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# Geometrical parameter measurement and phytoplankton process modeling based on video images of water samples from reservoirs

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ABSTRACT

There was developed a computerized system for measuring the geometric parameters and the number of phytoplankton instances in the water samples from reservoirs used for household purposes. The basis of these measurements is formation and computer processing of video images of water samples from these reservoirs. The measurement results are used to develop the mathematical models of phytoplankton processes, monitoring and forecasting of the status of reservoirs for household purposes, which are a source of water supply.

## 1. Introduction

Phytoplankton development in reservoirs is one of the major environmental problems. The most intensive phytoplankton development occurs in reservoirs and other bodies of water used for household purposes with limited water circulation. The result of this process is a significant degradation of potable water quality and a significant increase in the total amount of toxic substances in water.

To monitor and forecast these processes, it is required to determine the number of instances and biomass of phytoplankton in 1 $dm^3$ of water and identify the same by species. This can be done by taking water samples from reservoirs, placing these samples in a microscope with a digital camera, with subsequent generation and computer processing of phytoplankton video images. Thus, the basis for biomass identification and determination are geometric parameters characterizing the size and shape of each phytoplankton instance.

Therefore, the development of measurement tools for phytoplankton geometric parameters and its development process modeling is a relevant scientific and technical problem.

## 2. Analysis of existing research and publications

The issue of measuring the geometric parameters of objects at video images is highlighted in a number of papers of the prominent scientists [1–11]. However, these studies are lacking information about the measurement of phytoplankton geometrical parameters based on algorithmic processing of video images containing the metering information about these parameters. Also, the main obstacle to the implementation of the operational monitoring of water bodies is outdated known methods of measuring the phytoplankton geometric parameters as well as calculating its size and weight [11,12].

Recently, a number of scientific and technical developments on the study of microorganisms in water samples has appeared [13–18].

JR 5146791 and JR 6028453 [13,14] patents generate the video images of microorganism instances, and perform their classification by the linear size (length). However, this principle of classification cannot be used to identify phytoplankton by specie, because two phytoplankton instances can have the same linear size but different shape and belong to different species. JR 6034556 [15] patent generates the microorganism video image, this video image highlights individual instances of microorganisms, counts their number, but there is no procedure for measuring the geometric parameters, recognition and identification. JR 5192678 [16] patent determines the number of microorganisms in industrial wastewater stream based on digital processing of video images. This patent provides no definition of microorganism signs required for their identification by species.

Scientific article [17] considers the process of generating and processing the phytoplankton video images, as well as the procedure for its identification. Identification is carried out based on calculation of the video image spectrum and use of correlation analysis to compare the video image spectra of different phytoplankton instances. However, these spectral features allow comparing the video images of individual phytoplankton instances only. They are not directly related to geometric parameters and classification signs of form for phytoplankton

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species.

The scientific article [18] considers the technical means and the method of identifying 3 species of marine phytoplankton on the basis of their size and shape. The article also notes that identification in the real world and identification of other phytoplankton species (e.g. for freshwater pond phytoplankton) requires the modification and refinement of this method. Thus, the identification method given in the article cannot be used to identify phytoplankton in water bodies, containing several dozens of phytoplankton species and used for centralized water supply to settlements.

High labor intensity, low efficiency and speed of these measurement methods do not allow detecting the changes taking place in GPF development quickly, respond to them and develop the mathematical models of these processes.

There are also a number of research examples based on the use of a personal computer, measuring object image sensors and methods for digital processing and classification of object images [19,20,21], as well as examples of monitoring of environment condition and contaminations [22,23]. The examples relate to other branches of science and technology and cannot be directly used to control the development of phytoplankton in water bodies. However, they indicate the relevance of the proposed approach to measurement of geometric parameters of phytoplankton and the practical feasibility of implementing the measurements and methods of analysis and simulation of phytoplankton development in water bodies.

## 3. Computerized system for measuring of phytoplankton geometric parameters and quantity

Measurement of phytoplankton geometric parameters and biomass requires using a specific set of technical means generating and processing the digital video images to identify these mechanical values (Fig. 1a). The elements of this flow chart are complex technical means. Therefore, we used the existing standard technical means, and the required precision, speed and functionality of the computerized system was ensures based on algorithmic processing of measurement video information.

Measurements according to the chart shown in Fig. 1 is based on the principles, such as the use of standard technical means of generating and processing the digital video with parameters ensuring the required necessary metrological characteristics of computerized system (Fig. 1a); use of the algorithmic processing of measuring video information and ensuring the required functionality and accuracy characteristics of measuring instruments on that basis (Fig. 1b); search and selection of the required parameters of video image digital processing algorithms based on the characteristics of GPF measurement task, ensuring the required accuracy and performance of the automated system and improvement of these algorithms; the use of video image compression in the digital camera, which is essential for registration and entry of the available amount of measurement video information into the computing device and compact storage of this amount of video; application of modern technologies of artificial intelligence in the form of artificial neural networks for processing of measurement video information.

Samples of water containing phytoplankton are taken from household use water bodies by laboratory staff responsible for control of water quality, required from entity supplying water to population. Specimens are collected and handled in accordance with the procedure described in [8]. Specimen preparations are placed by the specified staff on a microscope slide. All subsequent actions on measurements of geometric phytoplankton parameters are carried out automatically by computerized system.

The process of measuring the phytoplankton geometric parameters and its biomass is ensured by technical means (microscope, digital video image generating device, digital computers and neuroprocessor) and software implementing the new methods and algorithms of digital video image processing.

Neuroprocessor is the most advanced computer in the computerized system. Compared to a common digital computer, a neuroprocessor provides better timing characteristics for digital imaging and higher probability of correct identification of phytoplankton specimens by images. These benefits are provided by parallel computing of digital images in neuroprocessor. When conducting research of changes in phytoplankton geometric parameters in reservoirs, it is usually required to use the personal computer when solving the production problems of monitoring the reservoirs for household purposes, i.e. industrial computer or microcontroller.

A central processor of a digital computer performs the following functions:

- Management of computerized system operation, including organization of image transfer from imager to computer environment, organization of measurement results visualization and their storage on external devices;
- Calculation of geometric parameters for each phytoplankton specimen depicted in the image, which are invariant to scaling, displacement and rotation of the specimen in the display area;
- Calculation of mass and quantity of phytoplankton of each species in terms of 1 $dm^3$ of water;
- Simulation of changes in geometric parameters and mass of phytoplankton by approximating measurement results obtained.

A neuroprocessor performs the following functions:

- Detection of each phytoplankton specimen by image digital processing and segmentation, including by using the Kohonen artificial neural network;
- Identification of each phytoplankton specimen by its species composition based on the calculated shape factors of these specimens and artificial neural network.

The microscope-based measuring complex with a built-in camcorder has a lens-tube-camcorder circuit. In this case, the image is projected from the lens directly at the “light signal” converter of the camcorder.

The computerized system uses the laboratory microscope CU 200T (Micros, Austria) with a digital full-color camcorder CAM 2800 (Fig. 2). The generated video images have the following features (Fig. 3): microscope zoom in $400^{\times}$; video size 640 × 480 discrete points; 15 pictures generated per second. This equipment provides for zoom in and video resolution sufficient to study the phytoplankton.

As regards the technical characteristics of the microscope and camcorder, resolution and accuracy of phytoplankton geometrical parameter measurement are essential. In this case, the resolution comprises the optical resolution of the microscope optical system and camcorder resolution limited by the number of discrete points in CCD.

We know that the resolution of the microscope optical system when observing the real objects is

$$\delta_s = \frac{\lambda}{2A},$$

where λ is the light wavelength; A is the numerical aperture of the microscope lens.

The numerical aperture gives the idea of the maximum effective zoom in as a product of 1000, i.e. such a zoom in which two adjacent objects of measurements are still distinguished as separate.

In Micros 200T, for visible light (λ = 0.53 μm) and $400^{\times}$ zoom in we have

$$\delta_s = \frac{0.53}{2\cdot 0.65} = 0.41 \text{ mcm}.$$

Let’s determine the camcorder resolution. For $400^{\times}$ zoom in, the camcorder field angle horizontally is 250 μm, and the size of the “light signal” converter is equal to 640 discrete points. Therefore, the

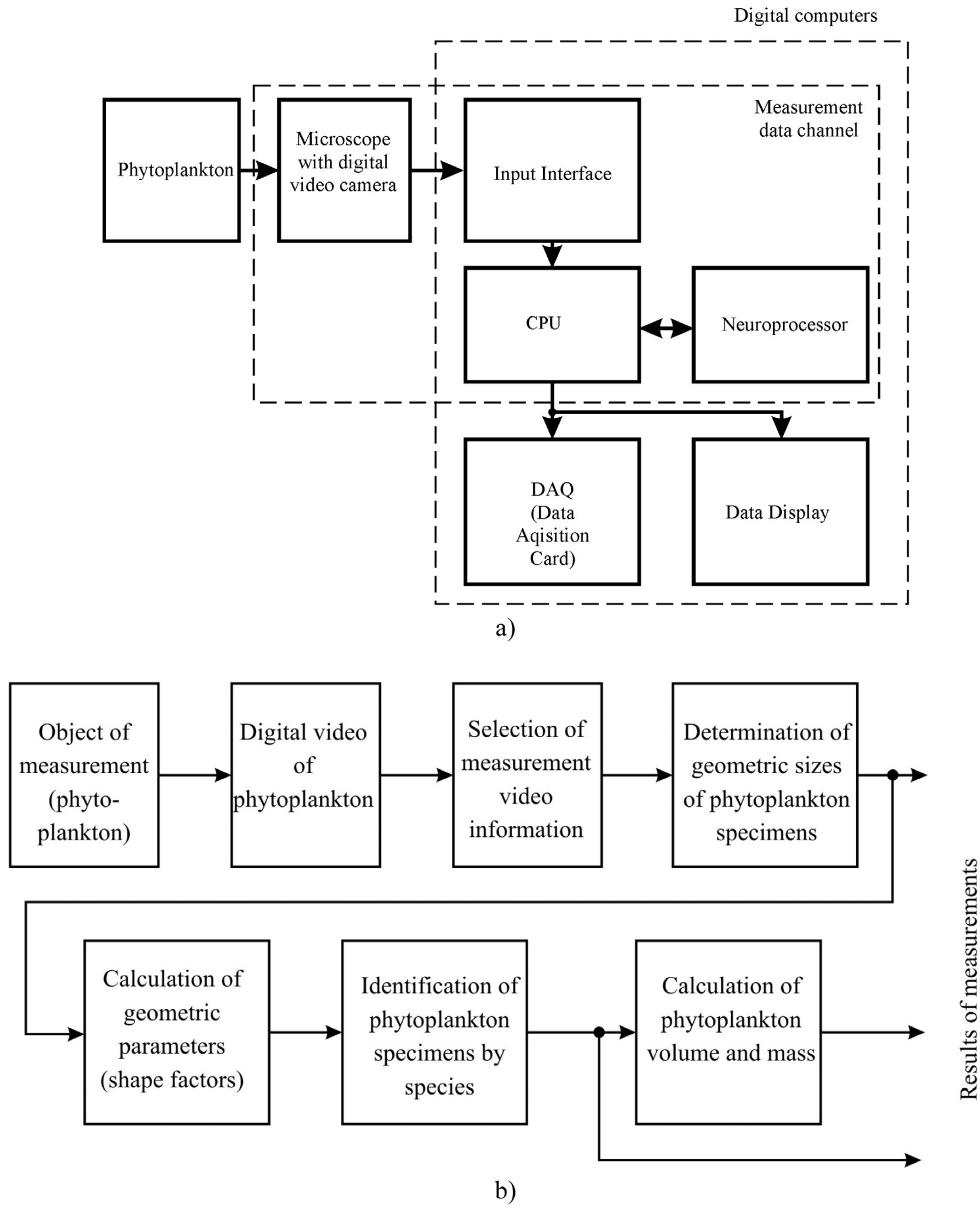


**Fig. 1.** Computerized system for measuring the phytoplankton geometric parameters: Flow chart (a) and Sequence of transformation and processing of measuring Information (b).

camcorder resolution is $\delta_{cc} = 250/640 = 0.39$ mcm.

Thus, the characteristics of the optical system and digital camcorder in the microscope are consistent ($\delta_{cc} \approx \delta_s$). The value of the optical system resolution defines the minimum distance between two points of measurement objects, which can be fixed at different coordinate values when measuring the geometrical parameters. The value of the camcorder resolution determines the minimum discrete error when measuring the size of phytoplankton instances.

The calculation results of measurement errors as regards phytoplankton geometrical parameters for a selected technology set (microscope MS 200T, camcorder CAM 2800) are shown in Table. 1.

Linear sizes of phytoplankton copies are defined as the difference between two measured coordinates of reference points belonging to the contour of phytoplankton instance. In this case, a systematic error in the measured coordinates is mutually offset.

According to the calculation, the maximum error of phytoplankton linear dimensions is about ± 2 discrete points. When using the microscope MICROS MC-200 with built-in digital camcorder CAM-2800 and $400^{\times}$ zoom in, this ensures the measurement error of phytoplankton linear dimensions max ± 1 μm. Such an error is quite acceptable to the problem of determining the quantity, biomass and identify of phytoplankton instances.

Algorithm for analysis of phytoplankton images contains the following operations:

1. Identification of each phytoplankton specimen by segmentation of images, that is, distribution of an image into separate areas corresponding to phytoplankton specimens and background area. Filtration of noise and conversion of image color scheme is made additionally before segmentation in order to separate information about brightness and color of image points. These operations are performed by a neuroprocessor.

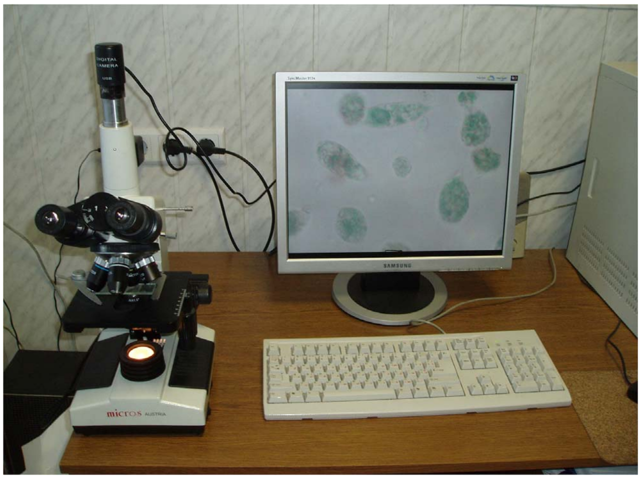

**Fig. 2.** The use of the instrument system to measure the phytoplankton geometric parameters, volume and biomass in the water samples from reservoirs.

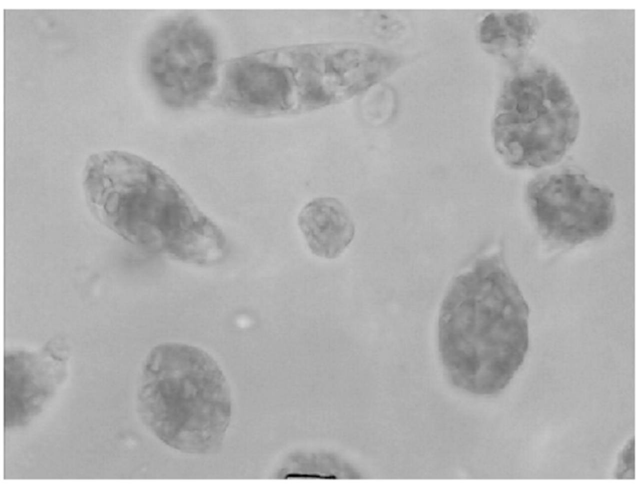

**Fig. 3.** Example of phytoplankton digital video image.

2. Calculation for each phytoplankton specimen of parameters characterizing its geometrical dimensions and position in the image (linear dimensions, area, center-of-mass coordinates).
3. Calculation for each phytoplankton specimen of geometrical parameters characterizing its geometric shape and being invariant to scaling, displacement and rotation of this specimen in the display area (length of maximum and minimum axis of inertia, equivalent diameter and shape factors, namely, eccentricity, convexity coefficient, fill factor).
4. Identification of each phytoplankton specimen by its species composition based on the geometric parameters and shape factors calculated by a neuroprocessor.
5. Calculation of mass and volume of phytoplankton of each species converted to 1 $dm^3$.

Since brightness of phytoplankton and background were approximately the same (the image was obtained using light passing through the microscope slide), segmentation was carried out by color of phytoplankton specimens and image background. Kohonen artificial neural network was used for segmentation [24].

The neural network used in the training mode on a test image with known phytoplankton specimens ensures detection of clusters and identification of their centers in attribute space. In this case, information about color of image discrete points is used as attributes. Herewith, the number of network inputs is the number of digital colorful image channels containing only color information, and the number of neurons in the layer of Kohonen neurons for this network is the number of identified phytoplankton species plus one for the background. Using only color information eliminates the impact of light irregularity and, accordingly, brightness within a single image or a sequence of images on the results of segmentation.

In working mode, Kohonen artificial neural network performs segmentation of a digital image into objects of measurement (phytoplankton) and background. For this purpose, affiliation of each discrete point of a digital image to one of the clusters in attribute space is determined, which is the result of image segmentation.

Objects that are not phytoplankton specimens are excluded from consideration on the basis of identification results (objects that are far away from centers of clusters) and results of analysis of brightness of objects in the light passing through the microscope slide (phytoplankton specimens are translucent and solid water impurities are opaque).

The following geometrical dimensions of phytoplankton specimens are determined directly by image: width and height of the specimen, as the difference between coordinates of extreme points; area as the number of image points belonging to the specimen; equivalent diameter

**Table 1**
Calculation of measurement errors for phytoplankton geometrical parameters.

| Error type | Systematic component, discrete points | Random components: | | |
|---|---|---|---|---|
| | | Maximum discrete point value | Root-mean-square value of discrete points | Distribution law |
| Error caused by discrete "light signal" transformer, discrete points | 0 | 1000 | 0.577 | Uniform |
| Error due to quantization of video signal amplitude, discrete points | 0 | 0.008[a] | 0.005[a] | Uniform |
| Error due to noise in the video image (at signal/noise ratio of 55 dB), discrete points | 0 | 0.022[a] | 0.007[a] | Normal |
| Error occurring during the digital data processing in the app, discrete points | 0.500 | 0 | 0 | – |
| Error of determining the coordinates of phytoplankton instances, discrete points | 0.500 | 1030 | 0.583 | Close to uniform |
| Accuracy of coordinate determination for phytoplankton instances subject to 400$^{\times}$ zoom in, mcm | 0.10 | 0.42 | 0.23 | Close to uniform |
| Error when determining the linear dimensions of phytoplankton instances, discrete points | 0 | 2060 | 0.816 | Close to triangular |
| Error when determining the linear dimensions of phytoplankton instances subject to 400$^{\times}$ zoom in, mcm | 0 | 0.83 | 0.47 | Close to triangular |

Notes: 1.
[a] – the result of conversion based on linear form of brightness difference based on the fact that the quantization of the video signal amplitude uses 255 discrete levels and the width of the brightness difference in the area of phytoplankton contours is 4 discrete points of the video image.

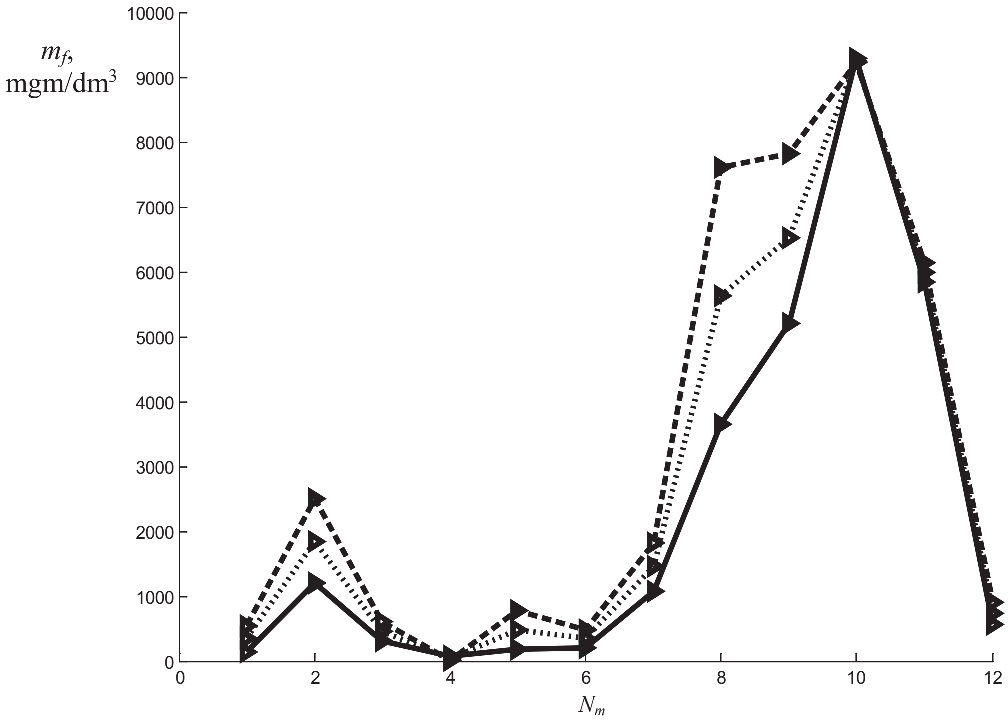


**Fig. 4.** Phytoplankton mass change study findings (on the example of blue-green algae): $m_f$ is the algae biomass; $N_m$ is the serial number of the month; Denyshi reservoir – a solid line, Vidsichne water intake – dashed line, average value for the two reservoirs – dots.

**Table 2**
The 5th degree polynomial coefficients for approximation of phytoplankton biomass change pace.

| $b_0$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ |
|---|---|---|---|---|---|
| 1361.0 | −2014.8 | 942.7 | −176.1 | 15.0 | −0.5 |

that is the diameter of circle with an area equal to phytoplankton specimen area; length of maximum and minimum axes of inertia of the specimen as a plane figure in the display area.

For further processing, phytoplankton specimens are equated to certain geometrical objects (ball, parallelepiped, cylinder, cone, etc.) that correspond to the shape of these specimens. In this case, the results of identification of phytoplankton specimens by species composition are used. Then geometric parameters of these objects are calculated. Volume of phytoplankton cells is determined according to known geometric formulas based on the received linear sizes of a certain phytoplankton specimen [7,25]. Relative density of specimens of freshwater phytoplanktonic algae (relative to water) is taken to be equal to 1.00–1.05. The calculated mass of each species is multiplied by its number and the result is given in mg/dm$^3$ or g/m$^3$. Integral indicators of state and development of phytoplankton as an integral part of water bodies are determined based on the measurement results.

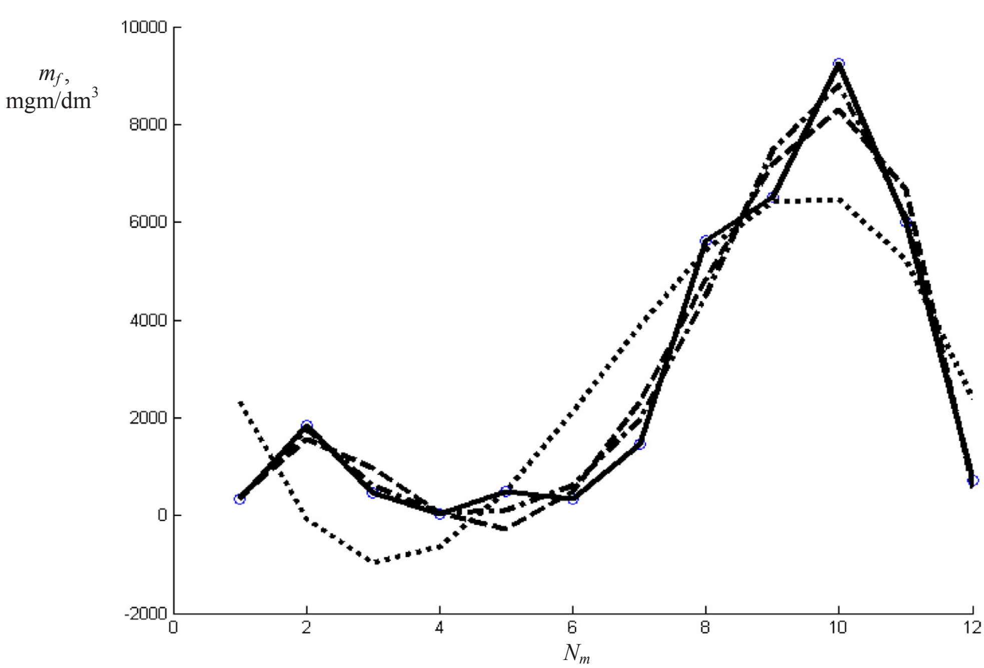


**Fig. 5.** Approximation of blue-green algae biomass change processes (average for two reservoirs): ○ – results of experimental research, dotted line – experimental data approximation by 3rd degree polynomial, dash-dotted line – approximation by 5th degree polynomial, dot and dashed line – approximation by 7th degree polynomial, solid line – approximation by 11th degree polynomial.

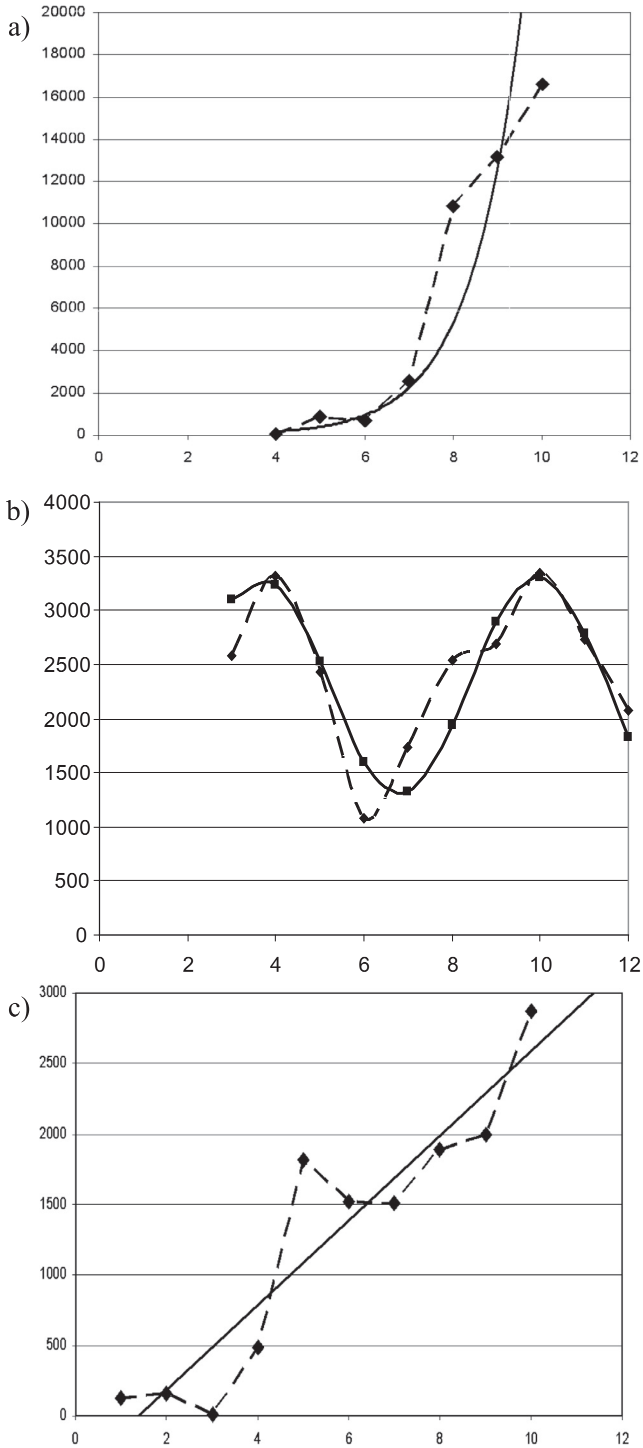


**Fig. 6.** Approximation of phytoplankton mass change processes, the average value for two reservoirs, horizontal – serial number of the month; vertical – phytoplankton biomass, mgm/dm$^3$; dotted line – experimental study findings; solid line – approximating curve; $R$ – correlation coefficient between two schedules; (a) blue-green algae, $m_f = 5.2542e^{0.866N_m}$ $R^2 = 0.9033$, (b) diatoms, $m = 1000\sin(N_m+3.2)+ +2300$, $R^2 = 0.75$, (c) green algae, $m_f = 300.96N_m - 416.78$, $R^2 = 0.869$.

## 4. Research and modeling of phytoplankton development processes in reservoirs

The developed computerized system was used to measure the geometrical parameters, determine the quantity and biomass, and identify phytoplankton by species in reservoirs of Teteriv River used for water supply in Zhytomyr (Ukraine).

The conducted research of phytoplankton indicate the cyclical changes in the geometric parameters, quantity and biomass of phytoplankton in reservoirs of Teteriv River, which is characteristic of water with limited water exchange. Throughout the vegetative period, diatoms are predominating, and in the second half of summer, they are gradually being replaced by blue-green algae (Fig. 4).

The results of identification by phytoplankton composition is as follows: blue-green predominating (56%), diatoms (26%) and green (16%) phytoplankton algae.

Let's consider the example of statistical modeling of blue-green algae development processes in Denyshi reservoir and Vidsichne water intake at Teteriv river by mean values obtained during three years for these two reservoirs.

The first modeling method was to build the statistical mathematical models. The coefficients of the polynomial (Table 2), approximating the experimental data, were determined as follows:

$$m_f = b_o + \sum_{i=1}^{k} b_i N_m^i$$

where $m_f$ is the weight or number of phytoplankton, $b_i$ is polynomial coefficients, $k$ is the polynomial degree, $N_m$ is the number of the month.

5th degree polynomial clearly reflects the development pace of the geometric parameters and mass of diatoms, blue-green and green algae during the year.

Fig. 5 shows an approximation of the masse values based on the example of blue-green algae development.

The second method of modeling the phytoplankton parameter and biomass changes consisted when selecting the type of approximating curve and calculating the curve coefficients ($a_i$, $b_i$, $c_i$) so that the approximating curve was the most consistent with experimental data for many years. To study the processes of blue-green algae development, their mass was approximated by exponential (Fig. 6a) for diatoms, by sinusoid (Fig. 6b) for green algae, by linear curve (Fig. 6c). All approximation reflect the development trend of these types of phytoplankton pretty well.

Drinking water supplied to consumers in their homes should be safe and comply with sanitary and epidemiological requirements. This is achieved through regulation of a range of parameters (organoleptic, chemical, radiological, microbiological, etc.) that must meet current requirements of sanitary legislation and be complied with by water supplier that takes water from household use water bodies [7,8]. Hygienic regulation is based on determination of limit values of content of harmful substances, phytoplankton and its byproducts in water bodies, which do not adversely affect humans and animals.

Geometric parameters of phytoplankton, its quantity, species composition and mass, obtained by a computerized system for measuring geometric parameters of phytoplankton are used by water supplier to calculate integrated indicators of phytoplankton development in water bodies and to monitor condition of water bodies.

Construction of mathematical models and relationships describing processes of change in parameters and species composition of phytoplankton allows us to assess the current condition of water bodies, to determine the effect of various factors on phytoplankton developmental processes, water pollution by its byproducts and hygienic condition of water bodies. Information obtained by a computerized system makes it possible to predict development of phytoplankton and take precautions against intensive development of phytoplankton, as well as to purify drinking water in accordance with the current indicators of water condition.

## 5. Conclusions

A computerized system to measure the geometric parameters, biomass and identify the phytoplankton. This system has an enhanced functionality, improved accuracy and speed compared to the existing measurement means. The video images of water samples obtained from reservoirs and placed in the microscope with a digital camcorder are used for measurements.

The accuracy of measuring the phytoplankton instance linear dimensions is NMT ± 1.0 mm (subject to $400^{\times}$ zoom in and the video image size of 640 × 480 discrete points), the time of measuring the geometrical parameters in one sample is 5 s, which is sufficient to meet the challenges of monitoring the ecological status of water bodies. The functionality of analysis, storage and display of measurement data on phytoplankton parameters was enhanced.

Phytoplankton in Denyshi reservoir and Vidsichne water intake is presented by diatomic, green, blue-green, euglena, gold and dinophyte algae. Both reservoirs are generally prevailed by blue-green (56%), diatoms (26%) and green (16%) algae. Throughout the year, there are some changes in the intensity of reproduction of some phytoplankton forms, which are characterized by active development of diatoms in the spring and autumn months (April-June and October-December), blue-green algae in summer and autumn (late July-early November) and green algae from April to early December.

The obtained experimental data on quantity, biomass and geometric parameters and their identified features are summarized in the form of linear and nonlinear statistical mathematical models of phytoplankton change processes parameters. These models can be the basis for predicting the ecological status of water bodies used for household purposes and development of practical measures to improve the water supply.

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