IMPACTS OF THE RESERVOIRS ON THE RIVER LOW FLOW AND MEASURES TO MITIGATE THE NEGATIVE EFFECTS

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ABSTRACT. – Impact of the reservoirs on the river low flow and measures to mitigate the negative effects. This paper aims to highlight the impacts of the reservoirs on the low flow downstream of dams. It is based on the analysis of the flow data sets (mean daily and monthly discharges, minimum monthly discharges) provided by gauging stations located downstream four reservoirs in Romania: Gilău, Siriu Pecineagu and Surduc. Statistical methods and comparative analyzes of low flow parameters in natural regime and modified regime were mainly used.

The results show that the impacts are differents from one case to another. Generally, the flow decrease significantly in modified regime, mainly in spring and summer periods (the breeding period for most aquatic species). This occurs downstream of the reservoirs Surduc, Gilău and Pecineagu. In the case of Siriu reservoir, the impact of the dam construction on the low flow is less significant, and the low flow in modified regime are higher that in natural regime.

Keywords: low flow, reservoirs, impact, Romania.

1. INTRODUCTION

The dams and reservoirs represent one of the most significant human interventions in the hydrological cycle. Although the economic benefits of the reservoirs are undeniable, they cause quantitative, qualitative and ecological significant changes to the rivers. While in the past, the dam design and operation did not take into account the environmental issues, in the last decades, an increase in environmental awareness has led to the recognition that the management of water resources includes a responsibility to protect the natural resources that depend on water, from impacts that causing degradation (Sally, 2000).

This paper aims to highlight the impacts of the reservoirs on the low flow in the different geographic regions of Romania. Based on the knowledge of this impacts, appropriate measures to mitigate the negative effects of the reservoirs could be considered.

2. DATA AND METHODS

The study is based on the flow data series (mean daily and monthly discharges, minimum monthly discharges) recorded at the gauging stations located

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downstream of four reservoirs in Romania (the data were provided by the National Institute of Hydrology and Water Management- NIHWM): Gilău reservoir on Someşul Mic River, Siriu reservoir on Buzău River, Pecineagu reservoir on Dâmbovița River and Surduc reservoir on Gladna River (Fig. 1 and Table 1).

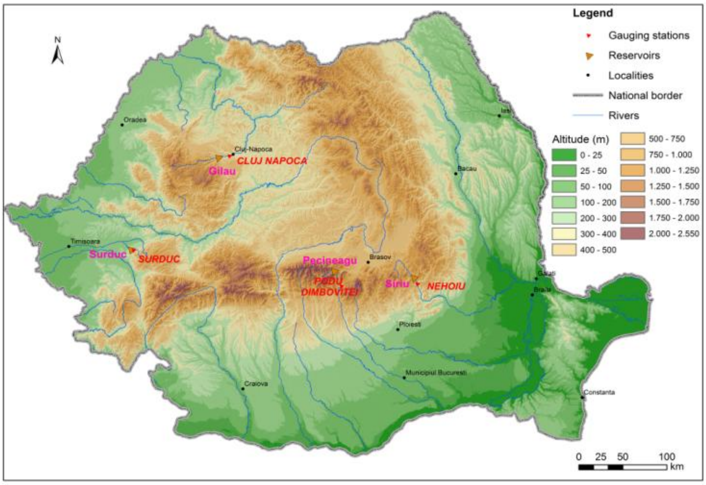

Fig. 1. ***Location of the analyzed reservoirs and the gauging stations***

Table 1. ***The main characteristics of the analyzed reservoirs and related gauging stations***

No.	Reservoir (year of putting into operation)	Total volume (mil. m^3)	Lake surface (ha)	Purpose	River	Gauging station	Altitude (m)	Area (km^2)	Mean annual flow (m^3/s)
1	Gilău (1971)	4.2	68	WS, E, F	Someşul Mic	Cluj-Napoca	977	1194	2.86
2	Siriu (1994)	155	420	I, FM, R, WS, E	Buzău	Nehoiu	1020	1549	4.23
3	Pecineagu (1984)	69	182	WS, I, E	Dambovița	Podu Dâmboviței	1415	260	0.86
4	Surduc (1976)	50	532	WS, I, FM	Gladna	Surduc	456	62	0.24

WS = water supply; E = energy; F = fisheries; I = irrigation; FM = flood mitigation; R = recreation
(Data sources: NIHWM, *Register of the large dams-Romania)*

Statistical methods and comparative analyses of low flow parameters under natural (before the reservoir/dam construction) and modified regime (after the reservoir/dam construction) are mainly used. The considered periods are mentioned in Table 2.

For the two periods (before and after reservoir construction), the lowest of the mean daily discharges, and the average and the lowest of the minimum monthy discharges were computed and compared. Based on the duration curve of the mean daily discharges and on the theoretical probability curve (Pearson III distribution) of the minimum monthly discharges, the values with the probability of 95% were selected and compared for the two separated periods.

Tabel 2. ***The lenght of the data series used in the analyses***

No.	Gauging station	Total period	Period with natural regime	Period with modified regime
1	Cluj Napoca	1951-2009	1951-1970	1971-2009
2	Nehoiu	1950-2009	1950-1993	1994-2009
3	Podu Dâmboviței	1950-2009	1950-1983	1984-2009
4	Surduc	1953-2000	1953-1975	1976-2000

The impact on the flow regime was highlighted by the comparative analysis of the monthly values in natural (pre-impact) and modified (post-impact) regimes.

The magnitude of the impact (rate of the change) was cuantified by the parameter k (in %), determined as ratio between the discharge (Q) after and before the impact caused by the reservoir construction, calculated using the formula:

$$k = \frac{Q_{after\_impact}}{Q_{before\_impact}} * 100$$

3. RESULTS

The analysis of the daily minimum average discharges (the lowest values of the daily average discharges) for the four gauging stations, before and after the dam construction, shows lower values in the period “after impact” comparative with the “before impact” period at Cluj-Napoca and Podu Dâmboviței gauging stations, higher value at Nehoiu gauging station, while in the case of Surduc gauging station the values are equal in both period (zero). The same situation is observed for the lowest of the minimum monthly discharge (Table 3).

Table 3. ***The lowest of the daily mean discharges ($Q_{daily\ average}$), of the minimum monthly discharges ($Q_{min\ monthly}$) and the average of the minimum monthly discharges at gauging stations located upstream of reservoirs, before and after the impact***

No.	Gauging station	River	The lowest $Q_{mean\ daily}$ (m^3/s)		k (%)	The lowest $Q_{min\ monthly}$ (m^3/s)		k (%)	The average $Q_{min\ monthly}$ (m^3/s)		k(%)
			before the impact	after the impact		before the impact	after the impact		before the impact	after the impact	
1	Cluj-Napoca	Someşul Mic	0.352	0.126	**35.8**	0.114	0.078	**68.42**	5.89	3.77	**64**
2	Nehoiu	Buzău	1.19	1.75	**147**	1.13	1.63	**144.25**	8.80	6.44	**73.22**
3	Podu Dâmboviței	Dambovița	0.134	0.05	**37.3**	0.061	0.039	**63.93**	2.38	1.16	**48.54**
4	Surduc	Gladna	0	0	**0**	0	0	**0**	0.406	0.05	**14.63**

The comparative analysis of the average of the minimum monthly discharges computed for the four case studies, in natural and influenced regime, shows important impacts on the flow downstream the reservoirs, mainly at Surduc gauging stations (only 14% from natural regim) and Podu Dâmboviței (48% from natural regime*)* (Table 2, Fig. 2).

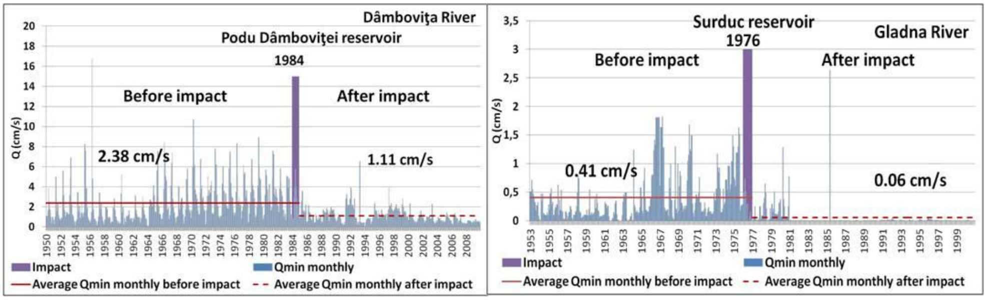

Fig. 2. ***Variability of the minimum monthly discharges and their averages before and after reservoir construction at Surduc and Podu Dâmboviței gauging stations***

For all studied gauging stations, significant decreases of the low flow (expressed by the average minimum monthly discharges) are found in influenced regime compared to the natural one. The smallest impact is observed at Nehoiu gauging station, while at Surduc gauging station the impact is considerable (Fig. 3).

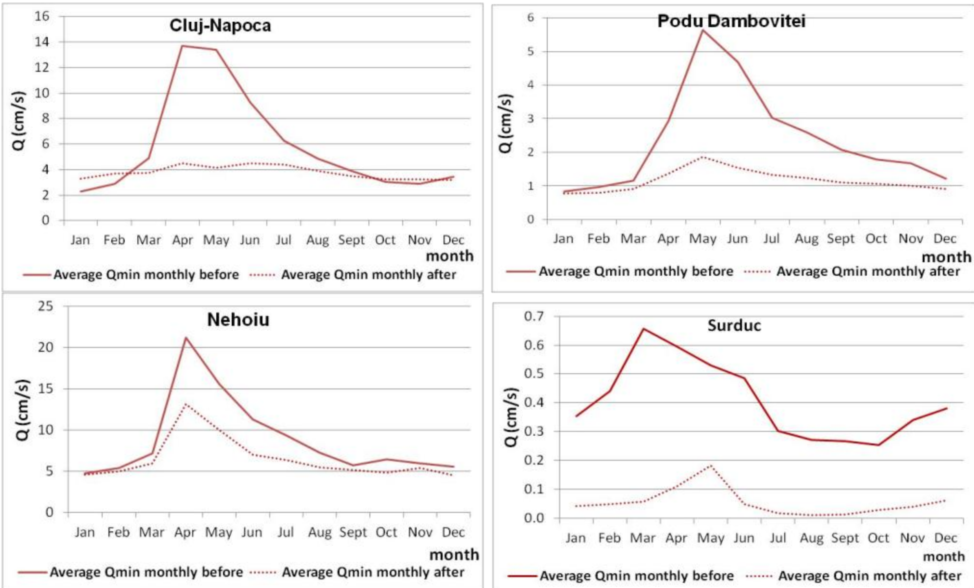

Fig. 3. ***The monthly variability of the averages of minimum monthly discharges at gauging stations located upstream of reservoirs, before and after their construction***

The analysis of variability of the lowest values of the monthly minimum discharges for the two periods shows also an important diminution of the low flow in the influenced regime. The most impacted are the flow regimes at Surduc, Podu Dâmboviței and Cluj-Napoca gauging stations, while at Nehoiu, the impact is less significant (Fig. 4).

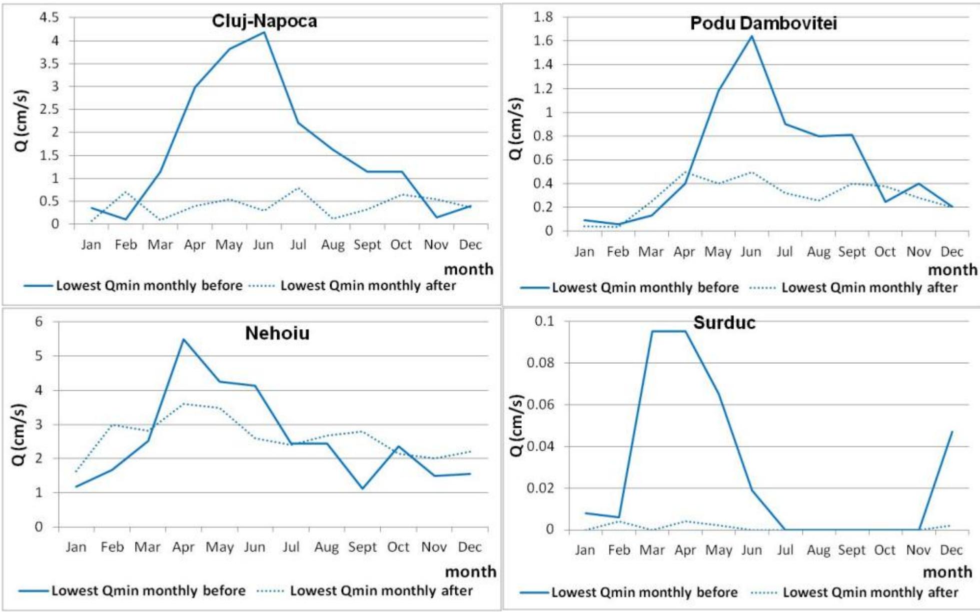

Fig. 4 . ***The monthly variability of the lowest values of minimum monthly discharges at gauging stations located upstream from reservoirs, before and after their construction***

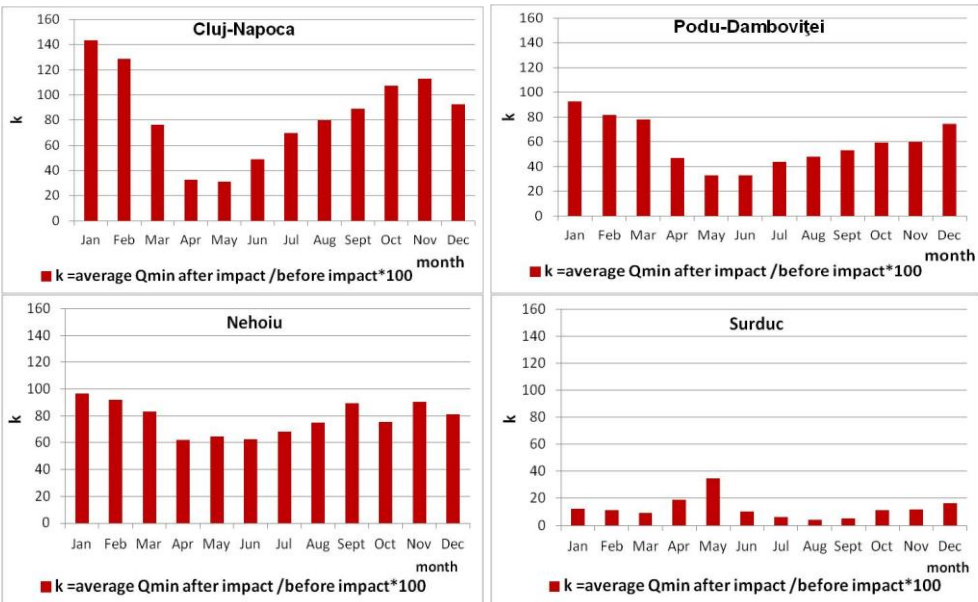

Fig. 5. ***The monthly variability of the rates of changes (k) of natural regime, considering the averages of minimum monthly discharges at gauging stations located downstream of the reservoirs***

Figure 5 shows the rates of changes for each month. Excepting Surduc gauging station, the most important changes are in the warm period (March – October), when the influenced discharges decrease up to 30% from the discharges in natural regime. At Surduc, there are significant changes all the month (excepting in May, the impacted discharges are less then 20% from the natural ones.

The comparative analyze of the average daily discharges with 95% probability of occurrence (obtained from the flow duration curve - FDC), before and after impact, shows lower values in influenced regime in case of Podu Dâmboviței and Surduc gauging station, and higher values in case of Cluj-Napoca and Nehoiu gauging station (Table 3). A similar situation is distinguished for the minimum discharge with 95% probability estimated based on Pearson III distribution.

Table 3. ***Dicharges with 95% probability of occurrence at gauging stations located upstream of reservoirs, before and after the impact***

No.	Gauging station	River	$Q_{95\% \text{ from FDC}}$ (m^3/s)		**k (%)**	$Q_{min\ 95\% \text{ probability}}$ (m^3/s)		**k (%)**
			before the impact	after the impact		before the impact	after the impact	
1	Cluj-Napoca	Someşul Mic	2.21	4.72	**214**	0.105	0.334	**318**
2	Nehoiu	Buzău	3.48	4.2	**121**	1.17	1.85	**158**
3	Podu Dâmboviței	Dâmbovița	1.1	0.55	**50**	0.146	0.143	**98**
4	Surduc	Gladna	0.065	0	**0**	0.004	0	**0**

$Q_{95\% \text{ from FDC}}$ = average daily discharges with 95% probability of occurrence derived from the Flow Duration Curve (FDC); $Q_{min\ 95\% \text{ probability}}$= minimum discharge with 95% probability estimated based on Pearson III distribution

Figure 6 summarize the monthly variability of the average daily discharges with the 95% probability of occurence (derived from the FDC) before and after the reservoir impact. The graphs illustrate significant reductions of the discharges at Surduc and Podu Dâmboviței gauging stations. At Cluj Napoca, in the period after impact, the disharges reduced, especially in the wet season (March to July) when aquatic species need more water for reproduction. In the case of Nehoiu gauging station, they are not significative differences between the natural and impacted regime and from August to February, after the reservoir construction, the discharges are even higher than in natural regime.

The analysis of the values of average monthly discharges with 95% probability of occurrence computing before and after dam impact highlights important changes of the low flow regime, similar to those revealed by the monthly variability of the average daily discharges with the 95% probability of occurence derived from the flow duration curve.

4. MEASURES TO MITIGATE THE RESERVOIRS NEGATIVE EFECTS

The alteration of river flow as a consequence of reservoirs/dam construction can have profound implications on river ecosystem. Artificial low flow conditions influence the quantity and quality of the aquatic habitat. As a consequence, disturbance adapted species instead the non-native species can be favorised. In order to mitigate the negative effects of dams on the low flow and rivers ecological state, some possible measures consist in the design and implement dam re-operation strategies and the environmental discharge releases to sustain downstream ecosystems.

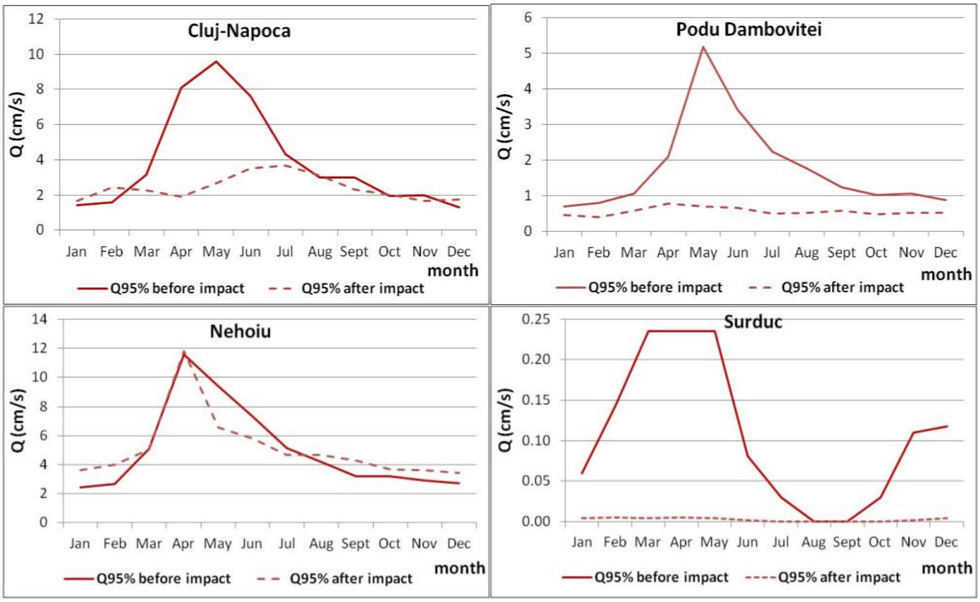

Fig. 6. ***The monthly variability of the discharges with 95% probability of occurence (derived from the flow duration curve) at gauging stations located upstream of reservoirs, before and after their construction***

The dam re-operation strategies involve measures for reduce the undesirable effects of a dam by modification of its structure or operation, or through changes in the management of the catchment related to the reservoir. Many of the dams not release the water downstream because its outlet works constrain opportunities for flow restoration. The new strategies for modifying dam operations refer to attain new goals of the original benefits for which the dam was built. The strategies aim to obtain the specified levels and types of flow restoration necessary to realize both the social and the ecological goals. Decision-support systems can be particularly useful in differentiating, prioritizing and optimizing among multiple objectives for dam management (McCartney et al. 2005). Minimising the negative environmental effects of dams must become a prime focus of attention for owners, operators, financial institutions and environmental managers.

Environmental flows releases is an important river restauration measure in order to sustain downstream ecosystems. In case when the flow has been greatly reduced, the aquatic habitat and species disappear and the river channel may look like a small pools and wetlands. The Water Framework Directive introduces new ecological objectives designed to protect and, where is necessary, restore the structure and function of aquatic ecosystems and the sustainable use of water resources. To achieve these objectives, environmental flows release must provide suitable habitat conditions for maintain the biological integrity of the ecosystem by ensuring a hydrological regime that reflect a large proportion from the natural hydrological regime.

5. CONCLUSIONS

The presented paper analyse the impact of dams and reservoirs on the low flow, through four case studies, in Romania. The results show that the impacts are differents from one case to another. The hydrological regime in the postimpact period (after construction of the dams/reservoirs) changes significantly, by reducing, generally the minimum flows in modified regime compared to the natural one. This reduction occurs mainly in spring and summer periods (from March to August), the breeding period for most aquatic species. This is the case, mainly, of the stations Cluj Napoca and Podu Dâmboviței. The most affected is Gladna river at Surduc gauging station, where the low flow reduced drastically in all month. At Nehoiu gauging station, the impact of the dam construction on the low flow is less significant, and the low flow in modified regime are higher that in natural regime.

Because the minimum flows play an important role on the ecological state of the rivers, its reduction disrupt the aquatic ecosystems. Consequently, measures to mitigate the negative effects of the flow diminution need to be implemented upstream the dams and reservoirs, especially for ensuring the proper habitat for the survival and the reproduction of the aquatic species.

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