PAPER • OPEN ACCESS

Determination of reduction of useful volume in water reservoirs due to sedimentation

To cite this article: A Arifjanov *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **614** 012079

IOP Conf. Series: Earth and Environmental Science **614** (2020) 012079 doi:10.1088/1755-1315/614/1/012079

Determination of reduction of useful volume in water reservoirs due to sedimentation

A Arifjanov[1], F Gapparov[2,*], T Apakxujaeva[1], and S Xoshimov[1]

[1]Department of Hydraulics and Hydroinformatics, Tashkent Institute of Irrigation and Agricultural Mechanization Enjineers, 100000 Tashkent, Uzbekistan
[2]Department of Geology and Hydrogeologys, Tashkent Institute of Irrigation and Agricultural Mechanization Enjineers, 100000 Tashkent, Uzbekistan

[*]Email: obi-life@mail.ru

Abstract. To develop a work plan for reliable and efficient use of water reservoirs, an accurate information about the volume of water stored in the reservoir for the safe operation of the reservoir facilities is necessary. The useful water storage capacity of reservoirs has been steadily declining over the years due to the sedimentation coming with the stream.
The article presents a method for determining the continuous change of the reservoir volume during operation due to sedimentation. A calculation method estimating the dynamics of the sediment distribution in the reservoir has been scientifically developed. The proposed calculation method was tested and compared in the field conditions. The analysis of the data collected in the Chimkurgan, Tashkent and South Surkhan water reservoirs under field conditions based on mathematical statistical methods showed a relationship between the relative turbidity and the reservoir depth. A new method of determining the decrease in useful water volume due to sedimentation in reservoirs has been proposed.

1. Introduction

At present, the development of methods for improving the hydraulic efficiency of reservoirs and for predicting hydraulic processes in these reservoirs are a pressing issue. It is therefore important to increase the operational reliability of reservoirs and improve the methods of estimating their useful capacity. In this regard, special attention is paid to the prevention of the reservoir sedimentation, water wastage and reliable operation.

Theoretical basis for the calculation of the useful volume of water reservoirs, their sedimentation levels, and reduction of useful water volumes in reservoirs is reflected in the work of a number of scientists [1-9] and certain positive results have been achieved. Numerous formulae and calculation methods [5, 6, 10, 11] have been developed to analyze the water balance, reduction of useful water volumes and sedimentation in the reservoirs.

Today, despite the numerous research activities in the country in this direction, such issues as change detection assessment in the useful volume of reservoirs, calculation of reservoir sedimentation and development of science-based measures based on these developments are insufficiently studied.

To develop a workplan for reliable and efficient use of water reservoirs, accurate information about the volume of water stored in the reservoir for the safe operation of these facilities is necessary. This volume steadily declines due to the sedimentation during the year-round operation of reservoirs. Millions of cubic meters of sediments can accumulate in reservoirs during a year, as a result of which the estimation of the useful volume of reservoirs is done inaccurately. Therefore, it is necessary to develop a scientific method of calculating the continuous change in the volume of reservoirs during operation and validate it based on observations in the field conditions [1, 12, 13, 14].

To calculate the volume of reservoirs, the water balance components of the reservoirs during the period of operation in previous years, i.e., the sum of incoming and outgoing water and changes in water levels in the last months of these years are used. A number of studies have shown increased reliability of the obtained results of estimating hydraulic processes in a reservoir based on the parameters in the years with design stagnant level (DSL) and the minimum water level close to the dead water level (DWL) [2,15-18]. The dependence of the above-mentioned water levels on the assessment of changes in the volume of the reservoir due to sedimentation in individual reservoirs has been identified in numerous research studies [1, 4, 6, 19-22]. In this paper, the decrease in the useful volume of water due to sedimentation is estimated in relation to changes in the water level.

2. Method

The water balance equation of a reservoir is written in the general form as (1):

$$\sum K - \sum Ч \pm A \pm D = 0, \tag{1}$$

where: $\sum K$ - the amount of water entering the reservoir, $\sum Ч$ - the amount of water leaving the reservoir, A - accumulation; D – sedimentation.

At different stages of construction and operation of the reservoir, the interaction between the individual elements of water exchange may differ. During the period when a reservoir is filled with water, the elements of water exchange change more intensively due to an increase of its volume and surface area. During the operation of the reservoir, a sufficiently strong correlation is formed between the elements of the hydrological cycle, which is characteristic of various reservoirs. It should be noted that the elements of water balance change significantly during this period.

One of the factors influencing the useful volume of a reservoir is the sedimentation. When the reservoir volume is filled with sediments, the technical characteristics of the reservoir deteriorate, large sedimentary silts are delivered into the irrigation canals and culverts, and the reservoir management capacity decreases. The above and other complications make it necessary to predict sedimentation, which negatively affects technical conditions and economic performance of the reservoirs.

The results of research studies conducted in field conditions show that the amount of designed sedimentation drastically differs from the measured amount.

Removing sedimentation from the reservoirs is of great practical and theoretical importance. On the one hand, this will serve to improve the reservoir utilization system, and on the other, the movement of river sediments to the irrigation canals will lead to the colmatation of these canals and further use of mineral-rich fine-size sediment particles as fertilizers.

Based on the work of [1-5], we consider the calculation of reservoir sedimentation in the following order. We use the theorem on the change of kinetic energy to estimate the distribution of the amount of turbidity in a reservoir.

$$\frac{dE}{dl} = F_i - R_x \ , \tag{2}$$

where: $F_i -$ - gravity and Archimedes forces:

$$F_i = -g(\rho_{\text{т}} - \rho V_{\text{т}} n \ sin\alpha \ , \tag{3}$$

$R_x -$ resistance force: $$R_x = \frac{1}{2}\rho V_{\text{т}} n \frac{d\vartheta^2}{dl} \ , \tag{4}$$

Then substituting (3) and (4) into (2):

$$\frac{dG}{dl} = -g(\rho_{\text{т}} - \rho)V_{\text{т}} n \cdot sin\alpha + \frac{1}{2}\rho V_{\text{т}} n \frac{d\vartheta^2}{dl} \ , \tag{5}$$

where: n - amount of solid particles per unit volume; sin α- slope angle of the flow; ρ_{T} ; ρ –solid particles and liquid densities, respectively; V_{T} - solid particle size; g - free fall acceleration; ϑ – average flow rate.

Kinetic energy of the sediment flow is: $E = \frac{2\rho_{\text{T}} V_{\text{T}} \vartheta^2 \cdot n}{3}$, (6)

We place expression (6) into (5), then the change in the kinetic energy of the sediment flow will be as follows:

$$\frac{dE}{dl} = -g(\rho_{\text{T}} - \rho) V_{\text{T}} \frac{3}{2} \frac{E}{\rho_{\text{T}} V_{\text{T}} \vartheta^2} \cdot sin\alpha + \frac{3}{4} \rho V_{\text{T}} \frac{E}{\rho_{\text{T}} V_{\text{T}} \vartheta^2} \frac{d\vartheta^2}{dl} , \quad (7)$$

Expressing the flow rate by consumption is, $= \frac{Q}{\omega}$,

(7) the equation will be as follows:

$$\frac{dE}{dl} = -\frac{3}{2} g \frac{(\rho_{\text{T}} - \rho)}{\rho_{\text{T}}} \frac{E\,\omega^2}{Q^2} \cdot sin\alpha + \frac{3}{4} \frac{\rho}{\rho_{\text{T}}} \frac{Ed(ln\vartheta^2)}{dl} , \quad (8)$$

integrating the equation (8)

$$E = C \cdot exp\left\{-\frac{3g(\rho_{\text{T}} - \rho)}{2\rho_{\text{T}} Q^2} \int_0^l \omega^2 sin\alpha\, dl\right\} exp\left\{\frac{3}{4} \frac{\rho}{\rho_{\text{T}}} \ln \vartheta^2\right\}, \quad (9)$$

determine the integration constant C from the initial conditions. l=0 ; $E = E_0$; and write the equation as follows:

$$E = E_0 \left(\frac{\omega_0}{\omega}\right)^{n_1} exp\left\{-\frac{3g(\rho_{\text{T}} - \rho)}{2\rho_{\text{T}} Q^2} \int_0^z \omega^2 \sin\alpha\, dl\right\}, \quad (10)$$

Based on the research results of [2,14,15,19], we move from the amount of sediment particles to the sediment concentration; the expression (10) will look as follows:

$$\frac{s_i}{s_o} = \left(\frac{\omega_i}{\omega_o}\right)^{n_1} \cdot exp\left\{-\frac{3g(\rho_i - \rho)}{\rho_{\text{T}}\, Q^2} \int_0^l sin\alpha\omega^2 dl\right\} \quad (11)$$

Sediment flow: $P_i = s_i\, Q$; (12)

Sediment volume: $V_i = s_i\, Q \cdot t$; (13)

Observing the flow surface in the section under consideration as a function of depth;

$$\omega_i = f(H_i)\,, \quad (14)$$

In inserting (14) and (13) into (11), we obtain the following expression:

$$\frac{V_i}{V_{\text{MDC}}} = \text{к} \left(\frac{H_i}{H_{\text{MDC}}}\right)^{n_1}, \quad (15)$$

where: H_{mdc} – depth corresponding to the DSL, V_{mdc} –volume of the reservoir corresponding to the DSL, κ and n_1 - coefficients determined during research activities in the field conditions.

The formula (15) expresses the dependence of the relative volume of sediments in the reservoir to the relative water depth.

3. Results and Discussions

The effective use of the above formula (15) requires determination of the quantities of n_1 and k. Analytical determination of the amount of these coefficients is substantially complicated by the variability of the reservoir volume. Therefore, the quantities of n_1 and k can be determined based on field data from the several reservoirs. In particular, field observations in the Chimkurgan, Tashkent and South Surkhan reservoir basins were used in the study (Tables 1). The collected data were processed using the statistical methods and a calculation formula was obtained that expresses the dependence of the relative turbidity volume in the reservoir on the relative water depth in that reservoir (16).

Table 1. Observation data from the Tashkent, Chimkurgan and South Surkhan reservoirs

Water reservoirs	Tashkent	Chimkurgan	Tashkent	Chimkurgan	South Surkhon	Tashkent	Chimkurgan
Depth H, m	2	2	4	4	4	6	6
$H/H_{МДС}$	0.0625	0.076	0.125	0.153	0.154	0.1875	0.229
$\Delta V_H / \Delta V_{МДС}$	0.036	0.044	0.072	0.083	0.055	0.107	0.143
6	8	8	9	9	10	10	11
0.231	0.250	0.305	0.344	0.346	0.3125	0.382	0.423
0.145	0.146	0.212	0.267	0.274	0.196	0.267	0.427

Data in Table 1 and the above expressions allowed developing a formula to determine the decrease in the useful volume of reservoirs located in the riverbed (Figure 1):

$$\frac{\Delta V_H}{\Delta V_{МДС}} = 0{,}95\left(\frac{H}{H_{МДС}}\right)^{1{,}26} \quad (16)$$

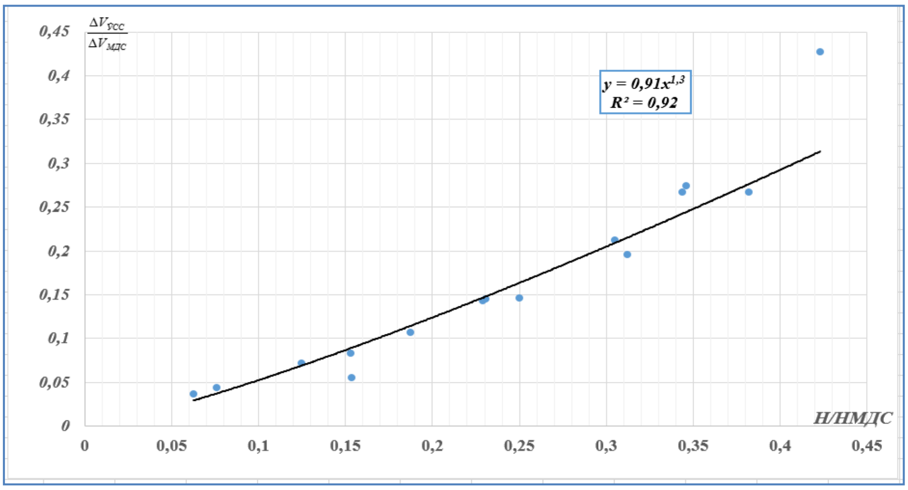

Figure 1. Relative sedimentation volume in a reservoir as a function of the relative water depth in that reservoir

The dependence of the relative sedimentation volume in the reservoir on the relative water depth in that reservoir is shown in Figure 1.
To determine the volume of the water inflow to the Chimkurgan reservoir, data on water consumption in the Kashkadarya River (Figure 2) for all years from the period of its operation (1960) and the average perennial water consumption until 1970 were used.

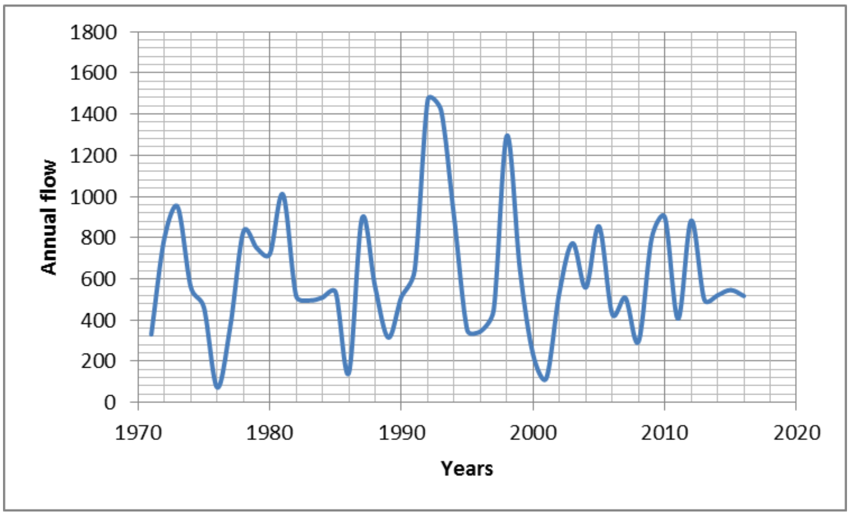

Figure 2. Annual flow in the Kashkadarya River, mln.m^3

The above formulas and based on the data on the volume of water entering the Chimkurgan reservoir allowed determining that the decrease in the volume of the reservoir is due to changes in the volume of water in the Kashkadarya River from 1980 to 2018.

4. Conclusions

Observations, historical data as well as the calculations according to the formula (16) allow estimating the indicators in terms of the sediment amounts in the reservoirs.
The amount of sediments in the Tashkent reservoir is 2 times higher than according to the design estimations. The sediment amounts in the Jizzakh reservoir are 8 times higher than in the design estimations. Research results and observation data of the Kuyimozor reservoir showed that the sediment amount in this reservoir is 2.9 times higher than designed, and in the Chimkurgan reservoir 3 times higher. According to the results of studies and measurements carried out at the Pachkamar reservoir, the sedimentation rate in the reservoir is 3.7 times higher. Measurements in 1975, 1985 and 2002 in the South Surkhan reservoir revealed that the sedimentation is 1.3 times higher than designed.
The average designed estimation of sedimentation in the Kattakurgan reservoir is 0.7 mln. m^3 per year. Studies show that this was only the case in 1975-1986. Recent observations in the reservoir showed an increase in the sedimentation in the reservoir, i.e., 202.5 mln. m^3, which is an average of 3.31 mln. m^3 per year during this year, and is 4.7 times higher than designed.
It can be concluded that the main reasons for the fact that the sedimentation rates are higher that in the designed estimation and during the actual operation of the water reservoirs are that both the design estimations and actual operation do not include the measures to cope with sedimentation.

References

[1] Jurík L, Zelenakova M, Kaletova T, Arifjanov A 2019 *Springer International Publishing* **65** 115-131.
[2] Arifjanov A, Samiev L, Akmalov Sh 2019 *International Journal of Innovative Technology and Exploring Engineering* **9** 2646-2649.

[3] Arifjanov A, Samiev L, Apakhodjaeva T, Akmalov Sh 2019 *IOP Conference Series: Earth and Environmental Science* **403**.
[4] Samiyev L, Allayorov D, Atakulov D, Babajanov F 2020 *IOP Conference Series: Materials Science and Engineering* **883**.
[5] Ikramova M, Kabulov Kh, Akhmedkhodjaeva I, Khodjiev A 2019 *IOP Conference Series: Earth and Environmental Science* **403**.
[6] Arifjanov A, Fatxullaev A 2020 *Journal of Physics: Conference Series* **1425**.
[7] Gapparov F, Nazaraliev D, Eshkuvatov Q 2020 *IOP Conference Series: Materials Science and Engineering* **883.**
[8] Fatxulloyev A, Gafarova, Hamraqulov J 2019 *International conference on information science and communications technologies* **88** 1-3
[9] Bai T, Wei J, Chang F-J, Yang W, Huang Q 2019 *Journal of Hydrology* **577** 123987.
[10] Rosas M, Vanacker V, Viveen W, Gutierrez R, Huggel C 2020 *Journal of Hydrology* **581** 124396.
[11] Haun S, Kjærås H, Lovfall S, Olsen N 2013 *Journal of Hydrology* **479** 180-188.
[12] Ranzi R, Le T, Rulli M 2012 *Journal of Hydrology* **422** 17-29.
[13] Khikmatov F, Jumabaeva G, Rakhmonov K 2020 *IOP Conference. Series: Materials Science and Engineering* **883**.
[14] Vente J, Poesen J, Verstraeten G 2005 *Journal of Hydrology* **305** 1-4.
[15] Rudis M, Valenta P, Valentova J, Nol O 2009 *Journal of Hydrology* **369** 326–335.
[16] Fatxulloyev A, Gafarova A, Otakhonov M, Allayorov D 2020 *IOP Conference Series: Materials Science and Engineering* **883**.
[17] Fatxulloyev A, Abduraimova D, Otakhonov M, Atakulov D, Samiev L 2020 *IOP Conference Series: Materials Science and Engineering* **883**.
[18] Khodjiev A, Ikramova M, Akhmedkhodjaeva I, Xoshimov 2020 *IOP Conference Series: Materials Science and Engineering* **883**.
[19] Khikmatov F 2007 *10th International Symposium on River Sedimentation* **Moscow II** 256-263.
[20] Khikmatov F, Aitbaev D, Jumabaeva G 2010 *Bulletin of the Civil Society of Uzbekistan* **35** 165-168.
[21] Arifjanov A, Xodjiyev N, Jurayev Sh, Kurbanov K, Samiev L 2020 *IOP Conference Series: Materials Science and Engineering* **869**.
[22] Liu Zh, Huang Y, Liu T, Li J, Xing W, Akmalov Sh, Peng J, Pan X, Guo Ch, Duan Y 2020 *Remote Sens*. **12** 2317.