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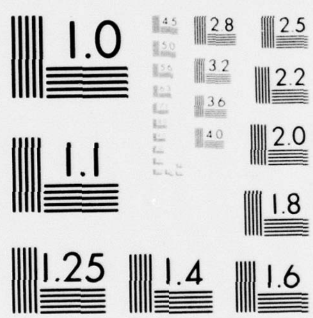

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CONTRIBUTION TO A METHOD FOR CALCULATING THE EXPECTED MINERALIZATION OF RESERVOIR WATER

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CONTRIBUTION TO A METHOD FOR CALCULATING THE EXPECTED MINERALIZATION OF RESERVOIR WATER

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[Article by Candidate of Chemical Sciences M. I. Kriventsov]

[Text] In studies known to us, dealing with calculating the mineralization of reservoir or lake water, N. M. Bochkov [1,2], G. I. Popov [3], O. A. Alekin [4], Ya. F. Pleshkov [5] and P. P. Voronkov[1] [6], the mineralization of reservoir water by the end of a given calculation period was calculated or recommended to be calculated by a formula derived from the equations of water and salt balance of the reservoir or lake. This formula in the notation adopted by us has the following general form:

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

where $V_{\text{н}}$ is the volume of water in the reservoir at the beginning of the calculation period

$W_{\text{пр}}$ is the volume of all kinds of water entering the reservoir, excluding atmospheric precipitation, during this period

$W_{\text{ст}}$ is the volume of water released and lost, except for evaporation losses, from the reservoir during this same period (release of water for irrigation, sluicing, operation of hydroelectric stations, industrial and communal purposes and losses of water in filtration)

$L_{\text{исп}}$ is the excess of water losses in evaporation from the reservoir surface above the amount of atmospheric precipitation during this period

$M_{\text{к}}$ is the average mineralization of water from the entire reservoir at the end of the calculation period

$M_{\text{н}}$, $M_{\text{пр}}$, and $M_{\text{ст}}$ are mean values of the mineralization of water in the corresponding volumes.

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1 In calculating the mineralization of water in the Rybinskoye Reservoir.

Ya. F. Pleshkov [5], based on the reservoir salt balance equation and employing integration, derived more involved formulas for calculating the expected mineralization of reservoir water. But in view of the technical difficulties in employing these formulas in practical calculations, he recommended other unique formulas; after the simplest transformations, these take on the form of Eq (1).

In Eq (1), as pointed out even by G. I. Popov [3], it is hardest to determine M_{CT}. In G. I. Popov's view, if one assume complex mixing of the water in the reservoir, M_{CT} changes during the calculation period from M_H to M_K, and it can be taken as equal to

$$M_{\text{ст}}=\frac{M_{\text{н}}+M_{\text{к}}}{2}.$$

O. A. Alekin [4], P. P. Voronkov [6] and Ya. F. Pleshko [5] also took M_{CT} as the mean of M_H and M_K, without justifying this step.

N. M. Bochkov [1] assumes that M_{CT} is functionally dependent on M_H and M_{np} and adopts

$$M_{\text{ст}}=\frac{V_{\text{н}}M_{\text{н}}+W_{\text{пр}}M_{\text{пр}}}{V_{\text{н}}+W_{\text{пр}}}. \qquad (3)$$

M. I. Kriventsov, K. G. Lazarev and N. G. Fesenko, in calculating the mineralization of water in the Kuybyshev Reservoir, took as M_{CT} the value suggested by N. M. Bochkov, by Eq (3). But, referring to G. I. Popov's comment, that M_{CT} depends not only on M_H and M_{np}, but also on evaporation losses, the following equality was presented:

$$M_{\text{ст}}=\frac{V_{\text{н}}M_{\text{н}}+W_{\text{пр}}M_{\text{пр}}}{V_{\text{н}}+W_{\text{пр}}-L_{\text{исп}}}. \qquad (4)$$

The formula they used in calculating the expected mineralization of water is

$$M_{\text{к}}=\frac{V_{\text{н}}M_{\text{н}}+W_{\text{пр}}M_{\text{пр}}-\dfrac{V_{\text{н}}M_{\text{н}}+W_{\text{пр}}M_{\text{пр}}}{V_{\text{н}}+W_{\text{п}}-L_{\text{исп}}}W_{\text{ст}}}{V_{\text{н}}+W_{\text{пр}}-W_{\text{ст}}-L_{\text{исп}}}. \qquad (5)$$

We easily show that after simplifications this formula becomes

$$M_{\text{к}}=\frac{V_{\text{н}}M_{\text{н}}+W_{\text{пр}}M_{\text{пр}}}{V_{\text{н}}+W_{\text{пр}}-L_{\text{исп}}},$$

that is, M_{CT} becomes equal to M_K, which cannot be assumed correct.

But if one assumes that $M_{CT} = (M_H + M_K)/2$, Eq (1), after transformations, becomes

$$M_{\text{к}}=\frac{M_{\text{н}}V_{\text{н}}+M_{\text{пр}}W_{\text{пр}}-0{,}5M_{\text{н}}W_{\text{ст}}}{V_{\text{н}}+W_{\text{пр}}-0{,}5W_{\text{ст}}-L_{\text{исп}}}. \qquad (6)$$

This formula also does not yield exact results in the calculation of $M_к$, since in some relations of water volumes appearing in the formula, and also $M_н$ and $M_{пр}$, $M_к$ becomes negative.

This is clear from the following.

Let us express $W_{пр}$, $W_{ст}$ and $L_{нсп}$ appearing in Eq (6) by $V_н$, and $M_н$ --by $M_{пр}$, that is, let us assume that $W_{пр} = aV_н$, $W_{ст} = bV_н$, $L_{нсп} = cV_н$ and $M_н = nM_{пр}$.

Then Eq (6) becomes

$$M_к = \frac{nM_{пр}V_н + M_{пр}aV_н - 0,5nM_{пр}bV_н}{V_н + aV_н - bV_н - cV_н}.$$

After transformations we get

$$M_к = \frac{M_{пр}\,[a + n\,(1 - 0,5b)]}{1 + a - b - c}. \qquad (7)$$

Let us examine what value $M_к$ has for different ratios of a, b and n.

If the final volume of water $V_к$ in the reservoir for the particular period is equal to or larger than the initial volume of water $V_н$, that is, $V_к \geq V_н$, and $L_{нсп}$ is a positive value, a is always larger than b. But if $V_к < V_н$ when $L_{нсп}$ is negative, a is always smaller than b.

Let us note, besides, the first, in normal reservoir operations the value of a in most cases is made not larger than b + 0.5, and usually smaller than this value and larger than b; second, in the freshet period, most important in the mineralizing of water in the reservoirs, b can be 2-5, and in some cases, even larger; thirdly, in the freshet period, however, especially for reservoirs of the southern parts of European USSR, the ratio n between $M_н$, which for the spring period characterizes winter water--most highly mineralized, and $M_{пр}$ can be 7-10 or larger.

Hence, let us look at the first case, when $a > b$. Let us assume that b = 2. Then for all n, the expression n(1 - 0.5b) in Eq (7) will equal zero, and Eq (7) becomes

$$M_к = \frac{aM_{пр}}{a - c}.$$

that is, it turns out that for this ratio of $V_н$ and $W_{ст}$, mineralization of water in the reservoir at the beginning of the calculation period $M_н$ does not affect $M_к$ at all. But this contradicts the fact that $M_{ст}$ equals the half-sum $M_н + M_к$, as was assumed in the derivation of Eq (6). Eq (6) thus turns out to be physically meaningless.

But if b is larger than 2, then as n grows larger, for the same a and b, $M_к$ decreases, and with a simultaneous increase in n and b, $M_к$ rapidly reaches zero and then becomes a negative quantity. So, when b = 3, Eq (7) becomes

$$M_{\kappa} = \frac{M_{\pi p}(a - 0,5n)}{a - c - 0,5}.$$

If in this case a equals b + 0.5, that is, 3.5, when n = 7, M_K becomes zero; but if n is larger than 7 or a is smaller than 3.5, M_K becomes a negative quantity.

On the condition a $<$ b, the probability of getting a negative M_K grows, since in this case b and n can be smaller than on the condition a $>$ b.

The possibility of getting zero and negative M_K by Eq (6) shows that it does not correspond to actual processes in reservoirs, and calculating with this formula cannot give us an exact value of M_K .

From the data of P. P. Voronkov [6], calculations of M_K for the Rybinskoye Reservoir for 2 years and different periods of the year gave an error in the results, from -14.1 to +16.0 percent.

The relatively smaller deviations in the calculated M_K from the actual mineralization of water cannot be held as confirming Eq (6).

This only shows that in this case the ratios of V_H , $W_{\pi p}$, W_{CT}, M_H and $M_{\pi p}$ were such that the ratios yielded M_K relatively close to the actual value. But even here large fluctuations in the error point to Eq (6) failing to correspond to processes occurring in the reservoirs.

This is explained not only by the fact that in deriving the formulas, in Eq (1) erroneous values were adopted for M_{CT}, but also by the fact that Eq (1) was set up on the assumption that the water present in, and arriving at the reservoir in the given period was completely mixed. From this assumption, as shown above, G. I. Popov operated [3], by inserting into Eq (1) the value

$$M_{\text{ст}} = \frac{M_{\text{н}} + M_{\text{к}}}{2}.$$

This was also assumed by N. M. Bochkov [1], when he spoke of a functional dependence of M_{CT} on M_H and $M_{\pi p}$. This dependence can exist only if in the reservoir there is mixing of water present in it at the beginning of the calculation period, with water arriving during this same period, and essentially this mixing must occur constantly during the calculation period.

Actually, mixing of water in reservoirs is difficult to expect. This is confirmed by data on the mineralizing of the far from homogeneous water in reservoirs. Thus, from the data of P. P. Voronkov [6], mineralizing of water in the Rybinskoye Reservoir fluctuated in September, 1946, from 90 to 150 mg/liter, and in September, 1947, from 100 to 200 mg/liter. From S. A. Gusinskaya's data [7], the content of chlorine ions in Dneprovskoye Reservoir water varied from its head water to the dam, in August 1934, from 6.06 to 11.20 mg/liter, and in August 1935--from 5.63 to 7.61 mg/liter.

N. M. Bochkov [1] recognized that Eq (1) fails to fit processes in reservoirs. He inserts into Eq (1) a corrective factor--the regeneration coefficient to bring M_K closer to the actually observed mineralizing of water in a reservoir. N. M. Bochkov calculated this coefficient from the ratio between mean mineralizing of water determined by analysis in an actual reservoir and M_K derived from Eq (1). This procedure cannot, obviously, be suitable for reservoirs newly built.

But even if it is admitted that M_K calculated by Eq (1) is close to the actual mineralization of water of a reservoir, it still will not be of practical value for major reservoirs, of the Kuybyshevskoye and Stalingradskoye type. In Eq (1) M_K is the average mineralization of reservoir water at the close of the period in question, that is, it is a nonspecific quantity, which cannot actually be related to any specific point in the reservoir. But when significant amounts of water is used from large reservoirs to irrigation and inundation, we must know the expected mineralization of water at particular reservoir points--at the dam and the headworks of canals.

Eq (1) cannot satisfy this requirement. This is another reason barring us from using Eq (1) in calculating the mineralizing of water in large reservoirs.

Considering the high flow rate and the consequent low hydrochemical inertness of the Kuybyshevskoye and Stalingradskoye reservoirs, P. P. Voronkov [6], in an approximate calculation of the mineralizing of water in these reservoirs, applied a simplified formula of calculation, of the form

$$M_{ст} = M_{пр} \frac{W_{пр}}{W_{пр} - L_{исп}}. \qquad (8)$$

This formula was derived by him from these equations of salt and water balance:

$$M_{пр} W_{пр} - M_{ст} W_{ст} = 0, W_{ст} = W_{пр} - L_{исп}.$$

P. P. Voronkov calculated the mean-seasonal and mean-annual mineralizing of water in the Kuybyshevskoye and Stalingradskoye reservoirs, but here no account was taken of the effect of changes in the mineralization of water in the Kuybyshevskoye Reservoir on mineralizing in the Stalingradskoye Reservoir. Besides, he did not consider that the flow rate in both reservoirs will be smaller than in the Volga River before it was controlled. This is pointed to by S. A. Gusinskaya's data [7] on the Dneprovskoye Reservoir. But a change in the flow rate of water in the reservoirs causes a shift in the time of arrival of the highest and smallest mineralization of water in reservoirs compared with the schedules existing for the Volga River before it was controlled. All this reduces the accuracy of the results P. P. Voronkov derived.

The foregoing shows that we need to work out a new way of calculating the expected mineralizing of water in reservoirs.

We suggest a scheme of calculating the mineralization of water for large reservoirs, by which two problems can be solved.

1. Calculating the mineralizing of reservoir water for specific reservoir points located near the reservoir head waters, and at the reservoir dam; but when sufficient data on the mineralizing of water at these points are available, mineralization can be calculated also for intermediate points.

2. Determining the mineralization of water not in certain seasons, but for each month and for spring and fall ten-day periods, to be able to plot the chronograph of water mineralization.

The calculation was founded on these assumptions. It is assumed that a reservoir is a somewhat transformed river and the water entering its head waters gradually displaces--during its damward motion--water from the reservoir by displacing it. Here water arriving in the reservoir is not mixed or is mixed only partially with the water present, while at the same time the reservoir water is completely mixed with the water of tributaries entering the reservoir, ground supply water and water forming as ice melts in the reservoir.

In these instances, mineralizing of water as it flows from the head waters to the reservoir dam changes owing to these causes:

1. Losses of water by evaporation and ice formation during the time the water travels from the head waters to the dam. From P. P. Voronkov's data [6], the mineralization of ice in the Rybinskoye Reservoir amounts to 20 percent of the mineralization of the water from which the ice was formed. So ice forming causes a rise in the salt concentration in reservoir water and in the evaporation of water from the reservoir surface.

2. Mixing with the water of tributaries, ground supply and water forming as ice thaws in the reservoir.

3. Dissolving of salts accumulating on the surface of the periodically exposed reservoir bed [3].

4. Possible partial mixing with preceding water present.

Therefore, in calculating the mineralizing of water near the reservoir dam, we must know:

a) in how many days at different periods of the river's life will the head waters reach the reservoir dam -- the period of water advance;

a) what percentage of water will be lost in the period of advance in evaporation and the forming of ice in different periods of water advance

c) how changes will occur in the mineralizing of water reaching the reservoir head water at the beginning of the period of advance owing to the mixing with side supply water (tributaries, ground supply and water formed in the thawing of ice) and the dissolving of salts accumulating on the periodically exposed reservoir bed.

As the basis of calculation we take the volume of water arriving at the reservoir from its head water during the day.

The periods of advance are calculated from the first of the above-adopted assumptions: water reaching the head waters of the reservoir from the river gradually displaces, as it moves toward the dam, the water from the reservoir by displacing it. The head water comes to the reservoir in the initial days of the calculated period of advance thus reaches the dam after as many days as is required to fill the reservoir with the total flow with all forms of water during the calculated period of advance. Here, the reservoir filling is assumed to be what happens in the end of the advance period, plus the losses of water from the reservoir during the calculated period of advance, due to filtration and evaporation.

The percentage of water losses in evaporation and the formation of ice during the period of the advance was calculated initially for each ten-day period (in spring or autumn) and each month comprising the period of advance, for the average volume of water in the reservoir and the volume of losses during the same interval of time, and then the resulting values are summed over the entire period of advance.

Calculation of the gradual change in the mineralization of the head water as it moves toward the dam is very involved. Moreover, in most cases there are not enough data. So instead of calculating the gradual change in the mineralizing of water, it is assumed that all forms of water flow into the reservoir not over its entire length, but only in the head water. The mineralizing of water arriving in the reservoir is determined as the mean-weighted arithmetic value of the mineralization of all forms of water, in the volume of their daily flow. Here the mineralizing and volume of water flow from the river to the head water of the reservoir is taken at the initiation of the calculation period of advance, and the means for the calculated period of advance are assumed for all other forms of water.

The data gotten from this calculation let us determine the mineralizing of water by the end of the advance period at the reservoir dam. This value can be gotten from the formula:

$$M_{пл} = \frac{M_{пр} \cdot 100}{100 - L}, \qquad (9)$$

where $M_{пл}$ is the desired mineralization of water at the reservoir dam by the end of the calculated advance period

$M_{пр}$ is the mineralization of water arriving in the reservoir at the start of the advance period

L is the percentage of water loss in evaporation and the formation of ice in the calculated advance period.

The variable $M_{пл}$ characterizes the mineralizing of water at the dam at the end of the period of advance on the assumption that the head waters, in flowing toward the dam, are not mixed with the water already in the reservoir.

In actuality, these forms of water obviously partially mix, but we do not have data on this. When these data are at hand, a correction must be inserted into the expression for $M_{п.в}$.

The assumption made when we calculated the mineralizing of Stalingradskoye Reservoir water, that the water in the calculated period is mixed with 20 percent of the water of the preceding period of advance, only slightly changes $M_{п.в}$.

The entire calculation is made under this scheme.

1. We set up a table of the water-management data we need for the calculation: a) the volume of water in the reservoir at the close of each month, and for the spring and autumn months and at the close of each ten-day period; b) the surface area of the reservoir during these same periods; c) the volume of water losses due to filtration from the reservoir in each month of the year and in each ten-day period, for the spring and autumn months; d) the volume of water released by the reservoir into the canals during these same periods; e) the river flow into the reservoir during these same periods; f) the total flow of water into the reservoir during these same periods; g) the excess of evaporation over precipitation or the thickness of the ice formed during these same periods.

We lay out an example of an arbitrary Table 1, not describing any specific object, to illustrate the calculation method.

2. From data on the excess of the evaporation from a reservoir over the precipitation on its area, ice thickness and the average area of the water surface for each month and ten-day period in the spring and autumn months, we calculate the volume of water losses due to evaporation and the formation of ice in the reservoir. The layer of water involved in forming the ice is calculated from the thickness of ice formed during a given time, assuming the conversion factor to be 0.9, and the fraction of pure water in the ice volume to be 0.8.

An example of the calculation of water losses in evaporation from the reservoir is in Table 2.

3. The duration of head waters advancing to the reservoir dam is calculated--the period of advance. This calculation rests on data from Tables 1 and 2 and the assumptions laid down earlier. An example of this calculation is in Table 3.

Calculations of the duration of advance periods are performed in sequence, one after the other, as shown in Table 3, until the close of the cycle of periods, that is, when the end of the last period will be close to the beginning of the first period. If the final days of one period have not arrived for each month and each ten-day period of spring and autumn, the periods of water advance are assumed to be such that the ends of each of them are characterized uniformly the whole year and in the spring and autumn ten-day periods.

Table 1. Main Water-Management Data for Reservoirs

(1) Дата	(2) Объем воды в водохранилище (в км³)	(3) Площадь зеркала водохранилища (в км²)	(4) Фильтрация из водохранилища (в км³)	(5) Отдача воды из водохранилища в каналы (в км³)	(6) Сток реки в водохранилище (в км³)	(7) Суммарный сток притоков в водохранилище (в км³)	Превышение испарения над осадками, или толщина образованного льда (в мм)
	(9) на данное число		(10) за предшествующий отрезок времени				(8)
31/III	21,50	2100	—	—	—	—	—
10/IV	22,00	2200	0,066	0,255	2,165	1,120	20
20/IV	22,00	2200	0,066	0,255	10,898	3,250	20
30/IV	22,00	2200	0,066	0,255	11,072	0,400	20
. . . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

Key:

1. Data
2. Volume of water in reservoir (in km^3)
3. Surface area of reservoir (in km^2)
4. Filtration from reservoir (in km^3)
5. Release of reservoir water into canals (in km^3)
6. Flow of river into reservoir (in km^3)
7. Total flow of tributaries into reservoir (in km^3)
8. Excess of evaporation over precipitation, or thickness of ice formed (in mm)
9. for a given date
10. for the preceding time interval

This scheme for calculating the advance periods was adopted by us when we calculated the mineralizing of water in the Stalingradskoye Reservoir. But it is quite admissible to calculate the advance periods separately from each other. The only thing we have to do is to have the final dates of the periods closely enough characterize the entire year and permit plotting of the chronograph of water mineralizing in the reservoir at its dam.

4. The percentage of water losses in evaporation and ice forming from the reservoir during the time the water is advancing from the head waters to the reservoir dam is calculated. An example of this calculation is shown in Table 4.

5. We next calculate the mean mineralization of water arriving in the reservoir, for the initial date of each advance period. This calculation is based on the formula

Table 2. Calculation of Water Losses from a Reservoir Due to Evaporation and Ice Formation

(1) Декада и месяц	(2) Превышение испарения над осадками, или толщина льда		(5) Средняя площадь зеркала водохранилища за декаду или месяц (в км²)	(6) Объем потерь воды на испарение или образование льда за декаду или месяц (в км³)
	(3) за месяц (в мм)	(4) за декаду (в мм)		
1—10/IV . . .	—	20	$\frac{2100+2200}{2}=2150$	2150×0,00002 =0,043
11—20/IV . . .	60	20	2200	2200×0,00002 =0,044
21—30/IV . . .	—	20	2200	2200×0,00002 =0,044
. . . .	. . .	. . .	. . .	. . .
1—31/XII . .	300×0,9×0,8= =216 мм	—	$\frac{1700+1600}{2}=1650$	1650×0,000216=0,356

Key:

1. Ten-day period and month
2. Excess of evaporation over precipitation, or ice thickness
3. in a month (in mm)
4. in a ten-day period (in mm)
5. Average surface area of reservoir in a ten-day period or in a month (in km^2)
6. Volume of water losses owing to evaporation or ice forming in a ten-day period or in a month (in km^3)

$$M_{пр} = \frac{M_в W_в + M_б W_б + M_г W_г + M_л W_{лт}}{W_в + W_б + W_г + W_{лт}} + M_c, \qquad (10)$$

where $M_{пр}$ is the mean mineralization of all forms of water arriving at the reservoir

$M_в$ is the mineralization of water coming from the river into the reservoir head waters by the start of the calculated advance period

$M_б$ is the mean mineralization, for the calculated advance period, of water in the tributaries emptying into the reservoir

$M_г$ is the mean mineralization of ground supply water in the reservoir during this period

$M_л$ is the mean mineralization of water forming when ice melts

M_c is the amount of salt carried by reservoir water and leached from eroded bank soils, per liter of the entire flow into the reservoir during the calculated period

$W_в$ is the flow of the river into the reservoir head waters during the initial days of the calculated period

Table 3. Calculating the Advance Periods of Water Flowing to a Reservoir

(1) № периода	(2) Дата	(3) Объем воды в водохранилище (в км³)	(4) Сумма потерь и отдача воды из водохранилища на данное время			(8) Всего потерь и отдачи воды (в км³)	(9) Суммарный сток воды в водохранилище на данное время (в км³)	(10) Календарные сроки и длительность периода
			(5) на испарение (в км³)	(6) на фильтрацию (в км³)	(7) в каналы (в км³)			
1	31/III	21,50	0,0	0,0	0,0	21,50	0,0	1/IV—25/IV
	10/IV	22,00	0,043	0,066	0,0255	22,364	3,285	!
	20/IV	22,00	0,087	0,132	0,510	22,729	17,433	(25 дней) (11)
	24/IV	22,00	0,105	0,159	0,612	22,876	22,022	
От таяния льда (12) (300·0,9·1650+200·0,9·1600++87·09·1550)·4:10=							0,342 22,364	
	25/IV	22,00	0,109	0,165	0,637	22,911	23,169	
От таяния льда (12)							0,428 23,597	
2	25/IV	22,00	0,0	0,0	0,0	22,00	0,0	26/IV—
	30/IV	22,00	0,022	0,033	0,128	22,183	5,736	
От таяния льда (12)							0,427 6,163	. . .
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	

Key:

1. Period number
2. Date
3. Volume of water in reservoir (in km^3)
4. Total losses and release of water from reservoir in a given period
5. due to evaporation (in km^3)
6. due to filtration (in km^3)
7. into canals (km^3)
8. Total of losses and release of water (in km^3)
9. Total flow of water into reservoir in a given period (in km^3)
10. Calendar periods and duration of advance period
11. (25 days)
12. From ice melting

Table 4. Calculation of Percentage of Water Lost in Evaporation and Ice Formation During the Periods of Water Advance

(1) Период добегания воды	(2) Расчетный период	(3) Средний объем воды в водохранилище	(4) Объем потерь воды на испарение и образование льда	(5) Потери воды	(6) Потери воды за период добегания (в %)
		(7) (в км³)	(7) (в км³)	(8) (в %)	
1	1—10/IV	$\frac{21,5+22,0}{2} = 21,75$	0,043	0,197	
	11—20/IV	22,00	0,044	0,200	0,497
	21—25/IV	22,00	$\frac{0,044 \cdot 5}{10} = 0,022$	0,100	
2	. . .	. . .	. . .	. . .	

Key:

1. Period of water advance
2. Calculated period
3. Mean volume of water in reservoir
4. Volume of water losses in evaporation and ice formation
5. Water losses
6. Losses of water during advance period (in percent)
7. (in km^3)
8. (in percent)

$W_Г$ is the mean daily flow of ground water during this period
$W_{ЛТ}$ is the volume of water formed when ice melts in the reservoir and mixes with head water as it flows toward the dam.

The value of M_g is taken from the chronograph of water mineralization for the river in the reservoir head water. $M_б$ is calculated as the arithmetic mean from available values of mineralization of water in the tributaries for the calculated period of advance or parts of this water, if the mineralization of tributary water changes markedly during the calculated period of advance. When sufficient data are at hand, $M_б$ must be calculated as the weighted arithmetic mean.

Mineralization of ground supply water $M_Г$ is determined from the data on the mineralization of ground water in the area of the reservoir and is checked from the ratio of the increments of ionic and water flows over the reservoir section during the winter months [8].

The mean mineralization of water forming as ice melts is taken as 20 percent of the arithmetic mean from the value for the mineralization of water during ice forming in the head water and at the dam of the reservoir.

The value $M_г$ can be calculated only roughly, from data on the content of water-soluble compounds in the soils of the reservoir bottom, from the amount of water evaporating from the soil surface and from the soil surface area. The reservoir regime is taken into account--the periods of exposure and flooding of the bottom and the volume of water in the reservoir.

The daily river flow in the initial days of the advance period $W_в$ is taken from the hydrograph of the river at the point located in the reservoir head water.

$W_в$ is calculated from the increase in the water flow of the river before it was regulated over the reservoir section, as done by B. V. Polyakov [8]. A model hydrograph of the ground flow was plotted with allowance for fluctuations in the water level in the reservoir. This variable, like $M_г$, can be calculated only roughly. But for large reservoirs with high flow rate, of the Stalingradskoye Reservoir type, the relative value of the ground supply is small, and the error in the calculation results caused by the approximate calculation of $M_г$ and $W_г$ will be small.

The daily flow of water into the reservoir can be determined in two ways. If the uniform tributary flow occurs during an extension of the total calculated advance period, $W_б$ is equal to the quotient from dividing the flow of all tributaries by the number of days in the period. But if the uniform flow occurs not during the entire period of water advance, the volume of tributary water mixing with the head water is determined from the formula

$$W_б = \frac{A \cdot W_c}{Б \cdot B}, \qquad (11)$$

where $W_б$ is the volume of water in the tributary flow mixing with the head water as it flows toward the reservoir dam
- W_c is the flow of tributaries debouching along the entire reservoir length during the part of the advance period in question
- A is the duration (in days) of the uniform flow of the tributaries arriving during the advance period in question
- $Б$ is the duration of the calculated period in days
- B is the duration (in days) of the uniform flow from the tributaries.

Let us clarify this formula. We assume that the flow from tributaries debouch- into the reservoir occurs during the second and third ten-day periods of April; and from the mineralizing of water for the different ten-day periods the flow differs, but is uniform through each ten-day period. The flow of all tributaries into the reservoir during the second ten-day period is W_c^1 and during the third ten-day period--W_c^2. The calculated advance period runs from 1 to 25 April and is 25 days. Under these conditions, the head water arriving at the reservoir on 1 April will be mixed not with the entire mean-daily flow of tributaries arriving at the reservoir during the second and third ten-day periods in April, but only with part of each of them. This assumption is grounded on the following. If the uniform flow of the tributaries into the reservoir occurred during the entire calculated period, the head water--flowing toward the dam--would be mixed each day with 1/25 of the mean-daily flow of all tributaries, and during the entire calculated advance period would be mixed with the mean-daily flow of all tributaries, for the given period.

In our example, when the uniform flow of the tributaries occurs in the calculated period only in the second and half of the third ten-day period, the head water moves during the second ten-day period over 10/25 of its path and--therefore--mixes only with 10/25 of the mean-daily flow of all the tributaries, equal to $W_c^1/10$, that is, with a volume that is $(10 \cdot W_c^1)/25 \cdot 10$, or $(A \cdot W_c^1)/Б \cdot B$. During the third ten-day period, the head water--from this same calculation--mixes with the volume of the flow from the tributaries, equal to $(5 \cdot W_c^2)/(25 \cdot 10)$, or $(A \cdot W_c^2)/Б \cdot B$.

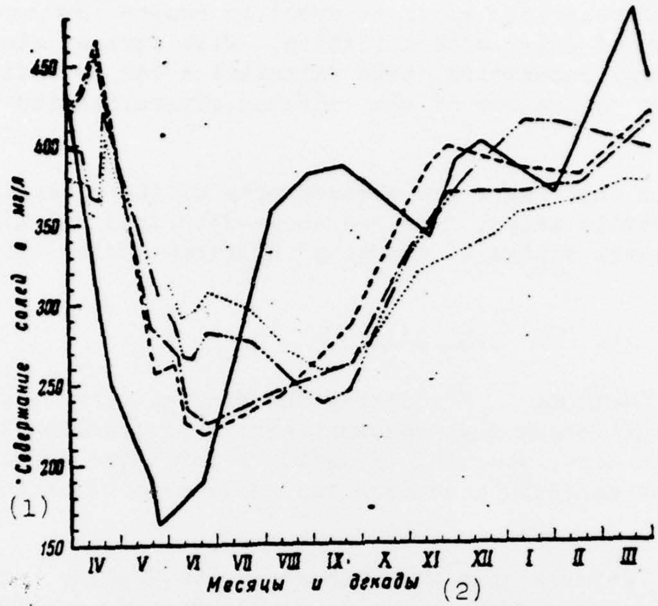
The variable $W_{лт}$ is determined from the appropriately altered Eq (11):

$$W_{лт} = \frac{A \cdot W_л}{Б \cdot B},$$

where A is the number of days in the calculated period, when the ice melts
is the duration of the calculated period in days
B is the ice melting period in the reservoir, in days
$W_л$ is the volume of water from all the ice melting in the reservoir.

If all the data for calculating the mineralizing of water entering the reservoir are not available, this value must be equated to the mineralizing of the water in the river before its control at the dam location in the beginning of the advance period, but with allowance for the time needed for the water to advance from the head water to the reservoir dam. For example, the advance period of 1-25 April was calculated. A comparison of the hydrographs of the river before its control at the head water and dam of the future reservoir showed that water advances in the beginning of the calculated period for 3 days. Therefore, we must take the mineralizing of the water by 4 April as $M_{пр}$. The mineralizing of water by this date is roughly equal to its value after mixing of the head water arriving upstream of the reservoir on 1 April, with water from lateral inflow (tributaries, groundwater supply and water from melting ice).

6. From Eq (6) we calculate the mineralizing of water at the reservoir dam at the close of the advance period. If needed, to this variable is added a corrective factor for the mixing of water in the calculated advance period with water from the preceding period.



Legend:

_________ mineralization of water in the Volga River and in the city of Dubovka

mineralization of water at the Stalingradskoye Reservoir dam

--------- in the mean-water-level year in the absence of the mixing of water in the reservoir

_._._._. in the mean-water-level with partial mixing of water in the reservoir

_..._..._ in a low-water-level year, in the absence of water mixing in the reservoir

.... in a low-water-level year, with partial mixing of water in the reservoir

Key:

1. Salt content in mg/liter
2. Months and ten-day periods

7. From the scheme presented, water mineralization at the other reservoir points is calculated. If there are no exact data, the volume of water in the reservoir from its head water to the point in question is determined from the ratio of distances from the reservoir head water to the calculation point and to the dam, and the volume of the entire reservoir; the reservoir is viewed as a cone with a base equal to the area of the wetted part of the dam.

The proposed calculation scheme is far from perfect, but it lets us calculate the mineralization of reservoir water at specific reservoirpoints and in the form of a chronograph of water mineralization. With further study of the water exchange in large reservoirs, this calculation can be refined; this will enable us to get the values of the expected mineralization of water more accurately.

By way of example, in the figure are chronographs of the mineralization of Stalingradskoye Reservoir water, from the above-described calculation scheme based on the water-level status of years and different calculation conditions.

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