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CONTRIBUTION TO THE PROBLEM OF FORECASTING THE MINERAL CONTENT AND CHEMICAL COMPOSITION OF RESERVOIR WATER

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This article examines the problem of forecasting the mineral content and chemical composition of reservoir water, the problem of the magnitude of calculation errors when using various forecasting methods and the tasks facing the forecasting of the chemical composition of reservoir water.

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CONTRIBUTION TO THE PROBLEM OF FORECASTING THE MINERAL CONTENT AND CHEMICAL COMPOSITION OF RESERVOIR WATER

Novocherkassk GIDROKHIMICHESKIYE MATERIALY in Russian Vol 45, 1967 pp 89-106

/Article by M. I. Kriventsov, Novocherkassk Institute of Chemical Hydrology/

/Text/ This article examines the problem of forecasting the mineral content and chemical composition of reservoir water, the problem of the magnitude of calculation errors when using various forecasting methods and the tasks facing the forecasting of the chemical composition of reservoir water.

Reservoir construction development in our country and the use of this water for industrial and home water supplies have made it necessary to calculate the expected mineral content and chemical composition of the water of these newly constructed and existing reservoirs.

N. M. Bochkov of VNII VODGEO /All-Union Scientific Research Institute of Water Supply, Sewer Systems, Hydraulic Engineering Structures, and Engineering Hydrogeology/ first became involved with the problems of forecasting the mineral content of reservoir water during the construction of industrial and drinking water reservoirs in the Donbass /1-3/. A number of authors subsequently worked on improving N. M. Bochkov's methods and developing new forecasting methods. Below we will examine the history of the development of this problem and the problem of the magnitude of calculation errors when using various forecasting methods as well as the problems facing the forecasting of reservoir water chemical composition.

N. M. Bochkov /based on salt and water balance equations/ has suggested a calculating formula which looks like this in our symbols:

$$M_{к}=\frac{M_{н}V_{н}+M_{пр}V_{пр}-M_{ст}V_{ст}}{V_{н}+V_{пр}-V_{ст}-V_{исп}}, \qquad (1)$$

where M_K is the expected water mineral content at the end of the calculation period; M_H, $M_{\Pi P}$ and M_{CT} are the average mineral content of reservoir water at the beginning of the calculation period; the weighted water mineral content of all types of water intake into and expenditure from the reservoir; V_H, $V_{\Pi P}$ and V_{CT} are the water volumes in the reservoir at the beginning of the calculation period, all types of flow into it and out of it, except for evaporation, during the calculation period; $V_{HCП}$ is the water loss through evaporation from the reservoir's surface during the calculation period.

All of the values on the right side of the formula, except M_{CT}, can be calculated quite accurately by studying physicogeographic conditions of the basin and region of the reservoir, the hydrochemistry and hydrology of the river which will feed the planned or is feeding the existing reservoir, and the project's water management calculations.

The value of M_{CT} was the most difficult to determine. Therefore, N. M. Bochkov suggested the following approximate value for calculating it based on the functional dependence of M_{CT} on M_H and $M_{\Pi P}$:

$$M_{\text{ст}} = \frac{M_{\text{н}} V_{\text{н}} + M_{\text{пр}} V_{\text{пр}}}{V_{\text{н}} + V_{\text{пр}}}. \qquad (2)$$

G. I. Popov[4] feels that M_{CT} will be changed during the calculation period from M_H to M_K, if it is assumed that the intake and reservoir water is fully mixed. He assumes that

$$M_{\text{ст}} = \frac{M_{\text{н}} + M_{\text{к}}}{2}. \qquad (3)$$

O. A. Alekin[5, pp 24-26; 6, pp 222-226], P. P. Voronkov[7-9], Ya. F. Pleshkov[10], A. V. Chibov[11] and for the long-term regulation storage period, including the years when flood waters were disposed through the dam, V. A. Baranov and N. M. Bochkov[12], use the value M_{CT} suggested by G. I. Popov and also when calculating according to formula (1).

After introducing formula (3) and the simplest transformations into it, formula (1) looks like

$$M_{\text{к}} = \frac{M_{\text{н}} V_{\text{н}} + M_{\text{пр}} V_{\text{пр}} - 0{,}5 M_{\text{н}} V_{\text{ст}}}{V_{\text{н}} + V_{\text{пр}} - 0{,}5 V_{\text{ст}} - V_{\text{исп}}}. \qquad (4)$$

Some authors divide the flow volume ($V_{\Pi P}$) into its components: V_P - flow from the river, $V_Б$ - intake from the side flows of the reservoir and the run-off from its drainage system, $V_Г$ - subsoil flow, $V_{атм}$ - rainfall intake on the reservoir's surface, $V_{Л.Т}$ - water intake during ice thawing in the reservoir, from V_{CT} they educe $V_{Л.О}$ - the water expended on ice formation. Its corresponding mineral content equates to these water volumes: M_P, $M_Б$, $M_Г$, $M_{атм}$, $M_{Л.Т}$ and $M_{Л.О}$.

When substituting these values in formula (4), it looks like this:

$$M_{\text{к}} = \frac{M_{\text{н}}V_{\text{н}} + M_{\text{р}}V_{\text{р}} + M_{\text{б}}V_{\text{б}} + M_{\text{г}}V_{\text{г}} + M_{\text{атм}}V_{\text{атм}} + M_{\text{д.т}}V_{\text{д.т}} - M_{\text{д.о}}V_{\text{д.о}} - 0,5M_{\text{н}}V_{\text{ст}}}{V_{\text{н}} + V_{\text{р}} + V_{\text{б}} + V_{\text{г}} + V_{\text{атм}} + V_{\text{д.т}} - V_{\text{д.о}} - 0,5V_{\text{ст}} - V_{\text{исп}}}. \quad (5)$$

M. I. Kriventsov, K. G. Lazarev and N. G. Fesenko [13] in forecasting the mineral content of the Kuybyshev reservoir, accepted a value for M_{CT} equal to $\frac{M_H V_H + M_{\Pi P} V_{\Pi P}}{V_H + V_{\Pi P} - V_{HCT}}$. As M. I. Kriventsov [14] had earlier pointed out, with the value of M_{CT} calculated as M_K (the average water mineral content of the entire reservoir at the end of the calculation period) it becomes equal to M_{CT}, which cannot be correct.

M. V. Tovbin, A. N. Almazov, M. B. Fel'dman and Yu. G. Maystrenko [15, p 40] in their forecast of the water mineral content of the Kakhovskiy reservoir, used the formula $M_K = \frac{M_H V_\Pi + M_{\Pi P} V_{\Pi P} - M_{CT} V_{CT}}{V_H + V_{\Pi P} - V_{CT} - V_{HCП} - V_{Д.О}}$, and they accepted M_K or M_H for M_{CT}. The divergence between the results obtained with the various values of M_{CT}, according to their data, did not exceed 3.1 percent. They made their final calculation with $M_{CT} = M_K$. It is impossible to acknowledge the correctness of either method.

Analyzing formula (4), M. I. Kriventsov showed that if the volume of drainage from the reservoir is more than double the volume of water in the reservoir at the beginning of the calculation period, then using a greater magnitude for the ratio of the average water mineral content of the reservoir at the beginning of the calculation period to the average water mineral content of the flow during the calculation period, it is possible to obtain a negative quantity for M_K.

O. A. Aleksin [6, p 226] had earlier pointed out that the smaller the term of the calculating period, the more accurate the calculation. P. P. Voronkov [9] had even earlier suggested that when using formula (4) and (5), one should use such calculation periods when the discharged water volume does not exceed by much the doubled water volume in the reservoirs at the beginning of the calculation period.

Ya. F. Pleshkov [10], S. N. Kritskiy and M. F. Menkel' [16] and A. P. Braslavskiy [17] have proposed more accurate calculation formulas. These formulas have been derived by the authors from differential equations of salt and water balances under the following conditions: 1) the absence of salt sediments in the reservoir and their entering and leaving through the air, 2) for the calculation period the mineral content of the intake and the degree of all components of the reservoir's water balance are constant, 3) water is promptly and fully mixed in the reservoir. The formulas of the first three authors have not found usage because they are too complex for calculation purposes. A. P. Braslavskiy compiled auxiliary tables for his formulas which have significantly simplified calculations. The author has achieved an even greater calculation simplicity in his second work [18] where, having modified the formulas somewhat, he replaced the auxiliary tables with nomograms.

For the clear water period, A. P. Braslavskiy's formula looks like this in our symbols:

$$M_{к} = M_{н} + \left(M_{пр}\frac{V_{пр}}{V_{пр} - V_{исп} + V_{атм}} - M_{н}\right)B, \qquad (6)$$

where $B = 1 - \left(\frac{V_{н}}{V_{к}}\right)^{1 + \frac{\frac{V_{ст}}{V_{к}}}{1 - \frac{V_{н}}{V_{к}}}}$

He suggested the following formula for the freezing period:

$$M_{к} = M + \left(M_{пр}\frac{V_{пр}}{V_{пр} - (1-a)V_{л.о}} - M_{н}\right)B, \qquad (7)$$

where $B = 1 - \left(\frac{V_{н}}{V_{к}}\right)^{1 + \frac{\frac{V_{ст} + aV_{л.о}}{V_{к}}}{1 - \frac{V_{н}}{V_{к}}}}$, and a is the ratio of the water mineral content in the ice to the mineral content of the water from which the ice was formed which A. P. Braslavskiy assumes as being equal to 0.2.

The average water mineral content of ice during the winter is calculated with the formula

$$M_{л.ср} = a\left\{M_{н} + M_{пр}\frac{V_{пр}}{V_{пр} - (1-a)V_{л.о}} - M_{н}\left[1 - \frac{B + \frac{V_{н}}{V_{к}} - 1}{\frac{V_{ст} + aV_{л.о}}{V_{к}}}\right]\right\}. \qquad (8)$$

In another work A. P. Braslavskiy [18] proposes a formula for calculating the average mineral content of the drainage water from the reservoir for the calculation period. This formula, somewhat modified by us, looks like this in our symbols:

$$M_{ст} = M_{н} + \left[\frac{V_{пр}}{V_{к}}M_{пр} - \left(1 - \frac{V_{н}}{V_{к}} + \frac{V_{ст}}{V_{к}}\right)M_{н}\right]\frac{\frac{V_{ст}}{V_{к}} - B - \frac{V_{н}}{V_{к}} - 1}{\left(1 - \frac{V_{н}}{V_{к}} + \frac{V_{ст}}{V_{к}}\right)\frac{V_{ст}}{V_{к}}}. \qquad (9)$$

In formula (8) B is equal to B of formula (7), and in formula (9) B is equal to B of formula (6). The value of B for all four formulas is determined by the tables attached to the author's work [17].

In recent years V. A. Baranov and L. N. Popov [19] and V. A. Baranov [20] (VNII VODGEO), having considered that the calculation formulas of the expected water mineral content which have been inferred from the equations of the salt and water balances of a reservoir do not fully correspond to all of the processes taking place in reservoirs and do not take into account all of the factors which determine the ionic composition and mineral content of reservoir water, have suggested that the expected water mineral content should be determined by charts constructed with empirical equations:

$$M_{\kappa}=f\left(\frac{V_1}{V}, M\right)=f(K, M) \quad [19] \text{ и } \pm\Delta M_{\kappa}=f(K') \quad [20].$$

where M_K is the expected water mineral content at the end of the calculation period, V_1 is the volume of water in the reservoir at the end of the calculation period, V is the greatest volume of water in the reservoir during the calculation hydrologic year (from the start of flood-time to the end of the winter low-water period), $M = \frac{M_H V_H + M_{\Pi P} V_{\Pi P}}{V_H + V_{\Pi P}}$, where M_H and V_H are the average mineral content and water volume in the reservoir before the beginning of flood-time, $M_{\Pi P}$ and $V_{\Pi P}$ are the average mineral content and volume of water intake in the reservoir during the calculation hydrologic year, $K = V_1/V$ is the relative capacity coefficient of the reservoir on a calculated date, ΔM_K is the increase in the mineral content of reservoir water when it is at maximum water level during flood-time when compared to the mineral content of the water before flood-time (M_K). $K' = \frac{M_H}{M_{\kappa p B 3}}$, and $M_{\kappa p B 3} = \frac{M_H V_H + M'_{\Pi P} V'_{\Pi P}}{V_H + V'_{\Pi P}}$, where $M'_{\Pi P}$ and $V'_{\Pi P}$ is the average mineral content and volume of intake water in the reservoir during the period from the start of flood-time to the time of maximum water level in the reservoir.

Both of these charts have been constructed on the results of a study of reservoirs mainly in the Donbass, partly in Kazakhstan and other individual USSR reservoirs. Therefore they can be used evidently only for reservoirs close to these in their geographical conditions.

V. A. Baranov and L. N. Popov have proposed a chart for calculating M_K in any period of the hydrological year on the condition that there is no summer rain flooding. With the presence of the latter, the hydrological year should be divided into two parts: from the start of the spring flood-time to the beginning of rain flooding and from the beginning of rain flooding to the start of the next year's spring flood-time.

In this chart the values of the expected mineral content of the water (M_K) have been plotted on the x-axis and the value of K on the y-axis. Additional straight lines located at various distances from the y-axis and at various angles to the x-axis have been laid out on the chart. These straight lines are used to determine M_K with various values for M equal to 250, 500, 750, 1000, 1250, 1750 and 2000 mg/l. The end points of each of the indicated straight lines correspond to the values of the expected mineral content of reservoir water (M_K) presented in the chart which have been plotted on the horizontal coordinates corresponding to the values $K = 1$ and $K = 0$. The positioning of these points has been determined with the author's original chart.

M мг/л	$M_к$ мг/л		M мг/л	$M_к$ мг/л	
	при K=1	при K=0		при K=1	при K=0
250	330	350	1250	1250	1830
500	460	720	1500	1460	2200
750	700	1090	1750	1720	2590
1000	950	1460	2000	1980	2980

When determining M_K with this chart, first they locate the value of M for the entire hydrological year or, when dividing it into two parts, for each part, then for the end of each calculation period they compute K and at the intersection of the value of K with the sloping straight line corresponding to the value of M, they locate M_K.

V. A. Baranov constructed his chart only for the rising water level period in the reservoir. For the period of a decrease in water storage he uses the chart of V. A. Baranov and L. P. Popov. The ratio between ΔM_K (plotted on the x-axis) for the end of the indicated period and the value of K' (y-axis) is expressed by the straight line whose equation, computed with the author's chart, has the form $\Delta M_K = -1388.8\ K' + 1432.2$. Calculated according to this equation or found through the chart, ΔM_K is summed up algebraically by the average mineral content of reservoir water at the beginning of flood-time--M_H. The value obtained M_K is for the end of the period of a rising water level in the reservoir.

At VNII VODGEO they are continuing to develop charts expressing the empirical ratios of M and the contents of separate ions at the end of the calculation period on those presented above and other values.

Recently I. M. Pavelko and M. N. Tarasov [21] proposed a simplified method of forecasting the mineral content and ion composition of reservoir water. They calculated with formula (5) but they took the data on the mineral content of the individual types of flow water from charts outlining the minimum, maximum and weighted mineral content of river water, according to drainage, for cold and warm periods of the year and also the value of the layer being evaporated from the water surface. The authors forecasted the mineral content of the existing reservoirs by using the charts which they had compiled for Kazakhstan. As a result of this calculation, values were obtained which deviate from those observed in real life by no more than 20-30 percent which is a satisfactory figure for rough estimates.

The authors propose to judge the ion composition of the water of future reservoirs with charts which depict the connection of the ion composition of river water to its mineral content.

All of the methods described for determining the expected chemical composition and mineral content of reservoir water have been based on the assumption that a full and, according to A. P. Braslavskiy, a prompt mixing of the flow water with the reservoir water will occur. In reality a full or close-to-full mixing of water can occur at separate periods of the year only in reservoirs of long-standing regulation, i.e., in reservoirs with slight water change and small in volume (on the order of 20-50 million cubic meters of water in them and having a length to average width ratio of roughly not greater than 3-4).

A full mixing of intake water with the reservoir water is not observed in reservoirs with a large volume of water, elongated in length, with seasonal or yearly control, especially with great water traffic. The full mixing of water both in long-term control reservoirs and in ponds[7, 18, 22-30] is not observed during a period of flooding.

P. P. Voronkov[7] when studying the problem of the expected mineral content of Volga reservoir water, characterized by a great water traffic, considered them as rivers having increased water losses through evaporation and somewhat slow currents. Proceeding from this, he suggested the following formula (in our symbols) for calculating the expected mineral content of the drainage water from them:

$$M_{\text{ст}} = M_{\text{пр}} \frac{V_{\text{пр}}}{V_{\text{пр}} + V_{\text{атм}} - V_{\text{исп}}}, \qquad (10)$$

and for a rough estimate of the mineral content of the water of the Kuybyshev and Volgograd reservoirs, he adopted the mineral content of Volga water near Saratov and Astrakhan'.

M. I. Kriventsov[14, 31] suggested river reservoirs, elongated in length, with seasonal or yearly regulation, should be considered as transformed rivers in which the intake water gradually replaces the water used and discarded through the reservoir's dam water. Moreover it is assumed that the intake water (running) is mixed fully with the water of the side flows of the reservoir, rainfall, soil-supply water and water from melting ice and is not mixed or mixed only partially with the reservoir's replaceable water. Considering that the speed of the water current in a reservoir is slow in comparison with a river's and the running time from one point to another cannot be determined through a correlation of the hydrographs of these points, he developed a method for calculating the running of water into the reservoir from its top to the dam or to another point, taking into account the water loss through evaporation or the ice formation of the running water.

This method of calculation makes it possible to determine the mineral content of reservoir water not only near its dam but at any point of the reservoir if the water volumes at the section from the top to the computed point are known.

In the method under consideration it is assumed that the change of the mineral content of the running water occurs during its journey from the top to the reservoir's dam not only influenced by the water mixed into it but also through the water losses caused by evaporation or ice formation.

In order to calculate the expected mineral content at one or another point of the reservoir according to this method it is necessary: 1) to determine the duration of the running of water in different periods of the year from the top of the reservoir to its computed point, 2) to determine water losses through evaporation and ice formation of the running water in percentages of its volume and 3) to compute the weighted mineral content of the running water after mixing it with other types of intake.

The length of the running period is determined by the time required to fill the entire reservoir or a part of it up to the calculated point with the running water to the volume corresponding to the end of the running period according to water management calculations. Moreover, the volume of all of the other types of inflow mixing with the running water is taken into account, as well as the volume of this same water which is lost through evaporation or ice formation. These losses are computed according to the size of the evaporated water layer or the thickness of the former ice layer and according to the surface area of the water at the section of the reservoir where the running water is for separate ten-day periods or months of the calculation running period.

The calculation of the weighted mineral content of the running water is carried out according to the formula

$$M_{лоб}=\frac{M_p V_p + M_б V_б + M_г V_г + M_{атм} V_{атм} + M_{л.т} V_{л.т} - M_{л.о} V_{л.о}}{V_p + V_б + V_г + V_{атм} + V_{л.т} - V_{л.о}} + S_{см}, \quad (11)$$

where V_p is the volume of river drainage forming the reservoir for the first days of the calculated running period; $V_б$, $V_г$, $V_{атм}$, $V_{л.т}$ and $V_{л.о}$ are the average daily intake of water volume flowing into the reservoir, the soil flow, rainfall, water from melting ice, water used in forming ice, for the computed running period. Moreover, the winter snow and the water from the melting ice are taken into account in the ice-melting periods and are not accounted for in the ice-freezing periods. M_p is the mineral content of the river water forming the reservoir for the first days or the nearest running periods calculated, $M_б$, $M_г$, $M_{атм}$, $M_{л.т}$ and $M_{л.о}$ are the average water mineral contents of the volumes corresponding to it, $S_{см}$ is the amount of salt mixed and extracted by the running water from the reservoir's banks during their flooding and erosion, calculating on one liter of volume of all types of intake during the calculating period of the running.

The mineral content of water at the calculating point $M_{p,T}$ is determined according to the formula

$$M_{p.T} = \frac{M_{\text{зоб}} \cdot 100}{100 - L}, \qquad (12)$$

where L is the percent of water loss through evaporation or ice formation by the running water for the calculating period of the running.

A. A. Zenin and K. G. Lazarev [32], when checking M. I. Kriventsov's method at the Kuybyshev reservoir, computed the period of water running from the top to the dam of the reservoir, dividing the water volume in the reservoir at the start of the calculating period by the daily expenditure of water from the reservoir, taking into account ice formation, ice melting and an increase of evaporation over precipitation. We fully accept this calculating method but it, like calculating the running period suggested by M. I. Kriventsov, must take into account not only the factors indicated by the authors but also the side and soil inflows entering the discarded water which influence the length of the running period.

O. A. Alekin [6], for forecasting the mineral content of water stretched throughout the length of reservoirs with seasonal or yearly regulation, suggested the use of a model of a reservoir's water replacement processes with whose results could be decided the future mineral content of the reservoir water. He considers the division of the reservoir along its length into several sections in accordance with the morphometry of the basin to be a less accurate solution to this problem. Calculating the expected mineral content of the water should be done consecutively along the sections from the upper to the lower ones according to formula (5). Moreover, he recommends, subject to the water interchange (ratio of volume of the inflow water to the volume of the water at the section) and morphometry of the section, mix the old water with the new at a ratio of from 1:3 to 1:1 for the calculating period, which should be equal to the period required for filling the given section.

The forecasting methods outlined were checked by various authors at several existing reservoirs. Thus, P. P. Voronkov [7] found that the calculation error using formula (5) for the expected mineral content of the water of the Rybinsk reservoir for the years 1944-45 and 1946-47 fluctuated from 1.1 to 16 percent compared to that which was actually observed. M. I. Kriventsov [33] compared the results of calculating the mineral content of the water of the Veselovskiy reservoir for the period from 20 July 1955 to 27 July 1956 for its different points according to his proposed method with those actually observed. It turned out that the calculation error fluctuated from 3 to 34 percent, with an average equal to 16 percent.

A. I. Denisova and A. M. Almazov[34] calculated the mineral content of the water of the Kakhovskiy reservoir for the period July 1956 to December 1958 using formula (4); in which M_{CT} was equated to M_K. A comparison of the results of this calculation with values observed in reality showed that the calculation error was equal to 13.4 percent on the average with fluctuations from 0 to 40.5 percent. Unfortunately, with these calculations for M_H of the first period and for that mineral content of the reservoir water observed in reality, they did not take the average mineral contents of its water but rather the mineral content of the water in the pre-dam section which is not the same thing. A. A. Zenin and A. G. Lazarev[32] have checked the results of forecasting the water mineral content of the Kuybyshev reservoir done by P. P. Voronkov[7] with formula (10) and M. I. Kriventsov with the running method and have concluded that if one correctly determines the mineral content of the intake water, then its values found through formula (10), taking into account the running and according to the method of M. I. Kriventsov, will be close to those observed in reality.

V. A. Baranov and L. N. Popov[19] compared the results of calculating the mineral content of the water according to the chart suggested by them with that observed in reality. The calculation error for the reservoirs of the Donbass turned out to be equal to ±10-20 percent.

M. I. Kriventsov, M. V. Petrenko and A. N. Khomenko[35] have checked some of the forecasting methods and their modifications at four existing reservoirs. These same authors, together with D. L. Patina, later checked these same and other forecasting methods at yet another seven existing reservoirs. All of the reservoirs at which the indicated check took place have been enumerated in table 1.

The expected water mineral content was calculated through formula (5) during a calculation for an entire reservoir and for two reservoirs in a calculation done consecutively by sections--according to the formulas of A. P. Braslavskiy, the chart of V. A. Baranov and L. N. Popov, the charts of V. A. Baranov and the running method of M. I. Kriventsov.

During the calculation using formula (5), M_{CT} was equated to $0.25\, M_H + 0.75\, M_K$, $0.5\, M_H + 0.5\, M_K$ and $0.75\, M_H + 0.25\, M_K$. The equation $M_{CT} = 0.25\, M_H + 0.75\, M_K$ can be observed in reservoirs of multi-year regulation during the flooding period when the low mineral-content flood waters pass through the reservoir at the surface levels and are discarded from the reservoir in greater amounts than the more mineralized winter waters of the lower levels.

The equation $M_{CT} = 0.5\, M_H + 0.5\, M_K$ is the generally accepted value $M_{CT} = M_H + M_K/2$ in formula (5).

Regarding the equation $M_{CT} = 0.75\, M_H + 0.25\, M_K$, this can occur with a greater water interchange and a fine vertical intermixing of water in the reservoir when the old water first runs out and the intake water replaces it, also mixing partially with the old water.

The values of the minimum, maximum and average calculation errors for the water mineral content observed in reality have been presented in table 1. This table also gives the characteristics of the reservoirs for water interchange (the ratio of drainage volume and all types of water consumption to the greatest volume of water in the reservoir during the calculated year) and the ratio of the length of the reservoir to its average width during NPG [normal backwater level].

From the results presented in table 1, one can make the following preliminary conclusions:

1. For reservoirs of the Karlovskiy and Ol'khovskiy types (a water volume of 25-27 million cubic meters, a 0.65 water interchange, a ratio of length to width of 12 to 4), the calculation of the expected mineral content of the water ought to be done according to the charts of V. A. Baranov [20], the formulas of A. P. Braslavskiy [17] and formula (5) with $M_{ст} = 0.25 M_{н} + 0.75 M_{к}$. Good results have been obtained for these reservoirs when also using the chart of V. A. Baranov and L. N. Popov [19].

2. For reservoirs of the Tsimlyanskiy type (water volume during NPG of 23.8 cubic kilometers, a 0.8 water interchange, a ratio of the length from the city of Kalach-na-Donu to the dam to the average width of 12), satisfactory and close results have been obtained when calculating according to the method of M. I. Kriventsov, the charts of V. A. Baranov and V. A. Baranov and L. N. Popov and the formulas of A. P. Braslavskiy.

3. The expected mineral content of the water of Veselovskiy type reservoirs (a water volume of about one cubic kilometer, a 0.62 water interchange and a ratio of the length to the average width of 45) should be computed consecutively by sections through formula (5) with $M_{ст} = 0.5 M_{н} + 0.5 M_{к}$ and through the chart of V. A. Baranov and L. N. Popov, and for the separate points of the reservoir through the method of M. I. Kriventsov (see page 96) with the presence of reservoir water volume data from its thinning-out area to its calculated point.

4. For Katta-Kurganskiy type reservoirs (a volume of 590 million cubic meters, a 1.1 water interchange and a ratio of length to width of 1) the best results are obtained using the chart of V. A. Baranov and L. N. Popov. Satisfactory results are also obtained for this reservoir when calculating with formula (5) for all values of $M_{ст}$ and with the formulas of A. P. Braslavskiy.

5. For the Samarkand and Kingirskiy type reservoirs (a volume of 170-350 million cubic meters, a 1.9 water interchange and a ratio of length to average width of 3-18) fine results have been obtained during calculations with formula (5) when $M_{ст} = 0.25 M_{н} + 0.75 M_{к}$ and with the formulas of A. P. Braslavskiy.

Table 1. Maximum Permissible and Average Errors of Calculating M_K for Various Methods and Reservoirs (in Percentages)

№ п/п	Водохранилище	Период расчета	Водообмен для периода расчета	Отношение длины к ширине	По формуле Н. М. Бочкова—Г. И. Попова (5)					
					для водохранилища в целом при					
					$M_{ст} = 0,25\ M_{н} + 0,75\ M_{к}$		$M_{ст} = 0,5\ M_{н} + 0,5\ M_{к}$		$M_{ст} = 0,75\ M_{н} + 0,25\ M_{к}$	
					ошибки					
					предельные	средняя	предельные	средняя	предельные	средняя
1	Новосибирское	1/IX-60—31/VIII-61	7,8	22	0,9—21,7	6,1	0—21,6	6,8	1,3—27,5	7,6
2	Кайрак-Кумское	15/III-58—20/III-59	5,1	7	0,9—23,0	14,3	1,8—20,2	12,2	2,4—16,5	10,9
3	Каховское	1/X-56—30/XI-57	2,9	27	4,4—20,3	10,7	3,6—21,5	10,8	2,4—22,3	10,6
4	Самаркандское	17/IX-59—1/XI-60	1,9	3	3,4—19,4	10,6	4,2—35,2	16,6	4,2—60,8	20,9
5	Кингирское	1/III-58—28/II-59	1,8	18	0,8—4,7	2,3	11,4—15,6	13,6	25,8—32,4	31,2
6	Старо-Крымское	1/IX-58—31/VIII-59	1,2	63	0—7,7	4,0	0,5—8,7	4,6	1,3—9,8	5,4
7	Катта-Курганское	1/VIII-55—31/VIII-56	1,1	1	0,2—24,1	11,0	0,5—23,5	11,2	0,9—22,7	10,2
8	Цимлянское	1/V-59—6/V-60	0,8	12	2,1—28,8	19,2	2,1—29,0	19,6	2,1—30,2	20,1
9	Ольховское	10/VI-55—10/VI-56	0,65	(4)	0—12,1	5,1	0,9—11,4	5,3	1,9—10,7	6,0
10	Веселовское	1/VI-54—1/VI-55	0,62	45	9,4—14,9	12,2	8,8—14,4	11,9	8,2—14,3	11,6
11	Карловское	1/I—31/XII-53	0,64	(12)	3,0—10,0	5,6	3,5—15,8	8,0	3,5—21,8	14,4

Table 1. (cont.)

№ п/п	Водохранилище	Период расчета	Водообмен для периода расчета	Отношение длины к ширине	По формуле Н. М. Бочкова—Г. И. Попова (5)					
					при расчете последовательно по участкам при					
					$M_{ст} = 0,25\ M_н + 0,75\ M_к$		$M_{ст} = 0,5\ M_н + 0,5\ M_к$		$M_{ст} = 0,75\ M_н + 0,25\ M_к$	
					ошибки					
					предельные	средняя	предельные	средняя	предельные	средняя
1	Новосибирское	1/IX-60—31/VIII-61	7,8	22	н/о	н/о	н/о	н/о	н/о	н/о
2	Кайрак-Кумское	15/III-58—20/III-59	5,1	7	н/о	н/о	н/о	н/о	н/о	н/о
3	Каховское	1/X-56—30/XI-57	2,9	27	1,2—31,3	13,0	1,6—33,5	13,1	2,4—34,3	13,3
4	Самаркандское	17/IX-59—1/XI-60	1,9	3	н/о	н/о	н/о	н/о	н/о	н/о
5	Кингирское	1/III-58—28/II-59	1,8	18	н/о	н/о	н/о	н/о	н/о	н/о
6	Старо-Крымское	1/IX-58—31/VIII-59	1,2	63	н/о	н/о	н/о	н/о	н/о	н/о
7	Катта-Курганское	1/VIII-55—31/VIII-56	1,1	1	н/о	н/о	н/о	н/о	н/о	н/о
8	Цимлянское	1/V-59—6/V-60	0,8	12	н/о	н/о	н/о	н/о	н/о	н/о
9	Ольховское	10/VI-55—10/VI-56	0,65	(4)	н/о	н/о	н/о	н/о	н/о	н/о
10	Веселовское	1/VI-54—1/VI-55	0,62	45	н/о	н/о	3,1—13,2	7,1	н/о	н/о
11	Карловское	1/I—31/XII-53	0,64	(12)	н/о	н/о	н/о	н/о	н/о	н/о

Примечание. н/о — не определяли.

Table 1. (cont.)

№ п/п	Водохранилище	Период расчета	Водообмен для периода расчета	Отношение длины к ширине	По формулам А. П. Браславского (6)—(8)		По графику В. А. Баранова и Л. Н. Попова		По графику В. А. Баранова		По методу М. И. Кривенцова	
					ошибки							
					предельные	средняя	предельные	средняя	предельные	средняя	предельные	средняя
1	Новосибирское	1/IX-60—31/VIII-61	7,8	22	0—18,0	6,2	н/о	н/о	н/о	н/о	0—10,4	2,8
2	Кайрак-Кумское	15/III-58—20/III-59	5,1	7	0,4—21,2	12,8	н/о	н/о	н/о	н/о	2,0—42,8	19,9
3	Каховское	1/X-56—30/XI-57	2,9	27	4,4—22,3	12,0	н/о	н/о	н/о	н/о	0,9—15,9	8,1
4	Самаркандское	17/IX-59—1/XI-60	1,9	3	3,4—27,2	13,8	8,6—25,7	16,6	8,6—72,3	27,9	н/о	н/о
5	Кингирское	1/III-58—28/II-59	1,8	18	3,4—8,7	5,5	7,5—13,0	10,4	7,5—32,6	15,4	н/о	н/о
6	Старо-Крымское	1/IX-58—31/VIII-59	1,2	63	1,4—6,0	3,5	0,9—13,9	6,8	0,9—13,9	5,5	6,3	6,3
7	Катта-Курганское	1/VIII-55—31/VIII-56	1,1	1	1,1—26,9	11,6	1,6—22,8	8,6	н/о	н/о	н/о	н/о
8	Цимлянское	1/V-59—6/V-60	0,8	12	2,1—25,6	17,0	8,4—22,5	15,0	8,5—22,5	14,9	15,9	15,9
9	Ольховское	10/VI-55—10/VI-56	0,65	(4)	0,6—12,3	6,8	3,5—21,4	8,9	2,3—21,4	8,2	н/о	н/о
10	Веселовское	1/VI-54—1/VI-55	0,62	45	3,8—14,6	8,8	1,0—10,2	6,6	н/о	н/о	9,2—53,0	31,1
11	Карловское	1/I—31/XII-53	0,64	(12)	1,5—12,6	5,2	0,7—31,8	9,3	0,7—12,5	5,1	н/о	н/о

Примечание. н/о — не определяли.

6. In calculating the expected mineral content of the water for the Staro-krymskiy reservoir (a water volume of 52 million cubic meters, a 1.2 water interchange and a ratio of length to average width of 63) fine results have been obtained with all of the calculation methods (calculating consecutively by sections has not been done because of the absence of data on the water volumes in the reservoir at its separate sectors). The closest values to those observed in reality were obtained with the formulas of A. S. Braslavskiy and with formula (5).

7. For reservoirs of the Kayrak-Kumskiy type (a water volume of 4.16 cubic kilometers, a 5.1 water interchange and a ratio of length to average width of 7) the best results are obtained when calculating according to formula (5) with $M_{CT} = 0.75\ M_{H} + 0.25\ M_{K}$.

8. Reservoirs with significant volumes of water (8.8-18.2 cubic kilometers), with a large water interchange (7.8-2.9) and a large ratio of length to average width (22-27) should be computed with M. I. Kriventsov's method which yields results having the least deviation from the values observed in reality. The work of A. A. Zenin and K. G. Lazarev [32] also confirms this conclusion.

There has been an insignificant number of analyses of their water mineral content for some of the reservoirs examined above. Therefore, when the average observed water mineral contents of these reservoirs, computed with available values to which the mineral contents of the water obtained through these calculations have been compared, it is possible, to some degree, that they deviate from their true values. This probably introduced some distortions into the magnitude of the errors. However, the relative relationships of the errors of the various methods must not change because of this and the conclusions presented above on the applicability of one or another forecasting method remain basically in force.

It is interesting to note that the magnitude of the calculation errors for the Karlovskiy, Ol'khovskiy, Staro-Krymskiy, Kingirskiy and Samarkand reservoirs, obtained through the formulas of A. P. Braslavskiy [18], have proven to be less than or equal to the errors obtained using the charts of V. A. Baranov [20] and V. A. Baranov and L. N. Popov [19]. This indicates that the so-called "intrabasin processes", to which the latter authors attach great importance and which they strive to take into account in their charts and which A. P. Braslavskiy does not take into account in his own formulas, do not have considerable importance in the salt balance of reservoirs. The divergence between the calculated and observed mineral content of reservoir water depends, to a significant degree, on the non-binding of water balances which fluctuate somewhere roughly around 10 percent.

Plans call for the continuation in the future of the work described by accumulating materials on the chemical composition of water and the water balance of the reservoirs and the rivers feeding them. There should be a broadening not only of the number of reservoirs which will make it possible to determine which calculating method is most suitable for which type of reservoir and to define more exactly the forecasting method, but also to calculate for a large number of years the most typical water content year for the year being calculated and its place in a series of previous years.

The conclusions presented above allow us to make a general inference that there is no way a universal forecasting method can exist which is suitable for different reservoirs differing in the degree of drainage regulation, water interchange, and morphology and morphometry. It is fully possible that in the final analysis it will be necessary to develop and use various methods for the separate hydrological periods of the year as they are already doing at VNII VODGEO.

At the same time these conclusions point to the necessity for broadening the work on studying the factors influencing the hydrochemical system of the reservoirs and the chemical composition and mineral content of their water.

The problem concerning the processes for mixing the intake water in the reservoir with its own water has the greatest importance. This question is important not only to improve the forecasting method of the normal ingredients for natural water, but its importance is particularly growing with the always increasing inflow into surface waters, including into reservoirs, of home and industrial effluents.

Unfortunately, the process of mixing intake water with the reservoir water has received little attention. Investigators are more interested in the problems of the flow and stratification of currents in reservoirs (N. M. Bochkov [36], I. Gabriel', K. Symon [37]) and the problems of mixing the waters of two rivers feeding the reservoir (A. A. Zenin [38]). These problems have great importance for forecasting the chemical composition and mineral content of reservoir water at its separate points. However, they still have not found such a quantitative concept which could be used in calculating formulas.

When calculating the expected mineral content of water it is necessary to know in what proportions in different parts of the reservoir and in different periods of the year the intake waters are mixed with the reservoir water. Required are data similar to that obtained by A. M. Almazov [39, pp 195-207] during a study of the mixing of river and sea waters in the Dnepr and other estuary areas, although the stratification and flow of currents are also observed in them.

We presented calculations for the content of the Tsimlyanskiy intake and winter water at the separate hydrochemical stations of the Bol'shoy Sadkovskiy Bay of the Veselovskiy reservoir for the non-icebound period in 1960, the content of intake and old water in the middle of the cross-sections of the Veselovskiy reservoir for the period June-September 1954 and for the Kingirskiy reservoir for the non-icebound period in 1958 and 1959.

The calculation was made with the equations

$$1)\ x = 100 - y \text{ и } 2)\ y = \frac{Cl - Cl_y}{Cl_y - Cl_x} \cdot 100,$$

where x and y are the portion of the flow water volume entering the reservoir for the calculation period and the portion of the winter and old water volume in percentages in the reservoir or bay station under investigation at the end of the calculation period, Cl_x is the weighted content of chloride ion in the flow water during the calculating period, Cl_y is the chloride ion content in the water of the station under study at the start of the calculating period, Cl is the same at the end of the calculating period.

The results of these calculations have been presented in tables 2-4.

Table 2. The Composition of the Water at the Middle of the Cross-sections of the Veselovskiy Reservoir at the End of the Calculating Period (June-September 1954)

№ разреза	Расстояние разреза от плотины, км	Доля старой воды, %	Доля воды притока, %	Объем воды на участке от вершины до разреза, млн. м³
3	73,6	0	100	78,6
4	60,8	1,4	98,6	133
5в	34,3	89,3	10,7	300
6	28,7	95,1	4,9	355
7	18,9	100	0	472

If you consider the flow volume for the calculation period and the water volume at sectors from the top to the calculated station, you will have the following picture.

Table 3. The Composition of the Water at the Mean Stations of the Bol'shoy Sadkovskiy Bay during the Period from 24 April to 15 October 1960 (in Percentages)

№ станции	Расстояние от устья до станции, км	Объем воды на участке, млн. м³	Дата конца расчетного периода					
			15/VI		6/VIII		15/X	
			зимняя вода	вода притока	зимняя вода	вода притока	зимняя вода	вода притока
а	22,6	н/о	0	100	0	100	4,2	95,8
в	21,8	"	10,4	89,6	0	100	7,5	92,5
г	21,2	"	24	76	0 / 1,2	100 / 98,8	6,4	93,6
д	19,2	5,5	87,3	12,7	н/о	н/о	н/о	н/о
е	14,0	н/о	н/о	н/о	5,4	94,6	6,4	93,6
ж	12,0	15,0	н/о	н/о	18,0	82,0	23,5 / 24,7	76,5 / 75,3
з	7,0	45,0	н/о	н/о	51,8	48,2	36,0	64,0
и	3,0	58,9	100	0	67,7	32,3	55,2	44,8
к	0	71,8	100	0	73,9	26,1	66,7	33,3

Table 4. Water Composition at the Median Stations of the Kingirskiy Reservoir

Расстояние от станции до плотины, км	Период расчета		Объем старой воды, %	Объем воды притока, %	Период расчета		Объем старой воды, %	Объем воды притока, %	Период расчета		Объем старой воды, %	Объем воды притока, %
	начало	конец			начало	конец			начало	конец		
	1958 г.				1959 г.				1959 г.			
20,1	27/II	24/IV	не определяли		8/V	10/VI	42,8	57,2	11/VI	15/VIII	не определяли	
8,9	27/II	24/IV	1,5	98,5	8/V	10/VI	93,0	7,0	11/VI	15/VIII	97,8	2,2
3,7	27/II	24/IV	23,1	76,9	8/V	10/VI	96,6	3,4				
0,2	27/II	24/IV	29,3	70,7	8/V	10/VI	100	0				

Some 257 million cubic meters of water entered the top at the Veselovskiy reservoir during the period June-September 1954.

Thus the first sector (from the top to section 3) had a water interchange of about 3, the second sector (top-section 4)--about 2, the third (top-section 5b)--about 1, the fourth (top-section 6)--around 0.7, and the fifth (top-section 7)--around 0.5. With such water interchange magnitudes, full mixing of theold water at thelower limits of the first and second sectors occurred, at the lower limit of the third old water mixed with flow water at a ratio of 9:1, at the lower limit of thefourth--in a ratio of 19:1, and flow water actually did not reach the lower limit of the fifth sector during the four months.

At the Bol'shoy Sadkovskiy Bay 40 million cubic meters of water entered the top from April 24 to June 15, 112 million cubic meters by 6 August, and 223 million cubic meters by 15 October. With such a flow water volume, the water interchange at the separate sectors was approximately equal to the values presented in table 5.

Table 5.

Участок	Водообмен		
	24/IV—15/VI	15/VI—6/VIII	6/VIII—15/X
а—д	7	13	20
а—ж	3	5	7
а—з	0,9	1,6	2
а—и	0,7	1,2	2
а—к	0,6	1,0	1,5

In this case a full mixing of the water at the a-d sector (table 3) did not occur by 15 June, even though the water interchange was two times greater than in the preceding case. The flow water did not reach the lower parts of the a-i and a-k sectors.

In the period from 15 June to 6 August the flow water replaced the bay's winter water not only in its upper parts but also in the entire a-d sector. The old water was replaced, to a significant extent, by the flow water at the d-e and e-zh sectors. At the zh-z, z-i and i-k sectors, the old water and the flow water occurred at the ratios 1:1, 2:1, 3:1.

In the period from 6 August to 15 October was observed the apparent return of theold water to the upper sectors and an increase of its share at these sectors of the bay. Apparently such a sharply different picture of mixing and substitution of old water with flow water in the bay is explained by the following. In October the feeding of Tsimlyanskiy water into the bay noticeably decreased and stopped on 14 October. Not only the Tsimlyanskiy water but also the ground water whose level appreciably increased over the level of the bay water because of the filtration of the water from two feeder canals passing close to the bay participate in feeding the bay. Therefore, the volumes of the separate types of water for 15 October at the upper stations of the bay were somewhat distorted.

One can cite the apparent influence of the ground flow into the bay to explain also the slowing down of the replacement of old water with flow water in the bay compared with its faster replacement an the reservoir.

Regarding the Kingirskiy reservoir, in the period from 27 February to 24 April 1958, 120 million cubic meters of flow water entered it with a water volume in the reservoir at the start of the period of 136 million cubic meters. The water interchange therefore in this period was equal to approximately 0.8.

From 8 May to 10 June 1959, the flow was equal to 16.9 million cubic meters, the volume of water in the reservoir was 171 million cubic meters, and the water interchange was 0.1.

From 11 June to 15 August 1959, the flow was equal to 4.7 million cubic meters, the volume of water in the reservoir was 157 million cubic meters, and the water interchange was 0.03.

Owing to the insignificance of the water interchange, a full replacement of the old water in the Kingirskiy reservoir with flow water did not occur even in the period of the 1958 flood-time. Nevertheless the old water was three-quarters replaced by the flow water. At the end of this period the ratio in the reservoir of old water to flow water was equal to approximately 1:3.

In two other periods when the water interchange was equal to 0.1 and 0.03, the old water predominated in the reservoir, the portion of the flow water only in the top-area part was equal to 57 percent on 10 June, at the remaining stations of the reservoir its portion was appreciably lower than 10 percent.

The accumulation of similar data on the process of mixing the flow water with the reservoir water will permit the establishment of the rules of this process, making it possible to improve the method of forecasting the chemical composition of reservoir water.

Besides studying the process of mixing flow water with reservoir water, it is necessary to pay attention to the study of the interaction of shore (ground) deposits with the reservoir water (the seepage of water into the shores and ground water drainage into them during the decrease of water storage, the deposit on the shores of salt and washout during their flooding, the erosion of their banks and the entry into the reservoir water of chemical compounds from their rocks, etc.) on the factors instrumental to the sedimentation of calcium carbonate from the reservoir water, on the mineral content and composition of ice, on the influence of plants on the chemical composition of the water and on atmospheric and windborne precipitation falling on the water surface of the reservoirs. It is possible that we should also pay attention to the solid particles carried by the wind during dust storms, whose composition has been insufficiently studied and which can in some regions of our country prove to be an influence on the chemical composition of reservoirs.

Of great importance is the study of the dynamics of organic and parasitic substances and the connection of their content throughout the entire reservoir and in its separate parts with the water interchange and morphology of the reservoir. These data make it possible to forecast the content of these substances not only by analogy but also through calculation.

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