

## WATER MANAGEMENT SYSTEM LIPTOVSKÁ MARA – BEŠEŇOVÁ IN THE CONTEXT OF CLIMATE CHANGE

Emília Bednárová\*, Juraj Škvarka, Patrik Václavík, Jana Poárová

The presented article briefly presents the impact of the Liptovská Mara – Bešeňová water management system operation on the runoff conditions downstream the dam. The analysis showed that its benefit is evident, especially in the period of extreme hydrological phenomena, with the occurrence of long-lasting low flows or in the event of short-term flood flows. In the area of Liptovská Mara and Bešeňová, this is evident mainly in winter and spring, because of a small amount of liquid precipitation in winter and melting snow in the surrounding mountain massifs in spring. Other hydraulic structures' actual experiences also convince us that Slovakia's variability of natural conditions requires artificial water sources. In the interest of raising living standards, protecting the environment, and sustainable development, their role is irreplaceable. In recent decades, there has been an increasing debate about the growing demands on water caused by registered climate change and its effects on weather extremes, as well as human demographic change. History confirms that water reservoirs can reduce negative impacts caused by extreme hydrological phenomena – floods and droughts. In line with the need for adaptation to climate change and sustainable development, in addition to measures close to nature, technical measures, reservoirs, and dams are also necessary.

KEY WORDS: reservoir, dam, climate change, floods, drought, minimum flow

### Introduction

The Liptovská Mara – Bešeňová water management system is located in the northern part of central Slovakia, in the upper section of the Váh River. It was built between 1967 and 1975, and it is one of the crucial hydraulic structures of the Slovak Republic. Its purpose is to produce electricity for peak hours, flood control, and improve the flows of the Váh for industry and agriculture. The Liptovská Mara reservoir, together with the second largest Orava reservoir on the Orava River, which is the right-side stream of the Váh, as top reservoirs control flows in the Váh, starting from the riverbed downstream Bešeňová reservoir to the estuary to the Danube (Fig. 1). Both hydraulic structures use the rivers' energy potential, significantly reducing flood flows and reducing possible flood damage.

Through coordinated action in the system, they improve the river's flow rates in favor of domestic water and industrial or irrigation. They also enable the dilution of wastewater and improve the self-purification of the river. They also play a significant role in ensuring a sufficient flow in the Váh and its derivation channels when using the hydropower potential at the Vážská cascade. Both reservoirs simultaneously compose the scenery of the landscape. These reservoirs are an integral part of

the country, and they enable sports activities and create centers of tourism.

Recurring hydrological extremes are also an accompanying feature of registered climate change and global warming. Short-term flood flows vary with long periods of drought. Thus, the question of the large water reservoirs' influence on the hydrological regime of streams under dams comes to the forefront. In this article, we present the impact of the Liptovská Mara – Bešeňová water management system operation on the runoff conditions in the Váh River.

### Basic parameters and a brief description of objects

The objects of the Liptovská Mara are the dam and the reservoir, appurtenant structures as intakes and outlets of the hydroelectric power plant, spillways, and bottom outlets, a channel downstream of the dam. The objects of the Bešeňová are the dam with a compensating reservoir, an associated appurtenant structure, and a channel downstream of the dam. The essential data of both structures are given in Table 1. Other objects of the water management system are dikes for the protection of adjacent municipalities, dikes of the canal between the Liptovská Mara power plant and the Bešeňová reservoir, and pumping stations (Bednárová et al., 2010).

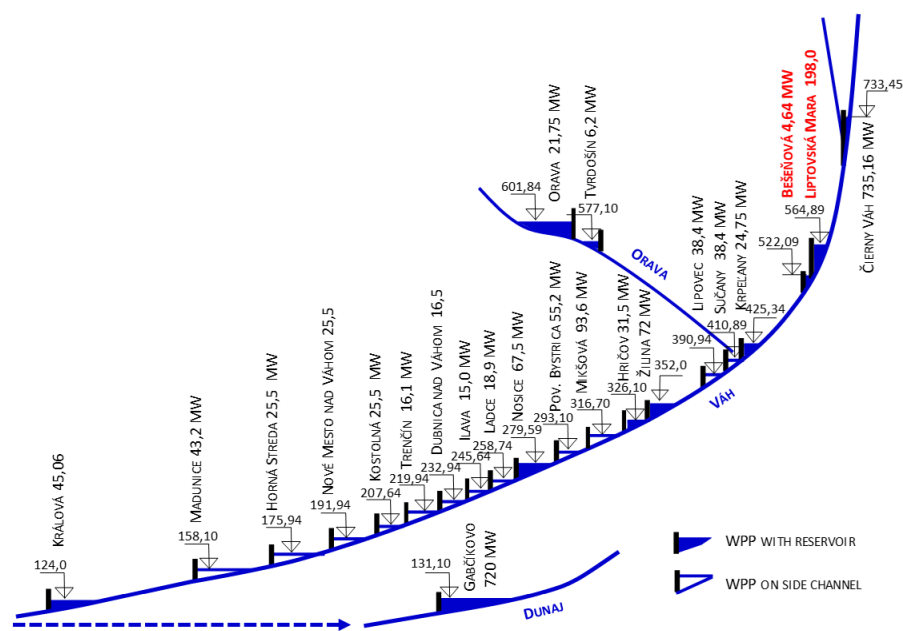


Fig. 1. Longitudinal elevation section of the Váh with plotted WPP in operation.

Table 1. Basic parameters of hydraulic structures

Basic information	Liptovská Mara	Bešeňová
construction	1967–1975	1967–1975
nearest municipality/stream	Vlachy and Vlašky / Váh	Bešeňová / Váh
height of the dam above the terrain / above the foundation joint	45 m / 52.5 m	12.5 m / 12.9 m
length of the dam's crest	1225 m	1109.4 m
volume of reservoir	361.9 mil m <sup>3</sup>	10.73 mil m <sup>3</sup>
purpose	electricity production, flood protection, flow improvement, recreation, fish farming	electricity production, compensating reservoir for Liptovská Mara, railway on the dam's crest

### Description of the Liptovská Mara dam

The Liptovská Mara dam is located on the Váh River. The dam is an earth-fill heterogeneous dam with silty sealing (Fig. 2). A double-layer filter protects the silty sealing.

Stabilizing prisms are made of gravelly and sandy soils, excavated in the alluvium of Váh. The subsoil of the dam was sealed from the grouting gallery by a grout curtain. The dam's upstream slope has slopes of 1:2.25 to 1:3; in the lower part 1:5. The downstream slope inclines 1:1.8; for every 10 m, there are 4 m wide berms. There is a drain on the downstream toe of the dam. A riprap protects the upstream slope; the downstream slope is humidified and grassed.

Appurtenant structures consist of a spillway in the area of the left valley slope. These are two fields, 11.0 m wide with a height of 3.6 m and a total capacity of

268.50 m<sup>3</sup> s<sup>-1</sup>. The left tunnel and the right tunnel used as bottom outlets with a total capacity of 80–280 m<sup>3</sup> s<sup>-1</sup>. The capacity depends on the water level in the Liptovská Mara and Bešeňová reservoirs. The hydraulic structure's integral part is a pumped-storage hydroelectric power plant with an installed capacity of 198 MW (2 x Kaplan + 2 x Dériaz, flow 2 · 140 m<sup>3</sup> s<sup>-1</sup> + 2 · 130 m<sup>3</sup> s<sup>-1</sup>).

The geological composition of the Liptovská Mara and Bešeňová consists of a Paleogene and a Quaternary. Slope sediments were formed mainly by weathering of the Paleogene. The Paleogene is formed mainly by flysch layers of claystone and various types of sandstones.

Quaternary sediments form slope debris with a low content of silty components. Fluvial sediments occur in two terraces, covered with a thick layer of sloping silt or clay. Eolithic sediments form a thick cover of terraces. In many cases, they are moved by deluvial material (mainly deluvial clays).

### Description of the Bešeňová dam

The Bešeňová dam is situated at the river kilometer of 335.22 (Fig. 3). The backwater level is at an elevation of 522.09 m a.s.l. and creates a reservoir that serves as a compensating reservoir for the peak load hydropower plant of the Liptovská Mara. It is an earth-fill heterogeneous dam with silty sealing. The sealing of the dam protected by a double-layer filter on both sides is embedded to the subsoil by a silty-concrete cutoff wall and grouting curtain. There is a railway at the crest of the dam. The hydroelectric power plant has two direct flow Kaplan turbines with a capacity of  $2 \cdot 20 \text{ m}^3 \text{ s}^{-1}$  and with a maximum output of 2.24 MW with bypassed alternators.

### Hydrological parameters

Liptovská Mara and Bešeňová are in the Liptovská basin, in the valley of the upper section of the Váh River. They are surrounded on the northeast by the Western Tatras, on the south by the Low Tatras, west by the Great and Little Fatra, and the northwest by the Choč Hills. The catchment area of the Liptovská Mara dam profile is 1,481.90 km<sup>2</sup>, and the Bešeňová dam profile 1,612.23 km<sup>2</sup>. The average annual rainfall is about 710 mm. There are 11 tributaries to the reservoirs, but Váh, Demenovka, Palúdzanka, Lupčianka, Jalovský, and Kvačianka have a significant influence (Fig. 4).

The measurement results for the period 1978–2019 (Fig. 5) show that the average monthly inflow into the reservoirs is  $27.988 \text{ m}^3 \text{ s}^{-1}$  and the average monthly outflow from the Bešeňová reservoir is  $26.184 \text{ m}^3 \text{ s}^{-1}$ . The difference between inflow and outflow can be

attributed to vapor losses and seepage.

The system of Liptovská Mara – Bešeňová, besides its activities (usage of hydropower potential, reduction of flood flows, flows improvement for the industry, agriculture, improving water quality, recreation, and sports, navigation, and fishing), has to provide a minimum flow of  $15 \text{ m}^3 \text{ s}^{-1}$  year-round in the river Váh downstream the compensating reservoir Bešeňová. Exceptionally, the outflow can be reduced to  $10 \text{ m}^3 \text{ s}^{-1}$  if the flow of the left-side tributary Váh – Revúca downstream the Bešeňová exceeds  $5.0 \text{ m}^3 \text{ s}^{-1}$ , or if the level in Liptovská Mara falls below the level of 562.00 a.s.l. in the period from July to December (due to reserving a sufficient volume of water in the reservoir for safe winter operation) (Lukáč et al., 1996).

### Influence of hydraulic structure on outflow downstream the dam

The operation's influence on the outflow conditions downstream of the dam can be presented by the probability curve of the inflow into the reservoirs ( $Q_p$ ) and the outflow into the riverbed downstream the dam ( $Q_o$ ) (Lukáč et al., 1991, Votruba and Patera, 1997). Fig. 6 shows the average monthly flows in the winter months (January February), in the spring months (April and May), in the summer months (July, August), and in the autumn months (November December).

The presented graphs show the minimum flow of  $15 \text{ m}^3 \text{ s}^{-1}$  and its reduced value of  $10 \text{ m}^3 \text{ s}^{-1}$ . The average monthly flow analysis shows that the water management system's operation redistributes them during the year. While in the winter months, the flows under the dam are significantly improved, in the spring months, the higher

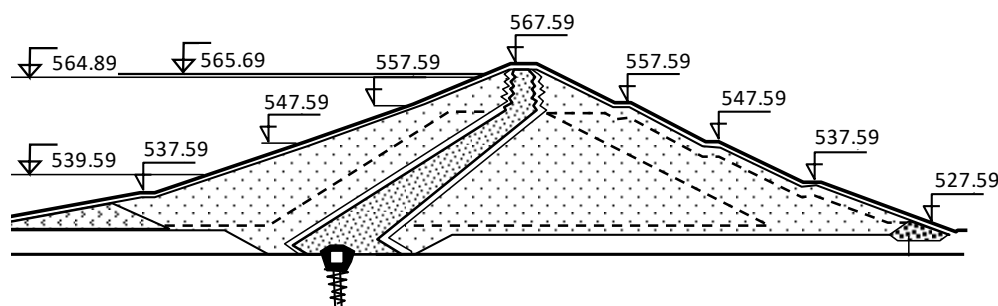


Fig. 2. Cross-section profile of the Liptovská Mara dam.

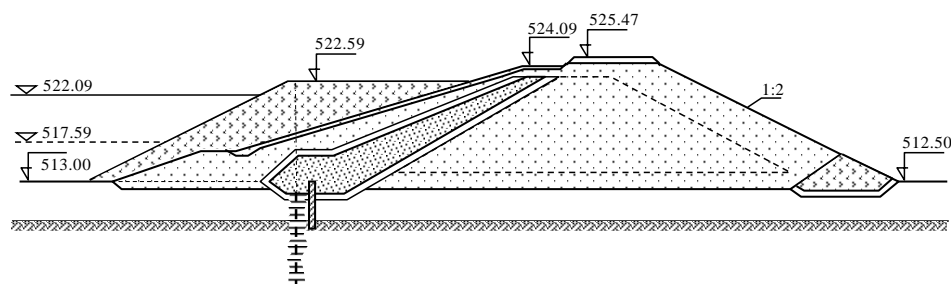


Fig. 3. Cross-section profile of the Bešeňová dam.

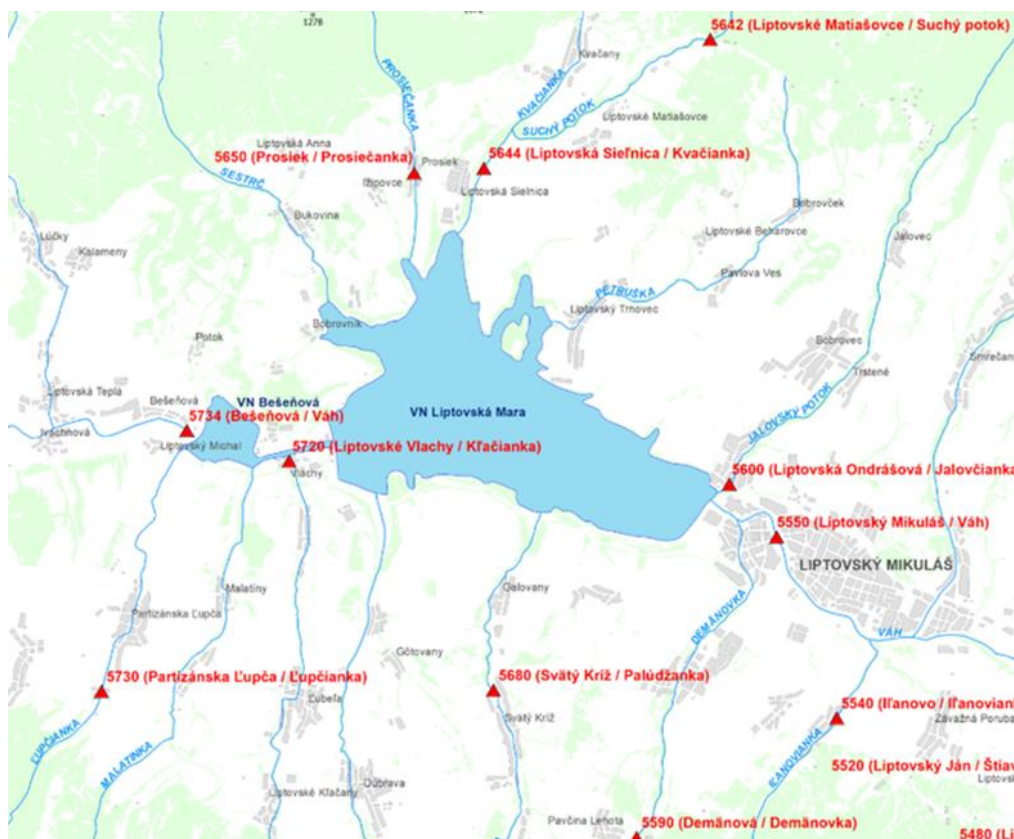


Fig. 4. The situation of water reservoirs de Liptovská Mara and Bešeňová with gauging stations of Slovak Hydrometeorological Institute.

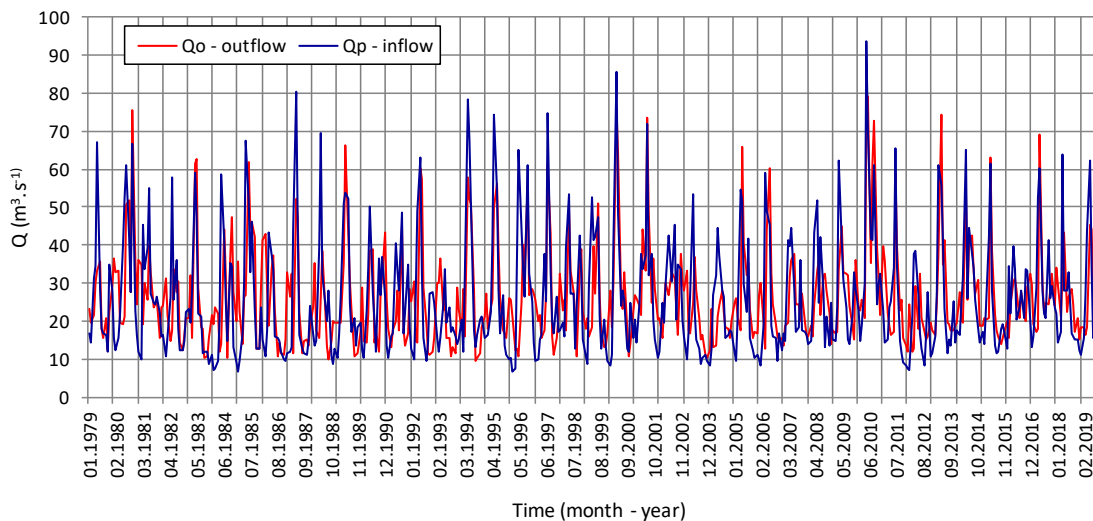


Fig. 5. Development of the average monthly inflow to the Liptovská Mara reservoir and outflow to the riverbed downstream the Bešeňová dam.

flows are reduced. In the summer and autumn months, the reservoir’s impact on the runoff conditions downstream of the dam is less significant. The water management system’s positive function on the outflow ratios in the Váh can also be registered in Fig. 7. There are presented inflows and outflows with a probability of 5% (increased flows), 50% (average flow values), and 90%

and 95% (low flow values). We can register the positive impact of the reservoir’s operation on the hydrological regime of the Váh downstream the Bešeňová dam profile. The positive effect of the Liptovská Mara operation on the redistribution of flows is evident from the fluctuating annual cycle of inflows – the accumulation of water in the spring months and increasing outflows in

the winter months. This is also confirmed by the decrease in the coefficients of the variation value of the analyzed average monthly inflows and outflows with a presented probability of occurrence of 5% to 95% (Table 2).

The documented results (Fig. 8) show that the most vulnerable is the winter period. Then the natural reliability  $P\alpha$  reaches the specified minimum flow of  $15 \text{ m}^3 \cdot \text{s}^{-1}$  with a probability of only 30 to 40%. Without

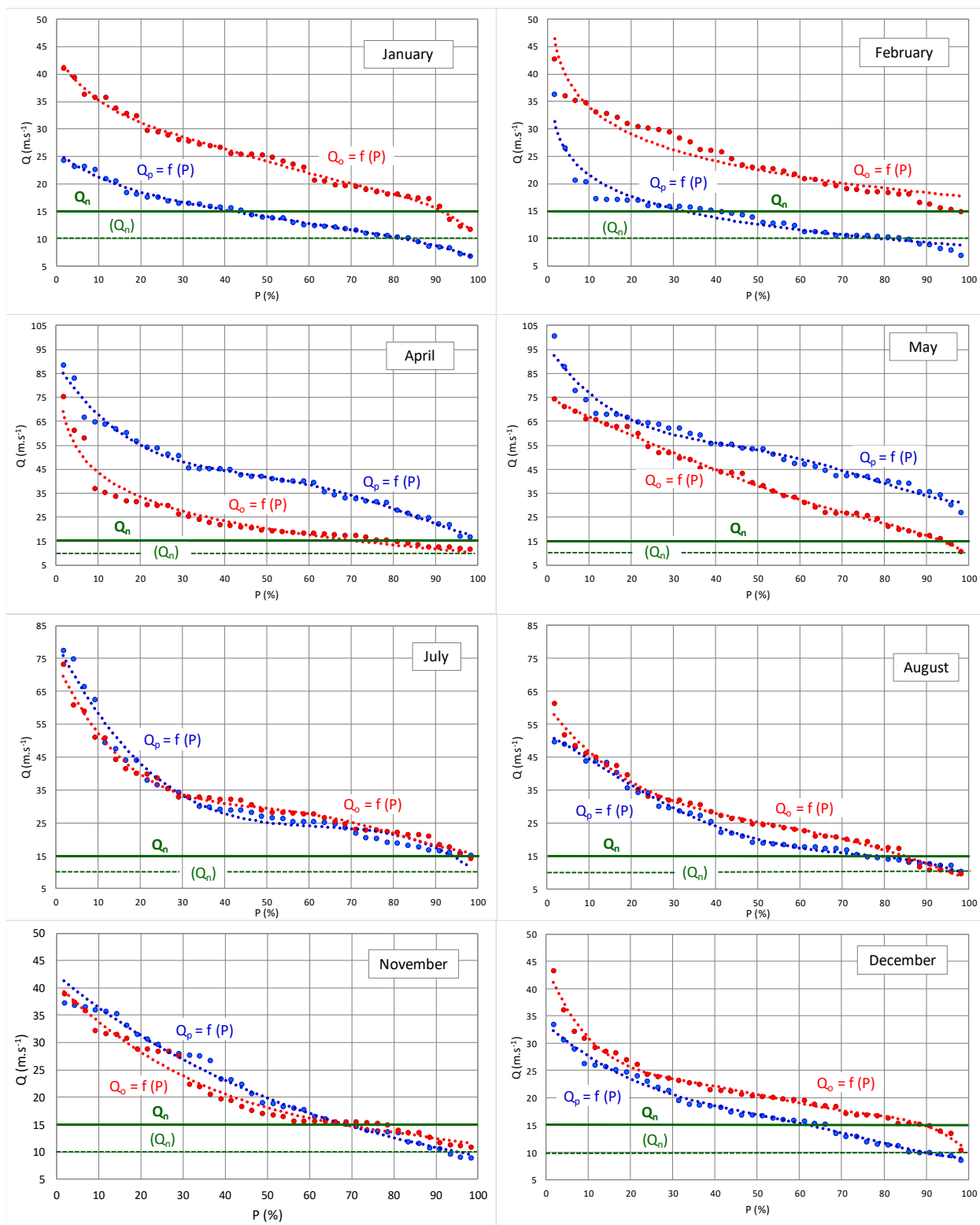


Fig. 6. Probability curves of inflow and outflow in winter, spring, summer, and autumn months.

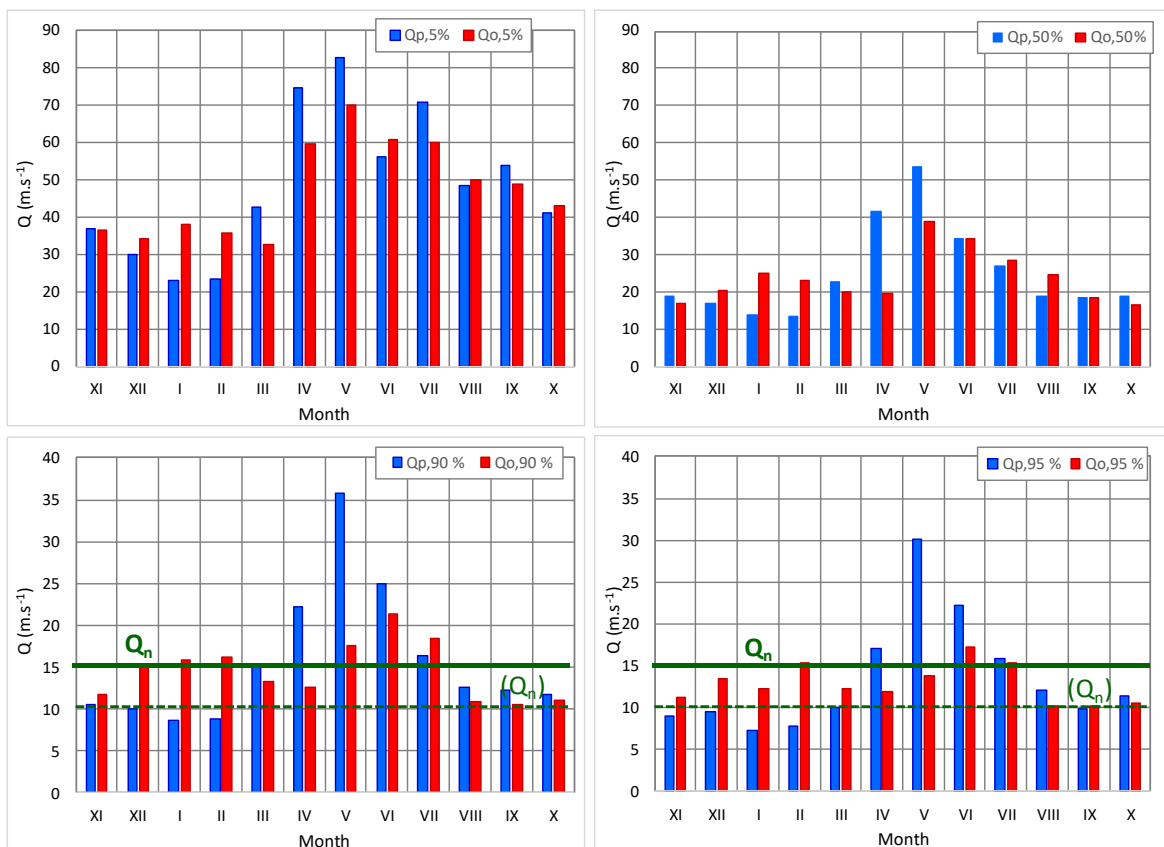


Fig. 7. Development of average monthly inflows and outflows with probabilities of occurrence of 5%, 50%, 90%, and 95%.

Table 2. Coefficients of variation of inflows ( $Q_p$ ) and outflows ( $Q_o$ )

$Q$	$Q_{p,5\%}$	$Q_{o,5\%}$	$Q_{p,50\%}$	$Q_{o,50\%}$	$Q_{p,90\%}$	$Q_{o,90\%}$	$Q_{p,95\%}$	$Q_{o,95\%}$
$C_v$	1.666	1.451	0.619	0.361	0.466	0.360	0.493	0.420



Fig. 8. View of the Liptovská Mara dam with the High Tatras in the background.

improving the flows in the Váh through the Liptovská Mara reservoir, with a probability of more than about 65% (almost two months from the three-month winter period), a minimum flow of  $15 \text{ m}^3 \text{ s}^{-1}$  would not be ensured in the Váh riverbed.

The flood control function cannot be neglected either when evaluating the impact of reservoirs on the outflow regime downstream of the dam. Data shows that there were often recurring major floods in the period before 1950 when there were no reservoirs and dams in Slovakia. On the Orava River we can mention floods in the years 1725, 1748, 1749, 1750 ... 1813, 1830, 1870 ... 1848, on the Váh River in the years 1557, 1593, 1594 ..., 1602, 1622, 1625 ... 1710, 1714 ... 1813, 1880 ... 1950 ... 1960. The construction of the Orava and Liptovská Mara reservoirs (Fig. 8) significantly eliminated their occurrence.

The production of green electricity must be added to the positives of the Liptovská Mara – Bešeňová water management system to ensure minimum flows under the dam. The Liptovská Mara and Bešeňová hydroelectric power plants have produced more than 6,500 GWh of green electricity from a renewable source – water, with an average annual production of 152.8 GWh (134.5 GWh + 18.3 GWh). An essential function of the water management system is also to improve the flow for hydropower plants throughout the Vážská cascade.

## Conclusion

The Liptovská Mara – Bešeňová water management system, which has been in operation for 45 years, reliably fulfills all planned purposes. These hydraulic structures have significantly reduced floods in the Váh basin since 1975. Using the energy potential of Váh, the water management system contributed to the energy network

by producing more than 6,500 GWh of green electricity. There is enough water for industry and agriculture by improving the Váh River flows through the Liptovská Mara reservoir. Within the framework of registered climate change and global warming, with recurring hydrological extremes, the function of this water management system is increasing  $10 \text{ m}^3 \text{ s}^{-1}$  under the Bešeňová dam. The analysis showed that the winter season is the most vulnerable. Without the accumulation storage of the Liptovská Mara reservoir, approx. 362 million  $\text{m}^3$ , for almost two months a year, the minimum flow of  $15 \text{ m}^3 \text{ s}^{-1}$  would not be ensured in the Váh River. The added value of the Liptovská Mara and Bešeňová reservoirs is also the completion of the landscape character, the development of tourism, the possibility of recreational and sports use of this area.

## Acknowledgement

*We would like to express our gratitude to the Slovak Hydrometeorological Institute for providing data and information.*

## References

- Bednárová, E. et al.: Dam construction in Slovakia. Originalities - Milestones - Noteworthy facts. Bratislava, Kuskus 2010, 207. ISBN 978-80-970428-0-6
- Lukáč, M. et al. (1996): Evaluation of selected water reservoirs' real operation impacts on the flow regime. Stage 2, SvF STU, 1996, 258.
- Lukáč, M., Bednárová, E., Štefanek, J. (1991): Reservoirs and water management systems. ES STU, Bratislava 1991, 277.
- Votruba, L., Patera, A. (1997): Reservoirs and water management systems. ES ČVUT Praha, 1997, 191. Hydrological data from the data SHMÚ set time.

Prof. Ing. Emília Bednárová, PhD. (\*corresponding author, email: emilia.bednarova@stuba.sk)  
Ing. Juraj Škvarka, PhD.  
Ing. Patrik Václavik  
Slovak University of Technology in Bratislava  
Radlinského 11  
810 05 Bratislava  
Slovak Republic

Ing. Jana Poórová, PhD.  
Slovak Hydrometeorological Institute  
Jeséniova 17  
833 15 Bratislava  
Slovak Republic