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PROBLEMS OF ECOLOGICAL MONITORING OF SURFACE WATERS

The main objectives of the Water Framework Directive 2000/60/EC of 23 October 2000, establishing a framework for Community action in the field of water policy, is to protect and to prevent all kinds of water from pollution and to achieve by 2015 a good ecological and chemical state of water. One of the tools used to achieve these objectives is monitoring, which should provide consistent and complete information on the state of ecological and chemical status of waters. Control of the dynamics of ecological state changes in aquatic ecosystems is a task of special ecological monitoring, which should be based on principles other than regular monitoring of environmental pollution. The most important component of the monitoring of surface waters is an assessment of their ecological status. For the assessment of ecological status of surface waters various criteria were developed. The main characteristics of the ecological status are usually the indicators of species diversity, reflecting the richness and diversity of water biocenosis. Despite their strength the indicators of biodiversity have some serious drawbacks. It can therefore be assumed that the most adequate criterion that reflects the ecological status of surface water is the material, energetic or kinetic balance of production and destruction of organic matter. At the same time, this balance characterizes the trophic state of water bodies, because the degree of water trophy is conditioned by the final balance of these processes. The indicators presented by the author can be used for the ecological monitoring, for assessing the trophic level of surface waters and at the same time their state of ecological balance. They also can be applied in solving engineering tasks and in mathematical modelling.

1. INTRODUCTION

Natural ecosystems, including surface water, are changing under the influence of natural processes and human-induced effects. After natural changes they can restore their characteristics and revert to the primary state. For example, seasonal fluctuations of temperature and pressure, rates of water flows, plants' and animals' biomass occur naturally. Changes due to human activity occur quickly, usually have a harmful impact on the natural ecosystems which leads to negative environmental, economic and social consequences.

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The monitoring of natural environment is an informative system and contains no management elements. However, it is obvious that the decision-making and proper management of the environment is a prerequisite to providing of information obtained in the process of monitoring

The system of environment observations, evaluation of its state and the prognosis on environmental changes under the influence of natural and anthropogenic factors is called *monitoring*. The system of surface water monitoring has to be the part of a general system of observations of the environment and based on the existing experience and organization structures.

The main objectives of the Water Framework Directive 2000/60/EC of 23 October 2000, establishing a framework for Community action in the field of water policy, is to protect and to prevent all kinds of water from pollution and to achieve by 2015 a good ecological and chemical state of water. One of the tools used to achieve the objectives of the Water Framework Directive is monitoring, which should provide consistent and complete information on the state of ecological and chemical status of waters. Control of quantity is an ancillary element in securing good water quality and therefore the measures of quantity, serving the objective of ensuring good quality, should also be established [4]. Programs for the monitoring of surface water condition apply to its ecological and chemical status and ecological potential.

2. PRINCIPLES OF ORGANIZATION OF ECOLOGICAL MONITORING

Ecological monitoring of environment, according to general definition, is an informative system of the observations, assessment and prognosis of changes in the environment created to allow the separation of anthropogenic component of these changes on the background of natural processes. In relation to aquatic systems, this definition can be specified in the following term: ecological monitoring is the system of observations, assessment and prognosis of aquatic ecosystem state.

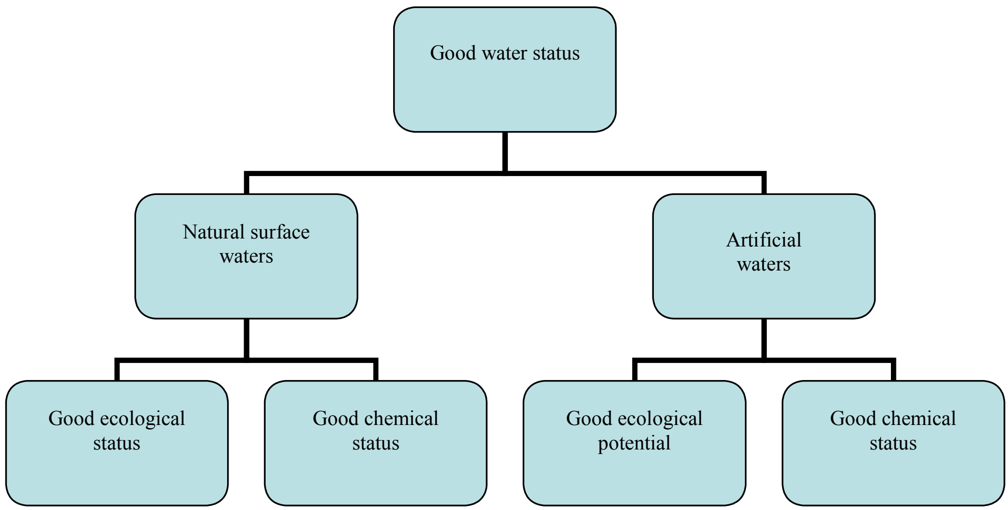
The system of monitoring according to the Water Framework Directive includes three elements: diagnostic monitoring, operational monitoring and investigative monitoring. Diagnostic monitoring of surface water bodies consists of the surveillance and assessment systems. The surveillance system, the first stage of diagnostic monitoring, allows observations of the factors and features of aquatic ecosystem affecting its actual state. The assessment system, the second stage of diagnostic monitoring, provides information on the qualitative and quantitative conditions of ecosystem and its anthropogenic transformations. The operational monitoring focuses on the water bodies which do not achieve high status and checks the effectiveness of investments taken to improve the status of water bodies. The investigative monitoring is undertaken for further information about surface water which is not provided in operational monitoring.

The ultimate goal of the programs of ecological monitoring of aquatic ecosystems is to estimate the rate of anthropogenic impacts, the changes of their features and the state in near or distant future as well as to determine the causes and implications of those changes. The forecast of water body changes is based on environmental mathematical models of different degrees of complexity [7].

Control of the dynamics of ecological state changes in aquatic ecosystems is a task of ecological monitoring, which should be based on principles other than regular monitoring of environmental pollution. The most important component of the monitoring of surface waters is the assessment of their ecological status. The concept of water status assessment, proposed by Water Framework Directive, where the assessment of ecological state is of the integral part of general assessment, is presented by the figure [4], [13].

Stages of this evaluation are: the selection of indicators and characteristics that allow for such an assessment and their measurement, the drawing up of ecological forecasts requires knowledge about pollutions' transformation and the change of the status of aquatic ecosystems as well as the development of mathematical models and calculation methods [6]. The basic activities in the field of environmental monitoring are:

- the observation of impact factors and the state of environment;
- the assessment of the current state of environment;
- the forecast of changes in environment and its assessment.



Assessment of water status according to Frame Water Directive [4]

Ecological monitoring should be implemented on the basis of mutual relations between biological systems and aquatic environment, and the system of assessment should be oriented towards the research on the ecosystem level.

The second aspect of the ecological monitoring, connected with the assessment of anthropogenic impact on aquatic ecosystem, is the development of mathematical models of ecosystems for the purposes of ecological rating. Such models can reproduce the phenomena occurring in real ecological systems after they have been transformed under the influence of anthropogenic factors, estimate the optimal state of ecosystems and establish the standards of anthropogenic impacts.

The data forming spatial and temporal orders of synchronous observations of hydrometeorological, hydrochemical and hydrobiological characteristics of ecosystem responses to different types of impacts create the bank of information for ecological monitoring. This information should be sufficient to:

- assess the state of ecosystems on the basis of calculation of the integral numerical indicators characterizing the state, quality, environmental sensitivity and ecological safety of aquatic ecosystems and to give a representative estimation of biotic and abiotic balance in ecosystems;
- formulate mathematical models of aquatic ecosystems and to verify these models on the basis of monitoring data;
- assess the scale and trends of anthropogenic impacts on the ecosystem;
- assess ecosystem state after anthropogenic impacts on the basis of experiments on the models.

The aim of a new approach to the assessment of surface waters in terms of their ecological state is to preserve natural homeostatic self-regulatory mechanisms, namely the stability of ecosystems and their resistance to anthropogenic impacts [7].

3. TRADITIONAL METHODS OF ECOLOGICAL STATE ASSESSMENT

The ecological state of surface waters is assessed based on various criteria. The main characteristics of the ecological status are usually the indicators of species diversity, reflecting the richness and diversity of water biocenosis. In practice, most often applied quantitative characteristics of ecological status are those based on the characteristics of the diversity of aquatic organisms, expressed mostly by their abundance and biomass. The diversity of species can be evaluated taking account of several components, whose response to geographical, ecological or anthropogenic factors is different.

The first such component is a species richness, i.e. the number of species compared with the number of individuals in the community. Such indicators can be used to compare different biocenosis.

The second essential component of diversity is the uniformity of individual organisms' distribution between species. The greatest diversity of species can be observed in the case where each individual organism in the biocenosis examined belongs to another species. This also means the greatest possible uniformity of the distribution of individuals among species [3], [14]. The smallest variety occurrs, in turn, when all the individuals belong to one species.

Other approaches to the assessment of biodiversity are based on the level of biota variety, derived from information theory, the main purpose of which is to measure the degree of ecosystem entropy [3], [8]. The best-known indicators of species' diversity of biocoenoses include: the indicators of similarity, indicators of biodiversity, indicators of dominance and indicators of uniformity.

Most often the following equations are used for the assessment of biodiversity:

- the equation of Shannon–Wiener:

$$\overline{d} = -\Sigma \frac{N_i}{N} \log_2 \frac{N_i}{N}, \tag{1}$$

- the equation of Simpson:

$$\overline{d} = 1 - \frac{N_i(N_i - 1)}{N(N-1)}, \tag{2}$$

- the equation of Margalef:

$$\overline{d} = \frac{S-1}{\log_e N}, \tag{3}$$

where:

$\overline{d}$ – the value of biodiversity indicator,
N – the total number of individual organisms of all species,
N_i – the number of individual organisms of the *i*-species,
S – the number of species.

Despite their strength the indicators of biodiversity have some sufficient drawbacks [11], [14], e.g.:

- the individual organisms ought to be rated as belonging to species level which requires advanced knowledge of the taxonomy of the groups examined,
- the values of indicators vary significantly, depending on the equation applied, the methods of sampling, the accuracy of the identification, characteristics of water body and the place of sampling; low diversity does not always mean pollution; in the indicators, both tolerance and sensitivity of species are not taken into account,
- sometimes the low level of pollution can increase biodiversity.

4. TROPHIC LEVEL AS THE INDICATOR OF ECOLOGICAL STATUS

Eutrophication of surface water leads to the disturbance of the balance of organic matter production and destruction which form the basis of biotic cycle of the substances in nature and the most fundamental characteristics of any ecosystem and biosphere as a whole [12], [15]. Almost all the instruments adopted for controlling the surface water quality are designed to show the changes in the balance of production and destruction of organic matter [2]. WINBERG [17] also states that typically dystrophic waters are characterized by a negative balance, while eutrophic ones – by positive balance, and oligotrophic waters reveal a sustainable balance of the rates of these processes [14]. A biotic balance in waters of different trophic status is presented in table 1.

It can therefore be assumed that criterion, which in a most adequate way reflects the ecological status of surface water, is material, energetic or kinetic balance of production and destruction of organic matter. At the same time, this criterion characterizes the trophic state of water bodies, because the level of water trophy is conditioned by the final balance of these processes. This approach shows that both the state of biotic balance, as well as trophic state in this context are the synonyms.

In light of the discussed issues the serious problem seems to be the choice of indicators on the base of which the production–destruction balance of organic matter in surface waters during the annual cycle can be measured.

Table 1

Biotic balance in the waters of different trophic state

Trophic level	Biotic balance
Dystrophic	$V_{prod.}/V_{destr} < 1$
Oligotrophic	$V_{prod.}/V_{destr.} \approx 1$
Eutrophic	$V_{prod.}/V_{destr.} > 1$

Traditionally the trophic status of water bodies is estimated on the basis of a whole number of hydrological and biological characteristics, which include, among other things: abundance, biomass, species' structure of water vegetation, the rate of photosynthesis, chlorophyll concentrations and many others.

The values of indicators listed above for different trophic levels, given by various authors, vary considerably, which resulted primarily from the diversity of geographical areas, which were examined by them, and the fact that the process of eutrophication in aquatic ecosystems depends on their morphological, hydrological, hydrobiological properties, climatic conditions and the type of land use catchment's area. The scale of variability of the indicators illustrates table 2.

Measurement and determination of these indicators, especially of hydrobiological indicators, is labour-consuming, expensive and requires high skills and narrow specialization of researchers. Not all of the criteria for the assessment of trophic status may be recommended for practical assessment, as they have some limitations and drawbacks.

Among the vast number of indicators for direct estimation of surface waters' trophic level, as the most convenient and most commonly used can be recognized four of them: biogenic matters' concentration, the rate of oxygen depletion in hypolimnion, transparency and chlorophyll concentration.

Furthermore, the above-mentioned indicators are not suitable for a variety of engineering calculations and mathematical models used to solve practical problems of water resources protection and management. Most of the traditional hydrobiological characteristics reflects mainly the production aspects of these processes, meanwhile the biotic balance state, as already mentioned, also depends on the destruction of organic matter.

Table 2

Scale of variability of the values of trophic level indicators according to different authors [10]

Indicators	Ultraoligotrophic	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Mineral nitrogen, mg/dm^3	< 0.2	0.2–0.4	0.3–0.65	0.5–1.5	> 1.5
Total phosphorus, mg/dm^3	< 0.005	0.005–0.04	0.01–0.06	0.025–0.1	> 0.1
Transparency, m	> 6–12	8–64	1.5–8.0	0.7–2.0	> 0.7
Primary production, mg C/m^2 d	0–50	50–300	100–1000	250–1500	–
Annual production of phytoplankton, g C/m^2	0–10	10–30	30–300	70–300	200–4000
Chlorophyll *a*, mg/dm^3	0–1	1–40	2–60	7–1000	> 1000
Biomass of phytoplankton, g/m^3	< 0.2	0.2–0.5	0.5–30	0.8–10	> 10
Number of bacteria, mln cel./dm^3	–	< 0.5	0.5–1.5	2–4	–

5. NEW APPROACH TO ASSESSMENT OF ECOLOGICAL STATE

As already mentioned, the fundamental characteristics of any natural ecosystem is the balance of organic matter production and destruction. In the process of organic production matter, solar energy is accumulated in organic compounds in the form of potential energy of chemical bonds (photosynthesis), while in the processes of destruction this energy is emitted. Kinetic balance of organic matter production and destruction in surface water is reflected by the biotic balance and therefore by trophic level.

In turn, the changes of the balance of these processes bring to corresponding changes of many hydrochemical characteristics of water quality, whose measurement is available and easy. Research carried out by the author has allowed her to propose the application of the following indicators for estimation of surface water trophic status: complex characteristic of trophic level *LT* and integral criterion of trophic state *ITS* [1], [9], [10]. The indicators can be estimated on the base of equations (4) and (5):

$$LT = 2.48 + 0.036 \lg ([N_m][P_m][Si_m])/(h\, t\, V), \tag{4}$$

where:

$[N_m]$ – sum of mineral forms of nitrogen (NH_4^+, NO_2^-, NO_3^-),

$[P_m]$ – mineral phosphorus (PO_4^{3-}),

$[Si_m]$ – silicate ion (SiO_3^{2-}),
h – depth of water body, m,
t – temperature of water, °C,
V – water flow rate, m/s.

$$ITS = \Sigma pH_i/n + a\,(100 - \Sigma\,[O_2\%]/n), \qquad (5)$$

where:
pH_i – pH value in measurement period t,
$[O_2\%]$ – oxygen saturation of water measured synchronously with pH measures in period t,
a – empiric coefficient,
n – number of measurements in period t.

In different trophic conditions of surface water indicator *LT* has the following values [7], [8]:

dystrophic 0.0–1.0,
ultraoligotrophic 1.1–2.0,
oligotrophic 2.1–3.0,
mesotrophic 3.1–4.0,
eutrophic 4.1–> 5.0.

The values of integral criterion *ITS* in the waters of different trophic status are presented in table 3.

Table 3

Values of *ITS* in waters of different trophic status [9], [10]

Biotic balance ($V_{prod.}/V_{destr.}$)	Trophic state	ITS
Negative ($V_{prod.}/V_{destr.} < 1$)	Dystrophic Ultraoligotrophic	< 5.7 ± 0.3 6.3 ± 0.3
Sustainable ($V_{prod.}/V_{destr.} = 1$)	Oligotrophic	7.0 ± 0.3
Positive ($V_{prod.}/V_{destr.} > 1$)	Mesotrophic Eutrophic	7.7 ± 0.3 > 8.3 ± 0.3

Both above mentioned indicators showed close statistical correlation with the most spread integral indicators of ecological state of aquatic ecosystems – the indicators of biodiversity (for *LT* the value of correlation coefficient $r = 0.96$; for *ITS* the value of correlation coefficient $r = 0.920$) [1], [9], [10]. The results of these researches show the possibility of using of the proposed indicators for assessment of trophic level of surface waters and at the same time of their state of ecological balance.

6. CONCLUSIONS

In order to make a decision on rational water management and water protection it is necessary, above all, to have an objective information on the state of water and the prognosis on its future. The condition of natural waters ought to be monitored in order to provide the competent authorities and water users with reliable information on the status of water bodies and water quality (first of all for the sources of drinking water and other). The existing system of surface water observation in European countries is necessary but insufficient for the purposes of ecological monitoring. It needs not only some improvements and additional operations to eliminate the asynchrony of hydrological, chemical, bacteriological and hydrobiological observations and analyses, but also the introduction of automatic tracking and alert systems and the use of remote surveillance methods, etc.

The system for water monitoring and forecasting their condition needs to be improved. In addition to the existing permissible rates of pollutions, the integral criteria of aquatic ecosystems' state and regional environmental standards should be developed.

It should be noted that the development of a universal criterion of water quality, taking account of the type of water use, is rather impossible task, because the multifunctional nature of anthropogenic activities prejudges the search for a variety of criteria, corresponding to different types of use, which are: drinking water supply, fish farming, aquatic and sport recreation, industrial water supply, irrigation goals, etc. For these purposes the permissible levels of water quality characteristics were developed in different countries.

The assessment of the complex properties of the above aquatic ecosystems is of particular importance. There is also a need to develop adequate ecological indicators of surface waters and ecological models to predict changes in surface water.

But so far the ecological diagnosing of water ecosystems as a functional entirety is not established satisfactorily. Such a diagnosis of reservoir or watercourse cannot be reduced only to the analysis of the full range of traditional abiotic and biotic characteristics used for the estimation of sanitary state of water. The analysis of the data bank, even derived from long-term observations, collecting hundreds of separate chemical and biological indices is not considered to be adequate for objectives.

The task of monitoring of ecological status of surface water is bringing a large amount of data on the state of water to one or more criteria [12].

So there is a need to develop integrated indicators, which would allow us to reflect emergence properties of aquatic ecosystems, because the entire ecosystems' response to stress is different from the reaction of individual organisms or even the entire population of organisms.

Ecological diagnostics of aquatic systems requires multifactor assessments of trophic level and quality of water and the research of the most important relations between the components of ecosystems in order to find the dependency of trophic level from ecological geographical factors and coastal zone management [3].

The proposed indicators *LT* and *ITS* are numerical indicators and can be used for the assessment of trophic level and ecological state of surface waters. The main merits of indicators described above are the following:

- proposed indicators reflect the state of biotic balance of water ecosystem,
- the indicators are based on simple hydrochemical indices of water quality measured in any routine monitoring,
- these indicators can be used for express-monitoring of surface water and assessment of its ecological state,
- these numerical indicators can be used for engineering calculations and for the purposes of mathematical modeling,
- proposed indicators can be the base for elaboration of ecological standards of water quality,
- the indicators are characterized by low costs and simple calculations.

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