Original Research Article: full paper

(2023), «EUREKA: Physics and Engineering»
Number 1

STUDY OF SEDIMENT DEPOSITION PROCESSES AND ASSESSMENT OF THE CHANGE IN THE W-H CHARACTERISTICS OF THE MADAGHIS RESERVOIR

Pargev Baljyan✉
Base Laboratory «Hydraulic Engineering»
National Polytechnic University of Armenia
105 Teryan str., Yerevan, Armenia, 0009
baljyan-1951@list.ru

Arestak Sarukhanyan
Department of Water Systems, Hydraulic Engineering and Hydropower
National University of Architecture and Construction of Armenia
109 Teryan str., Yerevan, Armenia, 0009

Eleonora Avanesyan
Hydraulic Laboratory
Shushi University of Technology
125 Armenakyan str., Yerevan, Armenia, 0047

✉**Corresponding author**

Abstract

The accumulation of sediments in reservoir is always a problem. Over time, these accumulations occupy the volume meant for water management, dramatically reducing the reservoir's effectiveness. The environment of the river basin below the reservoir undergoes significant changes. In this regard, assessing changes in volumetric W-H characteristics, particularly in reservoirs built on high turbidity rivers, is critical. The Mataghis Reservoir on Tartar River was chosen as the object of study. The quantity of accumulated sediments was established by original measurements and was calculated in three hydrologic ways at distinct stages of operation. The actual graphs showing the reservoir's W-H volumetric characteristics were made two decades after commissioning and are still in use. According to the findings, over 70 per cent of the reservoir volume has been filled with sediments over the course of the reservoir's thirty-year operation. A theoretical model of the sediment buildup process in basins has been created. Separate parameters have been created for the deposition of bottom sediments entering the reservoir and suspended particles in the flow. Based on them, the patterns of distribution of accumulated sediments according to the length and height of the reservoir were drawn out. The vertical pulsation velocity and the results of studies for determining the minimum rate of soil particle flow were used. To solve sedimentation problems in operating and newly constructed reservoirs, a methodology for evaluating changes in the amount of collected water and changes in the volume of water control, as well as a theoretical method for projecting their future behavior, can be applied.

Keywords: river, reservoir, solid flow, sediment, reservoir bowl silt, hard flow, sedimentation, accumulation density.

DOI: 10.21303/2461-4262.2023.002757

1. Introduction

Reservoir sedimentation, which is produced by the flow of water and silt into the reservoir, reduces the difference between the normal retention level and the bottom marks. As a result, the planned water volume is steadily decreasing. According to experience with reservoirs [1, 2], the majority of incoming sediments are accumulated at the beginning of the reservoir, occupying a useful volume. It is vital to have precise data on the water regime of the river that flows into the reservoir in order to appropriately assess the quantitative indicators of the accumulation. Many rivers and their tributaries in mountainous and foothill areas lack such information, or it is incomplete. Huge changes in flows are noticed in the minor and large tributaries feeding these rivers during the spring snowmelt or the periodic heavy rains. And the greatest flows are sometimes 200–250 times greater than the smallest outflows. If there is enough interconnected, flood-dependent soil in the river basin, such oscillations are documented in the size of the river outflow [3]. There were many instances where the amount of sediments produced during the floods that lasted several days was similar to the total for the entire year [4]. Simultaneously, a somewhat poor sediments regime is found in a number of river basins with constant petrographic-lithological parameters. The volume of soil mass accumulating in the reservoir, the pace of propagation, and the creation of the granular composition will all be influenced by the changing behavior of sediments. If possible, measures to eliminate accumulations are conducted [5, 6]. In many instances, these measures resulted in very positive outcomes [7].

Regular measurements of river basin conditions are required to solve problems connected to the buildup or disposal of water in reservoirs [8]. The following are the major criteria that distinguish them:

– river basin petrographic and lithological parameters;
– river fluid and sediments flows;
– grain size of soil in the flow;
– geometric quantities of the reservoir bowl;
– current water level during reservoir operation.

Due to natural and manmade forces, the river basin's circumstances change throughout time. As a result of the multi-year assessments, the indicated baseline data can be considered adequately credible.

Field study solves problems connected to the accumulation of sediments in the functioning reservoir with adequate accuracy [1, 4, 9]. These solutions, on the other hand, are keeping with the specific reservoir's characteristics [10]. For reservoir operation, general forecasting methods may be provided, especially for newly built reservoirs. They should be able to find adequately acceptable solutions to the sedimentation problems for each reservoir. Based on studies with reservoir's physical models, several such techniques have been presented [7, 11]. However, flaws in the modeling of two-phase fluids, particularly, the one of sediments, limit the trustworthiness of these solutions greatly. The equation of the balance of inflows and outflows from the reservoir serves as the theoretical foundation for the majority of the proposed methods [12]. This method provides good results in terms of accumulation volume and the amount of fine particles leaving the reservoir [13]. However, the lack of a description of the actual sediment accumulation makes it impossible to anticipate the form of volume of settled sediments, i.e. the growth of that volume along the reservoir's length and height. There is also no distinction between the accumulation zones of suspended sediments entering the reservoir and accumulation of bottom sediments.

2. Materials and Methods

2. 1. The object of research and its formal description

The operational efficiency of many reservoirs around the world has greatly decreased due to rapid sedimentation. One of them is the Mataghis reservoir on the Tartar River, which is the subject of research.

The goal is to assess the current state of the volume of the operating reservoir, estimate future changes, and provide theoretical substantiations of water accumulation processes in water basins. The Mataghis Reservoir, which is situated on the Tartar River, has been chosen as the site for a quantitative study of reservoir volume loss owing to sediment deposit. In 1974, the Mataghis Reservoir on the Tartar River became operational. The reservoir has a maximum surface horizon of 416.7 meters, a dead volume horizon of 401.5 meters, a total volume of 5.56 million m^3, and a useable capacity of 5.21 million m^3. The earthen dam is 28 meters tall at its highest point.

The Sarsang Reservoir, with a useable volume of 625 million m^3 and a catchment area of 2130 km^2, was established in 1976 on the Tartar River, 20 m above the Mataghis Reservoir. To put it another way, the entire Tartar water flow has only inundated the Mataghis Reservoir for three years. Since 1976, the sediment flow that feeds the Mataghis Reservoir has only grown over a 330-square-kilometer area, with half of it falling to the Trghi Tributary and the other half to side inflows. It is worth noting that the reservoir was completely drained in 1993 due to a malfunction of the reservoir's deep water bleeder valve, and streams from the drainage outlet were allowed to run freely until 2013. They flooded the Mataghis Reservoir and removed a large amount of sediment that had accumulated there (about 0.7 million m^3). In **Fig. 1**, a flood gorge was opened in sediment accumulations, with the bottom in the area adjacent to the dam reached the river's natural mark.

Fig. 1. View of the flood gorge from the dam of the Mataghis Reservoir. A river bed formed in the accumulated sediments due to hydraulic flushing

The first studies of the sedimentation situation in the Mataghis Reservoir were conducted in 2012, but their results are reflected the appearance steadied at the end of 1993, because in the next two decades, except for the partial flooding of the accumulated sediments, there has been no other change [14].

According to the field's research, turned out that as of 1993 sediment filled approximately 3.5 million m^3 of the reservoir's total volume of 5.56 million m^3. Given that the dead volume is just 0.35 million m^3, the reservoir's useable volume has been lowered from 5.21 million m^3 to 3.15 million m^3.

According to studies, the total volume of accumulated sediments was formed by the following sediment load flows:

1) flows from the Tartar River during three years before to the construction of the Sarsang Reservoir;

2) flows from the tributaries of the Sarsang-Mataghis river section after the operation of the Sarsang Reservoir;

3) a small amount of accumulations occurred in the same river section due to the Tartar riverbed flood.

The hydrometric data of the river's fluid and sediment flows, as well as the reservoir bowl's design parameters, will be used to compile the Mataghis Reservoir sediments balance.

In 2020–2021, the reservoir's next research was carried out [4]. As a result of the development, the nature of the reservoir volume decline due to sedimentation for the whole period of operation was revealed.

2. 2. Methods of research

As a result of sediment accumulation the structure's ability to regulate river waters is lost with time. In this case, estimating the degree of volume reduction and anticipating future changes is crucial, particularly for small to medium-sized reservoirs. There are no studies in the professional literature that have determined the patterns of reduction in a reservoir's volume. In the South Caucasus, the bulk of reservoirs are small to medium in size. As a result, the aforementioned issue is crucial for the countries of the South Caucasus.

The following information was used to calculate the volume of sediments accumulated at various periods of the Mataghis Reservoir's operation:

− data of sediment load flow measured at the Tartar River's «Mataghis» hydrometric station;

− estimated values of the same flow, which were derived by the existing link between river fluid and sediments [14] (the fluid flow values were obtained by measurements performed at the hydrometric station);

− the river basin flow module calculated the sediment load values.

To assess the volume of sediments collected in the reservoir, natural studies were conducted. The design and present state 2D and 3D models of the reservoir bowl were produced as a result of data processing, and the actual volume of sediments stored in the reservoir was determined.

The positive and negative aspects of the utilized hydrometric methodologies were evaluated as a result of a comparative examination of the volumes obtained from hydrological calculations.

The criteria for the installation of current-dependent sediments are defined by the theoretical model that describes the accumulation process in the reservoir. The patterns of accumulation distribution according to the reservoir's length and height were generated as a result of the solutions, allowing the reservoir's $W=f(H)$ features to be specified at any stage of operation. Publications in this approach are uncommon in reservoirs research [2, 13].

3. Results and discussion

3. 1. Evaluation of the Mataghis reservoir silt factors

New studies of the Mataghis Reservoir bowl were launched in 2020–2021 with the goal of determining changes in the sedimentation regime and the state of sediment accumulations in the reservoir over the previous decade, making predictions about their potential developments.

Based on the findings of geodetic measurements and calculations done in the first stage of the survey (2011–2012), the design graph of function $W=f(H)$ between the Mataghis Reservoir capacity and the water depth there was reconstructed (**Fig. 2**).

These studies showed that during the first two decades of operation (1974–1993) the reservoir's top surface of 3.5 million m^3 sediments accumulation rose to the absolute level of 411–411.5 m [4]. Using the obtained data, it was compiled in 1993. The actual schedule of the reservoir bowl corresponding to the condition (**Fig. 2**), from which it appears that there were about 2.1 million m^3 left in the reservoir for regulation volume. For the next two decades, the reservoir was in a state of emptiness and the incoming flows were leaving in transit. During those years, the water current washed away about 700 thousand m^3 accumulated in the reservoir sediments, opening a rather large floodplain in the deposits (**Fig. 1**). That is why in 2012 the current water volume in the Mataghis Reservoir has grown by 0.7 million m^3 and the $W=f(H)$ characteristics of the bowl is somewhat different from that of 1993 (**Fig. 3**).

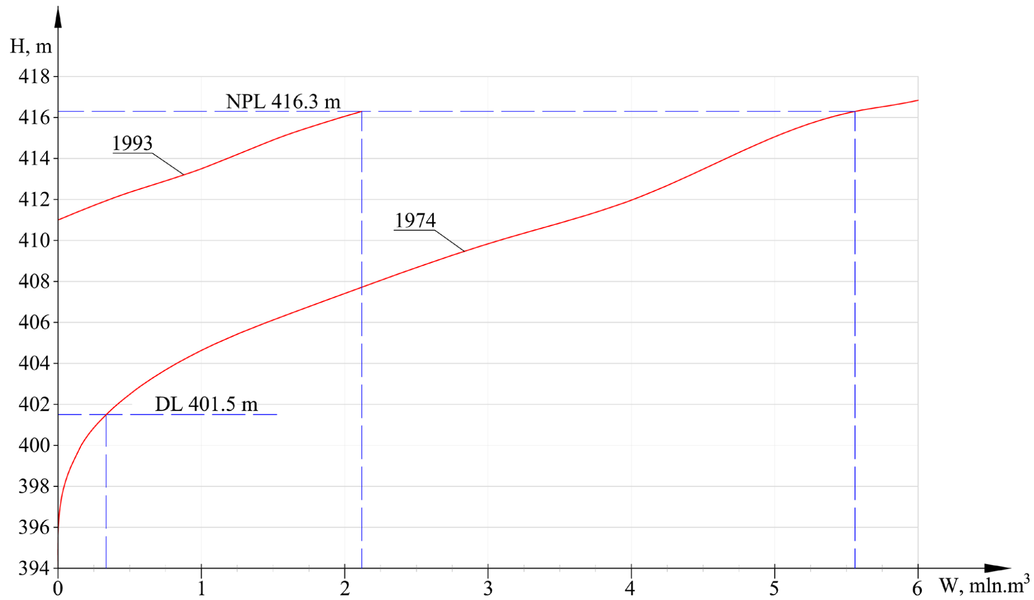

Fig. 2. $W=f(H)$ function curves plotted by design data given in 1974 and data obtained after two decades in 1993

The initial volume of the reservoir (5.6 million m^3 in 1974) decreased by 3.5 million m^3 due to silt formation during the 20 years of operation (2.1 million m^3 in 1993) and decreased by 3.5 million m^3.

In addition to the original research, hydrological methods were used to determine the amount of sediment accumulated each year from 1974 to 1993. The first technique relied on measurements taken at the «Mataghis» hydrometric station between 1949 and 1974 [15]. The station was submerged with water after commissioning of the Mataghis Reservoir and no more measurements were taken. According to measurements, the river's average annual flow of suspended sediment load was 13.9 kg/s. The sediments flow into the Mataghis Reservoir after construction in 1997 of the Sarsang Reservoir began its formation exclusively from the Sarsang-Mataghis River catchment region.

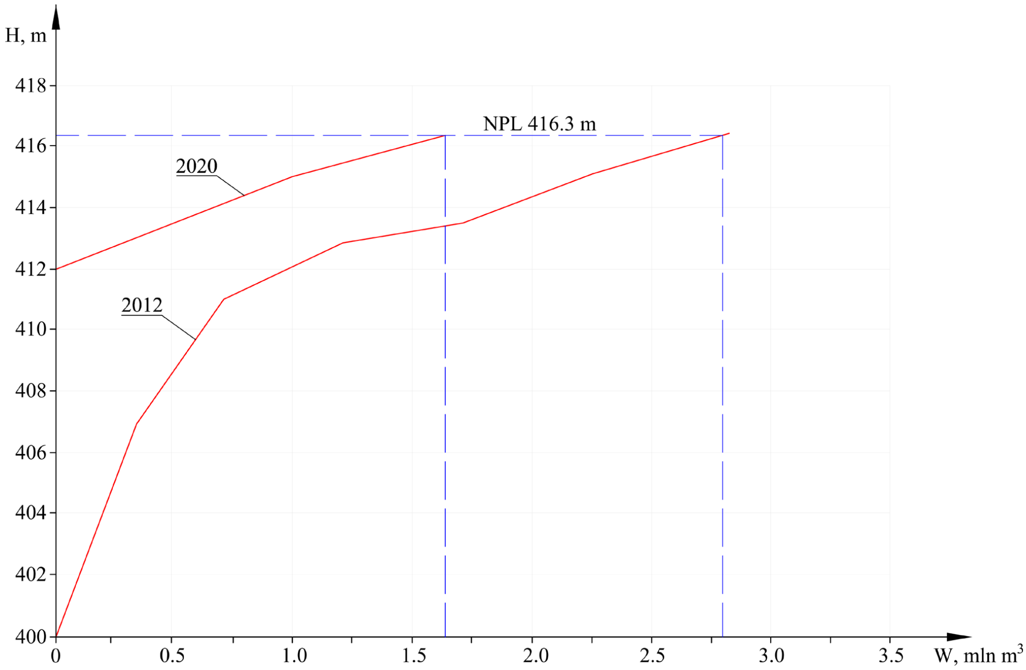

Fig. 3. $W = f(H)$ function graphs of relation between water level in Mataghis Reservoir and its bowl volume according investigations carried out in 2011–2012 and 2020–2021

Compared to 1993, after partial flushing of accumulated sediments (**Fig. 2**), the volume of the reservoir increased in 2012, and by 2020 decreased because of silt formation.

As a result of the recalculation, the flow of the suspended sediments decreased from 13.9 kg/s to 1.9 kg/s. According to studies of Eastern Transcaucasian rivers [16], approximately 50 per cent of suspended particles are of a diameter smaller than 0.05 mm. In non-big reservoirs, they leave without being settled. The bottom sediments flow of the river is assumed to be equal to half the total flow of suspended particles as a result of the same studies. Taking into account the mentioned hydrometric data 1974–1993 the amount of sediments accumulated in the Mataghis Reservoir is $m = 2.24$ billion kg. The volume of this mass is 1.4 million m^3 according to the below formula:

$$W = \frac{m}{\rho_s}, \quad (1)$$

where ρ_s is the average density of the accumulated soil (1600 kg/m^3).

The sediment flows were calculated by the below formula suggested for the specified region at that the second method was used [15]:

$$Q_s = 0.72Q^{0.95}, \quad (2)$$

where Q is the flows, measured at «Mataghis» hydrometric station.

According to (1), the average multi-year flow of suspended sediment into the Mataghis Reservoir was expected to be 13.4 kg/s until 1997, which is quite close to the actual amount (1.39 kg/s) measured at the same station. The volume of deposited sediments in the reservoir until is 1.35 million m^3 if this procedure is used.

To determine the sediment flow, based on the river basin module for 330 km^2 area in the Sarsang-Mataghis river section, the third calculation method was used. The volume of the bedded sediment in the reservoir until 1994 is 1.54 million m^3.

Thus, the volumes of accumulations obtained by three calculation methods are quite close to each other. However, there is more than twice the difference between these amounts and actual volume of measured sediments in the reservoir (3.51 million m^3). Because in the Sarsang-Mataghis section of the Tartar River since 1974 no measurements have been made, the current discrepancy may be a consequence of the following:

– inaccuracy of the above-mentioned estimates of the number of bottom sediments and small particles in transit through the reservoir;

– in the mentioned section, one or two mudslides flowed through the Trghi tributary, which joins the river, of which unregistered large amount of sediments increased the volume of accumulations.

After the repair of the damaged deep valve (end of 2012), the Mataghis reservoir was filled up, and the infilling sediments continued to accumulate. New studies carried out in 2020–2021 provide an opportunity to assess the changes that took place in the reservoir between 2013–2021.

Based on the 3.51 million m^3 volume of sediments accumulated in the reservoir, the actual flow of sediment entering the reservoir, by countdown is estimated 7.5 kg/s. Assuming that the reservoir after 1994 has not undergone sensible changes, from 2013 to 2021 the amount of sediments accumulated in the reservoir should have been $m = 7.5 \times 31.54 \times 10^5 \times 8 = 1.9$ billion kg or 1.2 million m^3.

Of that volume, 0.7 million m^3 was to be filled during 1994–2012 in the gorge caused by the flooding. The remaining 0.5 million m^3 volume will be distributed on the surface of accumulations up to 411 m mark, raising it to 412–412.5 m marks. It was not possible to make detailed measurements in the water-covered accumulations. However, their results show that the signs of the accumulation surface at the beginning of the reservoir are 1–1.5 m higher than the mentioned calculation points at. And the signs near the dam fluctuate in the range of 411.5–412.0 m. The development of this condition is a consequence of the fact that the water level has always been kept constant throughout the reservoir operation.

Thus, the results of the 2020–2021 research show that of the reservoir's 5.56 million m^3 total volume about 4 million m^3 of sediment was accumulated. Therefore, no more than 1.6 million m^3 is left for water regulation (**Fig. 3**).

It is difficult to make quite reliable predictions about the further course of the Tartar River's sediment load regime and further accumulations of the reservoir, as changes occur regularly in the river basin. They are conditioned by climatic factors, anthropogenic factors, especially the lack of regular measurements. It can be assumed that in such a situation the average sediment flow entering the Mataghis reservoir cannot exceed 4.5–5 kg/s. So, in these conditions, try to assess the upcoming changes in the volume of the reservoir. The volume of sediments to be accumulated in the next ten years according to (1) will grow by about 0.7 million m^3. Considering that there are currently about 4 million m^3 bedded sediment in the reservoir, then it can be predicted that the entire volume of the Mataghis reservoir in the next 20–25 years will be practically filled with sediment.

The analysis of hydrological calculations and results from the conducted studies shows:

– when assessing the volume of sediments in the reservoir, the calculated values defined by hydrological methods are significantly less than the actual values determined from field measurements, which is a consequence of the incompleteness of the output data or methods;

– on rivers with high turbidity, such as the Tartar River, the construction of small reservoirs is not effective. The obtained results indicate that if the Sarsang reservoir of 550 million m^3 has not been built above it three years after its operation, the Mataghis reservoir could be filled with sediment within a decade;

– in case of an urgent need to build a small reservoir on the turbid rivers, periodic flushing of accumulations during operation should be carried out or measures should be taken to reduce the output of water entering the reservoir.

3. 2. Theoretical justifications for sediment accumulation process

Changes in the volume of sediments accumulating in the reservoir, their deposition shape, and the design condition of the reservoir bottom run under the influenced of many factors, mainly:

– river water and sediments flows (Q and Q_S);
– sediments granulometric composition (d_S);
– geometric parameters of the reservoir bowl;
– reservoir water horizon (H).

Below the theoretical justifications of the sediment accumulation process is given. The balance of sediments accumulated in the reservoir for the dt period of time will be as follows:

$$dh_s = \frac{Q_s dt}{\rho_s BL}, \tag{3}$$

where dh_S is the average thickness of the accumulation layer; ρ_s is the density of the accumulated soil; L is the length of the accumulation section of in case of the current H depth of the reservoir; B is the average width of the bottom at that section.

There are floating suspended sediments and sediments traveling over bottom layers along the course of the river pouring into the reservoir. It is obvious that the accumulation of bottom sediments and suspended sediments in the reservoir will run under a variety of conditions. Larger particles that move across the bottom layers settle first. The beginning and the end of the length L of the accumulation segment will be determined by the following condition:

$$V_S \geq \beta V_m, \tag{4}$$

where V_S is the minimum velocity to keep the particle of a given diameter in motion [17]; V_m is the average velocity of the stream; β is the coefficient of transition from the mean velocity to the bottom layer velocity of the stream. According to the condition of fluid continuity:

$$V_m = \frac{Q}{A}, \tag{5}$$

where A is the area of the current section.

Substituting (5) in the (4) there is:

$$A \geq \frac{Q}{V_s}. \tag{6}$$

The boarders of the section of bottom particle accumulation can be determined using inequality (6). To this end at X_1, X_2, …, X_n distances starting from the dam, n number of section are chosen of which areas (A_1, A_2,…, A_n) are determined. For the largest and the smallest bottom particles ($d_{\max}$ and $d_{\min}$) of the bottom sediments the respective velocities ($Vs_{\max}$ and $Vs_{\min}$) are determined. The right side of inequality (6) is determined by Q output, β coefficient and $Vs_{\max}$. The smallest value that meets the condition (6) is searched in the A_1, A_2, …, A_n row of surfaces. That section is the beginning of sediment accumulation in the reservoir.

To determine the location of the accumulation endpoint, the same steps are performed for particles having $Vs_{\min}$ velocity. By the known values of L distance between two sections, average $B_{\min}$ width of the accumulation section, accumulation flow and sediments density (3) is integrated within limits corresponding to different moments of accumulation:

$$\int \mathrm{d}h_s = \frac{Q_s}{\rho BL}\int \mathrm{d}t. \tag{7}$$

As a result of integration, the pattern of the bottom sediments accumulation layer time-dependent growth is obtained. The above problem solution is applicable for both constant and time-dependent variation values. In case of suspended particles in the beginning of the accumulation site the largest will settle, and the smallest at the end. Based on granulometric composition ($d_{\max}$, $d_{\min}$), the length of the accumulation site will be determined by the following condition:

$$W \geq V_Z, \tag{8}$$

where W is the fall velocity of the particle, V_Z is the average velocity pulsating vertical component of the reservoir current section.

There is a connection between the mean velocity of the section and its pulsating V_Z component:

$$V_Z = \varphi V_m, \tag{9}$$

where φ is a coefficient which is determined by the results of experiments carried out at the US National Physical Laboratory [18] and by plotted curves in **Fig. 4**.

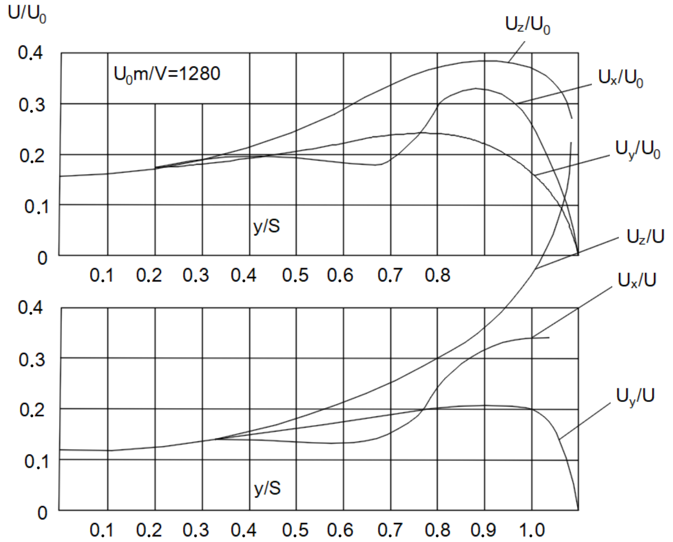

Fig. 4. The change of pulsation velocities of the effective cross-section around the average velocity, y/s – point relative coordinate

It can be seen from the plots that in the overwhelming part of the effective cross-section, the values of both the coefficient φ_z and the coefficients of the other pulsating velocities change in the range of 0.2–0.3. And paradoxically, the value of the coefficient φ_z increases, especially in the area near the walls of the bed.

By placing the condition of inviolability (5) in (9) and the obtained result in inequality (8), let's obtain:

$$A \geq \varphi \frac{Q}{W}. \tag{10}$$

The beginning of the suspended particles' settling corresponds to the fulfillment of the condition of (10) for particles of diameter $d_{\max}$. The right-hand side of inequality in (10) is determined by the values $W_{\max}$ [19] determined by the flow, coefficient φ_z, and $d_{\max}$ diameter. Among the areas of the reservoir's sections that minimum value in row A_1, A_2, …, A_n is searched for that satisfies inequality (10). This section is the deposition beginning of suspended sediments. The last point of deposition is determined by performing the same steps for the particle of $d_{\min}$ diameter. The displacement of the suspended particles during their falling down was neglected, which is calculable. Integration of (3) with quantities L, B, Q_S and ρ_s gives the regularity of the suspended sediments accumulation layer change with time [20].

Models describing the accumulation of bottom and suspended sediments are applicable if reliable data are available on river fluid and sedimentation regimes, particle sizes, and reservoir geometry.

For a reliable prediction of the sedimentation in the reservoir, it is necessary to clarify the sedimentation regime and the granulometric composition in advance and to choose reliable formulas for particle sizes and minimum velocities for the bottom sediments.

Hydrological methods can be used for assessing the sedimentation regime in the absence of hydrometric measurements from many small rivers in the mountainous zone. This problem has been partially solved at present and requires further investigation for the determination of the minimum velocity of the bottom sediment movement.

The relative values of the pulsation U_x, U_y and U_z velocities in the bed section with a width of $2S$ are given according to the average U_0 and average instantaneous U velocities. It can be seen from the graphs, that compared to the flow core, the pulsation velocities in the layers near the walls, and especially their vertical component, increase significantly.

4. Conclusions

During the filling of a reservoir by sediment-carrying rivers and streams, the design characteristics $W=f(H)$ of the reservoir bowl are continually changing.

As a result of this the actual volume of accumulated water reduces. The latter is necessary to take into consideration when the correct schedule of the reservoir operation is drawn.

The above said changes can be estimated by hydrological calculations if reliable data on the river fluid flow rates are available. Otherwise, periodic measurements in the reservoir should be taken to assess the quantity of accumulations and to specify the volumetric characteristics. The Mataghis reservoir's investigation proves that the reservoir volume has decreased by 60 per cent due to the 3.5 million m^3 of sediments accumulated in the first two decades of operation. From 1993 to 2012, the water in the reservoir has been drained and the new sediments have been removed in transit. At present, 70 per cent of the reservoir volume has been filled with sediment.

Theoretical models have been developed to describe the accumulation process of both suspended and bottom sediments. They enable the operating personnel to predict changes in the reservoir volume at various stages of operation, based on the reservoir's length and height.

Based on obtained data it is possible to predict changes occurring in the volume of the reservoir due to sedimentation in different stages of operation. With these changes, the reservoir's $W=f(H)$ characteristics should be adjusted on a regular basis to determine the actual volume of accumulated water.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The work has been carried out in the frames of Scientific and technical activity funded by Ministry of Education, Science, Culture and Sports RA Science Committee.

Data availability

Data will be made available on reasonable request.

References

[1] Kondolf, G. M., Gao, Y., Annandale, G. W., Morris, G. L., Jiang, E., Zhang, J. et al. (2014). Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. Earth's Future, 2 (5), 256–280. doi: https://doi.org/10.1002/2013ef000184

[2] Yuldasheva, K. A. (2011). Experience of sediment control in reservoirs. Tashkent, 72. Available at: http://www.cawater-info.net/library/rus/carewib/reservoir_sedimentation_review.pdf

[3] Hedrick, L. B., Anderson, J. T., Welsh, S. A., Lin, L.-S. (2013). Sedimentation in Mountain Streams: A Review of Methods of Measurement. Natural Resources, 04 (01), 92–104. doi: https://doi.org/10.4236/nr.2013.41011

[4] Baljyan, P. H., Kelejyan, H. G., Avanesyan, E. V., Tokmajyan, V. H. (2021). Evaluation of the actual state of the Mataghis reservoir W-H characteristic and forecasting of future changes. Bulletin of High Technology, 3 (17), 14–22.

[5] Liu, J., Minami, S., Otsuki, H., Liu, B., Ashida, K. (2004). Prediction of Concerted Sediment Flushing. Journal of Hydraulic Engineering, 130 (11), 1089–1096. doi: https://doi.org/10.1061/(asce)0733-9429(2004)130:11(1089)

[6] Gallerano, F., Cannata, G. (2011). Compatibility of Reservoir Sediment Flushing and River Protection. Journal of Hydraulic Engineering, 137 (10), 1111–1125. doi: https://doi.org/10.1061/(asce)hy.1943-7900.0000419

[7] Jansson, M. B., Erlingsson, U. (2000). Measurement and quantification of a sedimentation budget for a reservoir with regular flushing. Regulated Rivers: Research & Management, 16 (3), 279–306. doi: https://doi.org/10.1002/(sici)1099-1646(200005/06)16:3<279::aid-rrr586>3.0.co;2-s

[8] Hydrology, Hydraulics, and Sediment Studies for the Matilija Dam Ecosystem Restoration Project, Ventura, CA – DRAFT Report (2006). Sedimentation & River Hydraulics Group, Technical Service Center, Denver, CO. Available at: http://www.matilijadam.org/documents/Matilija%20H&H%20Design%20v2.pdf

[9] Liu, Y., Métivier, F., Gaillardet, J., Ye, B., Meunier, P., Narteau, C. et al. (2011). Erosion rates deduced from Seasonal mass balance along an active braided river in Tianshan. Solid Earth Discussion, 3, 541–589. doi: https://doi.org/10.5194/sed-3-541-2011

[10] Auel, C., Berchtold, T., Boes, R. (2010). Sediment management in the Solis reservoir using a bypass tunnel. 8th ICOLD European Club Symposium. Innsbruck, 438–443.

[11] Alahiane, N., Mouden, A. E., Lhaj, A. A., Boutaleb, S. (2014). Practical Method Proposed to Estimate Silting's Rate in Small and Hillside Dams. Journal of Water Resource and Protection, 06 (10), 930–943. doi: https://doi.org/10.4236/jwarp.2014.610088

[12] Mama, C., Okafor, F. (2011). Siltation in reservoirs. Nigerian Journal of Technology, 30 (1), 85–90.

[13] Ikramova, M. (2021). Regulation of the amudarya river runoff by the tuyamyun hydro complex. Warsaw. doi: https://doi.org/10.31435/rsglobal/032

[14] Baljyan, P. H., Poghosyan, A. A., Kelejyan, H. G., Namatyan, N. T. (2020). Quantitative evaluation of sediment accumulation in Mataghis reservoir. Bulletin of High Technology, 2 (13), 21–26.

[15] Khmaladze, G. N. (Ed.) (1971). Eastern Transcaucasia, In: Surface Water Resources of the USSR. Vol. 9. Keningrad: Gidrometeoizdat, 228. Available at: https://www.twirpx.com/file/1579884/

[16] Tokmajyan, H. V. (2016). On Movement of suspended particles in turbulent flow. Bulletin of High Technology, 1 (1), 3–10.

[17] Magomedova, M. R. (2014). Mathematical simulation of bed load movement in open channels. Makhachkala: ALEF, 136.

[18] Velikanov, M. A. (1958). Channel process (theory fundamentals). Moscow: Gosfizmatgiz, 395.

[19] Baimanov, K., Nazarbekov, K., Baimanov, R., Tazhibayev, S. (2021). Hydraulic calculation of irrigation settling tanks of Amu Darya irrigation systems. E3S Web of Conferences, 264, 03027. doi: https://doi.org/10.1051/e3sconf/202126403027

[20] Shamyan, V. L. (2021). Use of Various Thin-Layer Settling Schemes for Industrial Wastewater Treatment. Journal of Architectural and Engineering Research, 1 (1), 43–49. doi: https://doi.org/10.54338/27382656-2021.1-8

Received date 21.09.2022
Accepted date 26.12.2022
Published date 19.01.2023

How to cite: *Baljyan, P., Sarukhanyan, A., Avanesyan, E. (2023). Study of sediment deposition processes and assessment of the change in the W-H characteristics of the madaghis reservoir. EUREKA: Physics and Engineering, 1, 3–12. doi: https://doi.org/10.21303/2461-4262.2023.002757*