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Flood Wave Dynamics in the Transboundary Dniester River Floodplain under Reservoirs Impact †

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Abstract: Present research aims to evaluate the impact of stream reservoirs on the Dniester river floods wave dynamics. Main approach consisted in evaluation of the changes that occur in flood parameters for three periods: natural flow, flow regulated by Dubasary reservoir, flow regulated by the Dniester Hydropower Complex and Dubasary reservoir. Using hydrological time series from stations situated upstream and downstream of reservoirs, there were calculated and compared: flood characteristics, peaks of 10, 5, 1, 0.5 and 0.1% probability, and Environment Flow Components: high-flow pulses, small floods, large floods. The results show that high flood protection is specific to the Dniester Hydropower Complex, while through the Dubasary reservoir the flood wave passes mainly in transit. Due to flow regulating impact, small floods as well as their average peaks and duration were reduced to reservoirs downstream part. High-flow pulses increased in number after the Dniester Hydropower Complex construction due to hydropeaking effect, however downstream Dubasary reservoirs their reduction is observed. Large floods increase in number in the upper part but are transformed into small floods to the downstream, thus increasing flood protection capacity.

Keywords: the Dniester river; floods; reservoirs impact; Environment Flow Components

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1. Introduction

Floods are the most frequent calamities registered in the limits of the Republic of Moldova. From total number of natural disasters, that occurred in the last 4 decades, the floods count 50%, the damage share rising to the same values (45%) [1]. The main factor which determines flood wave generation is represented by extreme climatic conditions expressed by fast snow melt in winter and heavy rains in summer. The largest floods are formed in the floodplains of transboundary big rivers the Prut and Dniester, in conditions of large water volumes brought from the upper parts of the river basins from Ukraine. Also, significant damages are caused by flash floods generated as a result of the heavy rains and excessive slope runoff [1]. Certain measures are taken in order to reduce the impact of floods on humans, infrastructure and economic activity, among which are reservoirs and levee systems. Present research aims evaluate the impact of stream reservoirs on the Dniester river summer floods dynamics. In order to reflect the tendency of flood change determined by the reservoirs operation, several objectives were designed: identification of certain parameters that can show flood change; collection and analysis of hydrological data, evaluation of flood modifications is space and time, from upper lo lower course and from natural flow to regulated flow.

2. Study Area

The Dniester is a transboundary river and flows through Ukraine and the Republic of Moldova. The river length is 1362 km and the basin area is 72,100 km^2. Over 70% of the basin is situated in Ukraine, 27% belong to Republic of Moldova, and 0.34%—to Poland. The Upper part of the basin lays in Carpathians and represents only 30% of the basin area, but due to the high amounts of precipitations, 70% of Dniester runoff is generated in this area. Average annual flow in about 300 m^3/s [1,2,4]. The flow of the Dniester River is regulated by 3 reservoirs situated on the stream and one positioned lateral to the river. Three of these reservoirs form the Dniester Hydroelectric Complex (DHC): the Dnestrovsk reservoir with HPP-1 (water volume—2.6 km^3), the buffer reservoir with HPP-2 (volume of 37 mil. m^3), the artificial reservoir with pumped storage hydroelectric power plant (volume of 41.4 mil. m^3). DHC is situated at the border of the Ukraine and the Republic of Moldova. Also, regulation of the Dniester flow is performed by the Dubasary reservoir, positioned in the limits of the Republic of Moldova [3,4].

3. Materials and Methods

Main approach applied in order to investigate the impact of the reservoir cascade on the Dniester river flood dynamics consisted in comparative analysis of the hydrological data collected in natural conditions of flow generation, as well as during the impact of the DHC and Dubasary reservoir operation. This approach is in line with usually applied main designs: (1) Paired-Before–After Control–Impact, (2) Before–After, (3) Control–Impact, (4) Hydrological Classification and (5) Predicted Hydrological indices [5]. Also, one of modern approaches is determination of main Hydrological Alteration Indicators and Environment Flow Components, which is applied for estimation of impact of reservoirs operation on river flow [6–8]. Thus, hydrological characteristics were comparatively analyzed for three periods: the 1st corresponds to natural runoff, the 2nd coincides with Dubasary reservoir functioning (1956–1982 years), the 3rd represents the entire flood protection system operation (from 1987 till present). Analyzed times series were considered from the hydrological stations: Zalishchyky (situated upstream the DHC), Hrushca (situated downstream the DHC), Bender (situated downstream the Dubasary reservoir, in the lower part of the basin). Based on hydrological time series, there were calculated and compared for three time periods: flood characteristics, peak discharge attenuation coefficient, peaks of 10, 5, 1, 0.5 and 0.1% probability and Environment Flow Components: high-flow pulses, small floods, large floods.

The hydrological information used in the study was provided by the responsible data organizations in Moldova and Ukraine: the State Hydrometeorological Service (SHS) [9] and State Water Agency, data were collected through UNDP in Moldova, Ministry of Environment of the Republic of Moldova, the Commission on Sustainable Use and Protection of the Dniester River Basin (the Dniester Commission).

4. Results and Discussions

4.1. Dynamics in Flood Characteristics

Long time series on flow for the time before dams construction are present only for Zalishchyky and Bender, these station are also representative for estimation of reservoirs impact on flood, due to the fact that first one is situated upstream and the second downstream of hydrotechnical constructions. For three time periods the average flow peaks are 1781 m^3/s, 1609 m^3/s, 1558 m^3/s at Zalishchyky and 1172 m^3/s, 1024 m^3/s, 882 m^3/s at Bender. Spatially, from the upper to lower part of the river, the maximum flow is reduced by 609 m^3/s, 585 m3/s, and 687 m^3/s, flow change being large in the last period (Figure 1). Floods duration is 13–16 days at Zalischyky and 17–20 days at Bender, with no much differences between three periods. A certain impact of reservoirs is observed on rising and recession limbs of hydrographs. Thus, rising limb average duration, at Zalischyky, is 4 days for all periods. In the downstream of DHC, Grushka, the number of days increased from 4 days in the second period to 6–7 days in the third one, however, at Bender the number of days is 7 for all times. Flood wave recession limb is maintained within 11–12 days in the upper part of the DHC, while downstream of the DHC, it has a slight decreasing tendency, at

Grushka, from 14, in natural regime to 11 days, in regulated regime, but at Bender number of days is stable of 12.

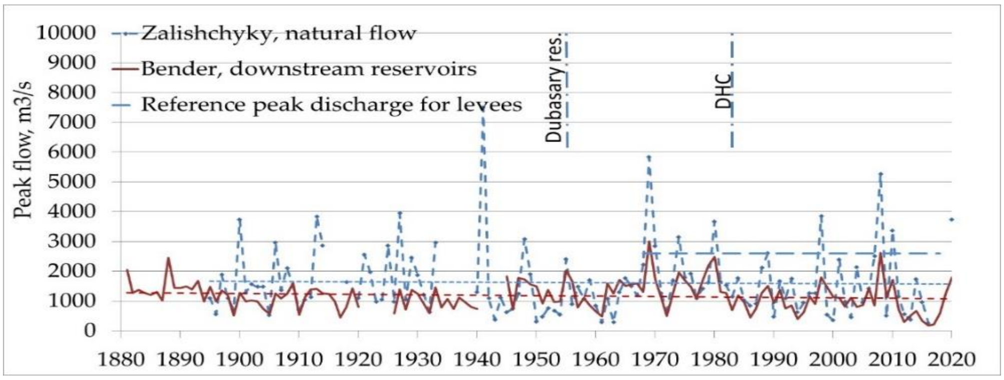

Figure 1. Flood peaks.

4.2. Peak Discharge Attenuation Coefficient Changes

The Dniester river floods propagation processes have changed in time and space due to certain modifications of the rived bed and floodplain. During the time period that corresponds to natural flow, flood dynamics were distributed in natural floodplain and reduction of the peaks was influenced by floodplain width and increasing basin area. In the seconds and, especially, the third time periods hydrotechnical structures (reservoirs and levees), constructed in the river floodplain, influenced river floods propagation by decreasing the peaks, redistribution of volumes under reservoirs impact, decreasing flooding area due to levee system. For evaluation of flood dynamics under different river bed conditions, peak discharge attenuation coefficient (K) was estimated. It was calculated as ratio between peaks from Zalishchyky and Bender station. Thus, this coefficient for natural runoff period is about 0.40 being relatively constant. The peaks of the flood of 1900, 1906, 1913, 1948 at Zalishchyky were about 3000–4100 m^3/s, at Bender station reduction being to 1300–1700 m^3/s. *K* ranged from 0,34 to 0,51.

Operation of Dubasary dam influenced in a certain way the Dniester flood wave dynamics. Analyzing the hydrographs of flood events of 1969, 1970, 1974, 1980 the change in the shape was observed. In the upper part the shape is classical triangular, while in the downstream part it is already trapezoid. The peaks of the mentioned floods were measured to the values of about 3000–6000 m^3/s at Zalishchyky and about 1700–3000 m^3/s at Bender. The *K* for this time period varied from 0.5 to 0.6., the average being 0.58. Dubasary reservoirs is a relatively small one, and intensive siltation processes decrease its flood protection capacity. The flood regulation storage decreased from 630 mln.m^3 (in 1956) to 401 mln.m^3 (in 1982) [1,10], and in these conditions, large floods would flow in transit through it, the reduction capacity being estimated only to 15%.

In conditions of the whole flood protection system functioning, including DHC and levees caused a better flood management. The peaks of larger floods that occurred in 1989, 1998, 2008, 2010 were in the limits of 2700 m^3/s (1989, 2010) and 4000–5600 m^3/s (1998, 2010) at Zalishchyky, while at Bender their values decreased to 1500–2600 m^3/s. Estimated *K* ranges from 0,44 to 0,62, average value of is about 0,52 being smaller in comparison with second period but higher than the one of the first period.

As a result of evaluation of peak discharge attenuation coefficient, it was observed that in natural condition flood peak attenuation was higher in comparison with actual situation. However, the need of lands for agriculture and settlements development caused construction of flood protection system that lead to decrease of the flood prone areas as well as capacity to reduce the peaks. Anyway, an effective flood protection is the results of a complex of measures, including DHC, levees, forecast, integrated flood management.

4.3. Changes in Statistical Parameters

Reservoir impact on flood flow was estimated through calculation and comparison of statistical parameters of hydrological time series measured at different river stations. The impact of the DHC was evaluated on the basis of analysis of the time series of the pluvial flood peak discharges from Hrushca (time series presented only for second and third time periods) as well as their probability distribution for the periods before and after construction of DHC (Figure 2). It was estimated that the average peak discharges for the third period is with 552 m^3/s lower than for the second one, and the peak discharges of 0.1–20% probability decrease with 905–3586 m^3/s (35–41%). Coefficient of variation (Cv) changes insignificantly from 0.54 to 0.48. The comparative analysis of the discharges of 1–10%, estimated on the basis of the dataset from the Dubasary reservoir, and probable peak discharge from its Operation Rules [10] indicates that the estimated probable peak discharges for the operation period are smaller with approx. 320–700 m^3/s (Figure 3), the reservoir having a lower effect in regulating the maximum runoff (12–15%).

As a result of the analysis of the time series from Bender st., it was determined that the average values of peak discharges are lower for the period of the entire flood protection system operation. Cv is 0.34, 0.43 and 0.44 for the three periods. However, the probability distribution shows an increase in the peak discharges of low and medium probability (0.1–10%) with ~ 22–44% in the second period, and with 1–21% in the third period, in comparison to those of the first period (Figure 4). The increase in extreme values can be explained by the fact that flood wave, flowing in conditions of anthropogenic impact, propagates through a narrower floodplain, limited by the levees, fact which determines the increase of both the discharges and levels, but also by the flood control by the Dubasary reservoir, and by occurrence of extreme synoptic situations that favored generation of more significant floods during the second and third periods compared to the first one.

The flood protection system reduces the probable peak discharges of 10–20% by 1–6%. It has a greater effect in regulating the flood runoff with the probability of up to 10%, especially during the period after the DHC construction. Thus, this hydropower complex has a more significant positive influence in the regulation of the flood runoff compared to the Dubasary reservoir.

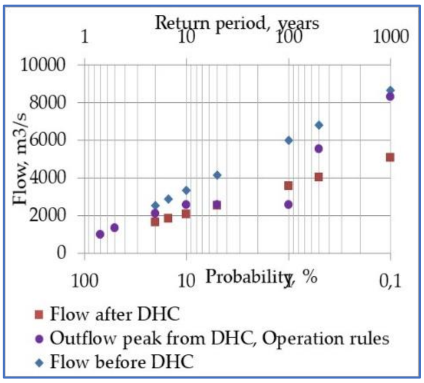

Figure 2. Distribution of peaks of different probabilities, Hrushca st.

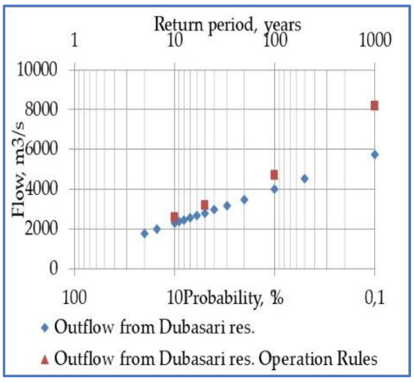

Figure 3. Distribution of peaks of different probabilities, Dubasary st.

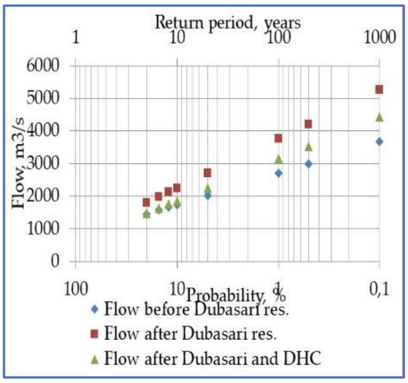

Figure 4. Distribution of peaks of different probabilities, Bender st.

4.4. Environmental Flow Components

Assessment of reservoirs impact on the Dniester floods was also performed by analyzing characteristics of the Environment Flow Components: high-flow pulses, small floods, large floods. Large floods, with peak discharges exceeding 2600 m³/s (reference peak flow indicated in DHC rules [11], as well as for levee system) at Hrushca st., were recorded in 1969, 1974, 1980 before the DHC and in 2008 after beginning of its operation (Figure 1). Small floods (with peak discharges exceeding 1200 m³/s—the multiannual average of peaks for entire monitoring period at Bender) are bigger in number. For the years 1945–1955 (before the Dubasary reservoir construction), at Zalishchyky and Bender on average 1 case of small floods in 2 years was recorded. In the period after reservoirs operation beginning, average number of these events was 1,4 event/year at Zalishchyky, 1,5 event/year at Hrushca, 0,8 event/year at Bender st. in the second period and 1 event/year at Zalishchyky, and 0,4 event/year for both stations in the downstream in the 3rd period. During the Dubasary dam operation, in the upstream (at Hrushca) 3 small floods were registered in 1968, 1976, 1978, 1980, 1981, in the downstream (at Bender) the same number being recorded only in 1968, and in the other mentioned years their number decreasing to 1–2 events. In the years after the DHC construction, at Zalishchyky, 3 small floods were registered in 1991, 2001, 2005, and 5 cases in 1998, and in the downstream more than 2 small floods/year were not recorded, but the number of years without small floods has increased (Figure 5). The average value of small floods peak discharges (Figure 6) was for the years 1945–1955–1584 m³/s at Zalishchyky, 1692 m³/s at Bender, for the period of only the Dubasari res. operation—1596 m³/s at Zalishchyky, 1670 m³/s at Hrushca and reduced to 1600 m³/s at Bender st. (downstream from the Dubasari dam), and for the period after entire flood protection system construction: 1662 m³/s at Zalishchyky, 1451 m³/s at Hrushca, and 1634 m³/s at Bender. On average, small floods duration was for the Dubasary dam operation period–10 days at Zalishchyky, 25,4 days at Hrushca and 65 days at

Bender, and for the period after DHC construction: 15 days at Zalishchyky, 23 days at Hrushca, and 47 days at Bender.

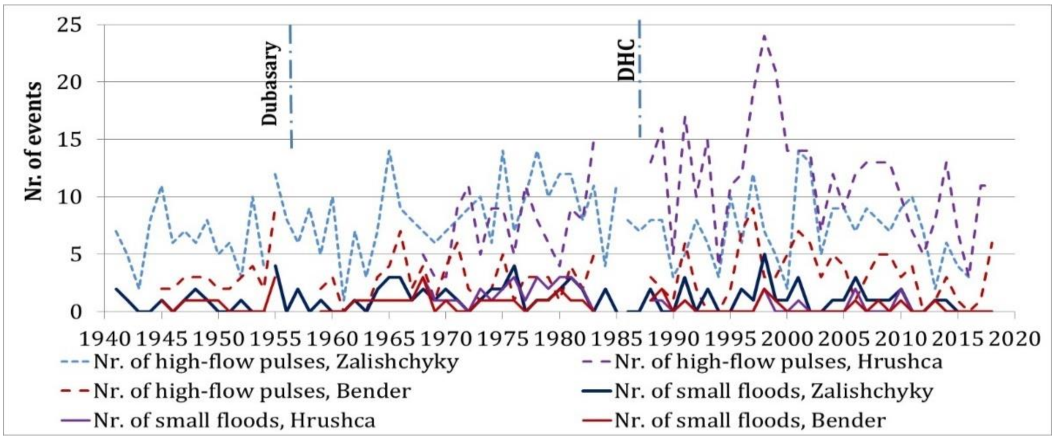

Figure 5. Number of cases of small floods and high flow pulses.

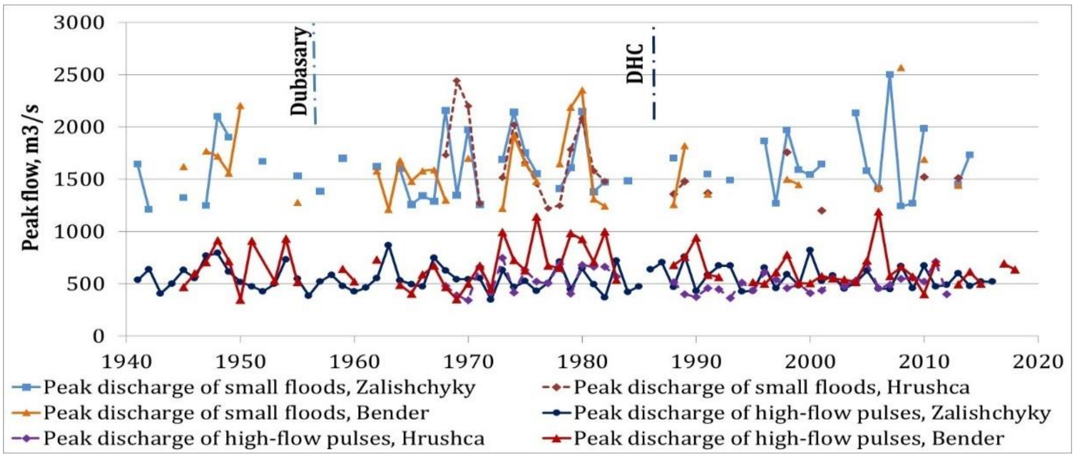

Figure 6. Average peak discharge of small floods and high flow pulses.

Annual frequency of high-flow pulses of ±30% (cases with peak discharges between 310/470–1200 m^3/s), for the 1945–1955, is characterized by values between 2 and 10 events/year (on average 6.3 events/year) with an average discharge of 578 m^3/s at Zalishchyky and values between 2 and 9 events/year (on average 3.2 events/year) with an average discharge of 664 m^3/s at Bender. Thus, in natural regime, a decrease of number of high-flow pulses is observed, on the sector from Zalishchyky to Bender the reduction being of 2–5 times. In the years following the Dubasary dam operation, the average frequency of high-flow pulses is 8,5 event/year at Zalishchyky, 7.8 events/year at Hrushca and only 2.8 events/year at Bender, the decrease of the number of these events under reservoir impact being even with 8–10 events. In this respect, examples can serve the years 1972 and 1977 when at Hruscha 11 and at Bender only 2–3 high-flow pulses were registered. A different situation is specific for the DHC post-construction period. The number of high-flow pulses is 7 events/year at Zalishchyky but at Hrushca it has increased considerably to 11. In 1997–2000, at Zalishchyky number of events was 5–14 while at Hrushca it increased up to 19–24. Thus, in some years, the number of high-flow pulses has doubled (1989, 1996, 2009, 2014) or even tripled (1991, 1998, 1999, 2000, 2013) at DHC downstream station in comparison to its upstream station. In the same years at Bender the number of these events is already of 3–9, i.e., 2–8 times less. The average peak discharges of high-flow pulses are 534 m^3/s at Zalishchyky, 530 m^3/s at Hrushca, 674 m^3/s at Bender during the Dubasary res. operation and 557 m3/s at Zalishchyky, 496 m^3/s at Hrushca, and 632

m^3/s at Bender after the DHC construction. Their duration is approx. the same: at Zalishchyky—3.8 days for the first and second period and 4.5 days for the third one, at Hrushca—4.5 days for all periods, and at Bender–14.5, 23.8 and 15 days for all periods.

5. Conclusions

Evaluation of the reservoirs cascade on flood dynamics of the Dniester river, show that high flood protection is specific to DHC, while through the Dubasary reservoir the flood wave passes mainly in transit. The flood protection system has a greater effect in regulating the floods with medium probability, especially after the DHC construction. The reservoirs caused a slight increase of coefficient of attenuation of peak discharges from 0.30 to 0.40 (in natural conditions) to 0.50–0.60 (in regulated flow conditions). Due to flow regulating impact, small floods as well as their average peaks and duration were reduced in reservoirs downstream part. High-flow pulses increased in number after DHC construction due to hydropeaking effect, however downstream Dubasary reservoirs their reduction is observed. At present, large floods increase in number in the upper part but are transformed into small floods to the downstream, thus protecting the region from inundation. Increasing frequency and occurrence of floods in the Dniester river basin should lead to improvement of flood management strategies, both in Ukraine and the Republic of Moldova.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jeleapov, A. *The Study on Pluvial Floods in the Context of Human Impact on Environment*; Tipogr. Impressum: Chișinău, Moldova, 2020; 254p. (in Romanian)
2. Jeleapov, A.; Melniciuc, O.; Bejan, I. Assessment of flood risk areas in the Dniester River basin (in the limits of the Republic of Moldova*)*. In *Management of Water Quality in Moldova*; Duca, G., Ed.; Springer International Publishing: Cham, Switzerland, 2014; pp. 157–173.
3. Jeleapov, A. Assessment of the impact of the Dniester Hydropower Complex on hydrological state of the Dniester River. *Cent. Eur. J. Geogr. Sustain. Dev.* **2022**, *4*, 24–49.
4. Regulations to Operate Water Reservoirs of the HPP and PSPP Dniester Cascade with Buffer Storage Reservoir Normal Headwater Level 77.10 m. Draft UKRGIDROENERGO. 2017. Available online: https://bit.ly/3U515GU (accessed on 12 September 2022).
5. Peñas, F.J.; Barquín, J.; Álvarez, C. Assessing hydrologic alteration: Evaluation of different alternatives according to data availability. *Ecol. Indic.* **2016**, *60*, 470–482.
6. Richter, B.; Baumgartner, J.; Powell, J.; Braun, D. A method for assessing hydrologic alteration within ecosystems. *Conserv. Biol.* **1996**, *10*, 1163–1174.
7. Richter, B.; Baumgartner, J.; Robert, W.; Braun, D. How much water does a river need? *Freshw. Biol.* **1997**, *37*, 231–249.
8. The Nature Conservancy. Indicators of Hydrologic Alteration Version 7.1 User's Manual. 2009. Available online: https://www.conservationgateway.org/Documents/IHAV7.pdf (accessed on 12 September 2021).
9. Hydrological Database of the State Hydrometeorological Service of Moldova and Ukraine 2020.
10. *Operation Rules of the Dubasari Reservoir*; : Chisinau, Moldova, 1983. (in Russian).
11. Operation Rules of the Reservoirs of the DHC. 2022. 38 c. Available online: https://bit.ly/3RUkhFI (accessed on 12 September 2022) (in Russian)