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Flood wave dynamics in the transboundary Dniester river floodplain under reservoirs impact

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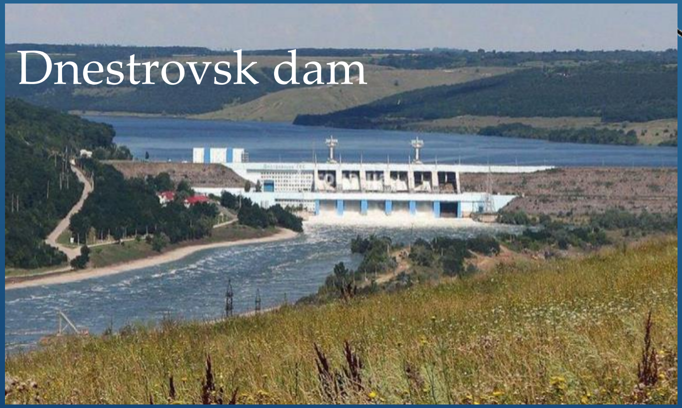

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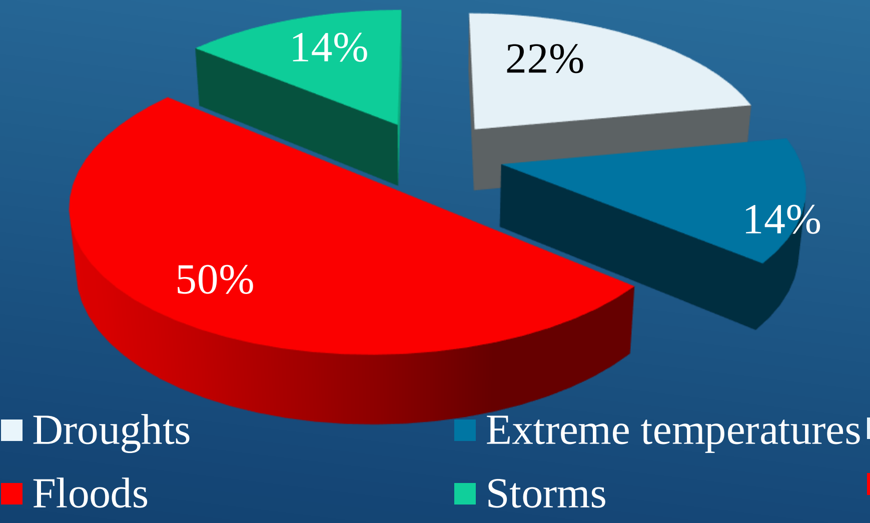
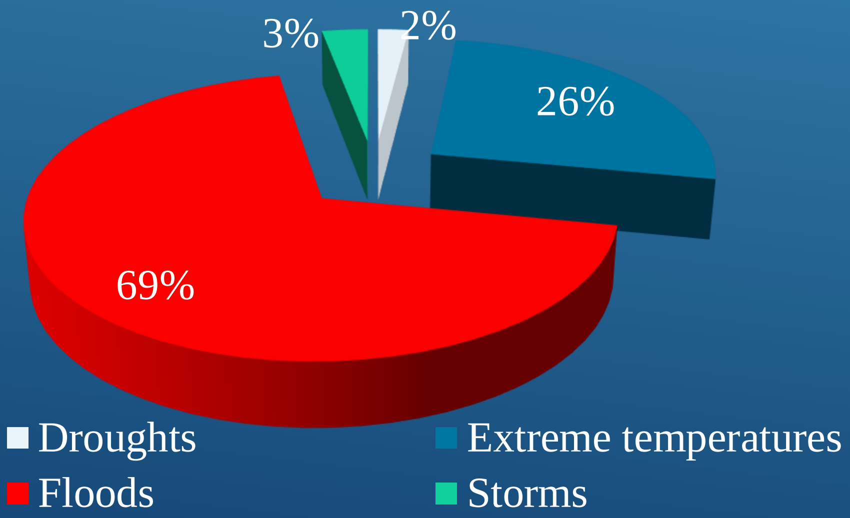
Introduction

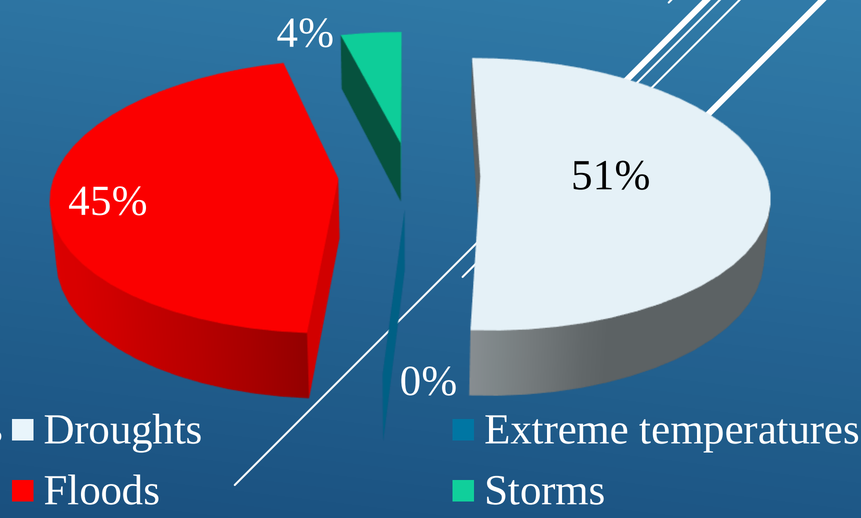
Extreme climatic conditions (heavy rains and/or fast snow melt due to high temperature) are the main factors which determine flood generation. The most significant damages are caused by the floods which occur in summer on big rivers the Prut and Dniester, in conditions of large volumes of water brought from the upper parts of the river basins from Ukraine, and also by flash floods caused by excessive slope runoff generated by the heavy rains with an increasing frequency in recent years. 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.



Number of natural disasters, Moldova



Number of victims dead because of natural disasters Moldova



Damaged caused by natural disasters, Moldova

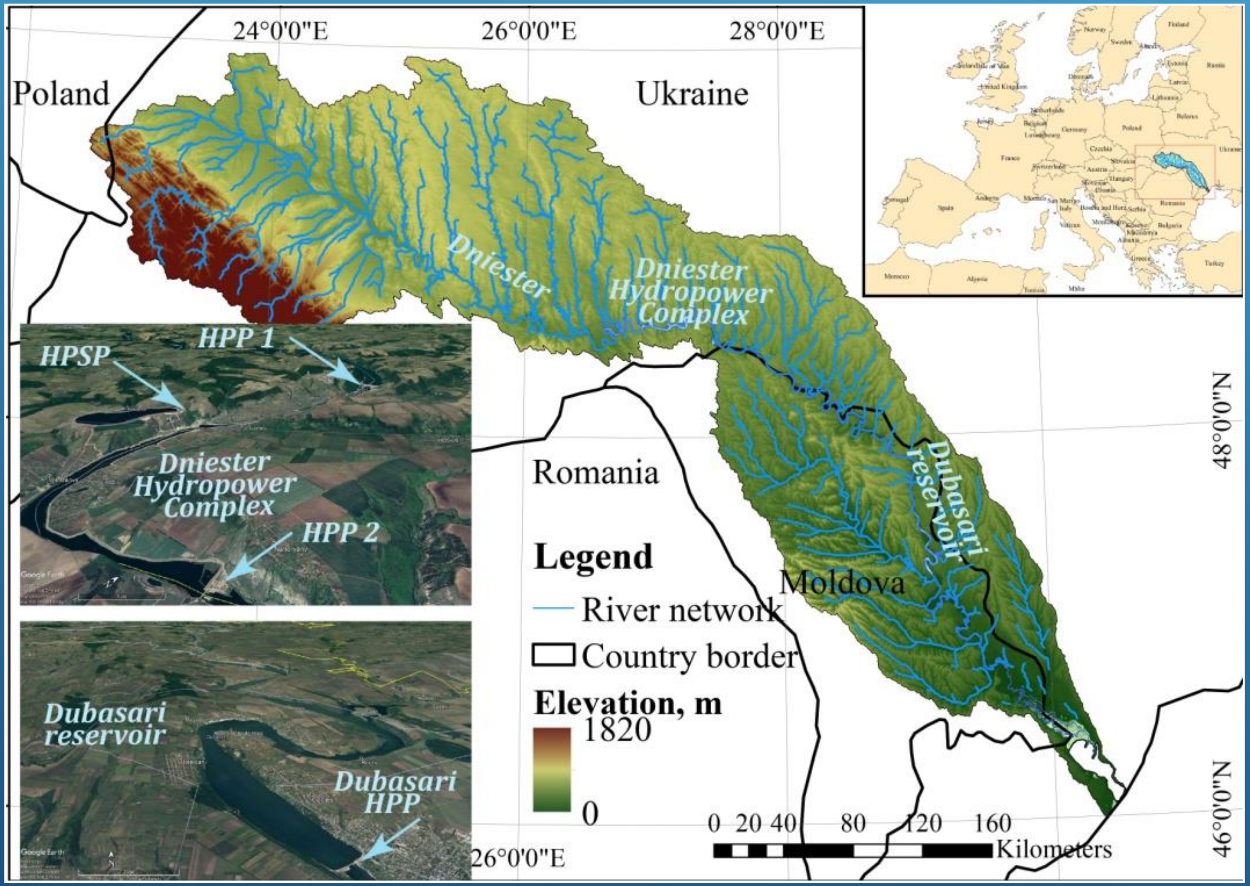
Aim and objectives

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.

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 km2. Over 70% of the basin is situated in Ukraine, 27% belong to Republic of Moldova, and 0.34% - to Poland.

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):

1. the Dnestrovsk reservoir with HPP-1 (water volume - 2.6 km^3),
2. the buffer reservoir with HPP-2 (volume of 37 mil. m^3),
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

Materials and methods

Main approach 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. Also, one of modern approaches is determination of main Hydrological Alteration Indicators and Environment Flow Components.

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).

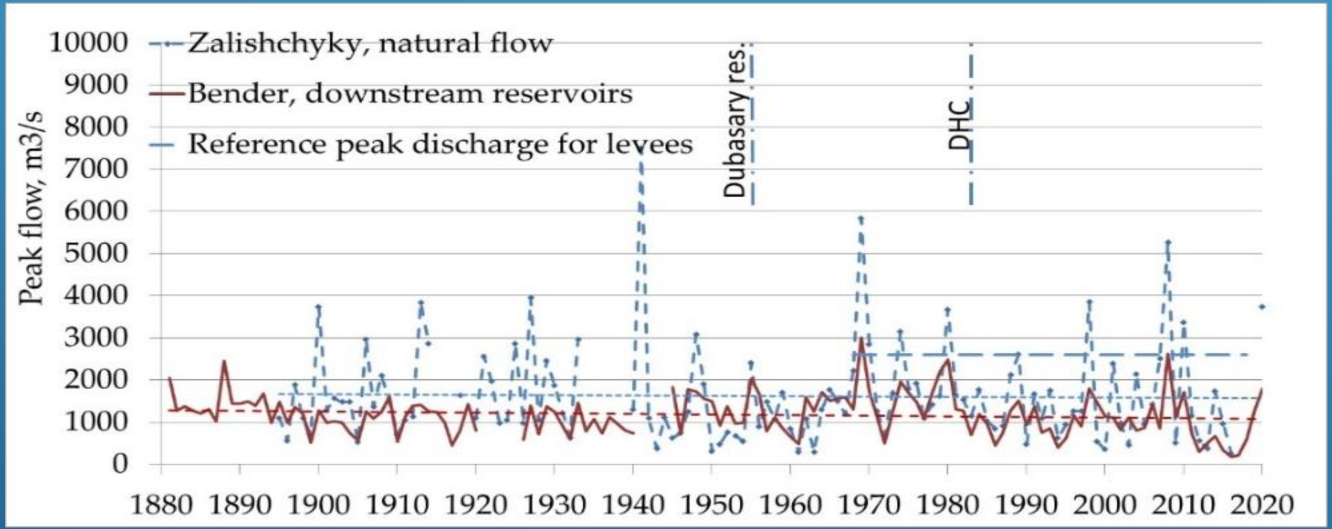
Analyzed times series were considered from the hydrological stations:
- Zalishchyky (situated upstream the DHC),
- Hrushca (situated downstream the DHC),
- Bender (situated downstream the Dubasary reservoir, in the lower part of the basin).

Analyzed parameters
- peak discharge attenuation coefficient,
- peaks of 10, 5, 1, 0.5 and 0.1% probability
- 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) 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).

Results and discussions

Dynamics in flood characteristics



Flood peaks

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. Floods duration is 13-16 days at Zalischyky and 17-20 days at Bender, with no much differences between three periods.

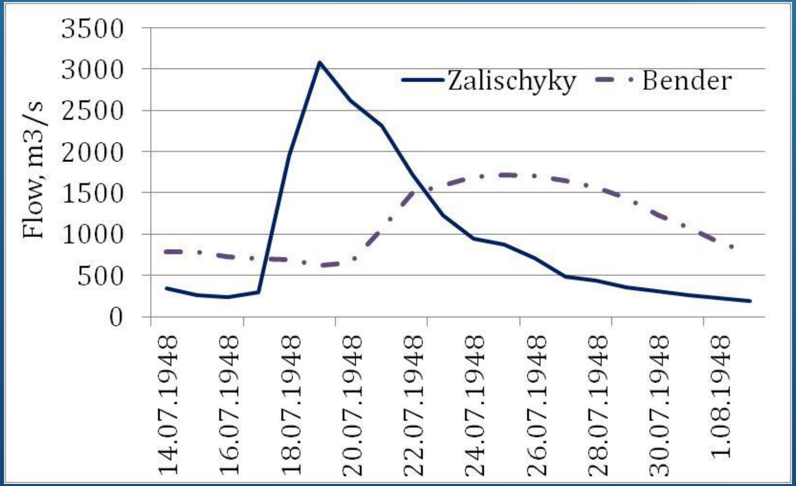
A certain impact of reservoirs is observed on rising and recession limbs of hydrographs. Thus, rising limb average duration, at Zalischyky, is 4 days for all periods. In the downstream of DHC, Grushka, the number of days increased from 4 days in the second period to 6-7 days in the third one, however, 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

Results and discussions

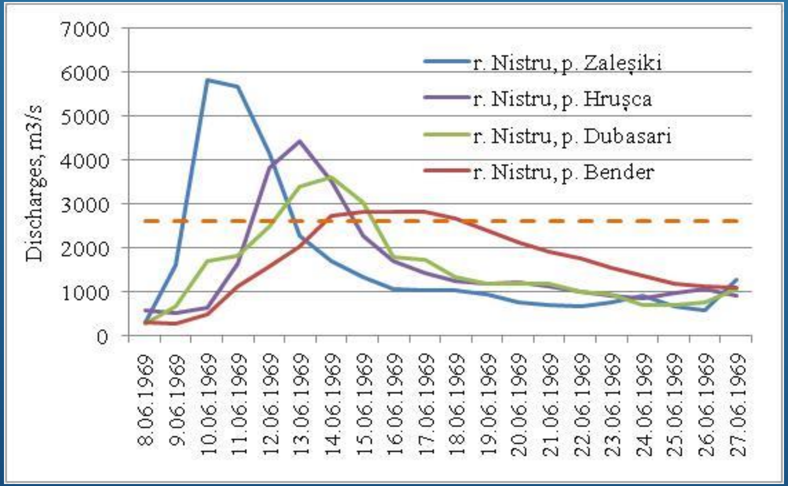
Peak discharge attenuation coefficient changes

Flood attenuation coefficient

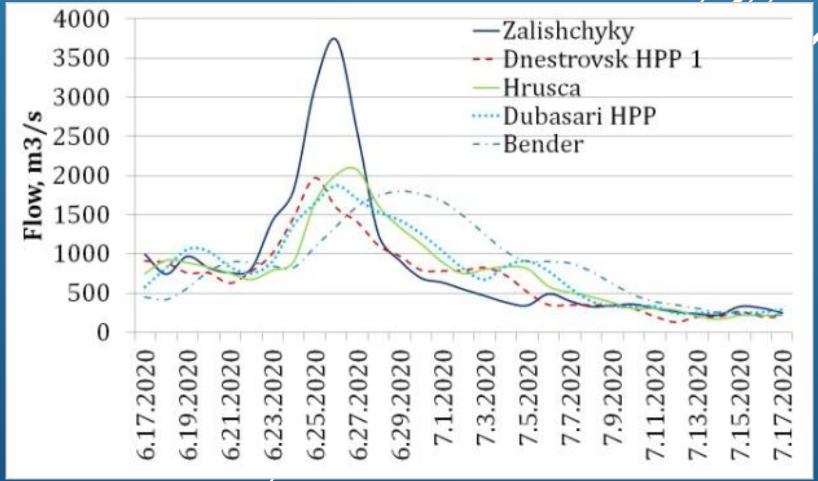
Period I: 1887-1955				Period II: 1956-1982				Period III: 1987-2010			
Year	Zalishchyky	Bender	K	Year	Zalishchyky	Bender	K	Year	Zalishchyky	Bender	K
1900	3730	1270	0,34	1969	5970	3000	0,50	1989	2700	1510	0,56
1906	3070	1260	0,41	1970	2950	1730	0,59	1998	4080	1800	0,44
1913	4120	1400	0,34	1974	3300	1960	0,59	2008	5600	2610	0,46
1948	3420	1730	0,51	1980	3910	2490	0,64	2010	2765	1700	0,62
			0,40				0,58				0,52



Flood hydrographs of 1948



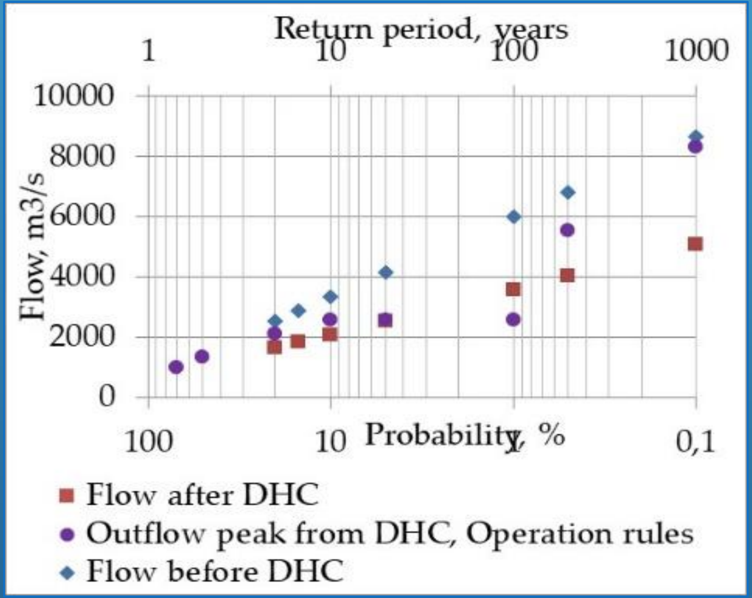
Flood hydrographs of 1969



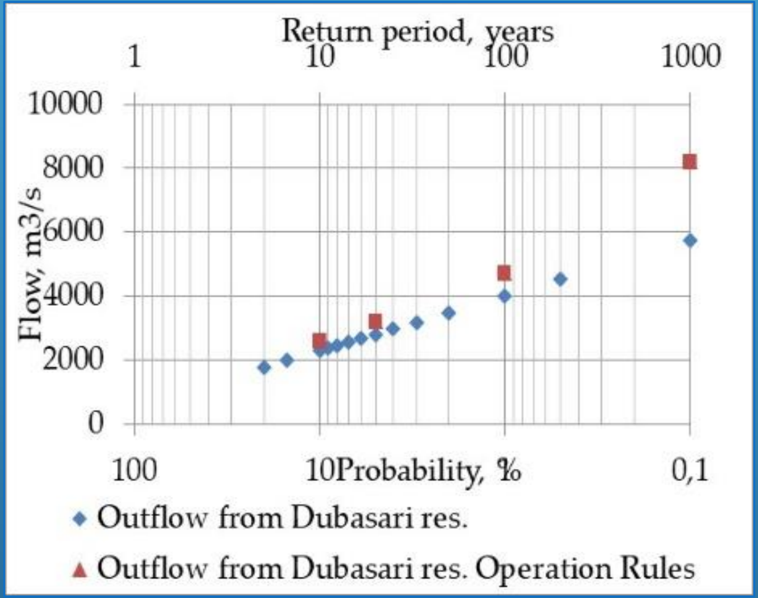
Flood hydrographs of 2020.

Results and discussions

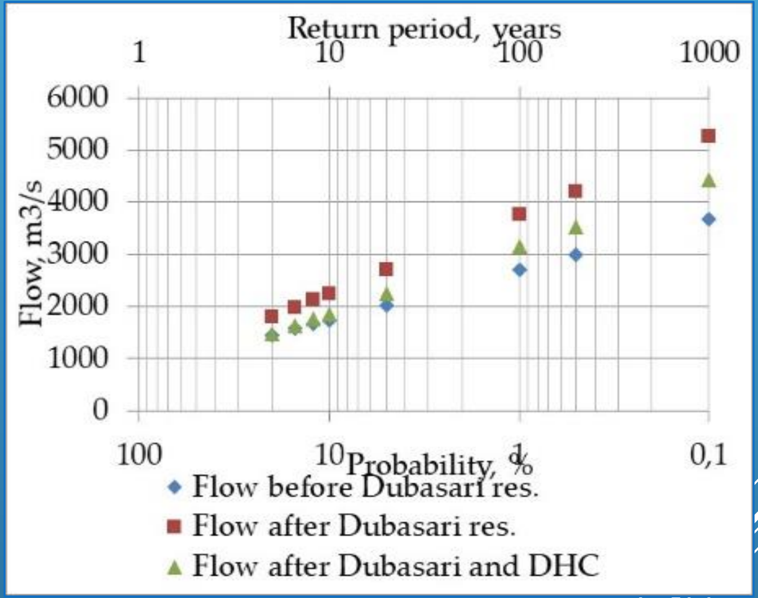
Changes in statistical parameters



Distribution of peaks of different probabilities, Hrushca st.



Distribution of peaks of different probabilities, Dubasary st.

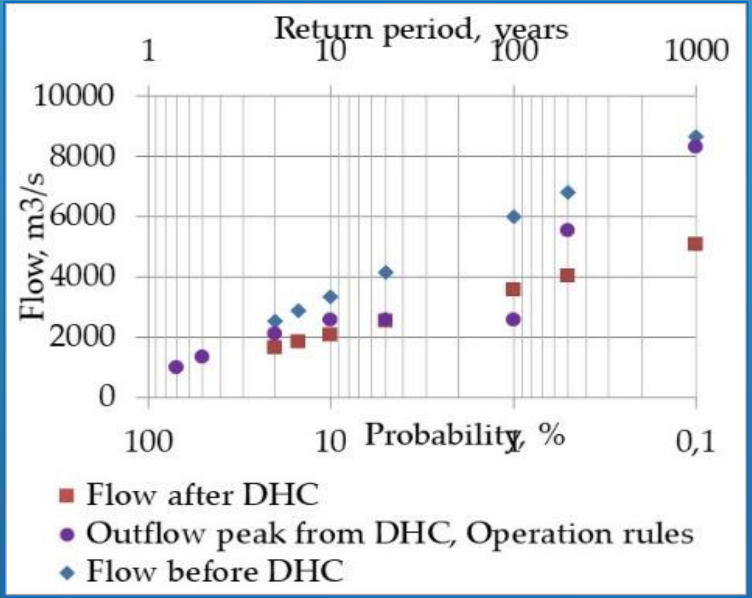


Distribution of peaks of different probabilities, Bender st

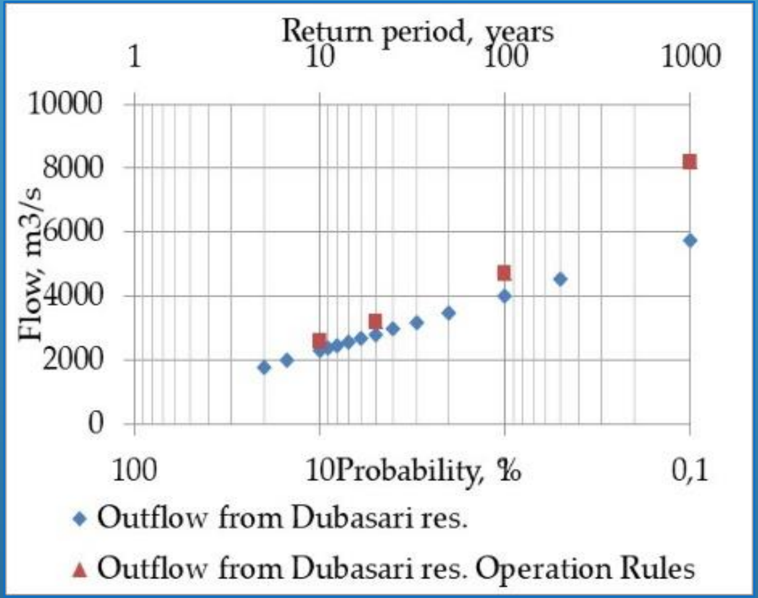
At Hrushca, the average peak discharges for the third period is with 552 m^3/s lower than for the second one, and the peak discharges of 0.1-20% probability decrease with 905-3586 m^3/s (35-41%). Coefficient of variation (Cv) changes insignificantly from 0.54 to 0.48. The comparative analysis of the discharges of 1-10%, estimated on the basis of the dataset from the Dubasary reservoir, and probable peak discharge from its Operation Rules indicates that the estimated probable peak discharges for the operation period are smaller with approx. 320-700 m^3/s, the reservoir having a lower effect in regulating the maximum runoff (12-15%).

Results and discussions

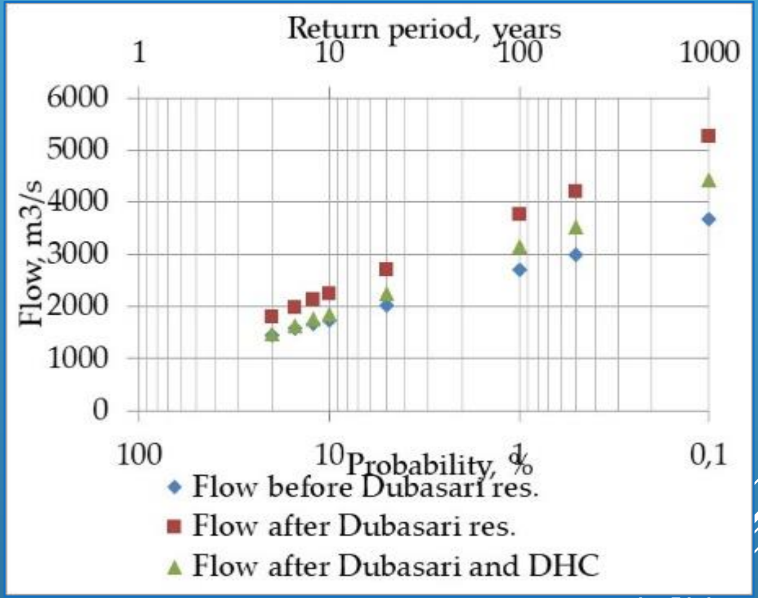
Changes in statistical parameters



Distribution of peaks of different probabilities, Hrushca st.



Distribution of peaks of different probabilities, Dubasary st.

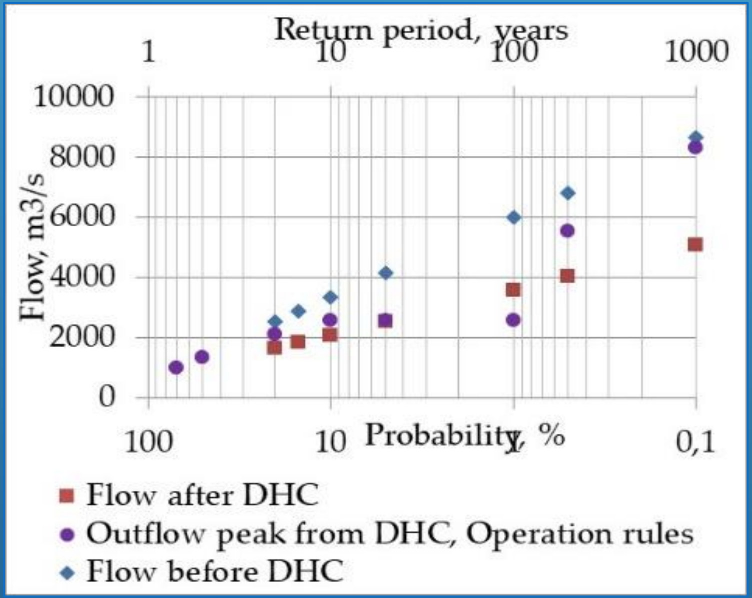


Distribution of peaks of different probabilities, Bender st

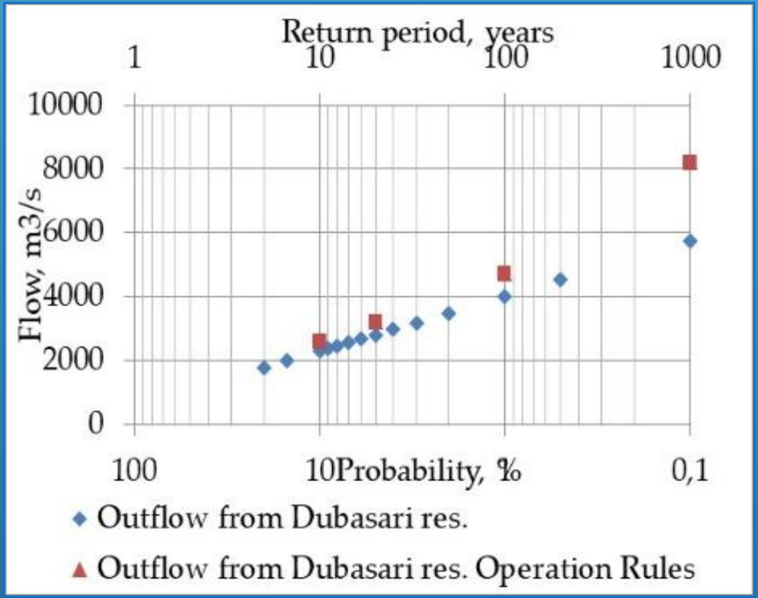
At Bender st., the average values of peak discharges are lower for the period of the entire flood protection system operation. Cv is 0.34, 0.43 and 0.44 for the three periods. However, the probability distribution shows an increase in the peak discharges of low and medium probability (0.1-10%) with ~ 22-44% in the second period, and with 1-21% in the third period, in comparison to those of the first period. 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.

Results and discussions

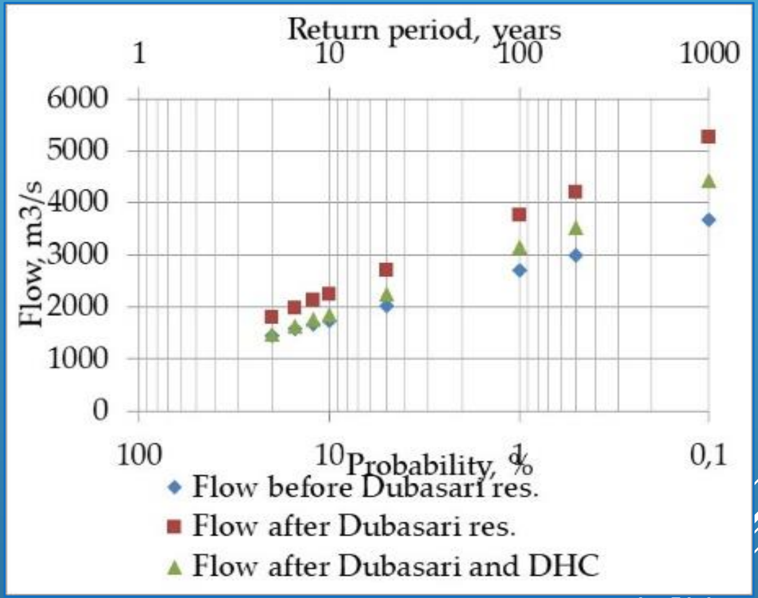
Changes in statistical parameters



Distribution of peaks of different probabilities, Hrushca st.



Distribution of peaks of different probabilities, Dubasary st.

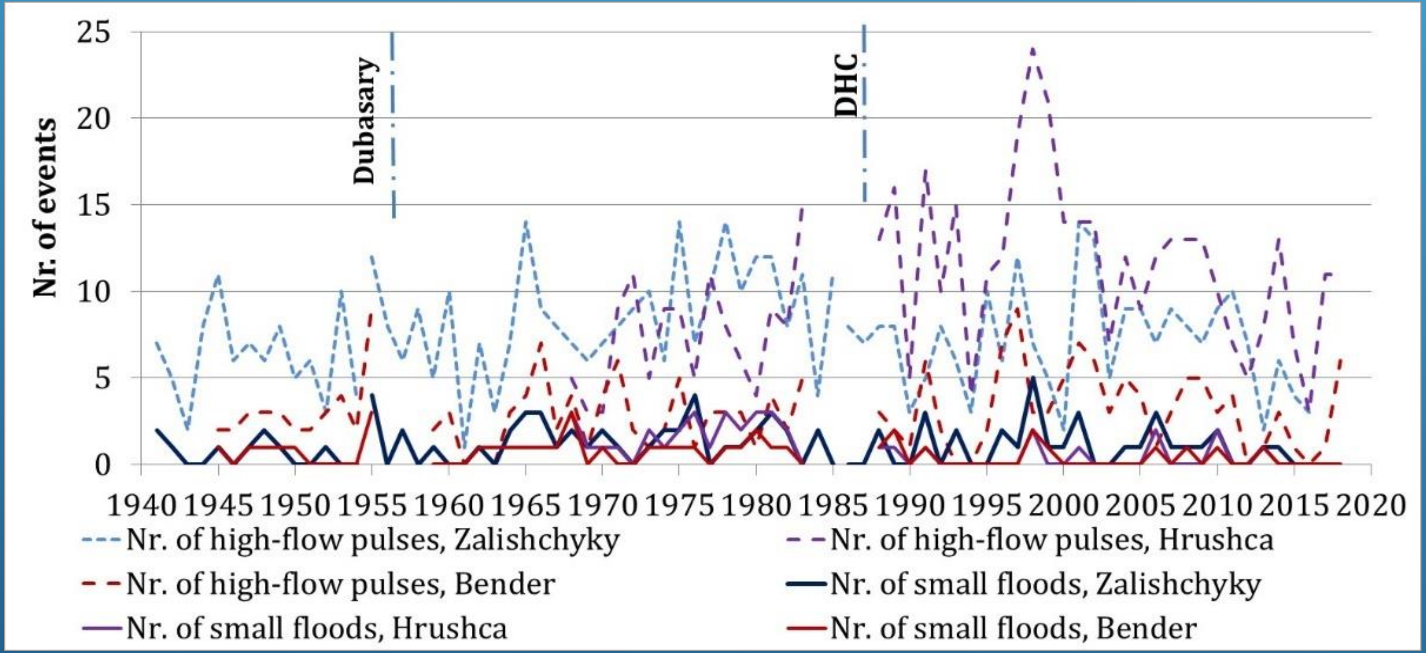


Distribution of peaks of different probabilities, Bender st

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.

Results and discussions

Environmental flow components



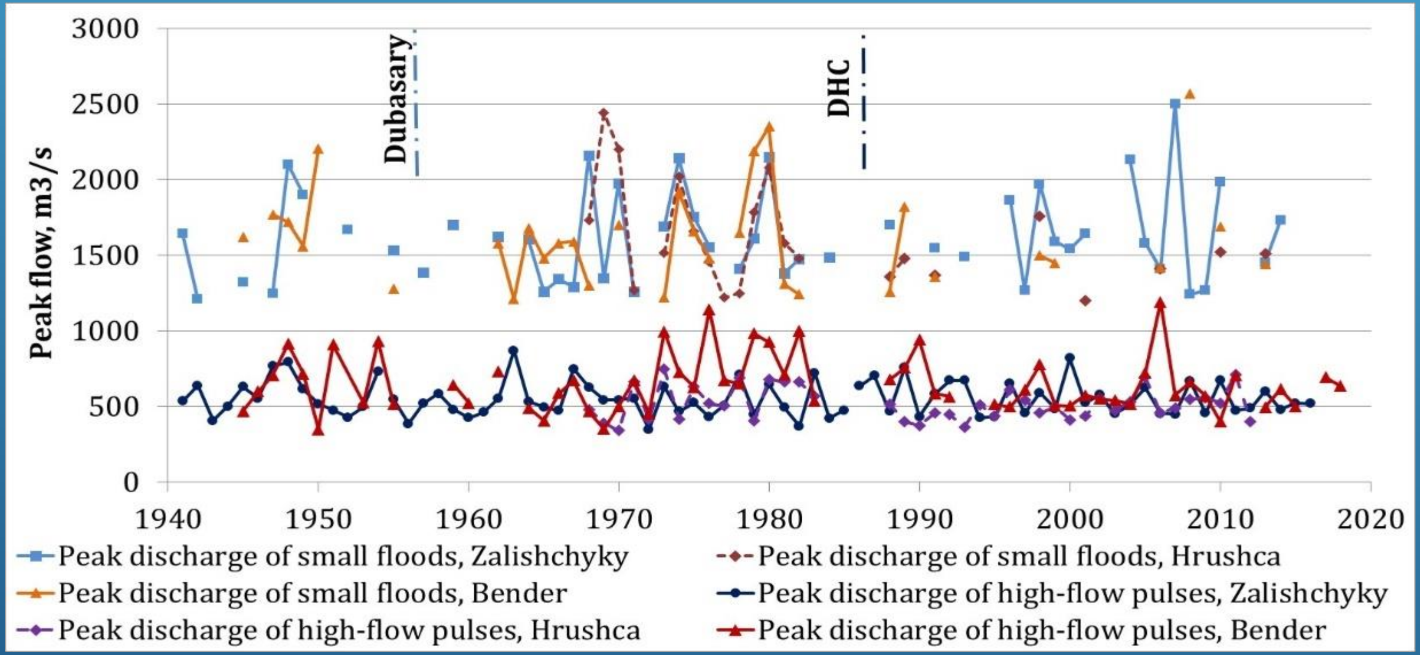
Number of cases of small floods and high flow pulses

Small floods: for the years of natural flow, 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.

The average value of small floods peak discharges was for the years 1945-1955 – 1584 m^3/s at Zalishchyky, 1692 m^3/s at Bender, for the period of only the Dubasari res. operation - 1596 m^3/s at Zalishchyky, 1670 m^3/s at Hrushca and reduced to 1600 m^3/s at Bender st. (downstream from the Dubasari dam), and for the period after entire flood protection system construction: 1662 m^3/s at Zalishchyky, 1451 m^3/s at Hrushca, and 1634 m^3/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.

Results and discussions

Environmental flow components



Average peak discharge of small floods and high flow pulses

Annual frequency of high-flow pulses of ±30%, 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. 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.

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 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 m3/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.

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.

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Thank you for attention