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Lessons Learnt During the Desilting of the Pucioasa Reservoir

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Abstract. The Pucioasa Storage Reservoir was designed as an earthfill dam with a maximum height of 30.50 m and an initial storage volume at the Normal Operation Level (NOL) of 10.6 hm3. The hydraulic system consists of the following elements: the reservoir, the earthfill side dams, the spillway dam, the water intake and the hydroelectric power plant. The Storage Reservoir is located in an area where the geology of the strata crossed by the tributaries in the river basin is mostly represented by fine compact layered, locally sandy marls, overlapped by medium and large alluvial deposits along the Ialomita River valley and clayey sands diluvium on the slopes. Therefore, the reservoir's silting process was observed since the very first years of operation (1974-1976), mainly during floods. The bathymetric surveys indicated a continuously increasing degree of siltation, with an annual rate of about 2.30%, with the reservoir's siltation degree as follows: 70.0% in 2006, 76.6% in 2016, 83.27% in 2019, reaching almost 100% in 2024. The advanced siltation of the reservoir threatens the safety of the dam structure itself and also increases the risk of overflowing the right bank of the closing dam. The overflowing risk of the right bank closing dam is favoured by both the alluvial deposits in the reservoir close to the NOL and the backwater propagation phenomenon. The backwater phenomenon is amplified by the development of vegetation at the reservoir entrance, increasing the roughness and also reducing the flow's section. The high degree of reservoir siltation makes it impossible to perform its main uses, namely flood mitigation and water supply to the beneficiaries, extremely important in the climate change and its effects context. This paper presents a practical case of desilting, part of a complex project carried out by The National Administration "Romanian Waters". It aims to highlight and analyse the challenges during the implementation of the project (e.g. the emptying of the reservoir and its consequences) and to provide insights on how to possibly overcome those challenges and to reduce the negative effects that may occur.

Keywords: Dam safety; desilting; reservoir uses

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INTRODUCTION

Siltation and the Effects of Siltation

Any watercourse carries sediments or suspended alluvium, until reaching a reservoir. Here, due to the change in the velocity regime and the longitudinal slopes of the free surfaces, the transport of alluvium stops, leading to accumulating deposits. Siltation begins at the tail of the lake, where large suspended particles and hardened alluvium are deposited, while smaller particles remain in suspension for a longer period of time and are deposited in the deepest area, along the bottom the reservoir, and even near the dam's upstream face.

The siltation process leads to the reduction of the Dead storage, and over time, it leads to the decrease of the Operational (useful) storage, thus affecting the reservoir's capacity and hence directly affecting its purposes.

The estimation of the siltation rate of the reservoirs mainly depends on the initial volume, the volume of the solid runoff and its distribution, the operation rules, the characteristics of the sediments and the percentage of retained sediments.

Main effects of siltation:

a) Decline of storage capacity

The main effect of siltation consists in reducing the storage capacity (useful storage), following the deposition of accumulated sediments. Reservoirs are gradually losing their role for which they were initially designed, respectively: flow regulator and/or water supply.

b) Influence on the safety of dams

Excessive sedimentation can also have harmful effects on the safety of dams because the capacity to contain floods is affected. Over time, even though mitigation measures were taken (use of very precise forecasts, presets, maintenance of all emptying organs in working condition), there is still the risk that the dam may overflow and even the dam may fail due to spillage.

c) Obstruction of hydromechanical equipment of outlets

Another important effect that can be generated by siltation consists in blocking the entrance of the outlets and with materials deposited near the dams. Such phenomena cannot always be avoided by washing manoeuvres and involve difficult and expensive works to unblock the respective holes. At the same time, these blockages could potentially lead to the loss of the operational consumers, which can lead to very serious consequences (water supply interruptions, important energy losses in the case of power plants, interruptions of production processes at industrial water consuming units)

d) Obstruction and abrasion of power plant equipment

Obstructions can also appear in the operation of hydroelectric plants. If normally the clay particles and dusty alluvium move without difficulty in the turbines, the sand particles behave like a real sandpaper. Excessive abrasion damages the rotor blades and rings as well as the shaft seals. In order to keep the groups in operation, frequent stops are necessary for the replacement/adjustment and repair of damaged parts.

e) "Delta" effects at the entry zone into the reservoirs

The siltation at the "tail" of the lakes has effects on the extent and configuration of the areas inundated by floods. This type of siltation can endanger settlements and various installations (industrial facilities, railways, roads etc.)

The State of Siltation in Romania

In Romania, an area of about 7.3 million ha (30% of Romania's territory) is affected by soil erosion and torrential processes, of which 5.3 million ha require extensive works to mitigate the phenomenon.

Giving the degree of siltation, for the storage reservoirs operated by the National Administration "Romanian Waters", the most affected area is the Arges valley, in the Southern part of the country, while the least affected areas are located in the Mures and Olt Superior basins, in the Central parts of the country, where the reservoirs have lower siltation rates.

CASE STUDY – PUCIOASA RESERVOIR

General Data

The dam and the reservoir were built between 1971-1975 and commissioned in 1975. The reservoir has multiple uses, namely: the drinking water supply of the municipality of Pucioasa, the water supply for trout farming, the water supply for downstream consumers, the production of energy, fish farming, recreation, as well as floods mitigation.

The hydrotechnical construction consists of: Tiered spillway dam, Right bank dike, Left bank dike, Outlet for the water supply of the city of Pucioasa, Service outlet, Outlet for the water supply and Energy outlet.

The Pucioasa dam and reservoir are located in the upper basin of the Ialomiţa river, immediately upstream of the Pucioasa town.

The Pucioasa Reservoir is located in an area where the geology of the strata crossed by the tributaries from the hydrographic basin, upstream of the dam, is mostly represented by fine compact, layered, locally sandy marls, on top of which are superimposed formations represented by medium and large alluvium along the Ialomita river valley and clay-sand deluge on the slopes, so that the lake's silting process could be observed from the first years of operation (1974-1976), when the first floods occurred. The carried-out bathymetry indicated a continuously increasing degree of siltation, with an annual rate of about 2.30%, respectively percentage of siltation: 70.0% in 2006, 76.6% in 2016, 83.27% in 2019, reaching so that in 2024 the reservoir is almost completely closed.

The Evolution of the Siltation Phenomenon

The evolution of the siltation phenomenon was determined by successive topo- bathymetric measurements. The first measurements took place before the lake was filled in June 1974, when obviously there could be no siltation, the resulting volume being 10.6 million m3. In 2002, the volume of water at NNR decreased to 3.489 million m3 corresponding to a degree of siltation of 67%. Between 1999 and 2002 there was a dramatic increase in the degree of siltation, when in addition to the usual training conditions, an exceptional flood occurred between June 18 and 23, 2001 when the flood on Ialomita (where the maximum flow recorded at Moroeni was 372 m3/s) overlapped with the flood on Ialomicioara (with a maximum flow measured at Fieni of 242 m3/s). These maximum liquid flows transported and accumulated solid flows of 6120 kg/s brought by Ialomita and 765 kg/s brought by Ialomicioara compared to a multi-year average of 0.5 kg/s at Moroeni and 4.12 kg/s to Fieni.

The bathymetric study carried out in 2006 indicated a volume at normal operating level of: V= 3.18 mil m3, that is, a degree of siltation of approx. 70%. The results of the bathymetry were influenced by the floods of 2003 and 2005, which were transited through the reservoir fully, using the evacuation capacity by opening the bottom outlets. Thus, the alluvium were washed and transported downstream along a sector located on approx. 850 m from the dam.

In September 2016, the Buzau Basin Forecasting, Hydrology and Hydrogeology Service carried out a bathymetric study that resulted in a volume of water at normal operating level (418.00 mdMN) of 2.22 million cubic meters, corresponding to a siltation percentage of 76.6% and an annual rate of siltation Rc%, of 1.78%.

The siltation of the lake continued, so that the bathymetric study carried out in 2019, shows a volume at normal operating level of the water in the reservoir of: V = 1.589 mil. m3, i.e. a degree of siltation of Pucioasa Lake of approx. 83.27%.

The evolution of the siltation of the reservoir is presented in the graph below (FIGURE 1):

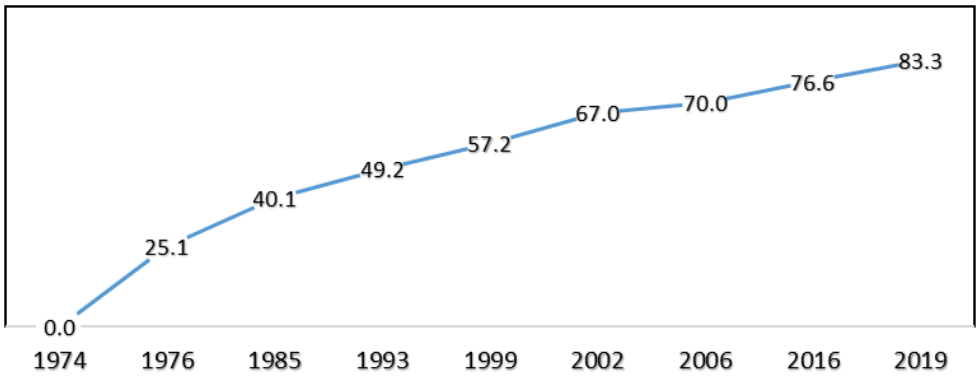

FIGURE 1. The evolution of the degree of siltation in the Pucioasa reservoir

Desilting of Sediments in the Pucioasa reservoir

The advanced stage of siltation of the lake presents a risk factor in the operation of the facility. According to the technical expertise carried out in 2019, the most unfavorable situation is at the tail of the lake. In this area, the roughness has increased significantly due to the excessive growth of vegetation, reducing the transit capacity, which can lead to the failure of the right bank dike due to spillage. Added to this situation is the phenomenon of backwater,

which leads to an increase in the amount of free surface. Under these conditions, there is a risk of failure of the right bank dike of the closure dam due to overflowing of the dam crest.

The desilting works were included in Part 1 - Safety of the Pucioasa Reservoir, of the integrated project "Flood Risk Mitigation in the Ialomita Watershed Downstream of the Pucioasa Reservoir" - 'Component I BH Ialomita Superioara'. This project responds to the strategy of Flood Risk Management Plan (FRMP) and it has as its main purpose reducing the flood risk in the Ialomita river basin, considering, at the same time, the improvement of the ecosystem and biodiversity conditions, the mitigation of the effects of climate change and the enhancement of the spatial planning and land use framework. The project aims to minimize the effects of natural disasters on the population, material assets and socio-economic objectives in BH Ialomita downstream of the Pucioasa Reservoir (32 localities and a number of approx. 176,314 inhabitants affected, at the integrated project level). The proposed measures respond to the major situations in the area of interest: the problems generated by the risk of flooding, as well as the problems caused by the erosion in the upper basin of the Ialomita and the siltation of the Pucioasa reservoir.

As a solution for the desilting of the Pucioasa reservoir, the designer proposed the creation of a channel with a base width of 50 m. The proposed solution is justified by the fact that at the tail of the lake has developed vegetation and it does not allow drawdown flushing. The solution was based on hydraulic calculations in the current regime and the planned regime. The width of the channel will increase as a result of the self-dredging phenomenon, by driving the material deposited at the tail of the reservoir, which is triggered when the bottom outlets are opened. The self-dredging is directly influenced by the dimensions of the channel/sailing line, in the sense that a small size of the channel/sailing line implies a high flow speed, consequently, over time, the channel/sailing line will increase its dimensions, through the effect of self-dredging.

The channelisation has been done with the lake completely emptied and it started from the tail of the lake so that the water from the alluvium drains downstream and the alluvium has a reduced humidity. The excavated material from the channel/sailing line will be transported and systematized on the degraded lands, located in the Valea Popii area of the Sotanga locality, Dambovita county, where later, on an area of 9.91, after the systematization of the excavated material, an ecological zone will be created, through afforestation. The afforestation will be carried out by the Ploiesti Forest Guard, partners in the project, based on the Partnership Agreement concluded between M.M.A.P., A.N.A.R - A.B.A. Buzau-Ialomita and Ploiesti Forest Guard).

The works started after approximately four years of preparing the financing application and obtaining the financing.

For the preparation of the works, the emptying of the lake began on May 8th.2024, respecting all the legal provisions, regarding obtaining all of the permits and authorizations and informing the downstream users. However, the emptying of the reservoir had its challenges.

The image bellow illustrates the reservoir immediately after emptying (Figure 2).

FIGURE 2. Aerial photo of Pucioasa reservoir after the emptying

Considering the high degree of siltation in the reservoir, combined with the fact that the alluvium was sedimented at the base of the bottom outlets, the emptying occurred with a high degree of turbidity. This aspect imposed the interruption of the water supply to the utilities downstream, a fact which attracted a series of complaints both from the owners of the utilities and from the local authorities.

The complaints were based, in addition to the visual impact caused by the high degree of turbidity, as well as the lack of water supply during this period.

It should be emphasized that the launch of the project was publicized, and the dissemination of the project, including the stages of its realization, had been done since the feasibility study phase.

To reduce the downstream turbidity, additional works were carried out, namely works to divert a flow of water from the upstream reservoir area to the downstream area. These had the purpose of bringing a flow of "clean" water with a reduced turbidity downstream of the reservoir.

Also, the effects of emptying the reservoir led to a series of meetings between the beneficiary of the works, the local authorities, as well as the owners of the utilities affected. All this led to delays in starting the channelization works.

The emptying of the reservoir at a specific date was imposed by several aspects. The first, and probably the most important, was the deadline for the completion of the project, imposed by the financing conditions, i.e. December 2025. In addition, the signing of the works contract happened after a period of approximately 6 (six) months at the launch of the procurement procedure, thus leading to delays in project implementation.

Moreover, following the emptying of the Pucioasa reservoir, a natural channel was formed on the right bank of the reservoir through which the Ialomita river now flows (Figure 3). Furthermore, at this moment, it could be observed a significant increase in the levels of alluvial material deposited in the reservoir, compared to the topographical study carried out in 2022, specifically alongside the proposed channel . To establish the current volumes of excavations, the results of the topographical studies from October 2024 and the drone measurements were used.

The current results indicated that using the initial path of the channel would lead to the excavation of a much larger additional volume of alluvium.

FIGURE 3. Aerial photo of Pucioasa reservoir a few weeks after the emptying

Under these conditions, it was proposed to change the initial path of the channel. The new path will a part of the natural channel formed after the emptying of the lake (upstream area and middle area) and in the downstream area on the initial one. This way, the additional volume of excavated alluvium will be smaller than the additional volume that would have been excavated from the initial path.

The geometric characteristics of the initial channel were:

- width at the base, b = 50 m;
- slopes, 1:1;
- the height of the excavated layer, h = 3.50 m – 10.90 m;
- channel length, L = 2,600 ml.

At this moment, the new channelization path is under approval from the beneficiary, followed by the execution of the channel.

The creation of the channel will ensure an increase in the volume of water that can be stored in the reservoir by approximately 0.436 hm^3, from a volume of 1.589 hm^3 in the initial situation (volume of water stored at the NOL in the Pucioasa reservoir, resulting from the topo-bathymetric profiles placed at disposition) at a value of 2,025 hm^3 (volume of water stored at the NOL in the Pucioasa reservoir after the works of channel/sailing line). The volume of approximately 0.436 hm^3 represents the volume of sediments removed from the lake following the implementation of the channel/sailing line works.

The channel/sailing line execution solution in the reservoir combined with the efficient operation of the outlets represents the scenario that will ensure the optimal flood mitigation of 1% protection according to the Romanian Flood Risk Management Strategy.

CONCLUSIONS

The Pucioasa dam and reservoir are located in a geological area that favors the lake's siltation process, which started from the first years of operation (1974-1976), when the first floods passed. The high degree of siltation made that in 2024 the reservoir is almost completely clogged.

The dam safety works were included in the integrated project “Flood Risk Reduction in the Ialomita River Basin Downstream of the Pucioasa Reservoir” - 'Component I BH Ialomita Superioara', implemented by the National Administration “Romanian Waters”. These works include works of desiltation of the Pucioasa Reservoir.

The desilting of the Pucioasa Reservoir will ensure an increase in the volume of water that can be stored in the reservoir by approximately 0.436 hm^3, from a volume of 1.589 hm^3 in the initial situation, to a value of 2.025 hm^3 (volume of water stored at the NOL in the Pucioasa reservoir after the channel/sailing line works). The volume of approximately 0.436 hm^3 represents the volume of sediments removed from the lake following the implementation of the channel/sailing line works. This volume will increase due to self-dredging effect.

The solutions proposed in the project implemented by the National Administration "Romania Waters" will ensure the optimal flood mitigation of 1% protection against floods according to the Flood Risk Management Strategy.

Lessons learnt:

1. There is a need of an enhanced coordination between all the stages of the project from planning to financing and implementation;
2. Stakeholder engagement is important throughout all the phases of the project;
3. The field conditions can change from a phase to another, adjustments to the initial technical documentations might be required;
4. Better regulation system is required to reduce the implementation period of a project.

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