ANALYSIS OF SEASONAL FLOOD PATTERNS FOR RESERVOIR SAFETY EVALUATION IN A SLOVAK MOUNTAIN CATCHMENT

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ABSTRACT

This study focuses on seasonal flood wave characteristics in the Liptovská Mara reservoir catchment, highlighting their importance for flood risk mapping and dam safety assessment. We used a multivariate statistical analysis to evaluate flood wave properties derived from the discharge time series (1989–2021). Two approaches for determining inflows were compared: (i) a simplified method using main stream time series to estimate total outflow, and (ii) a comprehensive approach integrating tributary inflows. Flood waves were identified and categorized as annual or seasonal (June–October and November–May) using the FloodSep tool. Results reveal distinct seasonal differences: winter floods, driven by snowmelt, show longer durations and higher volumes, while summer floods, often storm-induced, are shorter and narrower. This enhanced understanding aids flood risk mapping and dam safety assessment, as well as hydrological modelling in the reservoir catchment.

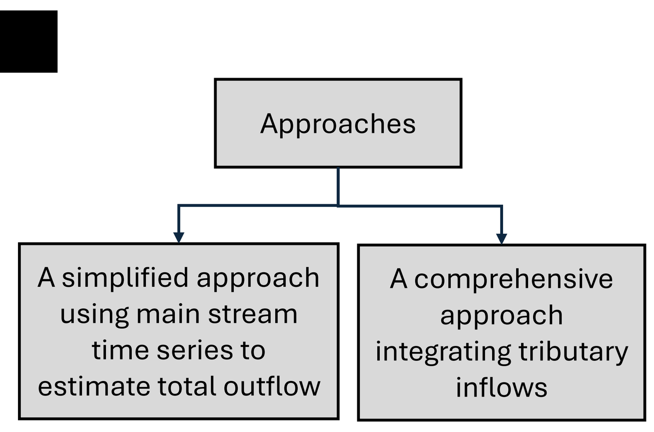
1 MOTIVATION

For effective flood risk management, it is necessary to correctly estimate the volumes of reservoirs and design the capacities of safety spillways and protective dams. Design flood hydrographs (a set of control flood hydrographs) are often used to design and assess water structures' safety, providing information not only on the peak discharge of the flood wave but also about its volume and time course. To obtain these characteristics, it is necessary to know the time series of discharges from which specific flow waves are selected for further analysis. As flood hydrographs determine the parameters of the engineering structures, as well as their efficiency and reliability, their incorrect estimation can lead to serious economic and material losses. This study presents methods and tools for determining flood wave characteristics and analyzing reservoir inflows, which are necessary for estimating design and/or control flood hydrographs to support further analyses, particularly flood risk mapping and dam safety assessment. The method was applied and tested in the mountainous catchment of the River Váh with an outlet at Liptovská Mara reservoir in Slovakia.

2 METHODOLOGY

DETERMINATION OF FLOWS INTO THE RESERVOIR

- The approaches use a hydrological analogy,
- Missing discharge data estimated based on the ratio of catchment areas and measured data from nearby stations,
- Adjusted discharge data to correspond to the total area of the estuary of the reservoir using the equations.



$$Q_{OP} = k \cdot Q_{GS} \quad [m^3.s^{-1}]$$

$$k = \frac{A_{OP}}{A_{GS}} \quad [-]$$

Q_{OP} – discharge in the outlet profile [$m^3.s^{-1}$];
Q_{GS} - discharge in the gauging station in the basin [$m^3.s^{-1}$],
k - coefficient expressing the ratio between the area of the basin up to the inflow profile and the area of the catchment up to the gauging station [-],
A_{IP} - area of the basin in the outlet profile of the basin [km^2],
A_{GS} - area of the basin up to the gauging station [km^2].

INPUT DATA PREPARATION

- Time series of river discharges in a sufficiently short time step,
- Positions of observed annual maximum flood waves.

OBSERVED FLOOD WAVE IDENTIFICATION

- Separation of baseflow using one of the pre-defined methods in FloodSep software,
- Identification of the beginning and end of each flood wave based on precipitation data.

OBSERVED FLOOD WAVE ANALYSIS

- Identification of flood peak, flood duration, and flood volume
- Identification for winter (November to May) and summer (June to October) seasons based on occurrence during the hydrological year
- Analysis of seasonal flood wave characteristics (seasonal flood patterns)

4 CONCLUSION

- The difference between the long-term average annual discharges determined by the approaches is **0.55 m^3/s,** or approximately **2.06%**. This small difference indicates that the approaches do not differ significantly. Therefore, the simpler first approach can be used in further analyses within the selected catchment, as only measured discharge data from the main river would be sufficient - **a practical advantage.**
- In the analysis of the annual maximum waves, it can be seen that the waves differ depending on their occurrence during the year, both in **volume** and **duration.** Therefore, it is necessary to consider the seasons when selecting the waves to capture both extremes - **whether snowmelt-driven waves or waves caused by heavy rains.**
- In this study, the **verified methodology** involves classifying flood events based on dominant flood processes in the region, with identifiable **flood-peak-volume-duration** relationships.

5 ACKNOWLEDGEMENTS

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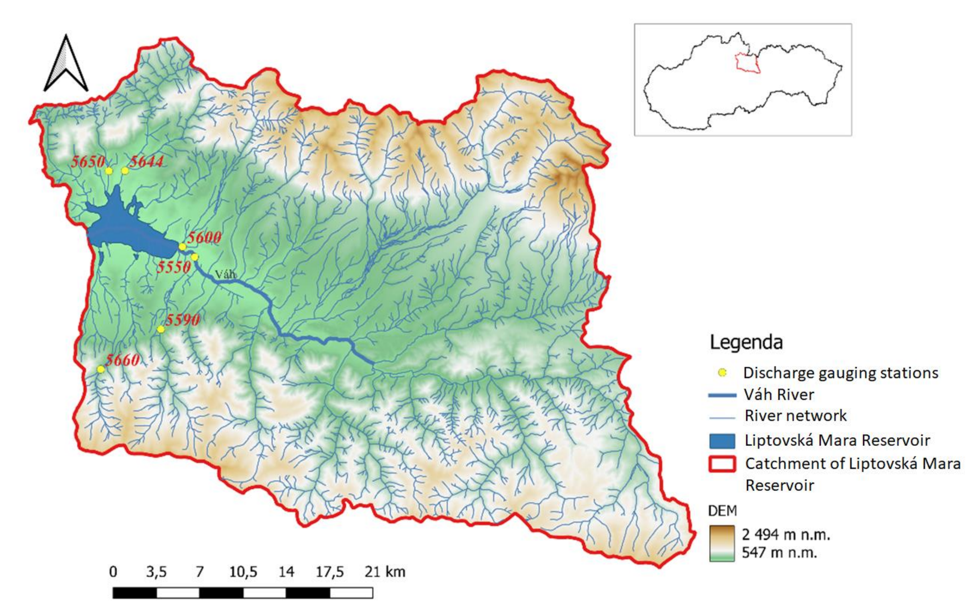
2 STUDY AREA AND DATA

The Váh River catchment is located in the northern part of Slovakia between the country's two highest mountain ranges - the High Tatras in the north and the Low Tatras in the south. It covers an area of 1,477 km^2, with the highest point reaching 2,494 m a.s.l. The water regime exhibits strong seasonal variability, with peak flows in May and the lowest flows during the winter months. Most floods occur in May, driven by rapid snowmelt combined with steady rainfall.



▲ ***Fig. 1:*** *Position of the catchment of the Liptovská Mara reservoir in Slovakia.*

Liptovská Mara is the largest reservoir in Slovakia, with a volume of 361.9 million m^3. The reservoir is built on the main sream of the Váh River, which is formed by the confluence of the Čierny Váh and Biely Váh rivers. The reservoir's tributaries are summarized in Table 1.

Input data:

- **Hourly/daily** catchment **discharges** (1989 - 2021)
- Daily catchment **precipitations** (1989-2021)

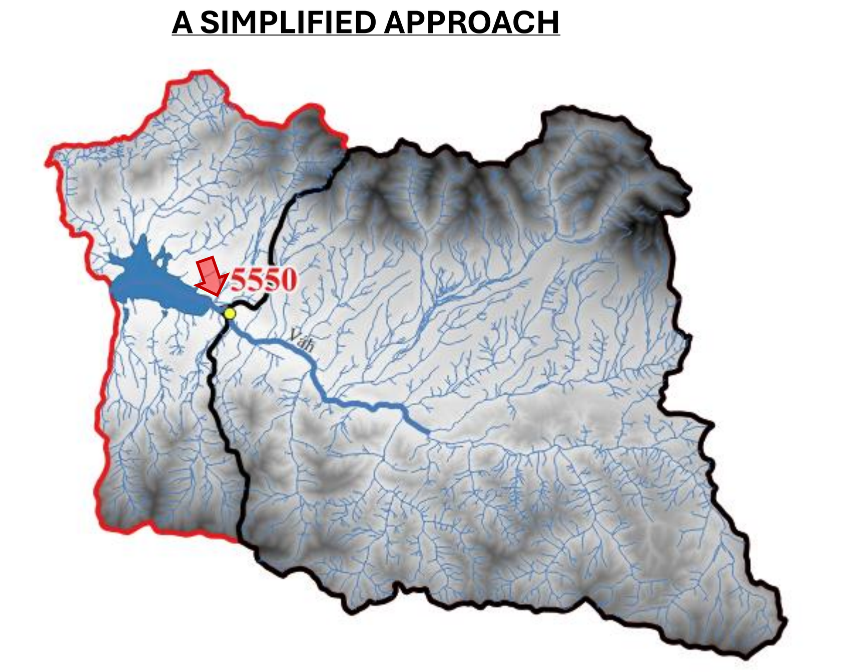
	Gauging Station ID	Gauging Station	Catchment / Stream	Observation	Time step
Right sided tributary	-	-	Sestrč	-	-
	5650	Prosiek	Prosiečanka	1968 - 2021	Daily
	5644	Liptovská Sielnica	Kvačianka	1976 - 2021	Daily
	-	-	Petruška	-	-
	5600	Liptovská Ondrašová	Jalovský stream	1971 - 2021	Daily
	-	-	Mútnik	-	-
	5550	Liptovský Mikuláš	Váh	1920 - 2021 1988 - 2021	Daily Hourly
Left sided tributary	5590	Demänová	Damänovka	1968 - 2021	Daily
	5660	Horáreň Hluché	Paludžanka	1969 - 2021	Daily
	-	-	Dúbravka	-	-

▲ ***Tab. 1:*** *Input data and tributaries to the water reservoir.*

3 RESULTS

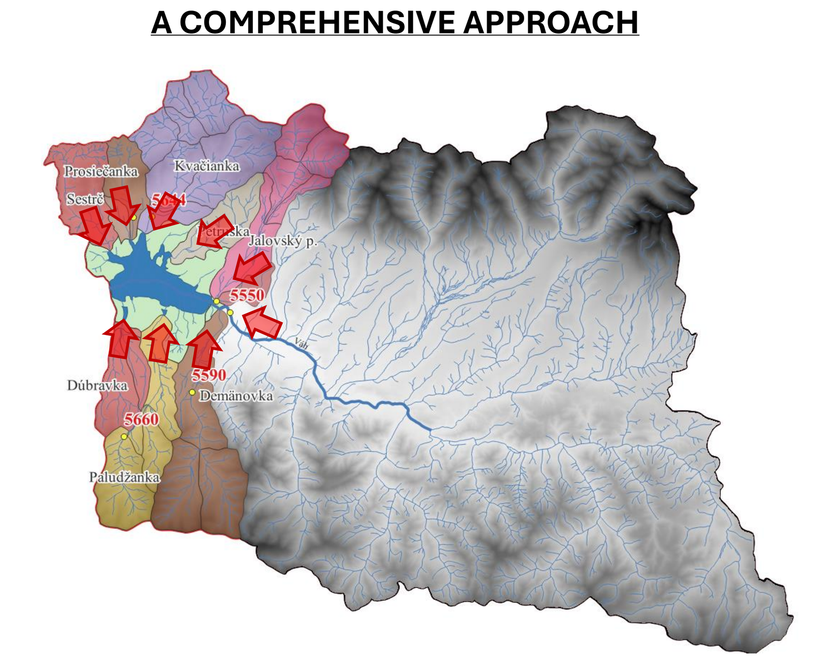
COMPARISON OF APPROACHES FOR DETERMINING THE FLOWS INTO THE RESERVOIR

A SIMPLIFIED APPROACH



- Adjustment of the measured discharges on the main stream (station 5550 Váh-Liptovský Mikuláš) to the dam profile using proportional calculations based on the catchment area.
- $\bar{Q}_{a,5550}$ = 19.9 $m^3.s^{-1}$; k = 1.34; $\bar{Q}_a$ = 26.64 $m^3.s^{-1}$

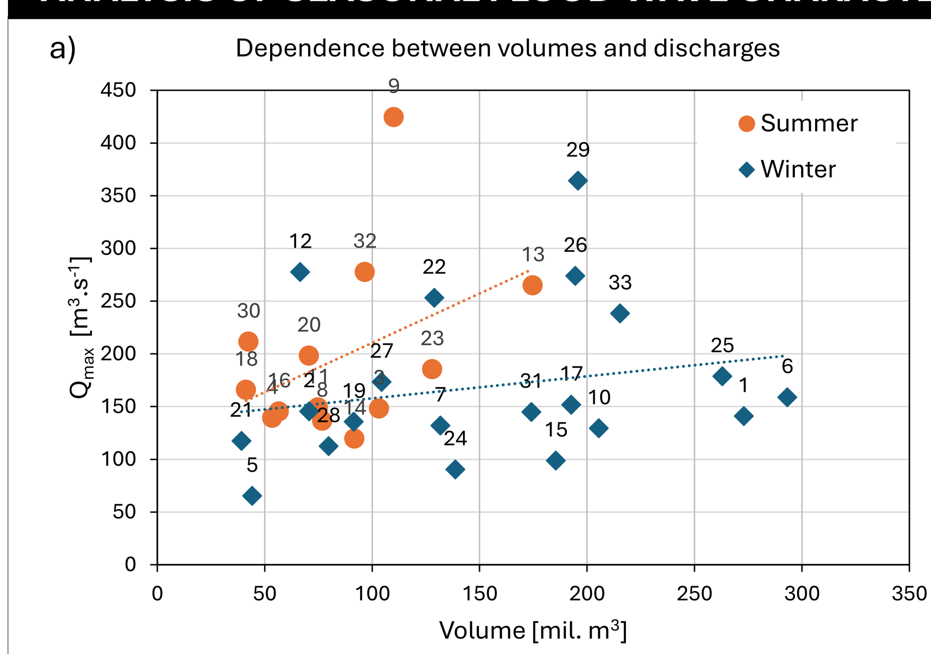
A COMPREHENSIVE APPROACH



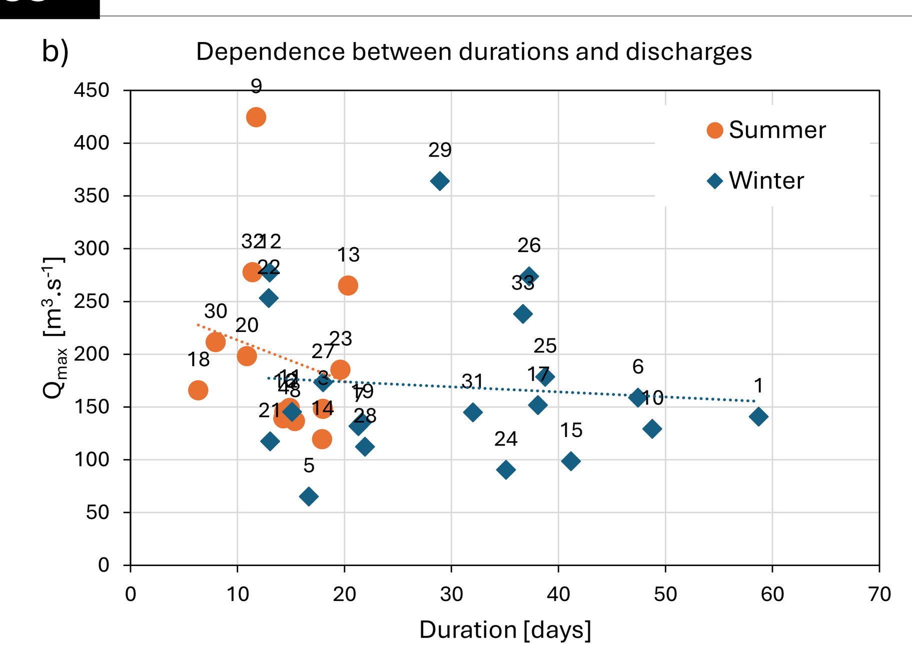
- Discharges were calculated proportionally based on the catchment area, with each tributary analyzed separately and daily discharges summed across all tributaries for the entire period.
- $\Sigma\bar{Q}_{a,OPi}$ = 27.19 $m^3.s^{-1}$

ANALYSIS OF SEASONAL FLOOD WAVE CHARACTERISTICS

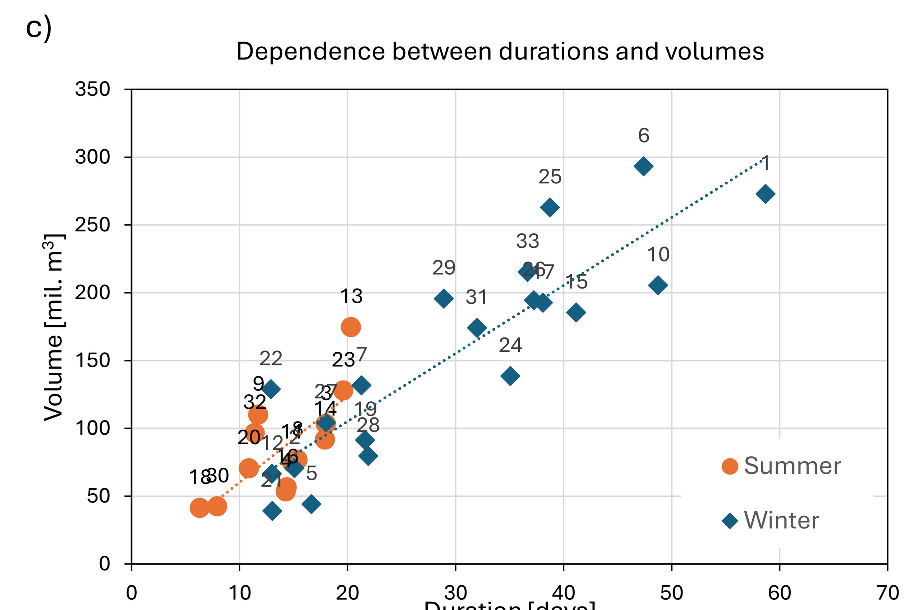
a)



b)



c)



- Results reveals distinct seasonal variations in flood wave characteristics,
- Winter waves, often driven by snowmelt or mixed snowmelt-rainfall events, showing longer durations and more significant volumes,
- Summer waves, typically triggered by convective storms, are narrower and shorter.

◄ ***Fig. 2:*** *Characteristics of the selected annual maximum waves; a) Dependence between volumes and discharges; b) Dependence between durations and discharges; c) Dependence between volumes and durations.*