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Re-operationalization of dams to adapt to climate change in Romania

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Abstract. Increased hydrologic variability has and will continue have a profound impact on the water sector through the water availability versus water demand and water allocation at the global, regional, basin, and local levels. The recent increases in the frequency and intensity of floods and droughts in Romania, combined with the reduced drought and flood storage buffering capacity of dams under a changing climate may have critical implications for the region's water supply and economy. Increasing the size and number of dams in addition to "dam reoperation" (i.e., modifying dam operations) may be necessary to offset the climate change impacts on flooding and drought vulnerability. The present paper deals with several examples of required changes in Romanian dam operation: the new constrains in operation of hydropower developments, the needed increase of attenuation volume for existing reservoir by lowering the reservoir level, the new concept in characterizing the flood by its volume instead of the peak inflow and the reasonable procedures to coope with the large siltation of some existing reservoirs.

Keywords: Dams, reservoir operation, climate change.

1. Introduction

A series of phenomena and processes from the last period - the global temperature increase, the increase in the frequency of heat waves, droughts, the change in the precipitation regime, the reduction of the snow layer, the change in soil moisture and surface runoff - are called global climate changes. For the reservoir operation they cause changes in the hydrological regime of the watercourses. Usually, dam safety management has been carried out assuming stationary climatic and non-climatic conditions. However, the projected alterations due to climate change are likely to affect different factors driving dam risk [1]. This includes impacts and

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adaptations that relate to the op*era*tion and use of reservoirs. The main operating purpose of a dam (e.g. flood management, hydropower or water supply) will influence dam reoperation strategies. Reoperation may require integration across sectors or involve multiple dams, enhancing benefits such as water supply or hydropower while simultaneously achieving ecosystem restoration.

The change in the hydrological regime, characterized by more frequent and larger floods and, in opposition, by prolonged droughts, leads to significant effects in the operation mode of the dams and to additional risks in their safety.

2.The impact of climate change on the discharge regime downstream of the dam

The effect of the reservoir on the regulation of downstream flows is globally expressed by the volume of water retained and respectively discharged into and from the reservoir. For flood control the actual effect is done not by the volume of the reservoir itself is but by the ratio between the reservoir and the annual stock of the river. An index of the degree of regularization can be defined if the volume of water temporarily stored in relation to the stock. Currently, the operating rules are based on the assumption that flood volume is constant, corresponding to the hydrological conditions at the design level. The changes in the natural flow caused by climate changes leads to reevaluation of the needed attenuation volume provided by the existing operation rules.

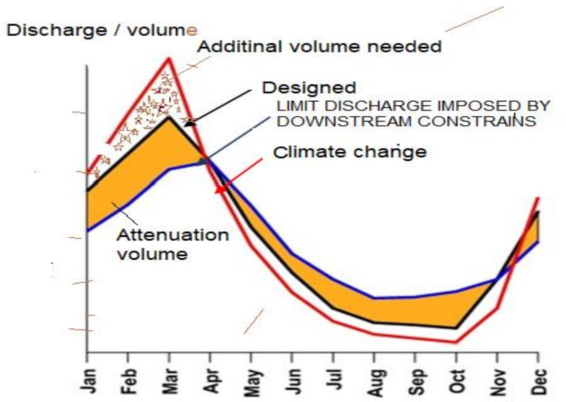

Fig. 1. Inflow and outflow variation.

The consequences of the changes of the inflow hydrograph corresponding to the maximum volume flood are rendered evident by the analysis of the hydrological safety of a very large flood control storage in Romania, i.e., Stanca Costesti reservoir with a total volume of 1400 mill. m^3. Stânca-Costeşti hydraulic development is located on the Prut River at the border between Romania and the Republic of Moldavia.

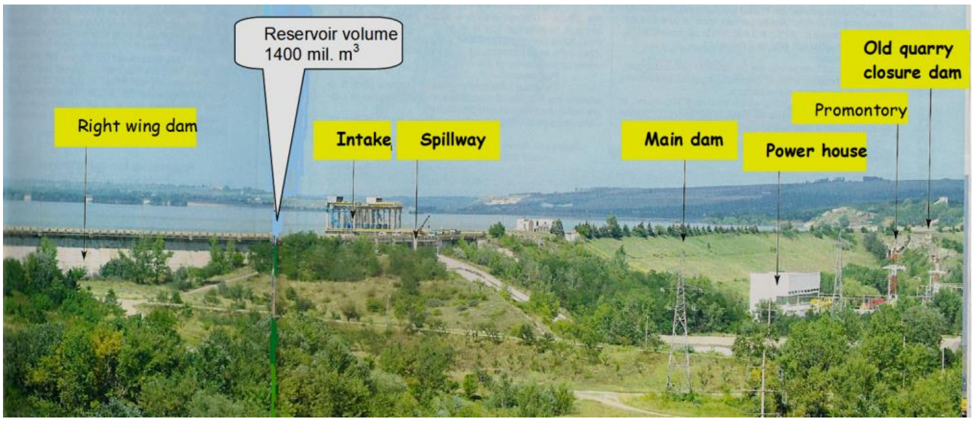

Fig. 2. Arial view of Stanca Costesti Dam.

The retention front has a length of over 3 km and includes a series of dams of different types and characteristics, connected among them, or separated by sectors of the natural ground with higher elevation. The maximum dam height is 47 m, the dam length is 740 m. The hydraulic development performed in the 1973-1978 period was commissioned in 1977.

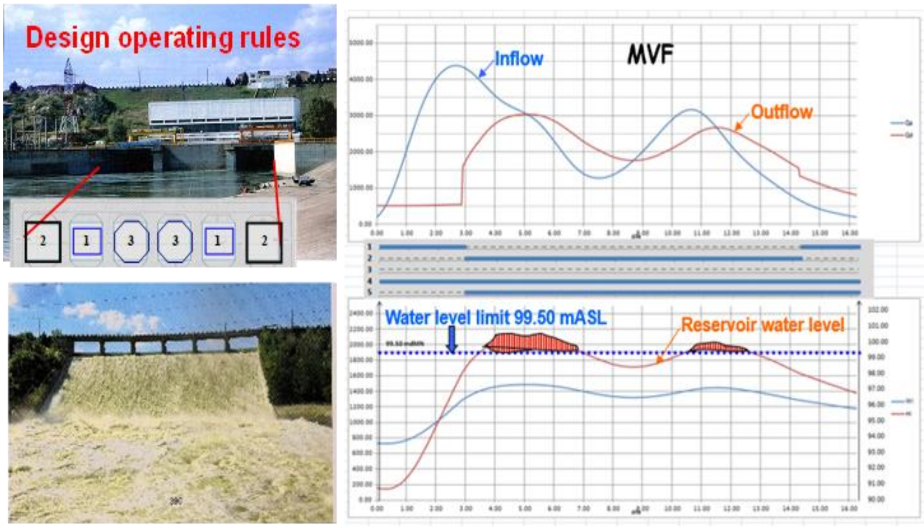

Fig. 3. Water level in the reservoir overpassed the flap gates.

The routing through the Stanca Costesti reservoir of some significant floods occurred in the last decades has shown the significant departures from the designed floods. The largest one was during 25 July - 02 August 2008 with maxim discharge 3380 m^3/s (15% larger than design flood) and a volume of 982 hm^3. By using the designed operation rules water level in the reservoir overpassed the upper limit of the flap gates on the main spillway [2].

In the case of Stanca Costesti reservoir new operating rules are in development. One alternative is to increase the attenuation volume [3]. The water level lowering will be in direct conflict with hydropower output and with lake shore existing developments. In many other cases the need to provide flood mitigation volume for the protection of downstream communities by pre-regulating the lake is in direct conflict with the need to have volumes of water available in the lake to compensate for the effects of drought, to supply water to the population and economic objectives and for the flow ecological. The negotiation to agree the two trends becomes much more difficult in the context of climate change, when both requirements become more acute - higher floods followed by prolonged droughts.
Changing the operating regime of the dams (more recently called re-operation) can partially solve the impact induced by climate change, but certainly, if the current trends persist, new accumulations will be needed, either frontal or lateral [4].

2. The impact of climate change on the operation of hydropower facilities

Hydropower reservoir alter the seasonal flow patterns and can be out of phase with the natural flow regime, reducing flow during high-flow periods and increasing flow during low-flow period. The regular operation pattern can be significantly changed by climate change. In many rivers, climate change will affect water availability for hydropower and ecosystems. The impacts of climate change on hydropower development are complex, often interactive, issues. Many studies have already focused on climate change impacts on the hydrologic cycle. The gross hydropower potential is expected to increase in with increased river flows.
Even before the signal brought by climate change, together with the changes regarding the approach to public security and environmental protection, there were also changes in the way of operation and maintenance of the existing hydropower facilities. They were imposed by the requirement to satisfy some additional stakeholders compared to those from the date of hydropower dam commissioned. The operation changes have to accommodate the new basin management policies: protection against floods, supply of water for the population and irrigation, ensuring a minimum ecological flow, restoring some wetlands, tourism development, etc. These requirements increase with climate change. In the vast majority of them, the re-operationalization lead to a reduction in the amount of energy produced. Thus, the increase in the guaranteed minimum flow downstream of the dam reduces the volume of water used by turbines, the maintenance of restricted lower elevations in the reservoir to provide the volume of flood mitigation reduces the power plant head, the restrictions on the seasonal variation of the water level in the reservoir imposed by tourism or fish farming affect energy regularization, etc. In all these situations, amplified recently, an optimization between conflicting uses is required.
In order to underline the effects of the re-operationalization, the case of Tarnita waterpower plant is presented in the followings, were the added water supply service lead to a reduction in the amount of energy produced.

The Tarnita arch dam, with a total height of 97 m, and a crest length of 237 m was commissioned in 1974 and provides the storage for the power station located at the downstream toe of the dam. The power station is equiped with two Francis units of 22.5 MW each. The favorable geological and morphological conditions have allowed for a thin double curvature structure with only 11 m thickness at the base (figure 4).

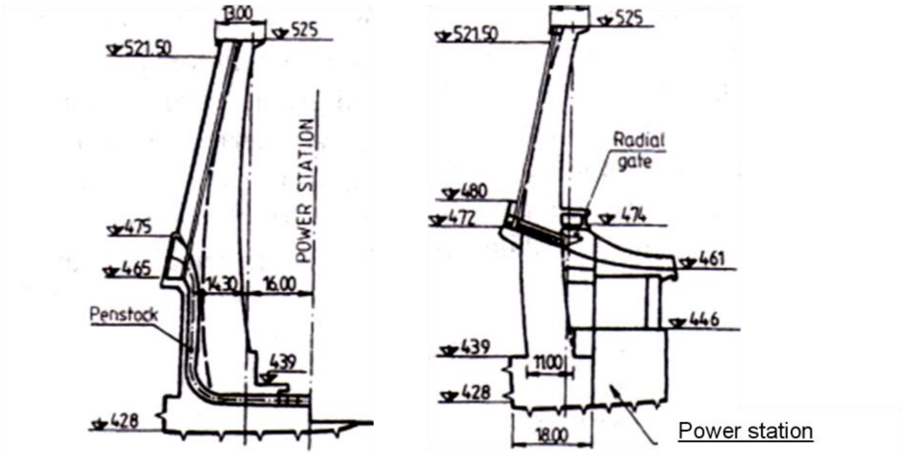

Fig. 4 Tarnita Dam.

The reservoir has a volume of over 70 million cubic meters and is fed by the waters of Someşului Cald and its tributaries from a watershed of 491 square kilometers. The surface of the lake is 220 hectares, and the maximum depth is over 70 meters.

Although built as a hydropower facility, the Tarniţa reservoir currently has a triple role. In addition to the production of electricity, the water from the reservoir is also used as water supply source for the towns of Cluj-Napoca and Gilău. The dam also plays an important role in flood control. The change in the reservoir operation rules was imposed by the constrains induced by climate change on the existing water supply sources- diminishing of water wells output due to a long period of drought and severe siltation of the Gilau reservoir that used to be a second source. In order to accommodate the new reservoir, function several civil works were needed including the construction of an intake tower and a 5 km water duct (figure 5).

Fig. 5. The new intake tower.

Some concluding data regarding the effect of the new imposed operation rules are: the water volume provided for population is, in a average, 32 943 000 m^3/year; the water power specific consumption is 3400 m^3/ MWh; the energy loss is 9.689 GWh/year [5].

On the other hand, it should be emphasized that the exploitation of hydropower potential is a component of water management. Recently, there has been a tendency to design hydropower facilities with the sole objective of "profitability", expressed as a specific investment and internal rate of return. Such an approach inherently leads to reservoirs with minimum volumes required for hydropower, neglecting both the concept of assured power and the full utilization of the water resources in the site. On the basis of the specific legislation and the national program for harnessing the hydropower potential, the hydropower development schemes with complex use must be updated, taking into account [6]:

- the regularization of the natural hydrological stock of the hydrographic basins to cover in the dry periods the water reserves necessary for the population, industry, agriculture;
- the flood protection for localities, roads, and agricultural lands;
- developing the tourist and fishing potential in the area of the future developments.

4. Dam safety under increased floods

Exceeding the designed capacity of the dam spillways, followed by crown overpassing, is by far the most common way of failure: over 30% of cases worldwide. The inflow is par excellence a random quantity, possibly transformed by upstream attenuation processes. The value and distribution of the spillway capability depends on the type of evacuator and its availability. The attenuation volume provided by the reservoir depends inextricably on the initial water level in the reservoir bat the time of flood arrival. All of them are random variables that must be included in the operation rules of the reservoir.

The change in the hydrological regime imposed by climate change directly affects both factors that define the safety of the flood control - the inflow and the water level in the reservoir. If for the first factor the effect is obvious, for the second the effect is caused by the need to store as large volumes as possible in the lake, in order to ensure the needs of the uses in the conditions of prolonged droughts and therefore to keep a high level in the reservoir.

At first glance, the engineering solution is to increase the capacity of the spillways through additional dischargers and/or through fusible dischargers. The solution is doubly wrong. First, it involves high costs and secondly, it produces a reduction of flood attenuation by passing it through reservoir generating higher flows downstream. The rational approach consists in creating larger volumes to mitigate floods, either by pre-emptying the reservoir, or by attaching lateral storing volumes.

For illustration, the case of the Mihailesti dam is presented. The reservoir with a volume of 52.7 hm^3 is realized by a concrete gated dam with maximum height of 25.50 m, a frontal earth dam on the right bank of 2 km and a longitudinal dam closing the left wing along 11.48 km, with a maximum height of 13 m.

The spillway of the dam is provided by 3 discharge bays, 10 m wide, equipped with radial gates with flaps (10 x 5.75 m^2) and three bottom outlets equipped with radial valves with (10 x 3 m^2). In addition, the dam was provided with a safety spillway implemented into left wing lateral dam, towards the tail of the reservoir. Its aim was to increase the discharge capacity of the spillway system in the event of floods that exceed the design flood ($Q_{0.1\%}$ = 2,935 m^3/s).

According to the design operating regulations, the design flood is partly retained into reservoir, by lowering the water level from 85 mdMB (normal operation level) to 82 mdMB. For the routed flow the discharge is achieved by using the full capacity of the gated dam and the by using, beside the gated bays, the safety spillway that can discharge an additional 385 m^3/s. Without operating the safety spillway the level in the reservoir reaches the crown elevation (89.50 mdMB), endangering the dam safety.

The designed operation rules are no longer valid. The entry into operation of the safety spillway leads to the flooding of a large area. At the design time the area was used as an agriculture land but, in the last 20 years, the use of land has been changed, by extending the inner-city limits to the vicinity of the left bank dam.

Under the new conditions, having in mind the possible increase of the river floods under climate changes, flood transit through the reservoir must be reviewed (re-operationalization). The rational approach is to increase the attenuation volume by increasing the pre- lowering of the reservoir and relying on the main spillway. Based on a warning with a three-day advance, it is possible to lower the reservoir to the level of 76.16 mdMB keeping the discharges towards the downstream in the limit of the river bed capacity. The procedure has to be extended if we will face increase in flows and volumes of floods produced by climate change.

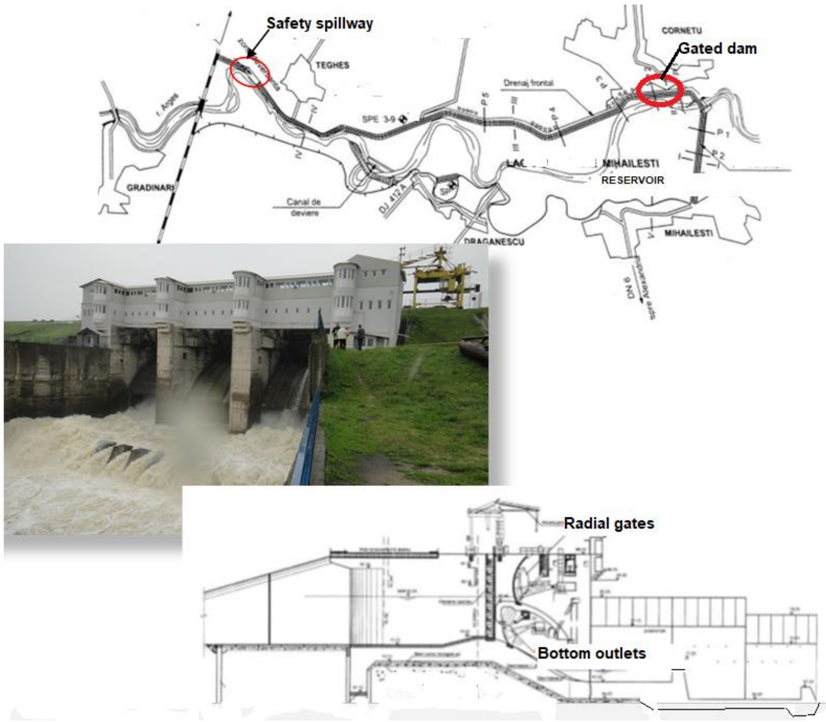

Fig. 6. Mihailesti Dam

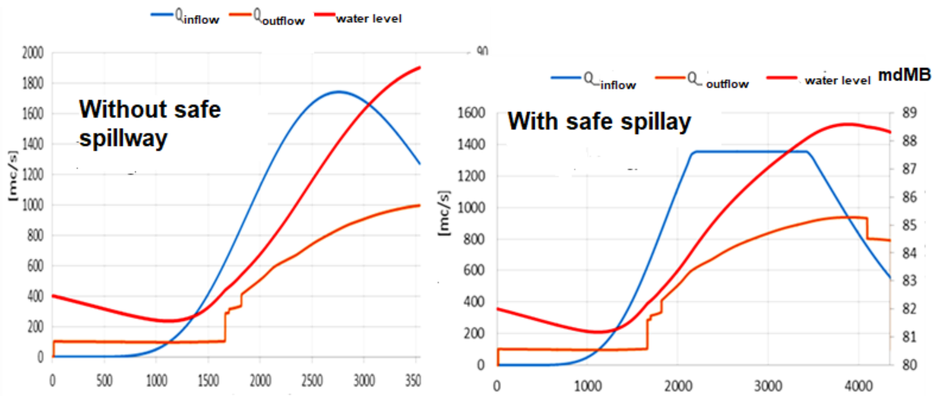

Fig. 7. Volumes and levels during the transit of the design flood

5. Increased siltation and its effects on reservoir operation

Among the consequences of climate change are the increase in torrential flows on the basin slopes, the activation of torrents on streams that are usually with no water and flush-floods of increasing magnitude. These changes in the regime of surface runoff lead to the amplification of erosions in the watershed and directly to the increase of the solid flow. A recent study conducted in the United States of

America shows an increase in solid transport by 1.7% for every 1% increase in precipitation volume.

For dam reservoirs, the phenomenon is extremely unfavorable, leading to their increased clogging. The immediate effect is the decrease in operating volume, affecting both the use of raw water supply and the ability to mitigate floods, for downstream protection. A situation often easily overlooked is the clogging at the tail of the lake. Over time, veritable alluvial dams are produced, intensely vegetated, sometimes even forested, which prevent the access of water into reservoir. The flood can bypass the reservoir with a direct effect on the dam safety, but especially with catastrophic effects for the localities located adjacent or downstream of the dam. To illustrate the issue the case of Pucioasa dam is presented in the following. The dam and the Pucioasa reservoir are in the upper basin of the Ialomita river, immediately upstream of the Pucioasa town. The dam has a height of 30.5 m. The gated dam has a 16 x 2.50 m flap gates and 3 bottom outlets of 4.00 x 4.00 m, equipped with radial valves. The reservoir is bordered by lateral dams with a length of 3,128 m.

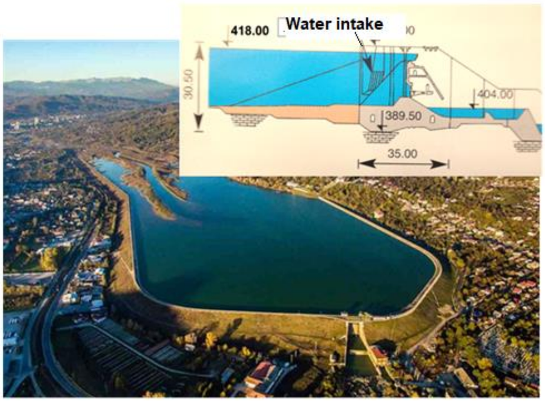

Fig. 8. Pucioasa dam and reservoir.

At the design time (1971), the volume of the reservoir up to the normal operation level was 10.6 million m ^{3}. In 1993 the volume was already reduced to 5.08 million m^3 , that is 47% clogging. In 2002, the volume was of 3.49 million m ^{3} , with a degree of reservoir clogging of 67%, and currently it has reached over 75% clogging.

Figure 9 shows a satellite view of the evolution of the lake's clogging. It is visible that in time the area at the tail of the reservoir has become clogged and covered with vegetation. The Ialomita River enters the lake through a corseted channel, and during floods, even modest ones, the river bypasses the accumulation by the right of the lateral dam and directly floods the town of Pucioasa downstream.

Fig. 9. The evolution of the silting of Pucioasa reservoir (Google Maps).

6. Concluding remarks

The increase in the frequency and in magnitude of floods and the increase of the severity and duration of drought periods, combined with the lack of regularization volumes in the reservoirs of existing dams can have critical implications in social and economic security and sustainability. Consequently, the new tendency induced by climate changes leads to significant effects in the operation mode of the dams and to additional risks in their safety.

In the context of climate change, the operation of hydropower facilities must take into account the regularization of the natural hydrological stock of the watershed in order to cover the water reserves for population, industry and agriculture. Their reservoirs have to provide also the safe transit of flood waves protecting localities, communication routes and agricultural land.

The change in the hydrological regime imposed by climate change may led to larger floods that endanger the dam safety. The rational approach for maintaining safety requirements consists in creating larger volumes to mitigate floods by pre-emptying the reservoir.

In the case of reservoirs with a very high degree of clogging, where the regularization volume is compromised, additional risk is the done by overflowing the tailing of the reservoir and leading the incoming flow outside of the reservoir thus flooding the neighboring areas.

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