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Estimation of sediment volume in Tuyamuyun hydro complex dam on the Amudarya River

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Abstract. The water reservoirs' sedimentation significantly impacts on its capacity and water supply efficiency, so estimation of sediment volume is an important action at management. Many methods are used for this purpose, including mathematical models, hydrologic and hydrometric methods, etc. However, each reservoir is a unique strategic object and when selecting a calculation method all specific characteristics should be taken into account. In the present research, a mathematical model and developed soft were used to estimate the water and sediment flows in the Channel reservoir of the Tuyamuyun Hydro Complex, located in the lower sides of the Amudarya River, Uzbekistan. The estimation is based on the evaluation of both suspended and bed-load sediments dynamics taking into account variation of the water level in the reservoir as affecting factor, i.e. its operation mode. The average multi-year sediment rating curve and empirical equations were corrected based on effective factors, such as time and conditions of measurement, which increased the model efficiency.

1. Introduction

Over the past 35 years in the Aral Sea basin, especially in the lower reaches of the Amudarya river, water shortages negatively impact on the socio-economic situation of the Karakalpakstan and Khorezm regions of the Republic of Uzbekistan. Taking into account climate change and an increase in the need for food production the water shortage will increase the risk of food security and the social sustainability of the region. In the paper, some results of the work provided within the research projects devoted to the effective use of irrigation systems, hydraulic structures, and reservoirs (2016-2020) are presented. Within the study, a mathematical model and a soft for calculating water and sediment flows have been developed.

Currently, Uzbekistan pays great attention to the construction and modernization of reservoirs to meet water demand in all sectors of the economy, identify factors affecting the efficient use of available water resources, prevent water and capacity losses, sedimentation and erosion processes, etc. In this regard, developing new modern hydraulic methods and hydrological calculations, improving methods for monitoring and forecasting hydrological processes in the upper and lower sides of the flow regulatory structures using modern scientific achievements, developing activities to prevent water losses and increase water use efficiency are urgent issues. Impact of reservoirs operation to the hydrological regime of rivers and the channel processes studied by many international and national scientists, such as Altunin S.T. [2], Babich D.B. at al. [3], Bai T. at al. [4], Du H. at al. [5], Higgins at.al. [7], Itoh at.al. [9], Jothiprakash V. at.al. [10], Lapshenkov V.C. [11], Morgan K. at.al. [13], Mukhamedjanov F.Sh [14], Poepl R.E. at.al. [16], Ran D.C. at.al. [17], Rosas M.A. at.al. [18], Sabah



S. [19], Skrilnikov V.A. et al. [20] etc. At present, prediction of water capacity dynamics in reservoirs, calculation of water balance and a new solution for the efficient use of available water resources using modern information technologies are not sufficiently worked out taking into account specific features of the Amudarya River [1, 8, 15].

The study object – the Tuyamuyun Hydro Complex (THC), is located on the lower reaches of the Amudarya River, constructed to regulate water flow in the interests of agriculture and municipal water supply for Khorezm and Karakalpakstan regions. The THC includes four interconnected reservoirs Channel, Kaparas, Sultansanjar, and Koshbulak. During more than 38 years of operation of the reservoirs, the Channel Reservoir sedimentation exceeded 1.2 km³. The Kaparas reservoir is currently used for drinking purposes, which imposes certain restrictions on the working regime of the other three reservoirs. The need to fill the Kaparas during the most stressful period (July-August), especially in the dry season, combined with the insufficient capacity of the discharge system from the Sultansanjar reservoir and decrease in its useful volume, sharply limits the possibility of satisfying the lower reaches with irrigation water. Also, average annual water losses from reservoirs due to evaporation and filtration are over 1.1km³.

The previous reservoirs' operation analyses and their impact on the river channel showed the importance of a specific study of the sedimentation process in the Cannel reservoir taking into account dynamics of the reservoir morphology linked with water surface elevation change (Froebrich J. et al. [6]).

This study was aimed to improve the THC reservoir system operation efficiency allowing rational regulating the flow and water supply, adjusting the reservoir operation mode taking into account the specific water management situation. Mathematical model and computer programs to improve the operation mode of reservoirs at different water availability have been developed, which allow regulating water and sediment flow, water losses due to evaporation and filtration. Special attention is paid to improve the sedimentation process monitoring, as well as the development of improved methods for calculating their volumes.

2. Methods

Analysis of field research data showed that the level of turbidity of the stream is divided into two stages:

i) at the first stage, the sedimentation coefficient ε is constant and equal to $\varepsilon = 1$;

ii) ii) at the second stage, the sedimentation coefficient varies with the increasing the ratio $\frac{W_{ch}}{W_{in}}$ in

the interval $0 \leq \varepsilon \leq 1$.

The criteria for the transition from the first stage to the second are equal to $\frac{W_{ch}}{W_{in}} = 0.12$. Based on these criteria, if the reservoir volume satisfies the condition $\frac{W_{in} \leq W_{ch}}{0.12} = 8.33W_{ch}$, the sedimentation process belongs to the second stage.

At predicting the volume and time of sedimentation of the reservoir, the indicators corresponding to water levels at inflow and outflow were taken into account. The volume of the reservoir was determined by the following formula:

$$W_{u(n)} = \frac{W_{in} W_{u,p} (\nabla_{HY} - \nabla_{CY})}{\nabla_{HY} - \nabla_{CY}} \quad (1)$$

In this case, the sedimentation coefficient is equal to

$$\varepsilon = 0.04 \left[\frac{\nabla_{NWL} - \nabla_{CY}}{\nabla_{HY} - \nabla_{CY}} \frac{W_p}{W_{UW}} \right]^{-1.5} \quad (2)$$

Here: ∇_{NWL} is the normal water level; W_{UW} is the useful volume of the reservoir at ∇_{NWL} , Mio m³; ∇_{HY} is the initial reservoir level; ∇_{CY} is the water surface elevation at water volume in the reservoir is equal to the channel-forming volume (Fig. 1).

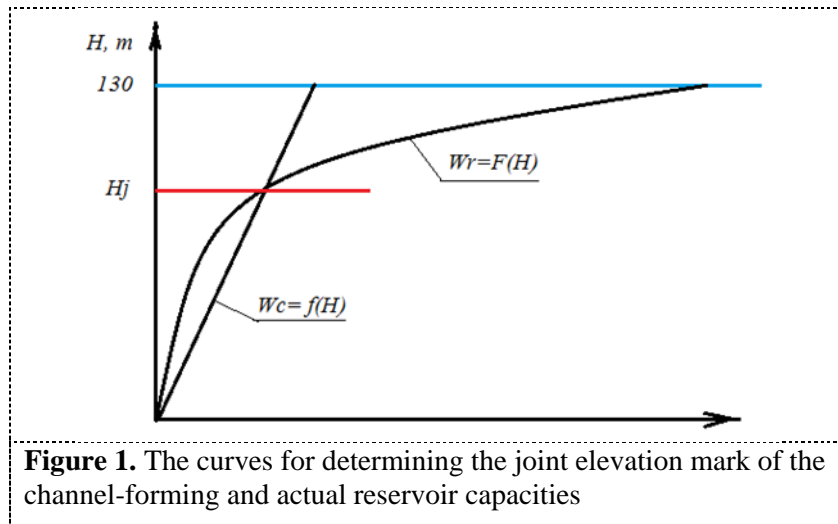


Figure 1. The curves for determining the joint elevation mark of the channel-forming and actual reservoir capacities

During the reservoir operation, water level variation affects the sedimentation process. The sedimentation volume calculation depends on the following conditions:

i). If the elevation of water surface varies from ∇_{NWL} to ∇_{CY} in the reservoir sedimentation process is takes place. In this case, the sediment deposition is estimated by the following formulas:

at water discharging:

$$\Delta W_{sed} = 1.2 \rho_{inf} W_{inf} \varepsilon \quad (3)$$

at water accumulation:

$$\Delta W_{sed} = 1,2 \rho_{inf} W_{inf} \left(1 - \frac{W_{in}}{W_{fin}} \right) (1 - \varepsilon) \quad (4)$$

here: ρ_{inf} is the inflowing water turbidity, kg/m³; W_{inf} is the inflowing water volume, Mio m³; W_{in}, W_{fin} are the water volumes in the reservoir at the beginning (initial) and end of the month (final) Mio m³; ε is the sedimentation coefficient.

ii). There are three states of water elevation:

a) if $H_{HY} > H_{CY}$ and $\nabla_{KV} < \nabla_{CY}$ also sedimentation of the reservoir is observed and its volume is determined as follows:

$$\Delta W_{sed} = 1,2 \rho_{in} W_{inf} \varepsilon A \quad (5)$$

Here $A = \frac{H_{HY} - H_{CY}}{H_{HY} - H_{KV}}$

When the water level in the reservoir is lower than the channel-forming level, erosion of sediments starts and its volume is defined as:

$$\Delta W_{eros} = 1,2\rho_{add}[W_{in}(1 - A) + (W_{CY} - W_{fin})] \quad (6)$$

here: , $W_{in} \cdot A$ is the discharged flow volume from H_{HY} to H_{CY} ; ρ_{add} is the additional load on the flow due to flushing of sediments, kg/m^3 :

$$\rho_{add} = \frac{B_p^1 \mu (H \sum sed - H_{KY})}{1,2iQ_p^1} \quad (7)$$

here: μ is the sediment washing intensity, mm/s ; $H \sum sed$ is the sediment layer elevation; Q_p^1 is the average monthly inflow, m^3/s ; B_p^1 is the riverbed width corresponding to water inflow, m .

b) If $\nabla_{HY} < \nabla_{CY} > \nabla_{KY}$, sediments are washed out to the downstream and its volume is determined as follows:

$$\Delta W_{sed} = 1,2\rho_{add}W_p^1 \quad (8)$$

here: $W_p^1 = Q_p^1 \frac{H_{CY} - H_{KY}}{\mu}$

In this case, if $W_p^1 > W_{in}$, at calculation will be used W_{in} . The channel width is calculated as

$$B_p^1 = \frac{Q_p^1}{V_p H_p} \quad (9)$$

$V_p = 1.0 \div 1.2 \text{ m/s}$; H_p is the depth of channel, m .

c) At the conditions of $H_{HY} < H_{CY} < H_{KY}$, water accumulation in the reservoir takes place. In this case of $H_{HY} < H_{CY}$ sediments will be eroded, and its volume will be calculated as follows:

$$\Delta W_{sed} = 1.2\rho_{add}[W_{inf}(1 - A) + (W_{in} - W_{CY})] \quad (10)$$

When the water level in the reservoir rises from H_{CY} to H_{KY} , the sediment will be deposited, and its volume is calculated by the formula

$$\Delta W_{sed} = 1.2\rho_{add}W_{inf} \left[(1 - A) - \left(1 - \frac{AW_{CY}}{W_{KY}} \right) (1 - \varepsilon) \right] \quad (11)$$

Thus, the determination of sediment erosion/or deposition volume in the reservoir is carried out taking into account its siltation stage at the initial estimated time, reservoir's operation mode, and water availability of the year.

3. Results and Discussion

Comparison of the calculation results of sediment deposition and erosion volumes with field measurements carried out from 1980 to 2016 show a fairly good convergence, i.e. deviation up to 7-10% (Fig.2).

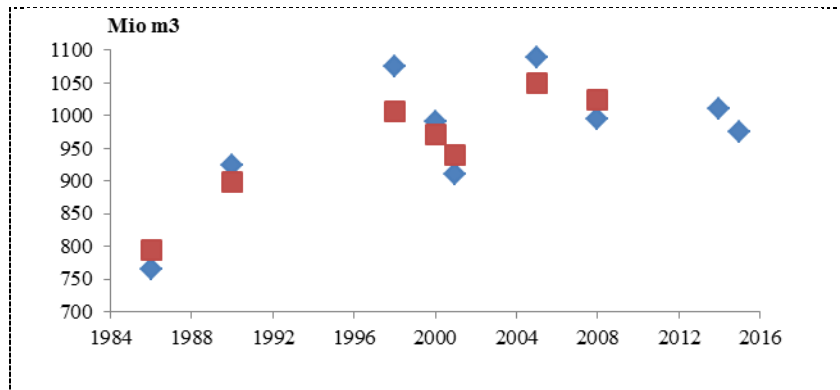


Figure 2. Matching of the calculated and field measurement features of the reservoir siltation

The calculation results of the Channel Reservoir’s sedimentation process at average water years are presented in Figure 3 and 4.

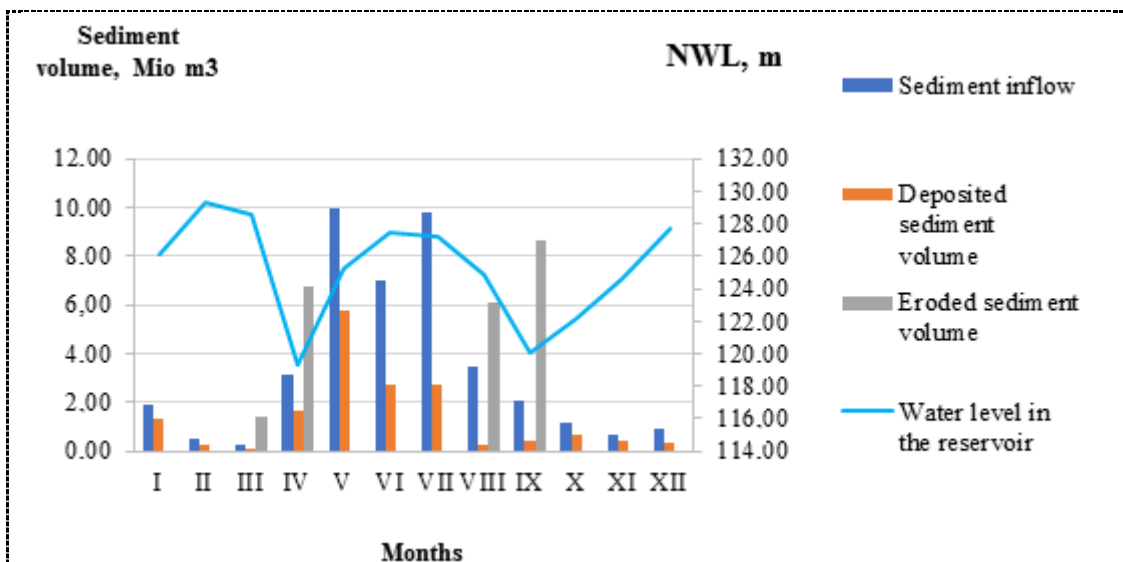
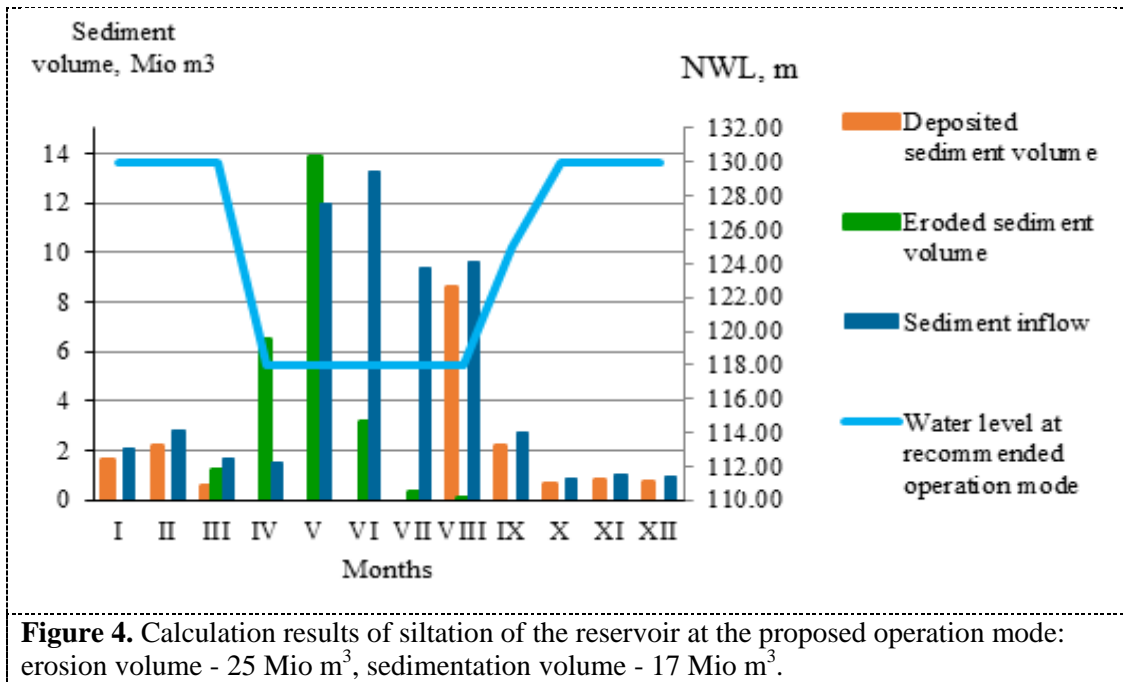


Figure 3. Sedimentation dynamics in the reservoir: erosion volume within 12 Mio m³, accumulated sediments volume is 26 Mio m³.



The results indicate the accuracy and stability of the developed calculation method. To assess the accuracy of the results, they are compared with the observed siltation data during 1995-2018 (Table 1).

Table 1. Comparison of sedimentation features in the reservoir

| Years | The reservoir volume | | Accumulated volume | sediment |
|-------|----------------------|----------|--------------------|----------|
| | calculated | measured | calculated | measured |
| 1995 | 1427 | 1427 | 913 | 913 |
| 1998 | 1416 | 1442 | 924 | 898 |
| 2002 | 1252 | 1290 | 1088 | 1050 |
| 2006 | 1346 | 1316 | 994 | 1024 |
| 2008 | 1376 | 1348 | 964 | 990 |
| 2013 | 1265 | 1304 | 1075 | 1026 |
| 2015 | 1350 | - | 990 | - |
| 2018 | 1429 | - | 911 | - |

4. Conclusions

Improving the Amudarya river flow regulation by the Tuyamuyun Hydro Complex reservoirs play a specific role for Karakalpakstan and Khorezm located in the lower reaches of the river. The

methodology can be used for performing predictive calculations of the sedimentation process. Thus, the forecast of the siltation of the reservoir can be made according to the above dependencies, taking into account its stage of siltation at the initial estimated time and the actually adopted or recommended operating mode of the reservoir in a dry, medium or high water years. The methodology also takes into account possible changes in accumulation or erosion processes, change of water level, and hydrological regime. Calculations showed that with average siltation intensity, the period of complete siltation of the reservoir is approximately 55-57 years.

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