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IMPACT OF FLOODS ON THE NERETVA BASIN 03/04.10.2024. YEAR ON THE OPERATION OF HPP ON THE NERETVA AND THE ROLE OF HPP IN FLOOD PROTECTION

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Abstract: In this paper situation on catchment of river Neretva with flash floods, consequences on hydro power plant facilities, damages, experience and learned lessons are described, as well as a positive impact of dam on flood protection of downstream areas. The short-term high-intensity precipitation that occurred in catchment of Neretva River had a consequence of almost instantaneous increase in the flow of small streams, tributaries, causing flash floods while the main stream, Neretva remains quite calm. In some area total rainfall occurred at night 03th/04h October acceded the most critical month values recorded up to now. Extreme amounts of rainfall in a very short time created strong torrents. This triggered landslides, rockfalls, earth drifts along with vegetation, which resulted in enormous damage in public infrastructure and energy facilities and hydro power plants, also. Roads, railway, telephone lines, mobile communications, even the power supply to some facilities was disrupted. A major challenge for hydropower plant operators was to enable production, assess the safety of energy facilities for exploitation, and urgently take measures for the safe operation of hydropower plants, as well as to take short-term and long-term measures to repair the damage. Experiences and lessons learned at that event can significantly help in making decisions in the future. At the same time, it has been shown that dams and reservoirs of hydroelectric power plants can play a key role in preventing flooding of downstream areas.

Keywords: Precipitation, flash floods, damage, hydro power plants, inflow

INTRODUCTION

The impact of climate change on hydropower generation is very visible. Summers are already drier, winters are milder due to less precipitation, there are periods with extremely dry periods as well as extremely low temperatures. There are also short periods with large amounts of precipitation in relatively short periods that cause floods [1]. In addition to climate change, local interventions in the area such as deforestation, stone exploitation, construction of roads and settlements significantly affect the microclimate and slope stability. The combination of climate change and local interventions in the area significantly complicates the planning of electricity production from water, as well as the maintenance of energy facilities.

A combination of extreme precipitation in a short period occurred in the Neretva River basin on October 3rd-4th, 2024, causing extensive flooding and damage to infrastructure.

1. WEATHER CONDITIONS

On the night from Thursday to Friday, (October 3rd to 4th, 2024), a warm and moisture-rich air mass from the south swept across Bosnia and Herzegovina (Figure 2). In the early morning hours of Friday, October 4th, 2024, this air mass spread to the mountainous north and northwest of Herzegovina, bringing specific meteorological conditions that resulted in heavy rainfall accompanied by thunderstorms. In the morning and before noon, the intensity of precipitation gradually weakens and mostly stops during the day (Figure 3 right). The amount of rain that fell in a few hours was more than the amount of rainfall recorded in one month ever.

In the hours preceding the start of the flood event, moderate intensity precipitation was recorded, which led to the saturation of the soil, which was no longer able to infiltrate heavy rainfall, and very soon after the start of the flood event, surface runoff occurred, which ultimately resulted in catastrophic torrents, rock and mud flows, landslides and floods. In addition to soil saturation, a part of the catchment area consists of karst, which can additionally accelerate runoff (Figure 4).

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Figure 1: Catchment area of river Neretva

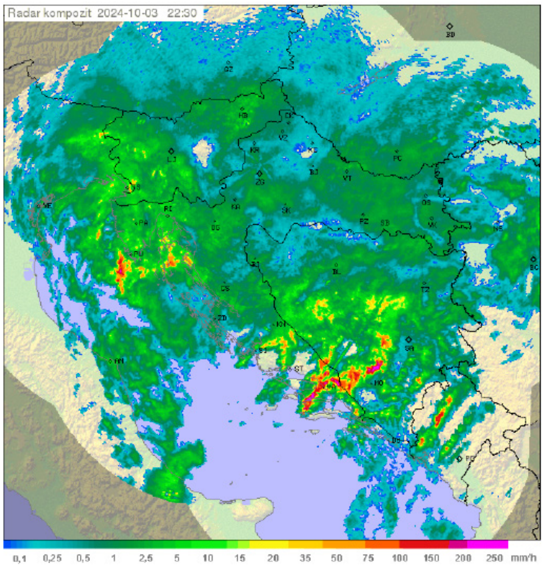

Figure 2: Rainfall intentisity over larger area according to radar image for 3.10. 22:30

Location	Precipitation
Goransko polje	450 mm
Dam Jablanica	323 mm
Dam Grabovica	270 mm
Drežnica	231 mm
Konjic	167 mm

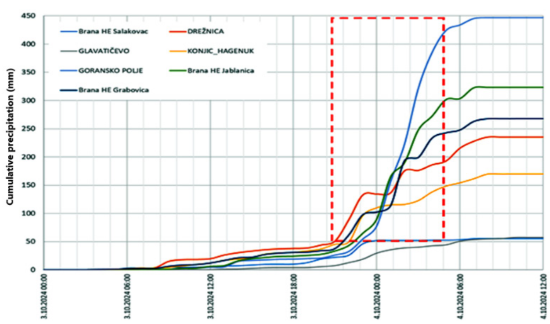

Figure 3: Cumulative precipitation recorded on the 5-station relevant for HPP (up); Precipitation recorded on wider area of Konjic and Jablanica in October (down).

Precipitation recorded on wider area of Konjic and Jablanica in October is shown in Figure 3 (up). It can be concluded that extremely high rainfall intensities were recorded simultaneously at almost all stations. Cumulative distribution of rainfall recorded at 5 stations relevant for HHP are shown in Figure 3 (down). As illustration maximum precipitation in a function of duration for Gorani station is shown in Table I.

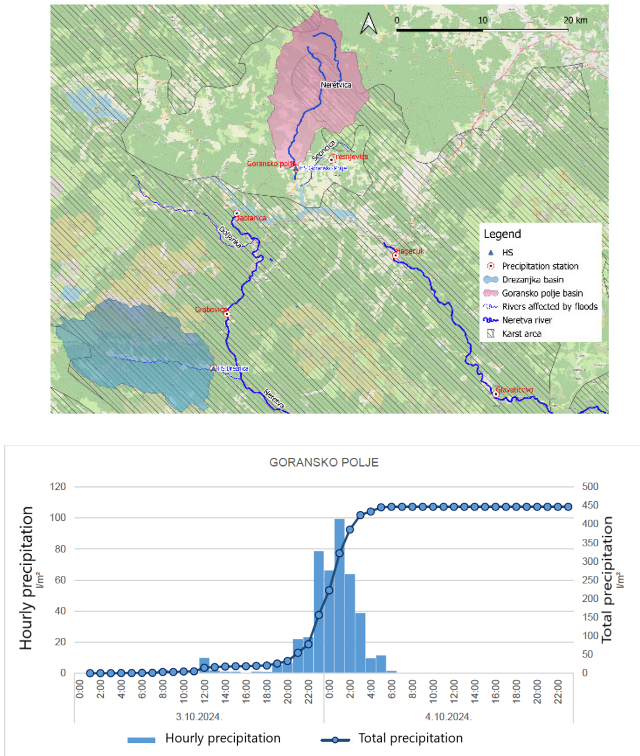

Figure 4: Wider area affected by flash floods from October 2024 (up); Precipitation recorded on the Neretvica river (down).

Table I. Maximum precipitation of selected duration for Goransko polje station

Duratioh (h)	1	2	3	4	5	6	7	8	9	10	...	24
Goransko polje	100	185	263	309	346	370	392	406	413	420		446

The Neretvica River is one of the most important tributaries of the Neretva River. It springs near the top of Vitreuš at 1510 m asl, and flows into Jablaničko lake. The boundaries of the orographic basin are shown in Figure 1 (up), with other rivers affected by the October 2024 floods (Figure 1 down). Basin height ranges from 285 to 1913 with average height 1106 m asl and the total area of 129.7 km2 (with karst share of 41 percent). From Figure 4, it can be clearly seen that in the hours before the flood, recorded precipitation intensity was weak to moderate, which caused extremely high surface runoff that ultimately resulted in catastrophic torrents, rock-mud flows, landslides and floods.

One of the one of the most extreme cases is station HMS Gorani –Neretvica, where the amount of rain that fell in a few hours was more than the amount of rainfall recorded

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in one month ever (Figure 5). For comparison, the period of the last 15 years was taken, namely data for the most critical days of the year.

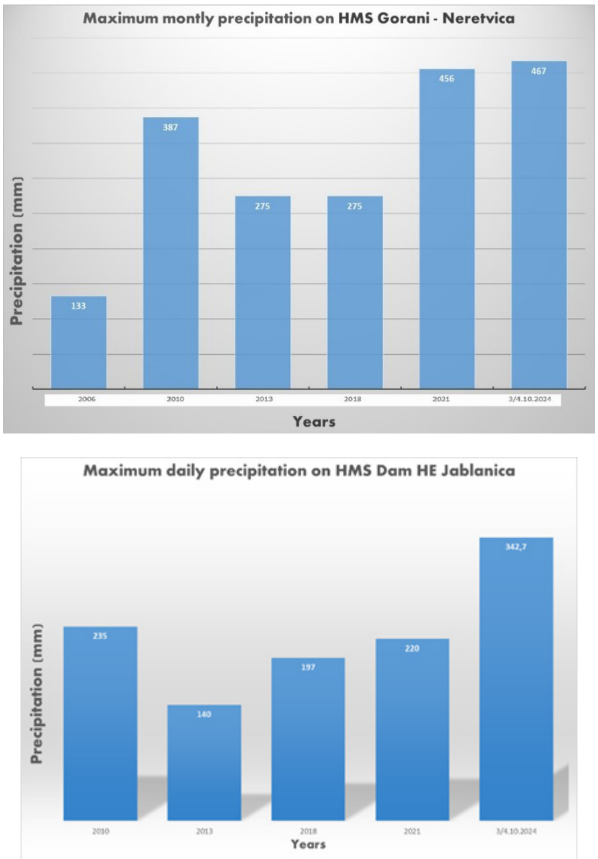

Figure 5: Maximum monthly precipitation on the HMS Gorani – Neretvica (up); Maximum daily precipitation on the HMS Dam HPP Jablanica (down).

2. COSEQUENCE OF FLOODING – DAMAGES

Floods are currently one of the most extreme disasters of our time, affecting millions of lives around the world. At the beginning of October 2024, central and southern Bosnia and Herzegovina experienced severe flooding, the worst since the May 2014. It was estimated that a total of 1,148 households were affected by flash floods, 27 people lost their lives, many landslides were triggered, and significant damage was recorded to the road and railway infrastructure. The total damage in the affected area is estimated at almost 90 million euros [2].

3. HYDRO POWER PLANT ON NERETVA RIVER – PROPERTIES

Hydroelectric power plants on the Neretva River basin represent a cascading series of hydroelectric power plants, which means that one hydroelectric power plant cannot be analyzed separately from other power plants in the series (Figure 6 up). All hydroelectric power plants in a cascade series form one unit. The primary purpose of the reservoirs is the production of electricity, while the level of accumulations is a consequence of hydrological conditions and conditions in the electric power system (safe operating of the electric power system and ensuring the orderly supply of electricity to consumers).

There are five hydro power plants in the middle course of the Neretva basin (Figure 6 downs). HPP Jablanica, HPP Grabovica and HPP Salakovac are owned by JP EP BIH, while HPP Rama and HPP Mostar are owned by JP EP HZHB [3].

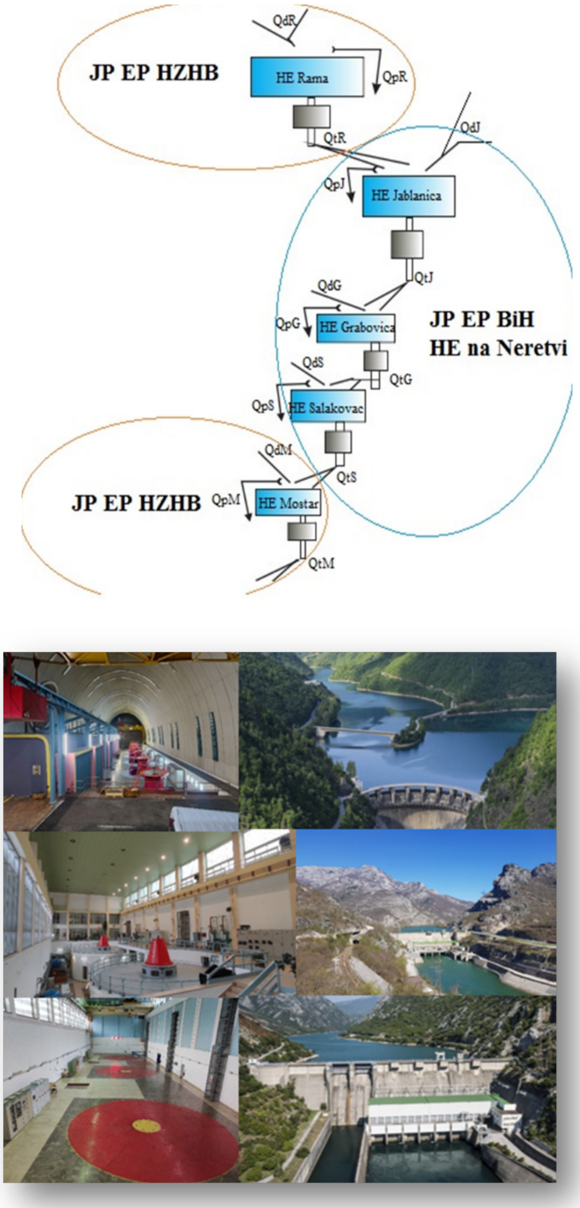

Figure 6: Cascading series of HPP on the Neretva River basin (up); HPP Jablanica, Grabovica and Salakovac (down).

Table II. Basic technical data of hydropower plants Jablanica, Grabovica i Salakovac

	HPP Jablanica	HPP Grabovica	HPP Salakovac
Year of commissioning	1955 -1958.	1981.	1981.
Average flow 1989 – 2018 [m3/s]	102,8	115,5	155,0
Installed flow [m3/s]	6 x 34,5	2 x 190	3 x 180
Total reservoir volume hm3	318	19,77	68
Useful volume of the reservoir hm3	288	5,43	15,6
Normal deceleration elevation m.n.m.	270,00	159,00	123,00
Number of units	6	2	3
Installed power [MW]	6 x 32,83	2 x 58,5	3 x 69,5
Annual production for balance sheet conditions [GWh]	693,0	260,4	356,6

4. CIRCUMSTANCES AND SITUATION ON HYDRO POWER PLANTS

On the 2th of October 2024, the Adriatic Sea Water Area Agency issued a Notice on the forecast of an emergency hydrological state for the period 03th/04th of October 2024, for most hydrological stations in the Adriatic Sea water area. An increase in water levels was forecasted, especially in the middle and lower Neretva with its tributaries, and the possible occurrence of torrential flows covering the cities of Konjic, Jablanica, Mostar, Capljina, Grude, Ljubuski and Siroki Brijeg [4].

The storm that hit part of the Neretva basin, especially the Jablanica and Buturovic Polje near Konjic, caused major problems in the operational management of hydropower plants during that period, and left significant consequences and damage to the operational, safe and future operation of the hydropower plants as well as the overall business of the JP EP BiH HPP on the Neretva River. In the first hour of 4th of October, the basement of the headquarters of the JP EP BiH HPP on the Neretva River had flooded, including the ICT infrastructure, which caused the interruption of the operation of all servers and support systems in HPP, as well as the interruption of communication, local telephone connections with all hydropower plants, loss of measurements from all measuring points in the hydropower plants and connection with the Dispatch Center (Figure 7).

Also, during the period of the worst storm intensities, there was a mobile network interruption in the Jablanica and Konjic areas. The Dispatch Center could communicate with HPP Jablanica and HPP Grabovica only via a fixed external connection, while it was not possible to establish any connection with HPP Salakovac. Communication with this hydroelectric power plant was carried out via HPP Grabovica, whereby each order for HPP Salakovac had to be given verbally by the dispatcher to the operating personnel of HPP Grabovica. At the same time, the 35 kV power supply of the HPP Jablanica - HPP Grabovica was cut off, which led to the external lighting in the HPP Grabovica facility being switched off.

Figure 7: Basement of HPP main building

Operation of HPP Jablanica was stopped during that period. The on duty-staff of HPP Grabovica doubted the accuracy of the measurements of the upper water level of HPP Grabovica, because the level was 155.97 m.a.s.l. at 01:00 and 157.54 m.a.s.l. at 02:00, they went to visually check the readings. They were abandoned due to stormy weather and lack of external lighting, and the situation was life-threatening. At the same time, at HPP Jablanica, water from the Dobrinja River entered the access tunnel to the generators, or machine rooms, which was successfully repaired by the intervention of the on-duty staff. Torrential sediment from the Dobrinja

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River buried the access road to the machine room of HPP Jablanica and the outlet of the drainage channels, causing the lower water level to rise, along with the already high upper water level of HPP Grabovica (Figure 8).

Figure 8: Destroyed access road to HPP Jablanica power house (up); The walls and protective layer of the outlet channel HPP (down).

A significant increase in torrential inflows into the HPP Grabovica reservoir, in parallel with erosive torrential deposits of soil and rocks into this reservoir, led to an increase in the reservoir level that has not been recorded in the history of this power plant. The level of the HPP Grabovica reservoir increased by almost two meters in a period of one hour, which is also not recorded in the history of this hydropower plant. Evacuation organs at HPP Grabovica were opened at 03:44. Due to the high level of the HPP Grabovica reservoir, Unit 1 did not have start conditions for synchronization, Unit 2 was under annual maintenance. After the accumulation level dropped to normal limits, the Unit 1 received starting conditions and began production [5].

Due to the large amounts of precipitation, accompanied by the entry of sediment and various materials into the HPP Grabovica reservoir, this reservoir was almost completely divided into two parts on the night of 3rd/4th of October, which additionally caused an enormous increase in the reservoir level as well as extreme record waves on this reservoir so far. Landslides recorded on the M-17 road (Komadinovo vrelo, Prenjska vrata, Donja Jablanica, near the "Kovacevic" restaurant) have largely contributed to the reduction of the cross-sectional profile of the reservoir HPP Grabovica on that places by up to 50% (Figure 9).

Figure 9: Landslides recorded on the M-17 road (Komadinovo vrelo, Prenjska vrata, Donja Jablanica)

Sediment deposits could threaten the safety and function of dams and hydropower plants. First, there was the possibility that river sediment, together with underwater and floating debris, block the entrance to the evacuation organs (outlets) at the dam or enter the turbine (Figure 10). Turbines demage, due to the abrasive effect of floating debris and deposits, is an unfavorable phenomenon that often occurs [6], [7].

Figure 10: Waste came to the surface of the reservoir and nearby dams

5. EMERGENY AND LONG-TERM ACTION

First activities of HPP staff on Neretva were aimed at inspecting buildings, plants and equipment, determining potential risks and clearing to ensure access to roads to HPP Jablanica and HPP Grabovica facilities, restoration of the transmission line DV 35 kV power plant - HPP Jablanica dam and normal shift work. Some shift personnel at the power plant were also working continuously for 24 hours at the facilities during that period. Also, it was necessary to urgently equip the outlet channels, culverts and drains to enable the normal flow of rainwater and avoid flooding of buildings and new landslides. The mechanization of construction companies and civil protection was activated to remove part of the sediments of soil and stones from the Dobrinja torrent that threatened to reach the outlet channels of HPP Jablanica, raise the level of the lower water and flood the HPP Jablanica. At the HPP Grabovica, the remont of Unit 2 was underway, which was planned to be completed by 15.10.2024. Given the circumstances, all available teams of the HPP on the Neretva were engaged and the overhaul was completed quickly, and the unit was put into operation on 08.10.2024. What proved to be one of the most important advantages throughout the event was the ability and efficiency of the operational staff to respond to the demands of the critical situation that arose.

The described flood event caused enormous direct material damage to the hydroelectric power plant facilities: access roads, regulated watercourses, torrential barriers, structures of the outlet channels of the power plant. It is assumed that indirect or currently immeasurable damage (due to sediment accumulation into the reservoirs and to the outlet channels of the plant) in the form of a significant reduction in the energy capacity of the reservoirs and the plant are significant too. This type of material damage can and should be established by geodetic survey of reservoir bottom and areas of the established control profiles. A special risk is represented by sediments on the outlet channels that can cause emergency flooding of the plant [5].

This analysis highlights significant regional differences in rainfall intensity and distribution, as well as the need for a localized approach in managing extreme weather events. Special attention should be directed to areas with pronounced rainfall maxima, such as Konjic and Jablanica, to minimize potential negative impacts of these extreme weather phenomena.

The study analyses have generally confirmed that the issue of reservoir filling is extremely complex and diverse [8], [9], [10].

The regimes and dynamics of filling of the Jablanica, Grabovica and Salakovac reservoirs have been part of regular analyses for the efficient planning and operational work of hydropower plants. However, the amount of sediment that, according to the first preliminary estimates, was evidently caused by the events of October 2024 is measured in an amount that exceeds the annual input of material into these reservoirs. The estimate was made only for the sediment that ended up in the reservoir during 3rd/4th of October, while the amount of sediment at the estuary of the rivers in the reservoir is almost twice as large. The consequences of the remediation exceed all the activities that JP EP BiH HPP on the Neretva River has had to carry out in its work so far. An extraordinary survey of sediment in all reservoirs is currently being carried out.

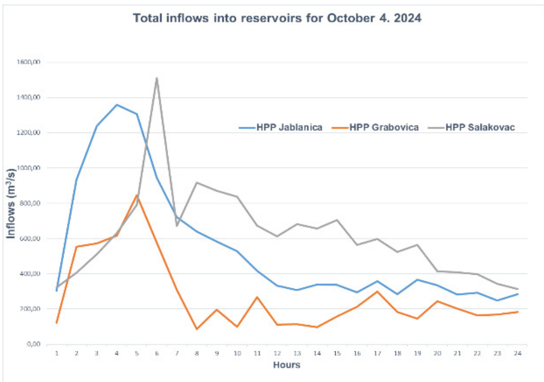
Despite technological efforts, government interventions in hydropower management and regulation should not be neglected. National, regional and local authorities should establish effective measures to promote the implementation of hydropower and other renewable energy projects, timely engage in the regulation and management of hydropower, to assist operators in flood control operations during high-flow episodes and improve water use procedures during dry periods, and to ensure the safety of the environment, ecosystems and socio-economic sectors [11], [12], [13].

6. POSITIVE IMPACT OF DAMS ON FLOOD PROTECTION

Numerous studies dealing with large-scale dams and multi-purpose reservoirs point to various functions of reservoirs other than hydroelectric power generation. As for other roles, the top three are recreation, flood control and irrigation [7], [14].

It is important to note once again that during the maximum accumulation levels of the Grabovica HPP the Jablanica HPP was not in operation. This means that there was no additional inflow from the Jablanica HPP to Grabovica reservoir (no overflows occurred - the accumulation level was approximately 9 m below the threshold of the spillway).

Precipitation began on 3.10.2024., and the average daily natural inflow in the reservoirs of the Jablanica HPP, Grabovica HPP and Salakovac HPP for that day was 36.04 m3/s, 18.74 m3/s and 34.83 m3/s, respectively. Already in the last hours of that day, the inflows at representative hydrological stations were increasing, so that the maximum total hourly inflows in the reservoirs of the hydropower plants were reached on 4.10.2024. at almost the same time: HPP 1358,41 m3/s in 04:00 a.m; HPP Grabovica 845,81 m3/s in 05:00 a.m; HPP Salakovac: 1509,42 m3/s in 06:00 a.m. (Figure 11).



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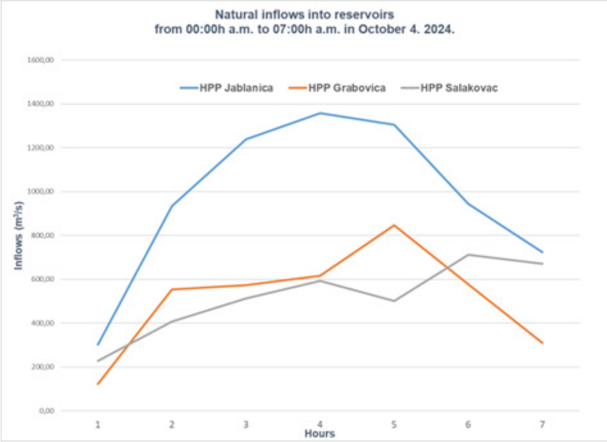

Figure 11: Total and natural inflows into hydroelectric power plant reservoirs for October 4, 2024

The maximum hourly value of the total natural inflow into the Jablanica HPP reservoir was in the range of a 1000 return period. Given that the upper water level of the Jablanica HPP reservoir was about 7 m below the planned value due to the previous dry period, the Jablanica HPP reservoir managed to accumulate a large amount of inflow without overflows. The maximum achieved natural inflow into the Grabovica HPP and Salakovac HPP reservoirs was estimated at 845 m3/s and 711 m3/s, respectively, and exceeded the amounts of 10.000-year return period of inflows into these reservoirs, as can be seen from the designed hydrological parameters of these power plants. If we take into account the maximum hourly inflow values in the HPP resevoirs on the Neretva River as well as the natural water inflow in the HPP Rama reservoir, which is approximately 40 m3/s, it can be concluded that the maximum natural water flow on the HPP Salakovac profile, if no hydroelectric power plant was built, would be approximately 3,000 m3/s [5].

In the conditions of natural disasters that affected this part of the Neretva River basin and due to all the technical limitations, they encountered, the operating personnel and dispatchers promptly and successfully performed the transformation of the water wave. This information is confirmed by the data on the hydrological stations Carinski most (located on Neretva River in Mostar city) which registered a maximum flow of 853 m3/s. On the profiles of HPP Grabovica and HPP Salakovac, the total water overflows, in energy terms, amounted to 1,685.8 MWh.

It must be particularly emphasized that during flood event, all communication with the power plants, road, telephone and IT communication, was completely interrupted or difficult. The power supply to the Jablanica dam via the transmission power line 35 kV was also interrupted. There was a certain risk of flooding of the Jablanica power plant's engine room. The connection with Grabovica was only possible by boat, but this was soon made impossible due to large amounts of floating waste.

The total inflow into all three hydroelectric power plants was 2,500 m3/s. Mostar is a large city located below a series of hydroelectric power plants. The maximum amount of water that flowed through the city of Mostar during this event was 880 m3/s. This means that over 1,700 cubic meters were retained in the upstream reservoirs. If there were no hydroelectric power plants, discharge downstream of dams would be approximately between 2,500 and 3,000 m3/s which would flooded the city of Mostar and have had catastrophic consequences: floods, destruction of infrastructure and, unfortunately, probably human casualties.

These figures and data indicate the benefits that dams offer, considering the likelihood of flood losses due to the increase in the negative impacts of climate change. Various stakeholders, local communities, agencies, regulators, including hydropower operators, will have benefit from this data as they assess the impact of hydroelectric dams on our communities, economies and ecosystems.

Dams play a crucial role in flood prevention, as part of their comprehensive water management function. Maximizing electricity generation and strategically lowering reservoir levels before the flood season can effectively prevent water spillover and minimize the magnitude of floods [12], [15], [16], which was the situation on the HPP on the Neretva River before the flood event from Octobre 2024. All reservoirs have contributed to flood control efforts. These reservoirs have regulated river flows by storing significant amounts of floodwater and carefully controlling the timing of water releases.

7. CONCLUSION

Extreme rainfall events can have a significant impact on the safety of dams and hydroelectric power plants [12], [17]. Heavy rainfall can cause the water level in a reservoir to rise rapidly, putting pressure on the dam and increasing the risk of failure. If a dam was to fail, it could lead to widespread flooding and damage downstream. Risk managers and utility executives need to know these risks and the additional liability they place on operations [11], [12], [15].

The problem of defining optimum operation rules for reservoir systems with multiple purposes indicate the need for more studies with better adaptation to climate changes. The expected impact of climate change, such as increased precipitation and extreme weather events, is understanding the dam's contribution to flood management. Data on the economic benefits of dams in flood management remain still generalized [6], [8], [9], [12], [15], [18].

Therefore, despite the projection of uncertainty, expected future trends in hydrology, all of which predict some impact of climate change, should be considered in future operating rules for dams and reservoirs [13], [17], [19], [20], [21] .

The adverse consequences of sediment deposition in reservoirs are reduction of usable volume, creation of shoals that further reduce hydro-power potential, reduce the aesthetic qualities of the reservoir, silting and deterioration of water quality [10]. On the other hand, pluvial waste is extremely dangerous due to possible damage to equipment and flow regulation devices, as well as the incidental entry of material into the turbine [5], [11].

Some of the proposal of measures to mitigate the consequences of possible new floods:

1. Establish a more comprehensive precipitation forecast system and hydrological model, and link them to the hydropower management system,
2. Prevent forest devastation and promote afforestation,
3. Regulate the area of stone mining,
4. Regulate tributary riverbeds and improve the system of flood barriers,
5. Establish orderly proactive training and simulation exercises for the power plant stuff,
6. Under take the study of the economic benefits of dams in flood management on the Neretva River basin,
7. Find an appropriate strategy to ensure the safety of HPPs, the environment, ecosystems and socio-economic sectors.

Any change in hydrological regime due to climate change may impact hydropower production. The power plant operators must be prepared to effectively respond to even the most demanding situations. Therefore, it is necessary to regularly carry out an active flood management system [20], [22] with training measures and simulation exercises for potential critical situations that may occur at hydroelectric power plants. The operators and planners must also take the new variable into account when making regular work plans and long-term electricity generation forecasts.

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