correlations between suspended matter concentrations and other water quality indicators. They allow the use of mathematical simulation models describing the content of suspended substances, with further recalculation of the necessary (correlated) indicator of water quality [7-12].

The assessment of pollution of natural waters by organic substances, primarily of anthropogenic origin, is an urgent task in the modern conditions of coastal development. These substances are responsible for reducing the dissolved oxygen content. The term hypoxia, meaning lack of oxygen, has been increasingly used in recent years in many works on the environmental problems of the shelf of oceans and seas, coastal waters. As a result of various studies by many authors, it turned out that the cause of bottom hypoxia is anthropogenic eutrophication of reservoirs. It causes disturbances in the functioning of aquatic ecosystems. These disorders are manifested in a sharp increase in the development of phytoplankton, overgrowth of coastal shallow waters by aquatic vegetation and a change in the natural hydro chemical regime of water bodies. Disorders of the oxygen regime balance are the result of an increase in the speed of bio productive processes (or an increase in the trophicity of reservoirs). Indeed, oxygen is used exclusively for biochemical processes, while hydrological

processes in the coastal zone only provide oxygen flow at different intensities

Analysis of the mesoscale variability of hydrological processes showed that in early to mid-summer, the development of hypoxia can be significantly influenced by the dynamic state of waters. First of all, these are long-range currents, shear turbulence, internal waves, wind wave activity and advection in the bottom layer of the sea [7-12].

Oxygen depression (with concentrations less than 2 ml $O_2$ $l^{-1}$ at the bottom occurs in the coastal zone of the coast in modern conditions in June-July. At the same time, hypoxia is most sharply manifested in estuary areas, coastal shallow waters and banks - in areas with characteristic hydrodynamic conditions where stagnation zones are formed. Thermal inhomogeneity at the boundaries of the thermocline increases as the quasi-uniform surface layer develops as a result of heating. The vertical temperature gradient increases significantly and becomes an effective barrier to mixing processes, thereby limiting the aeration of the bottom layer. At the beginning of the formation of oxygen deficiency, some periodicity can be noted, associated with mesoscale and synoptic fluctuations in water dynamics. But as the general process of eutrophying the aquatic environment develops, these fluctuations are smoothed out. They are absorbed by a powerful background of oxygen deficiency at the bottom, which even the most active storm activity is no longer able to eliminate [7-14].

## 2 Materials and methods

The purpose of this study is to analyze the physical factors of water exchange and to assess the quality of coastal zone water resources, including in enclosed and semi-enclosed areas, and to assess water exchange as the most important factor in the management of marine water quality in partially enclosed coastal areas.

Empirical and theoretical methods, such as data collection, study and analysis, generalization, comparison and classification, were applied during the study.

0-dimensional and system-dynamic models were used to assess the circulation of coastal marine waters and to change certain indicators of water quality, including in the presence of various coastal protection facilities.

## 3 Results and discussion

### 3.1 Physical water exchange factors for partially enclosed coastal areas

To understand the problems encountered and to choose the best way to solve them, you must first know what are partially closed coastal waters, what processes are decisive for the normal development and functioning of the existing ecosystems there. For example, lagoons are relatively shallow water zones parallel to the coast, separated from the sea by a barrier and connected with it by interspersed narrow entrances (characters for the Azov and Baltic coasts). Coastal lagoons can be divided into three main geomorphological types by the nature of water exchange with an open water area: practically non-flowing; medium flow; flowing. Practically non-flowing (deaf lagoons) are, as a rule, several ellipsoidal water zones connected by one narrow, long channel with an open sea. This inlet is a dynamic filter and reduces the impact of the tide.

The main hydrodynamic forces in such lagoons arise under the influence of wind, solar radiation and surface runoff. Medium-flowing lagoons are large and wide water zones connected to the rest of the water area by two or more channels. In such lagoons, as a rule, the influence of tidal forces is noticeable along with wind ones. Flowing lagoons are elongated, parallel to the shore water areas with a large number of channels connecting them with the open sea, and, therefore, the predominant forces determining the circulation in them are tidal. To determine the degree of closure of the water area, the following criterion can be proposed [7-12]:

$$E.I. = \frac{\sqrt{S_a}\, D_{p1}}{W\, D_{p2}}, \quad (1)$$

where E.I. is the closure index, S is the area of the water territories, W is the width of the inlet, Dp1 is the average depth of the water area, Dp2 is the average depth in the pop-river section of the inlet. If E.I. > 2, then the water area refers to closed ones, if 1 < E.I. < 2 - partially closed water area, if E.I. < 2 - open water area.

The deterioration reasons water quality in the closed and partially closed water areas of the sea can be the following: excessive accumulation of plankton and as result reduction of content of oxygen in water; the pollution brought by water users; technogenic accidents.

There are three ways of pollution abatement of the closed water areas: control and restriction of receipt of pollution; holding clearing events; increase in water exchange with the open water area if water exchange was limited artificially. Now there are opportunities to increase water exchange (washout). It, first, in a certain way to group bank protection constructions, and secondly, to use permeable breakwaters and other types of permeable bank protection constructions.

Mathematical modeling of the process of pollution of closed coastal waters can be divided into two stages. The primary models consider the physical processes of contamination propagation, as well as the chemical and biochemical processes of binding and transformation. Secondary models describing biological processes resulting from changes in pollutant concentrations are then constructed [7-9].

The approach to modelling pollution has many features related to the following circumstances: there are differences in density between seawater and runoff, this leads to more complex forms of pollution; a wide range of ways in which pollutants can enter the studied area (for example, surface runoff (from shore to water surface), from the bottom (sea pipelines), from the side of a small vessel, with recreants (introduced by vacationers); significantly greater diversity of ecosystems involved [7-12].

In calm and light weather, the current system is determined mainly by coastal shallow flow.

### 3.2 Calculation of coastal sea water circulation based on 0-dimensional models

Estimates of water exchange in closed or semi-enclosed water areas can be based on 0-dimensional models [7-10].

The degree of closure of coastal areas is determined by parameter E.I. (1) for coastal areas [7, 8] (Table 1).

Water exchange problems can be associated with hydrometeorological factors and the configuration of the enclosed section of the water territory.

The calculations can also be based on estimates of the propagation time of conserved or non-conserved impurity in the reservoir under the influence of turbulent diffusion on the basis of mathematical methodology and model shown in works [7-10].

**Table 1.** Degree of closure of coastal areas (source: ([7, 8]).

| ***Parameter value E.I.*** | ***Definition*** |
|---|---|
| E.I.>2 | Closed water area |
| 1<E.I.<2 | Semi-enclosed water area |
| E.I.<1 | Open water area |

Modeling is a practical tool for predicting circulation for real objects. At the same time, there is naturally a need for additional assessment of water exchange in the surge zone from currents induced by wave collapse [7].

### 3.3 Life cycle of water resource

The system for managing the ecological quality of coastal waters includes: in-ventilation of environmental hazards; environmental risk assessment; environmental protection database.

Environmental risk assessment includes not only technogenic risks, but also an assessment of the functioning of ecosystem elements in conditions of intense anthropogenic load characteristic of coastal tourist areas. The latter task is complicated by the incomplete availability of data on the stability limits of systems.

The interaction between water use and water in the natural body of water, which is the coastal zone of the sea, can be considered as the life cycle of the resource (by analogy with the life cycle of products) [8-10]. The life cycle of the water resource is shown in Figure 1.

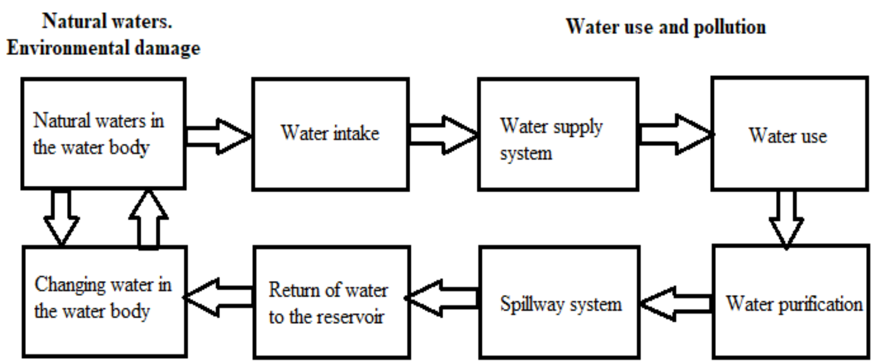


**Fig. 1.** Life cycle of water resource (source: [8]).

It is interesting to note that seven blocks of Figure 1 are sufficiently normalized by the corresponding normative documents and only the block "Water change in the reservoir" requires more detailed study using mathematical modeling [8].

The transformation of water quality characteristics in the reservoir requires detailed study using mathematical modeling.

The modern approach to life-cycle environmental impact assessment involves the analysis of three types of damage: human health, ecosystems and resources. Environmental damage to water resources can be considered in categories of damage to health and ecosystems.

### 3.4 Environmental damage to coastal zone water resources

The category "Resources" is relatively new to the methodology of environmental indicators. Before calculating damage to the water resources of the coastal zone of marine resort areas, it is necessary to understand what this damage is.

The waters of the coastal zone of the sea of tourist territories can be considered as a recreational resource of the environment. And, therefore, environmental damage should be analyzed in other categories of damage. Accessibility of clean coastal waters continues to be covered by categories of damage to the health of recreants and local populations, as well as ecosystems.

The amount of coastal waters is not a limiting factor, but their quality is such for tourism and recreation. Ecosystem quality is described in EI 99 [3-5] through energy, substance and information flows.

To characterize the quality of ecosystems, it is first necessary to assess the area of conditions in which flows are not significantly destroyed by anthropogenic effects. On the contrary, the poor quality of ecosystems occurs in the area of significant destruction of these flows. The degree of disruption of coastal ecosystem flows is a critical parameter for ecosystem quality monitoring.

Modelling of energy flows for coastal waters includes consideration of incoming energy flows essential for the coastal zone and their transfer. These flows are associated with waves, currents, rolling waves ashore, dissipation of wave energy during collapse, etc. The construction of coastal structures is an example of the violation of these flows as a result of anthropogenic activities, although they spawn the preservation of sea shores and beaches. The level of violation was considered in the works [8-10].

Modeling of material and information flows can be carried out using a Power Sim program or other computer systems intended for system-dynamic modeling. Flow modelling results can be used to assess ecosystem damage.

It is assumed that damage is determined by life-cycle products (LCs) that cause a temporary load on the aquatic ecosystem. Unlike his classic estimate (The Eco-indicator 99 1999), changes in water characteristics may not be estimated. This applies to changes caused by any water consumption [8-10].

Damage to ecosystems can be determined according to [8].

Thus, uneven damage to ecosystems is given and this is due to two reasons. First, different groups of species are used as members of the ecosystem as a whole, different levels are used to determine effects. That is, the levels at which species are exposed and, in particular, the critical levels at which species are destroyed. Second, different impacts are modeled using different models. For each such model, the relationship between impact and effect for species is described differently.

Modeling the effects on higher organisms is even more difficult, species migrate, use complex combinations in food, etc. The capabilities provided by system-dynamic modeling programs are very important. It is important to establish and maintain a database of water quality models of the coastal zone of the sea, which is an independent and complex problem.

Ecosystem damage caused by eco-toxic substances can be assessed using the EI 99 methodology based on the calculation of toxic stress for the ecosystem [7-10]. The latter is defined as the proportion of species potentially exposed (PAF). PAF can be interpreted as the proportion of species exposed to a concentration that is higher than the non-causing concentration (NOEC). A special dose-effect curve should be defined for this type of pollutant.

It is assumed that this curve may have the following form [7-10]:

$$PAF(c) = \frac{1}{1+e^{(\alpha - log c)/\beta}} \tag{2}$$

where c: is the concentration of the substance, □ - is a parameter determined by the average value of NOEC for an individual substance for all types, □ - is a coefficient determined by the standard deviation of NOEC for a given substance. □ - is an average logarithm of NOEC representing the average toxicity of the substance and □ is equal to about 0.5□ variations of NOEC.

Increasing acidity and eutrophication are most important to damage coastal zone aquatic ecosystems.

### 3.5 Modelling effects on coastal water systems

The increase in acidity and eutrophication is caused by accumulations of inorganic substances such as sulfates, nitrates and phosphates.

These substances can enter water directly or penetrate from the atmosphere. They can also accumulate due to insufficient treatment of wastewater before discharging into the sea or be supplied by water outlets, rivers, channels and sewage systems [7-10].

For almost all plant species, there is a certain optimal combination of the level of nitrates and acidity. Any deviations from this optimum are deadly for certain species. Therefore, changes in the level of nitrates in the main affect the diversity and population of species. Sometimes there is an increase in the number of species, sometimes there is a decrease.

The problem was to determine what changes could be considered damage. The European version of EI 99 provides a list of species for 40 ecosystem types. A set of species represents the natural state of the ecosystem [3-5].

Damage can be modeled for a selected coastal ecosystem cell. If such a cell system is installed, the accumulation effect can be modeled. Software capabilities (e.g., Power Sim) for such simulations are shown below for simulating phytoplankton concentration in a limited sea basin, e.g., in a compartment between two buns [8-14].

The main equation of the model in such calculations is the following [8-10]:

$$\frac{\partial n}{\partial t} = \frac{A_z}{\rho}\frac{\partial^2 n}{\partial z^2} - v\frac{\partial n}{\partial z} + n(P - R) - Hhn - q(n - n_R) \quad (3)$$

where n - is phytoplankton concentration, mg chlorophyll per м3, t - time, Az – coefficient of vertical turbulent diffusion, □ - density of water, z – vertical coordinate, v – deposition rate, P - photosynthesis rate for unit concentration, R - breathing intensity for single concentration, H – concentration of zoo-plankton, h - the eating ratio for the single concentration of zooplankton, q - the eating ratio for the single concentration of zooplankton, nR - the concentration of phytoplankton in the environment.

It is assumed that the horizontal dimensions of the water area in question are large enough compared to the depth to take into account only vertical diffusion. Moreover, it is assumed that vertical diffusion is not significant compared to other transfer factors on the right side of equation (3). Therefore, the first term on the right (3) can be neglected. A two-layer depth model including surface and bottom layers [8-10] can be used to estimate the deposition rate.

The photosynthesis rate is given by the simplified Smith equation [8-10]:

$$P = bIP_{opt} \quad (4)$$

where I - is the intensity of solar radiation on the surface of the water, b - is the coefficient. The optimal value of Popt is determined by the water temperature T (Celsius) as follows:

$$P_{opt} = \frac{3.1}{2} exp(0.09T) \quad (5)$$

The Power Sim model of phytoplankton growth in a reservoir with water exchange between the reservoir and the environment is shown in Fig. 2.

The simulation was carried out under the following initial conditions [8-10]: water temperature 22 C0, water depth 15 m, phytoplankton deposition rate 0.5 m/day, zooplankton concentration 0.001 mg/m3, discharge coefficient for a single zooplankton concentration 0.1 day-1/(mg/m3). The system was simulated at two water exchange intensities. The first was 0.01 days-1, which means a complete replacement of water in the region in 100 days. The simu-lation result is shown in Figure 3.

The concentration of phytoplankton increases dramatically and one can expect eutrophication of the water area and destruction of the aquatic ecosystem after about 50-60 days.

Increasing the intensity of water exchange changes the situation. Fig. 4 shows the simulation of the same situation with a water exchange intensity of 0.1 days-1, that is, when the volume of water in the water area is completely replaced in 10 days.

If water exchange is further increased, growth becomes stable - stabilization occurs after 50-60 days (Fig. 5). The simulation results in the figure correspond to a water exchange intensity of 0.25 days-1 or a complete replacement of water in the water area in four days.

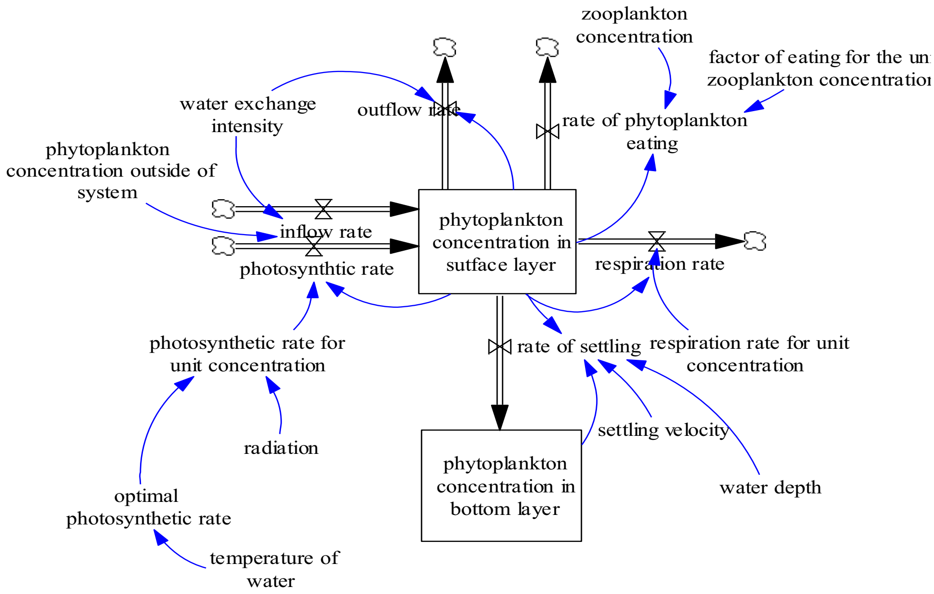


**Fig. 2.** Power Sim model of phytoplankton mass growth in the reservoir [source: 8, 13-14].

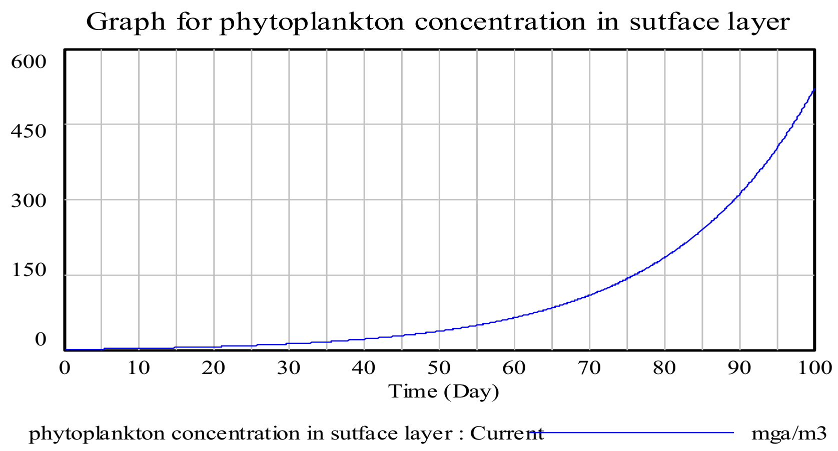


**Fig. 3.** Growth of concentration of phytoplankton in a blanket at weak water exchange [source: 8, 13-14].

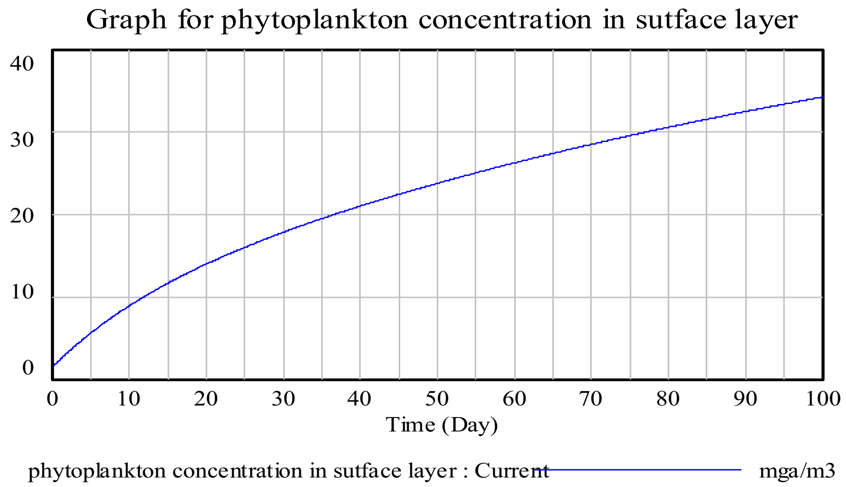


**Fig. 4.** Simulation of phytoplankton concentration growth in the surface layer during intensive water exchange [source: 8, 13-14].

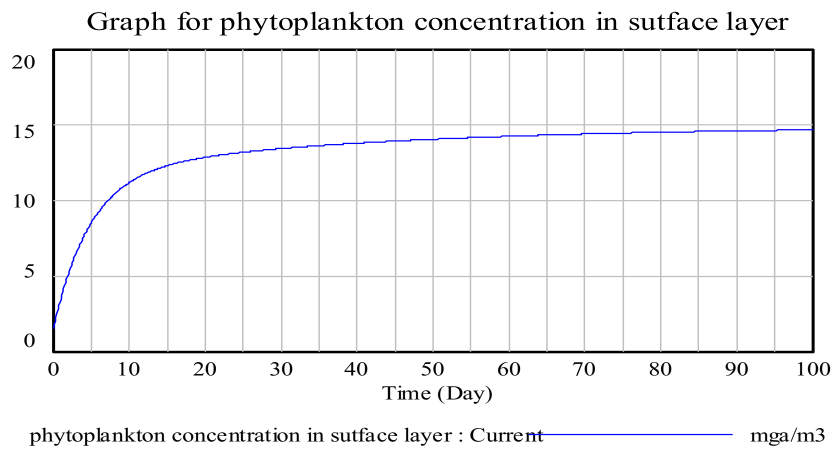


**Fig. 5.** Modelling of phytoplankton concentration growth in surface layer at more intensive water exchange [source: 8, 13-14].

Thus, it is possible to use a software tool for predicting the evolution of water quality in coastal waters with limited water exchange.

The results and techniques shown earlier are used.

### 3.6 Water exchange for areas with coastal protection facilities

A fundamentally different situation is associated with the modeling of water exchange for the region with coastal structures. Traditional coastal protection structures, such as boons, undulations and others, can partially or completely cover the coastal area, while weakening water exchange with the main water area. Water exchange factors for these areas are wind and currents induced by breaking waves.

Coastal protection facilities are located in the surf zone. This is an additional problem of using high-level mathematical models to simulate water exchange, since circulation varies significantly in time and space under the action of: refraction, diffraction, reflection of waves from structures, wave breaking, interaction of waves and currents, formation of breaking currents and stagnant zones. Moreover, lower-level models can produce satisfactory results despite the complexity of the simulated processes [7-8].

At the same time, turbulent diffusion in the surge zone is so strong that the applicability region of the 0-dimensional model can be achieved in a relatively short time. To estimate the time scale T, a horizontal turbulent diffusion factor is required. There are various approximations for the horizontal turbulent diffusion coefficient in the surge zone. Let's use one of them [7-16]:

$$D = \frac{H_b X_b}{T} \tag{6}$$

where Hb, Xb - are the wave height along the collapse line and the distance from the collapse line to the shore, respectively, and T – is the wave period. Taking Xb = L, Hb=db=L*tg□a, db – is the depth of water along the collapse line, tgα - is a representative bottom slope in the outermost zone.

Then the expression for diffusion coefficient can be rewritten as:

$$D = \frac{L^2 \tan\alpha}{T} \tag{7}$$

Use of (7) gives:

$$T_\varepsilon = \frac{4}{\pi^2} \frac{T}{\tan\alpha} \ln \frac{4}{\pi\varepsilon} \tag{8}$$

or

$$\frac{T_\varepsilon}{T} = \frac{4}{\pi^2} \frac{1}{\tan\alpha} \ln \frac{4}{\pi\varepsilon} \tag{9}$$

We accept the following typical conditions: tan α = 0.02, T = 5 c, e = 0.1b and get T = 258 c, which is only about 50 wave periods.

The performed analysis suggests that there are no serious limitations on the application of the 0-dimensional model in this aspect.

The performed analysis suggests that there are no serious limitations on the application of the 0-dimensional model in this aspect.

To illustrate 0-dimensional modelling of water exchange in the field of coastal protection facilities, the influence of typical coastal protection facilities on water exchange can be compared. This is shown in more detail in [7-15].

Typical coastal protection structures are boons, off-coast longitudinal wave breaking, underwater wave breaking and various combinations of these structures. Considering the boons, it can be seen that circulation zones occur when a single boom flows along a cross-section, both from the top and from the bottom (Fig. 6).

The water exchange of the circulation zone with the transit flow zone depends on the speed of the flow in shallow water, the length of coastal constructions, the average depth of the water and the volume of the water pool in which the circulation takes place.

In the case of an intermittent longitudinal wave breaking, the wave drift, which is directed towards the shore, interacts with the wave as a jet, and a compensatory flow towards the sea is formed in the area between the wave and the shore. Use of porous structures of structures can significantly increase water exchange in protected water area [8]. In particular, permeable booms significantly increase water exchange in the case of oblique waves.

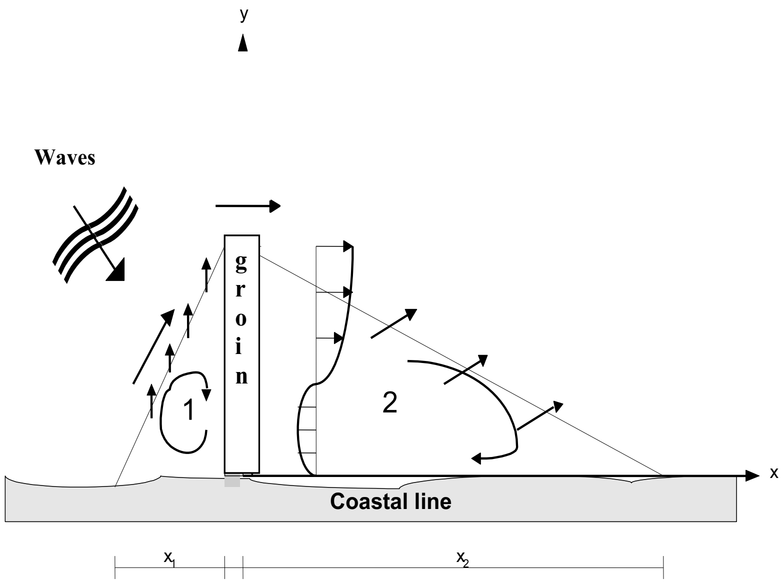


**Fig. 6.** Water exchange for a single boon. Flow diagram [source: 13-14].

There are some differences in the occurrence of circulations in the case of waves perpendicular to the shore. The flow rate in this case is lower than in the first case. The smaller the ratio of the distance between longitudinal wave breakers to the wavelength, the sooner the flow will concentrate in the center.

The use of underwater long-range waves is effective in beach restoration projects. Flooded with a wave can be designed with transverse traverses. With the oblique approach of waves to the shore, the water exchange between the fenced area and the main water area is so small that it can be neglected. With a normal wave approach, the mixing intensity near the crossarms is significantly reduced. Thus, such a coastal protection system can lead to a deterioration of water quality in the protected water area and requires additional analysis [8-15].

It is obvious that permeable structures contribute to an increase in intensity in general, especially in areas beyond the structures.

Thus, 0-dimensional models of water exchange can be used in studies, including in predicting the quality of coastal waters. In particular, this type of model provides comparative estimates of the effect of various typical coastal protection facilities on water exchange in protected coastal areas. Assessing the applicability of 0-dimensional models is an important part of such studies. It is advisable to develop this issue for higher-level models as well.

## 4 Conclusions

The quality of water in the coastal zone of the sea plays an important role in the ecological condition of coastal resort areas, in their desire for a state of sustainable development.

Analysis of physical factors of water exchange and assessment of water resources quality of the coastal zone of the sea, including in closed and semi-enclosed water areas, was carried out. It has been shown that water exchange is a critical factor in the management of marine water quality in the coastal zone, including for partially enclosed coastal water areas.

The obtained results made it possible to assess the circulation of coastal marine waters and the change in certain indicators of water resources quality, including in the presence of various coastal protection facilities.

It was shown that 0-dimensional models of water exchange can be used in studies, including in predicting the quality of coastal waters.

The results obtained can be used to predict the state of water resources in coastal waters.

## References

1. Environmental management systems — General guidelines on principles, systems and support techniques, ISO 1400 (2019) http://tic.tsu.ru/www/uploads/smart-section/19_ISO_14000.pdf
2. Federal Standard R ISO 14005-2019 Environmental management systems. Guidance on the flexibility of the phased implementation of the environmental management system (2019) https://allgosts.ru/13/020/gost_r_iso_14005 -2019
3. The Eco-indicator 99. A damage-oriented method for Life Cycle Impact Assessment. Manual for Designers. Second edition (2000) www.presustainability.com
4. I. Kantardgi*, The Eco-Indicating of the Black Sea Environmental Damage. Workshop Clean Black Sea Working Group, 2nd -5th June, 2005, Varna, Bulgaria,* Proceedings Book, Bulgarian Academy of Sciences, 36-37 (2005)
5. V.I. Korobko, *Damage assessment in environmental management systems*, Russian journal of resources, conservation and recycling **2**, 2 (2015) http://resources.today/PDF/04RRO215
6. Chemistry Handbook (St. Petersburg, Hydrometeoizdat, 391, 1989) http://elib.rshu.ru/files_books/pdf/img-224120733.pdf #1
7. I. Kantardgi, F. Mairanovsky, N. Sapova, *Water Exchange and Water Quality in Coastal Zone in the Presence of Structures,* Coastal Engineering **26,** 207-223 (1995)
8. T.B. Gordeeva, Development of methods for calculating water exchange for semi-enclosed water areas of the coastal zone, Autorepeat dissertation, Moscow State University (2002)
9. I. Kantardgi, *Natural Flushing of the Semi Enclosed Coastal Water Bodies. Typical Shore Protection Constructions.* Water Resources, Ports and Structures on the Shelf. Proc. of Moscow State Civil Engineering University 35-39 (2004)
10. I. Kantardgi, *Natural Flushing of the Semi Enclosed Coastal Water Bodies. 3-D and 2-D Numerical Models.* Water Resources, Ports and Structures on the Shelf. Proc. of Moscow State Civil Engineering University 40-43 (2004)
11. I.G. Kantardgi, E.V. Yakushev, L.V. Prokhoda-Shumskikh, *Sea water quality dynamic model,* Review of Applied and Industrial Mathematics **14,** 2, 306-308 (2007)
12. I.G. Kantardgi, E.V. Yakushev, L.V. Prokhoda-Shumskikh, Sea water quality modeling in the integrated coastal area management, *Proc. of the XXII International Coastal Conference "The problems of the control and sustainable development of the sea coastal zone"*, Gelendjik, May 16-20, 240-243 (2007)
13. L. Prokhoda-Shumskikh, Y. Dreizis, I. Kantardgi, *Dynamic Modelling of Coastal Water Quality. Proc. of the 8th Int. Conf. on the Mediterranean Coastal Environment,* MEDCOAST 07 **2**, 1207-1218 (2007)
14. L. Prokhoda-Shumskikh, Y. Dreizis, *Application of a system-dynamic model for predicting water quality in the Black Sea coastal zone,* Science of the Kuban 64-68 (2008)

15. Yu.I. Dreizis, L.V. Prokhoda-Shumskikh, Water quality estimation for the Russian Black Sea coastal zone. *Proc. of 9-th International Conference (MEDCOAST 2009)*, 10-14 November 2009, Sochi, Russia. MEDCOAST, METU, Turkey, pp. 863-874 (2009)
16. I. Kantardgi, V.C. Maderich, *Ensuring the quality of sea water in artificial coastal waters,* Engineering and Construction Journal **2 (37),** 75-80 (2013)