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DETERMINING THE DISTRIBUTION AREA OF ODOR, TASTE, AND OTHER POLLUTING SUBSTANCES IN THE TBILISI RESERVOIR

Khatiashvili Elizbar[1], Tsivtsivadze Nodar[1], Bregvadze Giorgi[1], Laghidze Lamzira[1], Ivanov Giorgi[1], Motsonelidze Nargizi[1], Paichadze Nino[1], Jorbenadze Natalia[2]

[1]Ivane Javakhishvili Tbilisi State University, I. Chavchavadze Ave., 3, Tbilisi, 0179, Georgia
[2]Nice University (France)

Abstract
Difficulties arising from the presence of different types of odors and tastes in water supply represent one of the most difficult problems to solve. There is no unified view on the issues of their origin, spread mechanism, and decontamination. When the water has an unpleasant taste, smell, or color, the consumer suspects that the water is unfit for consumption, even if the water is not contaminated with substances dangerous to health. In the presented article calculation method of polluted row water distribution in so called Tbilisi Sea (reservoir) is discussed. Characteristics of the smell and taste of water are conventionally divided into three categories:
a) of natural origin – which is found most often and their removal is associated with significant difficulties;
b) chlorophenol-type odors produced during chlorination;
c) of the results of industrial-economic waste waters' discharge into the reservoir.
Due to the determination of the last two groups, the methods of combating them are known and easy to implement.

Keywords: odor, taste, pollution, substances, turbulence.

Introduction

The main goal of the presented research was to improve the quality of Tbilisi reservoir water, primarily according to organoleptic (smell, taste, color) indicators, under the conditions of maintaining the performance of the main facilities at an appropriate level.

Odors of natural origin, usually similar to earth, mold, swamp and fish, are the results of biochemical processes and are caused by substances produced by the metabolism of bacteria, actinomycetes, fungi, algae, and higher vegetation. The development of these organisms is facilitated by the constant pollution of water bodies, in particular by phosphorus and nitrogen compounds (fertilizers, pesticides from agriculture, poly-phosphates included in detergents, etc.) As the water ages, the petroleum products in the water develop a musty odor, which can increase significantly when the water is chlorinated [1].

General Part

It has been pointed out more than once that the strong smell of earth in water is due to the soil microorganisms in it – actinomycetes or ray-like fungi, which can also exist in water, but more often they settle on algae. When the concentration of actinomycetes is 10 pieces/1 ml, the smell is practically not felt, but when the concentration of actinomycetes is 50 pieces/1 ml of water a smell is difficult to

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remove. Actinomycetes produce various chemical substances and metabolites during their activity: amines, aldehydes, organic acids, phenols, essential oil compounds, ammonia, sulfur-containing substances, etc. Romano and Zafferman isolated a yellow-brown substance with an unpleasant odor from Streptomyces griseoliuteus. Erber and Lechevalier obtained this substance geozimin in pure form and determined its structure. Dougherty and his colleagues during a strong explosion of mold smell from actinomycetes in the river Cedar (Iowa) have isolated a substance with a smell – mucidone. Medsfer isolated 2-exohydroxy-2-methylbornene, a substance with a strong camphor odor, from ray fungi [1].

The smell and taste of many algae are associated with the “blooming” period and carry grassy, fishy, smoky, and aromatic odors (Anabena, Aphanizomenon, Peridinium, Malozira, Flagillaria, Cyclotella, Pandorina, etc.).

In addition to the odors listed above, algae emit sulfurous odors: dimethylsulfide, n-butyl mercaptan, isobutyl mercaptan, isopropyl mercaptan, and others (Enteromnorpha, Intestinamismanaben species, Microcytis, Oscilatoria). At low concentrations, the smell of dimethyl disulfide is similar to the smell of fish [1].

Below are some odor-causing organisms and the substances that cause this odor.

Table 1. Odor-causing phytoplankton

Name	**Smell**
Volvox	fish
Straurastrum	Musty
Anabaen	Musty
Pandorina	fish
Spirogura	Musty

The distribution of the above-mentioned substances from the coast to the depth of the reservoir is caused by various mechanisms:

1) as a result of molecular diffusion;
2) under the influence of turbulent diffusion and dispersion processes [2, 3];
3) convective (direct wave and drift currents, incoming currents) as a result of transfer [3, 4].

Turbulent and dispersive transport processes are caused by both wind and waves, as well as currents entering the reservoir. During the prevailing winds directed along the shore (which is usually the case for reservoirs located in valleys), the over-shore flow is triggered, in such a case, impurities spread in the direction normal to the shore under the influence of the transverse coefficient of turbulent and molecular diffusions.

The convective-diffusion equations of mass transfer of i-type impurities (in particular, odor and taste), when the destruction of impurities obeys first-order kinetic reactions, are written in the following form:

$$\frac{\partial C_i}{\partial t}+\frac{\partial C_i V_j}{\partial x_j}=\frac{\partial}{\partial x_j}\left(D_j\frac{\partial C_i}{\partial x_j}\right)-k_i C_i \qquad (1)$$

where j=1, 2, 3. Is the concentration of C_i - i impurity; V_j - flow rate components; D_j - diffusion coefficient; k_i - the coefficient of destruction of i substance; k_iC_i - represents the reduction in impurity concentration caused by various processes (adsorption, consumption by various organisms, chemical reactions, sedimentation, etc.), although more often k is defined as the total value of the reduction

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caused by these joint factors and is determined based on experimental and natural studies. Such an approach is used below.

Since the concentration of impurities is small and has no significant influence on the structure of the differential equation of fluid motion, they are written in the usual (Navier-Stokes) form [4].

For turbulent motion, the quantities included in the equation can be imagined as follows:

$$V_x = \overline{V}_x + V'_x;\quad V_y = \overline{V}_y + V'_y;\quad V_z = \overline{V}_z + V'_z;\quad C = \overline{C} + C' \qquad (2)$$

Taking (2) into account and following the Reynolds averaging procedure, we obtain the equation for the transfer of impurities by the turbulent flow in the following form:

$$\frac{\partial C}{\partial t} + V_x\frac{\partial C}{\partial x} + V_y\frac{\partial C}{\partial y} + V_z\frac{\partial C}{\partial z} = \frac{\partial}{\partial x}\left(D_{xsr}\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_{ysr}\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D_{zsr}\frac{\partial C}{\partial z}\right) - kC \qquad (3)$$

Where D_{ifull} are the full exponents of the diffusion coefficient and $D_{ifull} = D_{imol.} + D_{itur.}$; $D_{imol.}$ - molecular, and $D_{itur.}$ - turbulent diffusion coefficients ($i = 1,2,3$), while $D_{itur.}$ has the following equations:

$$-D_{xtur.}\frac{\partial\overline{C}}{\partial x} = \overline{V'_x C'};\quad -D_{ytur.}\frac{\partial\overline{C}}{\partial y} = \overline{V'_y C'};\quad -D_{ztur.}\frac{\partial\overline{C}}{\partial z} = \overline{V'_z C'}.$$

Equation (3) can be reduced to a one-dimensional form for most practically important tasks (it is in such cases that there is a place for the processes under consideration).

As a result of using the Boussinesc procedure and if we take into account the continuity equation of fluid motion, we will have a one-dimensional equation of convective and turbulent-molecular diffusion transfer of impurities (after a series of transformations) in the following form

$$\frac{\partial C}{\partial t} + V_x\frac{\partial C}{\partial x} = \frac{\partial}{\partial x}\left(D^*_{sr.}\frac{\partial C}{\partial x}\right) + \left(k + \sum_i \frac{q_i}{w_i}\right)C \qquad (4)$$

Where, q_i - is the inflow or outflow of impurities from bounding surfaces; w_i the flow area; D^*_{full} - is equal to:

$$D^*_{full} = D_{xmol.} + D_{xtur.} = D_{xmol.} + D_{xtur.} + \left(D_y\right)_{xtur.} + \left(D_z\right)_{xtur.} \qquad (5)$$

Here, $\left(D_y\right)_{xtur.}$ and $\left(D_z\right)_{xtur.}$ represents the transverse and vertical diffusion coefficients along the x axis which is directed normally towards the shore.

In addition, formula (4) does not take into account $D_{ymol.}$ and $D_{zmol.}$, because the corresponding flows do not influence the current processes. w - is the area of lateral flows inflow and outflow. In the (4) formula, the $\left(Cq\right)$ face members represent the convective and diffusive flow of impurities from the lateral and horizontal boundaries k, - the coefficient of destruction.

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In our case, both the convective and diffusion flow of impurities entering and leaving along the y coordinate (shore) does not affect the change in the concentration of impurities along the axis (direction normal to the shore), so they can be neglected, for the existing situation (algae spread to the free surface) the flux of impurities is equal to zero for the surface as well. Taking into account this circumstance and due to the fact that the x axis neglect of convective transport with respect to the z axis is allowed (due to scarcity), we get the equation for the diffusion of odors, tastes, and other polluting substances from the coastal zone (algae spreading zone):

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} - C\frac{q_{zdif.}}{w_1} - kC ,$$

where, D_x is given by the (5) formula, and the vertical diffusion $z = H_1$ for the surface is taken into account by the member $-C\frac{q_{zdif.}}{w_1}$, or if we note $\frac{q_{zdif.}}{w_1} = k_1$; where k_1 is the intensity of the impurity diffusion flux, we will have

$$\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} - C\left(k + k_1\right) \qquad (6)$$

Let's solve equation (6) with the following boundary and initial conditions (in addition, we assume that due to its smallness $L \approx 100 \div 150$ m for the area under consideration, the terms of destruction and outflow are very small $k = 0.02 \div 0.5$ in 1/day-night for most polluting substances):

Boundary condition

$$C_{x=0} = C\left(0,t\right) = \tilde{C}_0 \qquad (7)$$

(equal flow of impurities in the initial section), initial condition

$$C_{t=0} = f\left(x\right) = \begin{cases} 0, & 0 < x < x_1 \\ C_0, & x_1 < x < x_2 \\ 0, & x > x_2 \end{cases} \qquad (8)$$

Thus, we proceed to the solution of equation (6) under conditions (7) and (8). First of all, let's get the solution of formula (6) for the conditions of an infinite reservoir. In such a case, only the initial condition is applied to the search function [5]:

$$C\big|_{t=0} = f\left(x\right) \qquad (9)$$

where, $f\left(x\right)$ - is defined as an integer on the axis. This kind of problem is Cauchy's problem.

Let's transform formula (6) by introducing a new $\tau = D_x t$ variable. We transform $C = \bar{C}e^{-(K+K_1)t}$ in advance, we have

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$$\frac{\partial \overline{C}}{\partial \tau} = \frac{\partial^2 \overline{C}}{\partial x^2} \qquad (10)$$

Let's use the Fourier method, which consists in the separation of variables, to find the solution in the form of a $X(x)\cdot T(\tau)$ function. Inserting it into (10) gives us the differential equations:

$$\frac{T'(\tau)}{T(\tau)} = M \text{ and } \frac{X''(x)}{X(x)} = M \qquad (11)$$

whose private solution will be written as follows:

$$C = (\alpha \cos \lambda x + \beta \sin \lambda x) e^{-\lambda^2 \tau} \qquad (12)$$

where α , β - are any constants, λ - also denotes any number on which the family of private solutions of equation (10) depends.

For the solution of (6) under the conditions of an infinite aquifer, we obtain through the Fourier integral:

$$C(x,\tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} d\lambda \int_{-\infty}^{\infty} f(\xi) \cos \lambda (x-\xi) e^{-\lambda^2 \tau} d\xi \qquad (13)$$

which satisfies the initial (9) condition as well.

If we transform the variable $\lambda = \frac{\sigma}{\sqrt{\tau}}$ and introduce the notation $\frac{x-\xi}{\sqrt{\tau}} = w$, while recalling that $\tau = Dt$, we get:

$$C(x,\tau) = \frac{1}{2\sqrt{D\pi t}} \int_{-\infty}^{\infty} f(\xi) e^{-\frac{(x-\xi)^2}{4Dt}} d\xi \qquad (14)$$

Now, if we consider the spread of the impurity from the shore in the direction of the Tbilisi Sea depth along Ox axis and meet the boundary and initial conditions of (7) and (8), and if we continue the $f(x)$ function on the negative half-axis in an even form, which gives us solutions for the positive half-axis, after a series of transformations we get:

$$C(x,t) = \tilde{C}_0 \left\{ 1 - \varphi\left(\frac{x}{2\sqrt{(D_m + D_d)t}} \right) \right\} + \frac{C_0}{2} \left\{ 2\varphi\left(\frac{x}{2\sqrt{(D_m + D_d)t}} \right) - \varphi\left(\frac{x-\ell}{2\sqrt{(D_m + D_d)t}} \right) - \varphi\left(\frac{x+\ell}{2\sqrt{(D_m + D_d)t}} \right) \right\} \qquad (15)$$

where, φ - represents the Laplace function and we get that $x_1 = 0$; $x_2 = \ell$

Let's calculate the values of the concentrations for the Ghrmaghele station for the most severe situation.

The coefficient of turbulent diffusion (its transverse coefficient) is equal to $D_{tur.} \approx 0.7 \cdot 10^{-2}$ m²/s $D_{mol.} \approx 10^{-10} \div 10^{-12}$ m²/s.

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Calculations produce the strongest smelling phytoplankton (actinomycetes), which can be smelled even at very low mg/L concentrations. The approximate grading of the smell in such a case is as follows: 1 point - $C_1 = 10^{-8} \div 10^{-6}$ mg/l; 2 points - $C_2 = 10^{-5} \div 10^{-3}$ mg/l; 3 points - $C_3 = 10^{-2}$ mg/l; 4 points - $C_4 = 10^{-1}$ mg/l; 5 points - $C_5 = 0.2 \div 0.3$ mg/l.

Calculations in the direction of the Ox axis (along the shore normal). We take 40,000 s = 11 hours as a unit of time, i.e. Approximately the period when the active cycle of odor emission will be observed.

$\tilde{C}_0$ = 0.5÷0.7 mg/l (maximum release); C_0 = 0.1 mg/l in algae strip ℓ =15 m; then x_1=0 – shore; x_2≈15 m – the last cross-section of the algae spreading.

1. x =30 m, then

$$\varphi\left(\frac{x}{2\sqrt{(D_m + D_d)t}}\right) = \varphi\left(\frac{30}{2\sqrt{(0.7\cdot 10^{-2} + 10^{-1})t}}\right) = 0.79;$$

$$\varphi\left(\frac{x-\ell}{2\sqrt{Dt}}\right) = \varphi\left(\frac{15}{33.6}\right) = 0.47; \quad \varphi\left(\frac{x+\ell}{2\sqrt{Dt}}\right) = \varphi\left(\frac{45}{33.6}\right) = 0.94$$

$$C_{30}(x,1) = C\left(30.4\cdot 10^{-4}\right) = 0.7\left[1-0.79\right] + 0.05\left(2\cdot 0.79 - 0.47 - 0.94\right) = 0.155 \text{ mg/l.}$$

2. x =50 m

$C_{50} = 0.7\cdot 0.04 + 0.0035 = 0.03$ mg/l, concentration is falling down till 3 point.

3. x =70 m; $C_{70} = 0.0038$ mg/l.

So at a distance of 70 meters from the shore, the concentration of odorous substances in the surface layers drops from 0.7 mg/l (odor – more than 5 points) to $3.8\cdot 10^{-3}$ mg/l, i.e. up to 2-3 points.

In the depth of water, the concentration of odorous substances in the direction of the z axis decreases due to the reduction of turbulent diffusion. In such a case, the concentration decreases exponentially $C_\tau = C_{zed.}\cdot e^{-\frac{2z}{kH}}$, where k =0.4 is Karman's constant [4,5].

Calculations show that at a distance of 70 meters from the shore, for water intake depths of 5, 10 and 15 meters, we get that the concentration drops from 0.7 mg/l (odor greater than 5 points) to the following value:

$C_{z=5} = 1.1\cdot 10^{-3}$ mg/l – the upper limit of 2 points;

$C_{z=10} = 3\cdot 10^{-4}$ mg/l – intermediate value of 2 points;

$C_{z=15} = 8.7\cdot 10^{-5}$ mg/l – approaching the upper limit of ≈1 point.

The water depth here reaches 22-23 meters. It is clear that the concentrations of substances with odors decrease even more when water is taken near the bottom, but the processes of decomposition of benthic bottom organic compounds become intense near the bottom, the concentrations of dissolved oxygen sharply decrease, as a result, water quality indicators deteriorate.

The depth distribution of temperature and dissolved oxygen concentration was determined for the aquaria surrounding the pumping stations of Ghrmaghele and Samgori. The results are presented in the table based on the calculations and the analysis of the depth distribution of temperature and dissolved

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oxygen concentrations, we determine that the arrangement of water intake is not favorable either in approaching the free surface or the bottom.

The optimal descent for water intake for the Avshniani pumping station is ≈15÷17 meters, the distance from the shore is ≈70 meters (Figure 1).

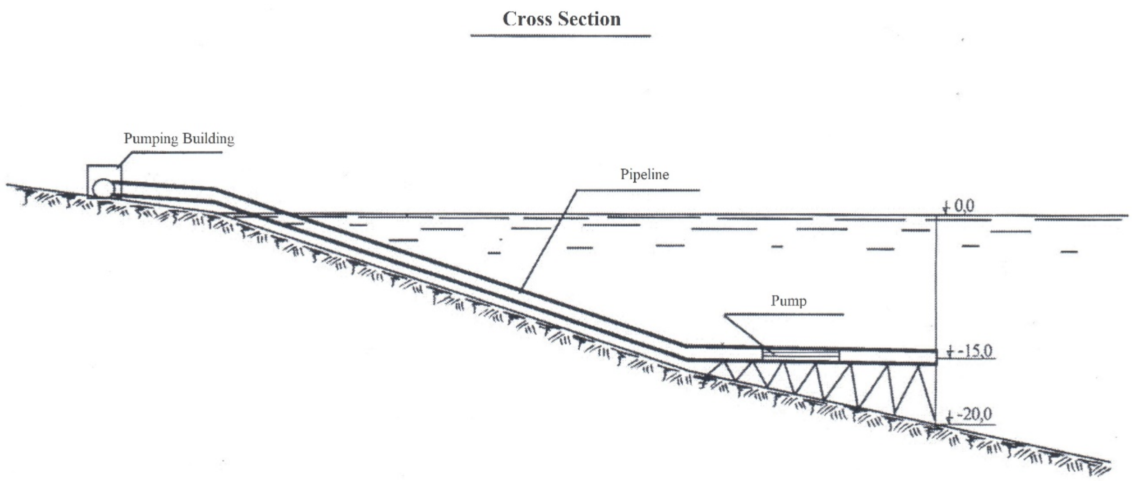

Figure 1. Schematic drawing of water intake

Table 2. Changes in Tbilisi sea water temperature and dissolved oxygen concentrations according to depth for Ghrmaghele and Samgori pumping stations

Depth H m	IV 2006				VII 2006				IX 2006			
	Ghrmaghele		Samgori		Ghrmaghele		Samgori		Ghrmaghele		Samgori	
	t^0	O_2	t^0	O_2	t^0	O_2	t^0	O_2	t^0	O_2	t^0	O_2
0	9.0	12.34	9.3	11.48	21.9	7.5	22.2	9.2	19.2	9.8	-	-
5	8,8	11.4	9.0	11.0	20.5	7.2	21.0	8.5	18.9	9.5	-	-
10	8,2	10.3	8.4	10.06	19.0	6.9	19.1	8.4	16.1	9.1	-	-
15	8,1	9.5	8.0	9.2	17.3	7.0	17.5	7.8	16.0	8.2	-	-
20	7,8	8.17	8.0	8.0	14.1	6.3	13.8	6.5	15.4	6.4	-	-
25	-	5.5	-	7.2	14.0	4.9	13.5	4.4	14.0	4.2	-	-

Conclusion

According to the carried out researches, during the last 20 years, was much increased the indicators of biological pollution, of the water body of Tbilisi reservoir, in the result of phytoplankton and zooplankton number increment, besides of elevation of macrophyte algae' distribution. This was caused due to constant change of biogenic elements, including organic nitrogenous and phosphorous compounds, which are decisive for the development of phyto and zooplankton. Additionally favorable physical and chemical conditions were created, by the construction of Zhinvali reservoir, the regulation of the Aragvi River flow in the area of the main structure, which led to its speed reduction and the water level stabilization in Tbilisi reservoir etc.

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It should be mentioned that the hydro-biological observation data obtained in various services appeared are not only of insufficient value, but even the existing individual observations are too superficial and unprofessional, they are literally useless. So it became necessary to conduct full-fledged observations.

As it was told above, in recent years, the deterioration of water quality, mainly according to organoleptic indicators has increased. Although the Tbilisi Sea has not turned into a eutrophic type of water reservoir, but for a certain period when algae were spread (mainly in summer and early autumn periods), in some cases drinking water could not meet the requirements for them. The need to develop measures to prevent events from developing in such a way is on the agenda. Because of this, a full cycle of necessary hydrobiological observations and analyses (on phyto and zooplankton, macrophyte algae, and fish fauna) was performed.

Based on numerous studies conducted both by us and abroad, such measures and recommendations have been developed that will slow down and, with proper efforts, prevent the processes of eutrophication of the reservoir.

Based on the calculations made with the relations obtained from the solution of the diffusion and dispersive transport equation of impurities, as well as taking into account the change of background parameters with depth (with increasing depth, the content of dissolved oxygen decreases, as a result, water quality deteriorates, this indicator drops significantly near the bottom), a selection of water intake points was developed that it will improve and prevent the deterioration of organoleptic parameters of drinking water in the near future. New optimal location and parameters of water intake points: distance from the coastline ≈70÷100 m, optimal water intake depth 15÷18 m, etc. In this case, the smell decreases from 5 points to ≈1.2 points. As a result of which organoleptic characteristic of raw water is a little bit improved. So after the disinfection smell and taste of drinking water become acceptable.

Recommendations

In case of a new arrangement of water intake points, it is necessary to install a new type of submersible pump and creation of a pneumatic curtain belt (one or two rows) around the ends of the pipes at water intake points. Calculation of the parameters of the pneumatic curtain and the compressor station. The use of a pneumatic curtain protects water intake pipes from getting in algae and ichthyofauna. At the same time, intensive aeration of water takes place in this zone, which significantly improves water quality, as a result, odor and other organoleptic characteristics decrease (see the article by E. Khatiashvili and co-authors published in the same collection). Fish are also stopped, besides, odor-causing bacteria and other pathogenic bacteria are destroyed, due to which the organoleptic indicators of water are improved. By carrying out such a complex event, a high quality of organoleptic indicators will be ensured in the nearest period (8-10 years).

It is advisable, step by step, depending on the possibility, to make a transition to the treatment of raw water with sodium hypochlorite, which is actually safe, does not produce toxic compounds, its efficiency is higher than chlorination, and which is safe to transport. It should be noted that several countries are introducing this method.

One of the most important biologically harmless means of destroying phytoplankton is the breeding of plankton-eating fish, namely white carp (white carp is much more effective than other plankton-feeding fish: mirror carp, carp, thick-fronted carp, black carp, especially in destroying blue-green algae).

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In order to prevent the increase of pollution and to be able to reverse the processes, it is necessary to:

1. To create or adapt prognostic relations, on the basis of which, taking into account the growth of economic and demographic indicators of the region, the values of polluting loads that will come to the Tbilisi reservoir from the Aragvi, Zhinvali, Sioni and Samgori water basins will be calculated, in order to take appropriate measures to prevent pollution (cleaning facilities near industrial enterprise facilities arrangement, decontamination of agricultural runoff water, cleaning and sewerage of household runoff, etc.). For the research system, on the basis of the predictive mathematical model, which reflects the quantitative change of phyto, zooplankton and ichthyofauna, appropriate measures should be taken to regulate their development.

2. Taking into account the changed conditions, sanitary protection zones of the main buildings should be developed, all possible measures should be taken to fulfill the requirements of the existing and subsequently developed sanitary protection zones.

3. Based on the available data and forecast calculations, the issues of stability of the system of differential equations describing the hydrological system under study should be identified in order not to allow more deviations than expected during the evolutionary development of the system.

4. Continuous monitoring and control for the water quality coming from the Aragvi River, Zhinvali, Sioni and Samgori reservoirs, also over the pollution of the environment should be carried out. Hydraulic, hydro chemical, hydro biological and microbiological services corresponding to modern requirements should be established with the monitoring service.

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