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Determination of the siltation volume of riverbed reservoirs

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Annotation
For the Republic of Uzbekistan, assessing the degree of siltation of reservoirs is of paramount importance; it is important to take into account changes in the process of siltation in the past and trends in its future changes when planning and managing water resources. The article presents a methodology for calculating the volume of siltation in riverbed reservoirs located on the territory of the Republic of Uzbekistan. The dependence of the intensity of siltation of riverbed reservoirs on their geographical location and reduced turbidity was obtained. The forecast of siltation of the reservoir was made based on a comparison of design characteristics taking into account the stage of siltation of the reservoir at the time of the estimated time.
Key words: reservoir, solid runoff, reservoir siltation, method for calculating reservoir siltation, reduced turbidity, dead volume, useful volume.

Introduction. Recently important tasks in the world are to improve methods for determining hydrological processes in the upstream of regulatory structures using modern scientific advances, to develop measures to reduce wasteful water losses in them and increase their efficiency. In this regard, special attention is paid to increasing the operational reliability of reservoirs and reducing the degree of their siltation, as well as the development of advanced methods for calculating their useful volume.

Currently, when water shortages are steadily growing every year, in our republic much attention is paid to the construction and modernization of reservoirs in order to meet the demand for water in all sectors of the economy, identify factors influencing the efficient use of existing water resources, prevent water losses and siltation, as well as the implementation of measures to reduce unproductive water losses in reservoirs and increase their efficiency. In this regard, the special attention is paid to increasing the operational reliability of reservoirs and reducing the degree of their siltation, as well as developing improved methods for calculating their useful volumes. Therefore, the development of methods for calculating the volume of siltation in reservoirs and determining the annual solid runoff of the rivers that feed them is the most pressing direction in this area.

The research methodology is based on the analysis of long-term data on siltation of all large (with a capacity of more than 50 million m3) river-bed reservoirs of the Republic of Uzbekistan, which showed that the ratio of the volume of sediment in the dead volume to the total volume of sediment in reservoirs can be described by the equation:

$$K_2 = \frac{W_{з.м.}}{W_{з.о.}} = 0{,}17 + 0{,}13\frac{W_{з.м.}}{W_{м.}} \qquad (1)$$

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there: $W_{з.м.}$ - volume of deposits in dead volume; $W_{з.о}$ - total volume of sediments; $W_{м.}$ - dead volume of the reservoir; К2 - is a coefficient characterized by the ratio of the volume of siltation of a dead reservoir to the total volume of siltation.

Dependence (1) is inconvenient in calculations, since the $W_{з.м.}$ quantity is on both sides of the equation. Therefore, we present equation (1) as:

$$\frac{W_{зм}}{W_{зо}} - 0{,}13\frac{W_{зм}}{W_{м}} = 0{,}17 \;, \quad \text{where} \quad W_{зм}\cdot\left(\frac{1}{W_{зо}} - \frac{0{,}13}{W_{м}}\right) = 0{,}17 \,,$$

and, transforming, we get:

$$\frac{W_{зм}}{W_{м}} = \frac{0{,}17\cdot\dfrac{W_{зо}}{W_{м}}}{1-0{,}13\dfrac{W_{зо}}{W_{м}}} \qquad (2)$$

denoting $\frac{W_{зо}}{W_{м}} = n$, $\frac{W_{зо}}{W_{м}} = \frac{0{,}17\cdot n}{1-0{,}13\cdot n}$, we get

$$K_2 = \frac{0{,}17}{1-0{,}13\cdot n} \qquad (3)$$

The first stage of reservoir siltation (when all sediment brought by the river remains in the reservoir bowl) ends when the dead volume silts up completely and sediment begins to flow into the lower pool. This case corresponds to the equality $W_{зм} = W_{м}$.

Substituting $W_{зм} = W_{м}$ into formula (2), we obtain that $n = 3{,}33$.

From here:

$$K_2 = \frac{0{,}17}{1-0{,}13\cdot n} = \frac{0{,}17}{1-0{,}13\cdot 3{,}33} = 0{,}3$$

In stage II of reservoir siltation, it is assumed that the dead volume is completely silted, and part of the sediment is carried into the lower pool. During field studies, sediments carried into the tailwater are not measured, so their quantity must be determined indirectly. To do this, we extrapolate equation (2), taking $W_{зо} = W_{м} + W_{нб}$, where $W_{нб}$ – is the volume of sediment entering the tailwater.

If we assume that in the second stage of siltation the pattern of siltation is preserved, then we can write:

$$K_2 = \frac{W_{нб}+W_{м}}{W_{зо}} = 0{,}17 + \frac{(W_{нб}+W_{м})}{W_{м}}\cdot 0{,}13$$

after transforming this expression and replacing $\frac{W_{зо}}{W_{м}} = n$, we get:

$$\frac{W_{нб}}{W_{м}} = \frac{0{,}3\cdot n - 1}{1-0{,}13\cdot n} \qquad (4)$$

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The obtained calculated dependencies make it possible to make a complete calculation of siltation of irrigation reservoirs by stages.

Figure 1 shows the graph of the dependence $K_2=f(W_{3M}/W_{3O})$.

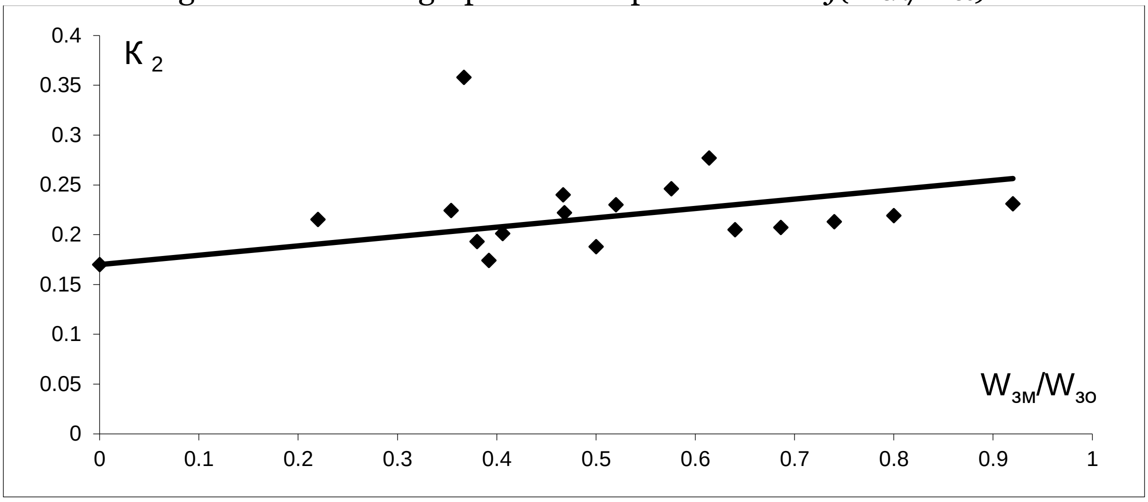

Fig. 1. Dependence graph $K_2=f(W_{3M}/W_{3O})$.

Method for calculating solid flow. During the operation of the reservoir, the level regime changes, and therefore, the conditions affecting the process of siltation of the reservoir change. Based on the range of changes in the channel capacity ratio at the beginning of the calculation period. W_H to the corresponding reservoir capacity at the end of the calculation period. W_K can be judged about the processes occurring in the upper pool.

The service life and regulating capacity of reservoirs during their operation depend on the intensity of siltation, which is characterized by the value of reduced turbidity α. At the same time, the value of the ratio of the total volume of siltation (W_{3O}) to the dead volume, obtained in the process of processing field data on siltation of reservoirs, is W_{3O}/W_M=3,32, which is a criterion that allows us to determine the end of the first stage of siltation.

The reduced turbidity α and the annual reduced solid runoff of the reservoir are determined at known values of the NSL and W_o, where W_o - is the total design capacity of the reservoir:

Find the value:

$$\alpha = \frac{R_\Gamma}{\Delta t} \cdot \frac{2}{W_H + W_K} \qquad (5)$$

there: R_Γ - volume of sediment deposition in the reservoir for the calculation period, million m3/year; Δt - duration of the period, in years.

All these data were plotted on a logarithmic grid and a dependence graph was constructed $\alpha = f(H\Pi Y)$ (Fig. 2). It turned out that all points lie on the curve (or near it), described by the following relationship:

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$$\alpha = \left(\frac{H_{Н}}{НПУ} - 1 \right) \cdot 0,004 \qquad (6)$$

there: $НПУ$ - - normal supported level; Hn=1600; Hн=1600 m - m is the height above which there is practically no sediment (Fig. 2).
Knowing the capacity of the reservoir, the solid flow of the river in the first year of operation is determined:

$$R_{Г} \cdot \Delta t = \alpha \cdot W_{O}$$

Given the duration of the period Δt (in years), we calculate the average capacity of the reservoir:

$$W_{ср} = \frac{W_{Н} + W_{К}}{2}$$

At the beginning of operation, the volume of water in the reservoir is equal to the design one $W_{Н} = W_{0}$.

The total solid river flow entering the reservoir over the period Δt is determined:

$$R_{Г} = \frac{\alpha \cdot W_{ср}}{\Delta t}$$

The remaining reservoir capacity is determined:

$$W_{К} = W_{Н} - R_{Г} \cdot t$$

The resulting dependence for determining solid flow:

$$R_{Г} = \alpha \cdot \frac{W_{Н} + W_{К}}{2} \cdot \frac{1}{\Delta t}$$

recommended only for river-bed reservoirs located in Central Asia. For other territories this relationship should be clarified.
Based on the results of calculating the intensity of siltation of riverbed reservoirs, a dependence graph was constructed $\alpha = f(НПУ)$ (Fig. 2), from which it can be seen that the higher the geographical elevation of the reservoir's FSL, the lower the intensity of siltation, and vice versa, the lower the FSL elevation, the greater the intensity than the design one.

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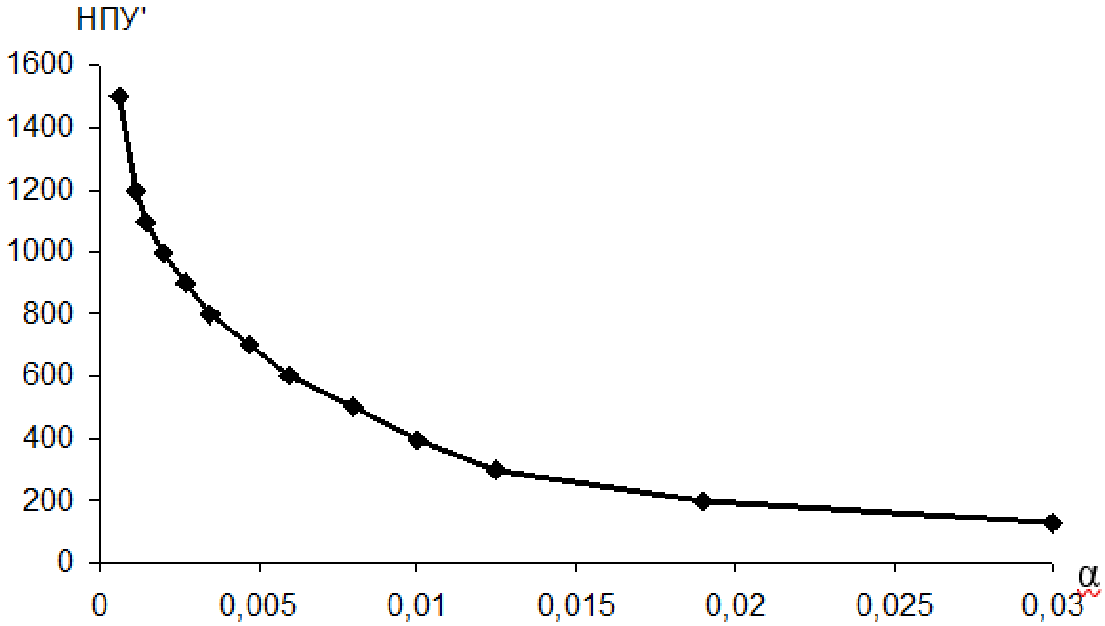

Fig. 2. Dependency graph of $\alpha = f(НПУ)$

Conclusions. Existing methods for calculating siltation in reservoirs have a number of disadvantages. First of all, there is a sharp discrepancy between nature and forecasts for the same initial data due to the lack of a comprehensive assessment of various factors and the lack of uniform principles of approach to solving the problem. The service life and regulating capacity of reservoirs during their operation depend on the intensity of siltation, which is characterized by the value of reduced turbidity.

Comparison of the results of siltation calculations made using the proposed method with actual data on reservoirs showed good convergence.

Unlike methods for calculating solid runoff and siltation volumes by other authors, the proposed method does not require cumbersome additional calculations to determine the initial degree of tail water clarification.

The proposed method for calculating solid river flow makes it possible to more accurately and without cumbersome, time-consuming calculations predict the volume of siltation of riverbed reservoirs and determine the duration of their service life.

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