sciendo
Slovak Journal of Civil Engineering
Vol. 32, 2024, No. 4, 50 - 59
DOI:10.2478/sjce-2024-0025

# COMPARISON OF ECO-HYDROLOGICAL LIMITS AS WATER SCARCITY INDICATORS FOR THE WATER BALANCE INVENTORY OF SLOVAKIA

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***Abstract***

*Various methods for determining environmental flows can be based on hydrological characteristics, a combination of morphological and hydrological characteristics, or solely on hydraulic characteristics. Such methods may also be based on multi-criteria decision-making, where a low flow regime and its variability are considered. The methods for determining environmental flows as hydrological limits (sometime called desktop methods) are solely based on hydrological statistics and are believed to implicitly incorporate links to the state of river ecosystems. In the paper, we compared the performance of several methods in the set of the 137 official water balance inventory profiles of the Slovak Hydrometeorological Institute, which are evenly distributed over the territory of Slovakia. The analysis also accounted for the dependence between hydrological characteristics and environmental flow values. We also compared the frequency of the occurrence of their critical values (eco-hydrological) in the reference periods 1931-1960 and 1991-2019. We proposed an intermediate system of regionalized relationships based on simple Tennant methods, which does not disturb the existing system of water allocations and uses in the water balance inventory.*

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***Key words***

- Hydro-limits,
- Environmental flows,
- Flow duration curves,
- Hydrological methods.

## 1 INTRODUCTION

Globally and regionally, freshwater biodiversity and the functionality of ecosystems have gradually declined. In Central Europe, the water balance and river flows in particular are subjected to continuous stress due to abstractions and other regime changes evoked by population growth, changing lifestyles, and flow alterations caused by land use and climate change (Szolgay et al., 2020; Blaškovičová et al., 2022; Bolla et al., 2022). These factors have led to significant alterations in natural river flow regimes and, in turn, are impacting river ecosystems and their ecosystem services. The concept of environmental flows (e-flows) has emerged to address these challenges and improve the ecological state of rivers. In general, e-flows refer to the allocation of water to maintain the sustainability of riparian and instream ecosystems and riverine environments and their habitats. The concept originated in the 1940s and gained momentum in the 1970s, evolving from 'minimum required flow' to 'ecological flows' and 'environmental flows' (Bhuiyan, 2022). Consequently, the renewed Brisbane Declaration and Global Action Agenda, which was backed by 57 nations, advocated for the international implementation of e-flows concepts (Arthington et al., 2018).

As detailed by Poff et al. (2017) in their comprehensive assessment of methodologies, numerous frameworks and approaches exist for practitioners to estimate e-flows. According to Poff and Mathews (2013) and Gebreegziabher et al. (2023), in the evolution can be categorized into five phases:

1. The foundation works phase (pre-1980s) recognized rivers' aesthetic and ecological value, with initial efforts to set minimum flow requirements.

2. The emergence and synthesis phase (late 1980s-mid-1990s) established an increased awareness of river hydrology's variability and ecological importance, which has led to more comprehensive flow management approaches.

3. The consolidation and expansion phase (mid-1990s - mid-2000s) focused on developing key concepts like a natural flow regime and indicators of hydrologic alterations, focusing on ecosystem-level management.

4. The globalization and new challenges phase (mid-2000s - 2020) brought a broader recognition of e-flows, their integration into policy making, and addressed new challenges like climate change.

5. The post-globalization advances phase (2020 onwards) is developing continued refinements of e-flow frameworks and methods through the incorporation of the effect of climate change and new technologies.

Various methodologies are used to assess e-flows, including hydrological, hydraulic rating, habitat simulation, holistic, and hybrid methods. Each has its criteria and thresholds, but more consensus on the best approach must be reached. The main challenges include the balance between development and environmental conservation and the inadequacy of some methods (Poff et al., 2017; Bhuiyan, 2022).

Hydrological methods use historical flow records to estimate the water needed to maintain river health. They often rely on simple indices like the percentage of annual or monthly flows. Their strengths are the low cost and data requirements, which mark them as primarily for initial assessments. Since they are often too simplistic, they may not capture the complete ecological needs of the river (Poff et al., 2017). Among the most known are the Montana method (Tennant, 1976), which uses a look-up table of percentages of average annual flows to determine desired river conditions, and the Range of Variability Approach (Richter et al., 1996), which is based on statistical metrics to characterize the alteration of flow regimes. The method proposed by Smakhtin and Anputhas (2006) uses flow duration curves to derive e-flow recommendations.

Hydraulic rating methods link river flow levels to hydraulic variables (e.g., wetted perimeters, depths) to determine suitable e-flows for supporting aquatic ecosystems; for example, the wetted perimeter method defines the minimum acceptable discharge to maintain a wetted habitat (Annear et al., 2004). The relatively moderate amount of data needs make these useful for specific habitat requirements, but they also have a limited ecological scope and are often used in conjunction with other methods.

Habitat simulation methods mathematically model physical habitat conditions under different flow scenarios to determine the best flows for target species. Their detailed species specific high resolution represents significant progress compared to previous methods, which are relativized by high data and resource requirements and often have a limited focus on a few species. The Instream Flow Incremental Methodology (IFIM), which provides a framework for applying the PHABSIM software in a water resource decision setting (Bovee, 1982), and the MesoHABSIM, which focuses on microhabitat simulation for habitat modelling, are among the best known (Parasiewicz, 2007).

Holistic methods attempt to consider an entire ecosystem, including hydrological, hydraulic, geomorphological, and ecological components. Being comprehensive, they intend to integrate multiple disciplines and be adaptable to various contexts. Their applicability is limited by their high degree of complexity, which requires significant expertise and resources. The Building Block Methodology (BBM) uses expert judgment to determine flow requirements for maintaining on ecosystem's health (King and Louw, 1998). The Downstream Response to Imposed Flow Transformation (DRIFT) is a scenario-based approach for evaluating alternative water management scenarios (King et al., 2003). The Ecological Limits of Hydrologic Alteration (ELOHA) is a framework for developing regional environmental flow standards (Poff et al., 2010).

All of these methods have evolved to address the diverse needs of river ecosystems and the challenges posed by human activities and climate change. Each method has strengths and limitations that make it suitable for various environmental flow assessment contexts and objectives (Poff et al., 2017). Although the necessity is universally acknowledged, the practical implementation encounters several obstacles (Harwood et al., 2018; Tickner et al., 2020; Twardek et al., 2021). However, the limited adoption of e-flow concepts is not mainly due to insufficient biophysical information but rather to intricate socio-political dynamics (Pahl-Wostl et al., 2013; Poff, 2018). Implementing environmental flows is challenging in water-scarce systems due to intricate water governance frameworks, insufficient authority for environmental water allocation, and diminishing water availability resulting from economic development and climate change (Tickner et al., 2017; Anderson et al., 2019; Wineland et al, 2022). Consequently, there is a need to identify sustainable strategies that reconcile the intricate trade-offs between human and environmental water requirements, which remains the primary problem to address (Marston et al., 2020; Poff, 2018).

Slovakia is one of the few countries that, since the second half of the last century, has acknowledged the necessity to implement and integrate environmental flows (e-flows) into water management and policy to guarantee water sustainability for both humans and ecosystems. Since introducing the National Water Balance Inventory as a systematic activity at the country level in Slovakia, solving conflicting water needs has incorporated a specific e-flow component. Blaškovičová et al. (2015) describe a comprehensive analysis of the history of introducing eco-hydrological limits in managing water resources in the former Czechoslovakia. Estimates of such limits first traditionally included the values of M-day discharges (the average daily discharge reached or exceeded on the average over M-days in a year estimated from a long reference period), Blaškovičová et al. (2017). Blaškovičová et al. (2022, 2023), Pavelková et al. (2023) and Poórová et al. (2023) have also highlighted the challenges and uncertainties (currently 1961-2000). For example, the first State Water Management Plan in 1956 used, the $Q_{355d}$ flow to limit values. The Water Management Plan from 1975 brought about a significant change to the system. A National Water Balance inventory was instituted after 1977 (the State Water Balance), (Holko et al., 2024). The so-called minimum lance discharge (flow) MQ was introduced as an eco-hydrological limit when it became evident that a deeper comprehension of the challenges associated with e-flow implementation in water-scarce systems, where the biophysical dimensions of e-flows are inadequately researched, was necessary.

In principle, the minimum balance discharge (flow) MQ is a guaranteed right to water resource use for environmental protection. It intends to maintain the stream and its surroundings in a good ecological state. In a system of allocating water use, it is connected to the minimum residual flow, which limits the use of surface water to maintain the functions of the watercourse and protect aquatic habitats. In this respect, the MQ value is a high-priority claim for water resource use. For the use of MQ in a water balance inventory, its values have been reevaluated multiple times since 1977; it uses the reference periods 1931-1960 and 1931-1980 as the basis for its estimates (Blaškovičová et al., 2023).

In the Czech Republic, where they are also reviewing the determination of e-flows, they have focused on the regionalization and distribution of seasons for determining MQ (in more detail, Balvín and Vizina, 2018; Balvín et al., 2021). The authors also base the methodology on hydrological characteristics to maintain a link to the variability of water availability in the river network.

The Slovak Republic's water management concepts are based on implementing the EU Water Framework Directive and require redefining such low flow limits to protect water resources from undesirable abstractions or regime modifications. Since the late 1990's, several attempts have been made to define new hydro-ecological restrictions to water use and ecological flows. However, these studies as of yet have not produced a universally applicable flexible methodology, which would lead to a modern procedure that would allow for the abandonment of the rigid, outdated methodology for determining MQs for the entire Slovak Republic and introduce a flexible method respecting the complexity of the issue and the wide range of individual physiographic and ecohydrological conditions in Slovakia.

In conclusion, the key hydrological methods in Slovakia used to estimate environmental flows include traditional hydrological methods and statistical approaches. Advancements such as the integration of environmental variables are less present (Szolgay et al., 2023). These methods impact the accuracy of estimating environmental flows by either providing fixed values throughout the year or by incorporating dynamic environmental variables. Challenges associated with using hydrological methods include the need for sufficient knowledge of natural hydrological regime and the integration of nonflow-related environmental factors. Advancements in hydrological methods include proposals for improved hydraulic methods and the use of environmental tracers to separate streamflow components. This paper does not focus on detailed e-flow implementation and river basin management policies. However, since determining e-flow difficulties can affect river management strategy and riverine environment preservation in Slovakia, we intend to pinpoint directions that could positively influence the change to a new system applicable in the water balance inventory of Slovakia.

Among the so-called "desktop" methods for determining ecohydrological flows and their respective indicators (sometimes also called eco-hydrological limits), we are considering in this study those that are based solely on simple hydrological statistics without using any experimental or site-related ecosystem data (i.e., without any definable link to the state of the river ecosystem). In this analytical study, we will sometimes refer to them as "statistical-computational methods". We will compare the performance of statistical-computational methods in a set of sites of the official Slovak National Water Balance Inventory network with the traditional MQ discharge, which is the present e-flow in water inventories and the allocation of water resources.

By using the results of the comparison, we will look for an intermediate step in the transition from the traditional rigid concept of determining a minimum necessary allocation using more advanced hydrological statistics (without having explored the relation of that type of eco-hydrological limit and the ecological status of aquatic habitats), to an intermediate system, which is based on simple hydrological indicators. This step will not disturb (at the beginning) the existing system of water allocation rights and uses. However, it could open the way to include aspects such as the changing climate and the seasonality of eco-hydrological limits into the water balance inventory system.

## 2 MATERIAL AND METHODS

The Slovak Hydrometeorological Institute maintains 137 water balance inventory sites (BPs), which are distributed throughout the territory of Slovakia (Fig. 1). The hydrological characteristics from the period 1961-2000 and the current valid values of the minimum balance flow in these BPs will be used as input data. The catchment areas of the BPs range from 44.9 km$^2$ (the Turček profile on the Turiec river) to 17 8530.53 km$^2$ (Danube state border). The BP on the Little Danube (BP51), which has a partially regulated flow regime that is fed from the Danube River, has been excluded from the assessment as an anthropogenically influenced river. For a better interpretation of the results, the 3 BPs on the Danube in some cases will also be excluded from the analysis due to their extraordinarily high flow magnitudes and the allochthonous character of the river. BPs located below reservoirs closer than 20 km to the dam were considered as anthropogenically influenced and also excluded.

The valid MQ values were taken from the water balance inventory database estimated for the 137 Water Balance Profiles using the reference period 1931-1980 according to the principles set by the Water Resources Planning:

1. MQ = $Q_{355d}$ for sites below reservoirs,
2. The following formula applies to the other sites:

$$MQ = (Q_{min,mes} + Q_{100,min,d})/2, \text{ where } (Q_{364d}/2 < MQ < Q_{364d} \quad (1)$$

where:
$Q_{min,mes}$ - a lowest mean monthly discharge value taken from a probability field of mean monthly flows typically with a probability of exceedance of 98%.

$Q_{100,min,d}$ - the mean daily minimum discharge with an average return period of 100 years determined by a statistical method.

An eco-hydrological limit estimate based on the hydrological characteristics for the Czech Republic proposed by Balvín and Vizina (2018) as follows:

$$MQ_{cal} = (1 - Q_{355d}/Q_a)\, Q_{330d} \quad (2)$$

where:
$Q_{355d}$ - 355-day discharge from the flow duration curve,
$Q_a$ - long-term average daily discharge,
$Q_{330d}$ - 330-day discharge from the flow duration curve.

When analyzing and creating eco-hydrological limits as indicators for environmental flows, it is also necessary to examine the existence of the dependence between hydrological regime characteristics and values of eco-hydrological limits. These were analysed in the period 1961-2000 for all the water balance inventory sites.

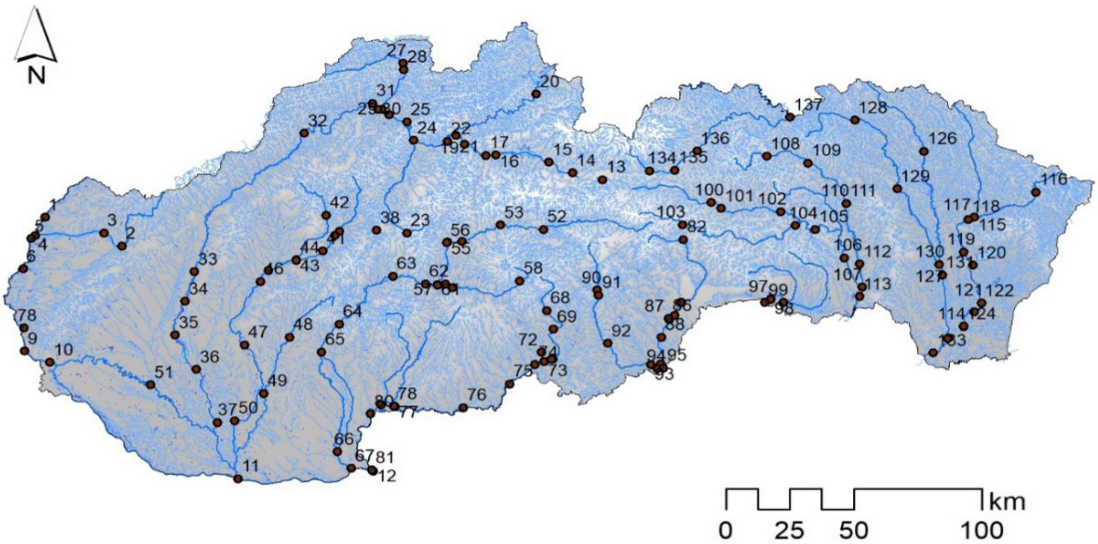


**Fig. 1** *Location of the 137 official Slovak water balance inventory profiles*

## 3 RESULTS

When analysing and creating hydrological limits, it is also advisable to take into account the existence of the dependence between hydrological characteristics and hydrological values. The following figures show linear regression lines of the relationships between the actually valid MQ values and selected ecohydrological indicators (hydrological statistics) $Q_{364d}$, $Q_{355d}$ and $Q_{330d}$ for the reference period 1961-2000 for all the balance profiles, along with the parameters of the regression equations. For better interpretability of the results, the relationship between $Q_{364d}$ and MQ, without the 3 BPs on the Danube is presented in Fig. 2.

The strongest relationship was observed between the 364-day discharges and the MQ values with $R_2$ exceeding 0.99, followed by regression with the 335- and 330-day discharges (0.98 and 0.96 respectively). These results are partially influenced by the fact, the 364-day discharge was used as the cut-off value in the algorithm for the MQ estimation (the limiting conditions are ½ $Q_{364d} < MQ < Q_{364d}$, Blaškovičová et al. (2015)). However, it has to be noted that the estimation of the MQ values was based on flow data $Q_{min,mes}$ and $Q_{364d}$ from the reference period of 1931-1980, whereas the values of $Q_{364d}$, $Q_{355d}$ and $Q_{330d}$ used here were based on the more relevant reference period of 1961-2000.

This discrepancy in the reference periods means, that there are 11 BPs in this set that have a MQ value lower than the ½ $Q_{364d}$ limit.

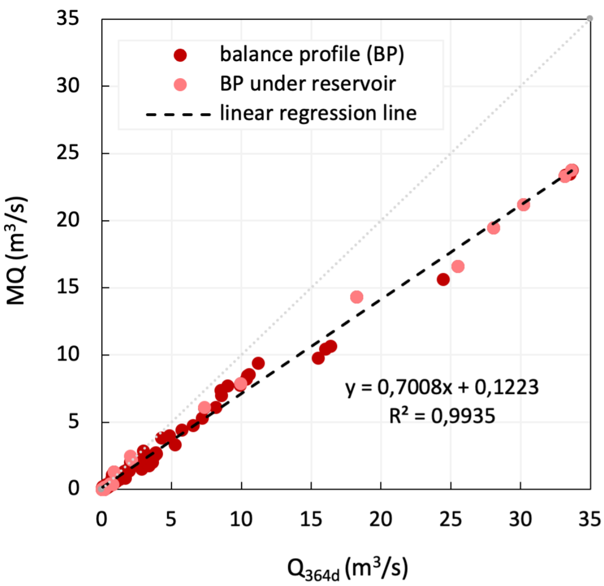


**Fig. 2** *Relationship between $Q_{364d}$ and MQ without data from the 3 BPs on the Danube*

As the next step in the attempts to convert the official MQ values system to a new one based on statistical hydrological indicators, we compared the current MQ values to $MQ_{cal}$ recommended by Balvín and Vizina (2018) in Fig. 3. As seen in Fig. 3, the values proposed by Balvín and Vizina for Czechia are not only systematically higher compared to the actual MQ values for Slovakia over the whole range, but also in the case where a subset of the sites become outliers. The values around the regression line correspond in this case to approximately 25% of $Q_a$.

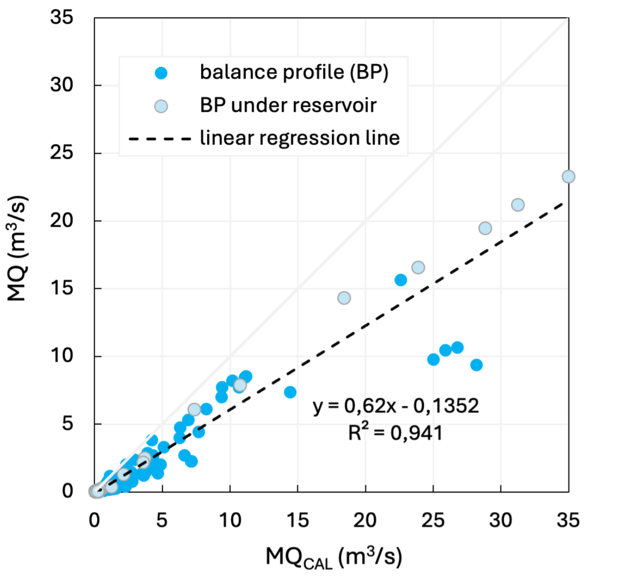


**Fig. 3** *Relationship between MQ and $MQ_{cal}$ without data from the 3 BPs on the Danube*

As a temporary compromise, the exclusion of the outliers could improve the predictability and help to abandon the outdated and rigid concept of MQ estimation in most of the existing water balance inventory sites, but that would not ensure that the empirical relationships would hold when additional new sites would extend the set of inventory sites. Consequently, other low flow related hydrological indicators as a substitute for the present outdated concept need to be tested in the future.

Following the recommendations of Tennant several studies recommended using a fraction of the long-term average flow as an ecohydrological indicator for setting ecohydrological limits as shown in the introduction. However, it is important to be aware of the effects of the length of the time period on the determination of the long-term mean annual discharge $Q_a$ (Poórová et al., 2023). Introducing such an approach could lead to a more flexible framework when abandoning the present rigid historical MQ methodology with the perspective that not only adjustments of eco-hydrological limits to the changing hydrological regime could be flexibly made later, but also other required factors could be more easily implemented and their ecological consequences predicted.

It is often recommended that at least 10% or up to 20% of the long-term flow rate be set as an appropriate minimum limit. The results of comparison showed that when choosing 10% of the long-term annual flow as an ecohydrological indicator for setting ecohydrological limits, the current MQ values are higher in most BPs, especially for flows above 5 m³/s.

In contrast, in cases of setting the indicator as 20% of $Q_a$, most of these values are higher compared to the current MQs. Optimizing the cutoff rate in the regressions leads to its value being around 18 percent as appropriate in the present set of water balance inventory sites (Fig. 4). However, the set of sites occurred as outliers again. In particular, three BPs on the Morava river (pod Dyjou-Morava, nad Malinou-Morava, Devínska Nová Ves-Morava) and 6 BPs in East Slovakia in the Bodrog basin (Latorica nad Laborcom-Latorica, Uh ústie-Uh, Vojany, Ižkovce-Laborec, ústie do Latorice- Laborec, Latorica nad Ondavou-Latorica, Streda nad Bodrogom-Bodrog).

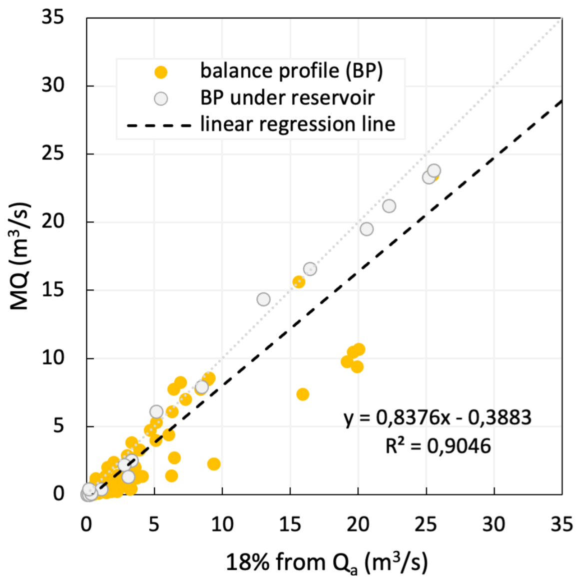


**Fig. 4** *Relationship between the 18 percent cutoff from $Q_a$ and MQ without the 3 BPs on the Danube*

These results point to the problem that the high variety of hydrological regimes and the variability of low flow extremes, which are illustrated in Figs. 5 and 6, do not permit to arrival to a practically usable and simple regression relationship between $Q_{355d}$, $Q_{330d}$, and $Q_a$ and with the official MQ eco-hydrolimit.

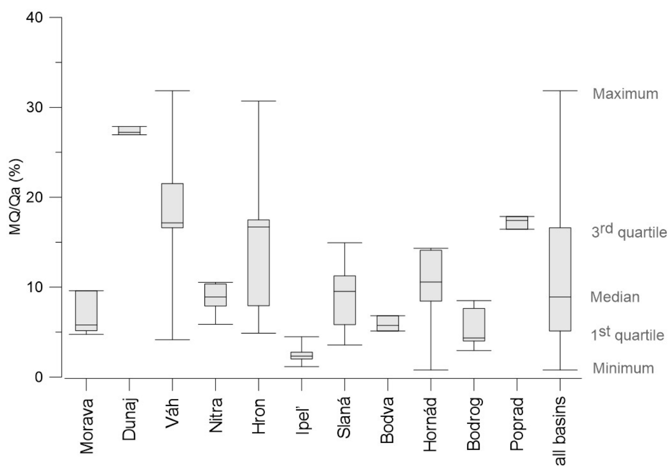


**Fig. 5** *Box plots of the $MQ/Q_a$ ratio in the water balance inventory profiles for basins in Slovakia*

The lowest values of the ratio $MQ/Q_a$ (less than 5%) occur in the Ipel basin. Relatively low values are also found in the

Bodva (5 - 7%), Bodrog (up to 9%), and Morava tributaries (up to 5%). The values are up to 10% on the main Morava river. In the Váh basin, low values occur on the Kysuce (4 - 6%); the Orava and the middle part of the Váh are in a range of 11 - 20%, and higher values are, on the contrary, on the Váh above its confluence with the Orava (20 - 30%). The Turiec river is in a range of up to 22 - 30%. Also in the Slaná basin, lower $MQ/Q_a$ values occur on the Rimava (4 - 10%); on the main stream of the Slaná, the values are in a range of 10 - 15%. In the Hornád basin the values are in a range of 7 - 14%, while on the Poprad, they are between 16 - 18%. The relative values in the Nitra basin range from 6 to 18%.

Relatively larger values of $MQ/Q_a$ are in the Hron basin (15 - 19%), while an extreme value occurred on the Bystrica tributary (up to 30%). Also these values are higher on the Danube, i.e., around 28%. The spatial variability of the results clearly $MQ/Q_a$ ratio hinders to select one Tennant type coefficient. Regionalization of a Tennant type formula could be a temporary solution on the way to a more flexible eco-hydrolimit selection methods. One simple attempt which was tested first, is looking for the known altitudinal zonality of precipitation and runoff on the territory of Slovakia in the patterns of the ratio $MQ/Q_a$ in Fig. 6.

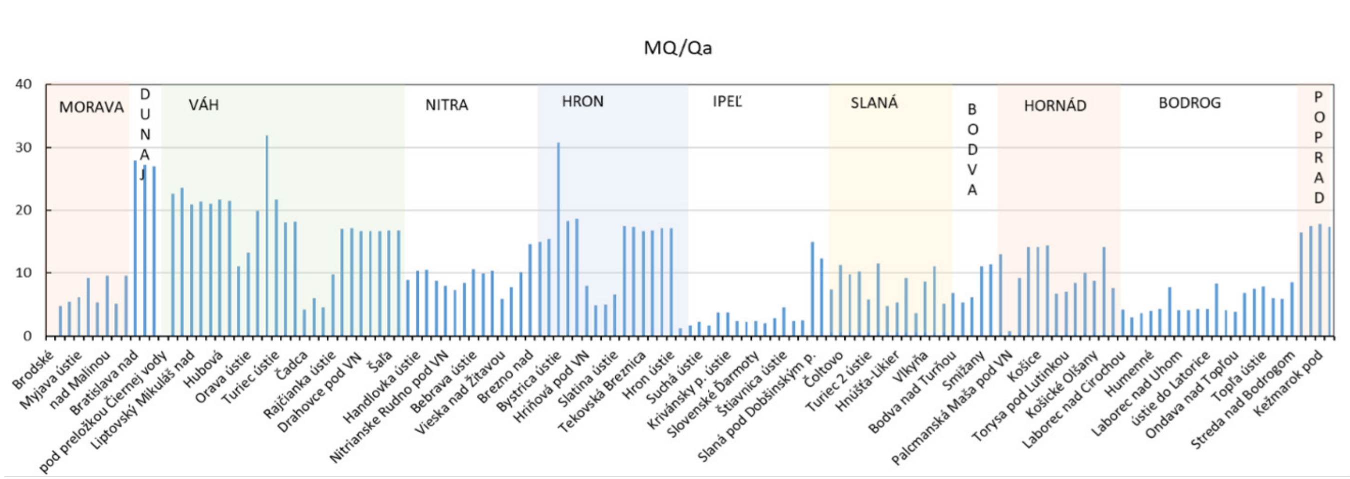


**Fig. 6** *Comparison of the ratio $MQ/Q_a$ values in the balance profiles of the water balance inventory profiles for basins in Slovakia*

From the observable patterns of changes of the $MQ/Q_a$ ratio along the main river in Fig. 6, only an altitudinal dependence can be depicted in the Váh and Slaná basins, whereas clear patterns of changes cannot be described in the other rivers. This can be explained by the morphology of the respective river networks and the location of the water balance inventory sites. Another attempt to regionalize the coefficients in the Tennant method is to categorize its values into intervals and look for these spatial patterns in Slovakia in Fig. 7.

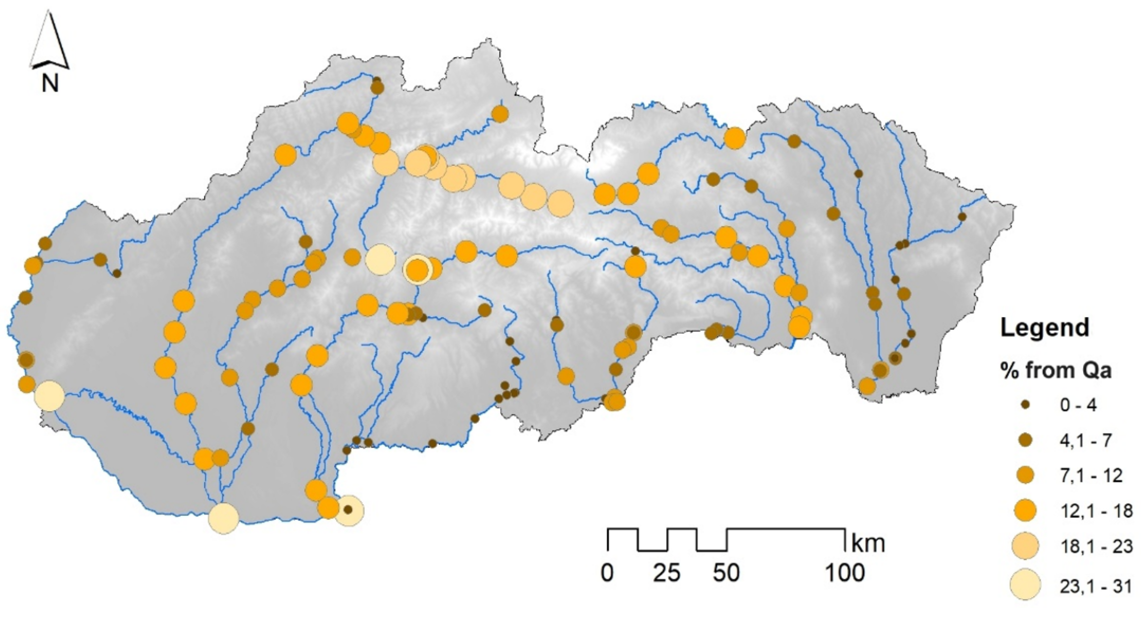


**Fig. 7** *Regions with similar of the $MQ/Q_a$ ratio in the water balance inventory profiles for basins in Slovakia*

It can be seen that when choosing appropriate intervals, it is possible to group sites of the official water balance inventory into geographically continuous regions along the main rivers. This allows us to select a set of coefficients in the Tennant method as the centers of the classification interval and keep the estimation error acceptable level for practical purposes.

## 4 DISCUSSION

The variability of the hydrological regime, as well as change in the climate, also influence the determination of hydrological limits. Using the example of the Banská Bystrica station (ID 7160) on the Hron, which is also a water balance inventory site, we will present as an illustration in Fig. 8. The deviation of the mean annual streamflow in each year from the long term mean $Q_a$ is shown for the period of observation 1931- 2019 and the reference period used in this study.

The deviations of the mean flows in each year from the long-term mean were above $Q_a$ in the first half of the last century. In the last 40 years of the dataset, in contrast, the deviations have been below average. The whole series shows a downward trend, which is confirmed in Table 1 in the comparison of the basic statistics of the mean annual flows. This points to a decline in the flows (or at least to fluctuations of long wet and dry periods). The variability of the series also declined.

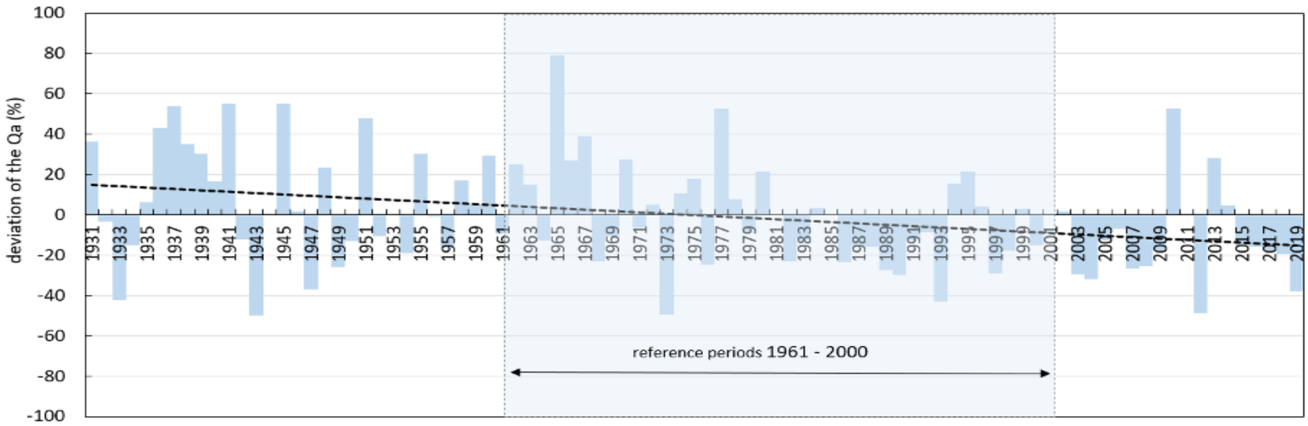


**Fig. 8** *Example of the water level deviations at the Banská Bystrica station on the Hron for the entire monitoring period*

In comparison, the M-day discharges used herein ($Q_{330d}$, $Q_{355d}$, $Q_{364d}$), the Balvin and Vizina index for the whole (hydrological) year ($MQ_{cal}$), MQ, $Q_a$, and the $Q_a$/MQ ratio are compared in Table 1 for the three 30-year reference periods 1931-1960, 1961-1990, and 1991-2019. The 30-year periods were chosen in accordance with the WMO recommendations to represent quasi-stationary periods for a comparison of the changes in the selected low flow characteristics.

**Tab. 1** *Basic statistics of the mean annual discharge of the Hron River in Banska Bystrica*

| Statistics | 1931-1960 | 1961-1990 | 1991-2010 |
|---|---|---|---|
| Mean | 27.9 | 26.1 | 23.1 |
| Standard deviation | 7.6 | 7.0 | 5.7 |
| Coefficient of variation | 0.273 | 0.268 | 0.245 |

**Tab. 2** *Comparison of M-day discharges $Q_{330d}$, $Q_{355d}$, $Q_{365d}$, Balvin and Vizina index ($MQ_{CAL}$), MQ, and MQ/$Q_a$, and for each 30-year period*

| Eco-hydrological indicators | | 1931-1960 | 1961-1990 | 1991-2010 |
|---|---|---|---|---|
| $Q_{330d}$ | $m^3/s$ | 9.2 | 8.9 | 8.2 |
| $Q_{355d}$ | $m^3/s$ | 7.4 | 7.5 | 7.0 |
| $MQ_{CAL}$ | $m^3/s$ | 6.8 | 6.4 | 5.7 |
| $Q_{364d}$ | $m^3/s$ | 5.4 | 6.5 | 5.9 |
| MQ | $m^3/s$ | 3.9 | 5.2 | 4.6 |
| MQ/$Q_a$ | [%] | 14 | 20 | 20 |

It can be seen that the fluctuations of the low flow statistics based on the eco-hydrological indicators $Q_{355d}$, $Q_{364d}$ and MQ may become sensitive to the selection of the representative period and do not follow the general downward trend in the mean and variability (Table 2), which have been recently reported in several studies about Central Europe (Keszeliová et al., 2021, 2022; Halmová et al., 2024; Bolla et al., 2024). This makes them less favourable as an indicator used a water permits in a water balance inventory. Closer to the mean indicators as $Q_{330d}$ and $Q_{CAL}$ seem to preferred in this particular respect; the same applies to the fraction of $Q_a$ (Tennant index, Tennant (1976)).

## 5 CONCLUSION

As set out in this paper, environmental flow in streams or wetlands is needed to support ecosystems when water uses are competing, and flows are restricted. Introducing principles of integrated water resource management offers the chance to provide (at least in theory) optimal allocation of the entire water resource among all the uses and adaptive management. As such, it is perpetuated by eco-political decisions (Arheimer et al., 2024). Slovak legislation and international conventions hold that environmental flows can define ecosystem conditions, and the water regime needed to maintain them. Quantifying environmental flows requires understanding ecosystem-river flow regime interactions, regardless of the approach. Identifying environmental flow requirements can involve two approaches: determining the necessary water/flow for a given ecosystem and allocating it, or allocating a water/flow to ecosystems and assessing the ecosystem's condition. The second approach is historically prevalent in Slovakia, which includes nature as a water user by introducing the MQ values.

In the paper, we were looking for an intermediate step in the transition from the traditional rigid concept of determining a minimum necessary allocation using simple hydrological statistics (without having explored the relation of that type of eco-hydrological limit and the ecological status of aquatic habitats) only in relation to the needs of the National Water Balance Inventory system in Slovakia. We showed that due to the changing climate, the consistency between the officially recognized MQ values in the water balance inventory (estimated in Slovakia from the meanwhile abandoned and outdated WMO reference period) as eco-hydrological limits and simple hydrological indicators respecting the changing hydrological regime does not exist. The officially valid MQ values are not even in accordance with their formal definition since the hydrological basis of their estimates has changed. They refer to a nonexistent hydrological regime from the past and thereby call into question the correctness of the legal framework of the water balance inventories, which casts doubt on their useability as the basis for issuing water use permits. Moreover, that can have a directly negative influence on the hydro-ecology of the particular river reaches and can have consequences for the successful implementation of the requirements of the Water Framework Directive.

We tested the application of several hydrological e-flow concepts by analyzing the correlation between the minimum balance flow MQ and statistical flow characteristics, such as the selected M-day discharges and the long-term average annual discharge Qa, to assess the hydrological limits. The above analyses aimed to show the possibilities of determining the minimum balance flow as a function of these characteristics or their combination. We showed that using just low flow-based simple statistical hydrological indicators cannot reliably replace the present eco-hydrological limit MQ. We proposed an intermediate system of regionalized relationships based on simple Tennant methods, which does not disturb (at the beginning) the existing system of water allocations and uses in the water balance inventory. However, it would open the way to include aspects such as the changing climate and the seasonality of eco-hydrological limits. As a temporary solution, the change from MQ to regionalized coefficients in the Tennant method would enable the abandonment of the aforementioned drawbacks without a radical intervention in the present evaluation of the water balance inventory. The declining trend in the hydrological water balance could be respected, and a space for introducing ecologically appropriate ecohydrological limits, including seasonal variation, could be opened.

This study is only intended to identify unresolved challenges and gaps in the National Water Balance Inventory's environmental flow regulations and practices. After a brief review and hydrological analysis of e-flows, this paper has proposed reexamining and revising the notion through in-depth research on ignored concerns. To maintain a water balance in a catchment, this study recommends determining e-flows and examining their river-wise applicability. Season-specific assessments should follow natural flow patterns and variability. A more precise and focused study is needed to predict the consequences of climate-change on river flow, and the e-flows regulation should be updated.

*Acknowledgements*

This work was supported by the Slovak Research and Development Agency under Contract Nos. APVV 20-0374 and APVV 23-0332; and VEGA 1/0577/23.

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