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# Evaluation of flow frequency on streams in the South Moravian Region for the last 40 years

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The aim of the mentioned article is to evaluate the flow frequency in selected water gauging stations in the South Moravian Region from the CHMI network over the last 40 years. Use derived series of M-day discharges for evaluation, which are based on the flow duration curves of the time series of mean daily discharges and the corresponding probabilities of exceeding. The series of M-day discharges in the observed profiles will be evaluated for the current reference period 1981–2010 and the newly proposed period 1991–2020. To orientate the trend analysis in the time series, use a mass curve of mean daily discharges. The result will therefore be to describe the changes in flow frequencies between these reference periods. The above-mentioned results and conclusions will serve for practical use in applied hydrology, e.g. as a basis for determining the minimum discharges in water management and other purposes within the provision of standard hydrological data of surface waters according to ČSN 75 1400.

KEY WORDS: South Moravia, flow frequency, minimum discharges, flow duration curve, Morava River

## Introduction

The South Moravian Region is specific in terms of hydrography in that most of it lies in flat depressions, where the largest watercourses in Moravia have their mouths. The Morava River, draining the Jeseníky and Beskydy Mountains, or Svratka, flowing through the city of Brno, brings water from areas of several thousand of these squares. These watercourses flow through larger cities, where a possible increase or longer decrease of flows to historical lows can have a significant impact on the socio-economic sphere. The aim of this concept is to evaluate the flow frequency at selected water gauging stations of the CHMI network for a period of 40 years. The findings are then used to compare the series of M-day discharges in the observed profiles between the current reference period 1981–2010 and the newly proposed period 1991–2020. Use a mass of curve of mean daily discharges to orientatively analyze the trend in time series. These evaluated time series are used in applied hydrology as a basis for providing standard hydrological data of surface waters according to ČSN 75 1400.

## Material and methods

### *Selection of suitable water gauging stations*

Before the actual analysis of flow frequency on streams in the South Moravian Region, it was first necessary to select suitable water gauging stations (see Fig. 1) to meet the criteria in the length of the time series of mean daily discharges of 40 years, i.e. from 1 November 1980 to 31 October 2020 (hydrological year used).

The length of the 40-year period was chosen because it corresponds to the beginning of the time series of daily mean discharges, which was used to evaluate the reference period 1981–2010, which is still used in applied hydrology in providing hydrological data according to ČSN 75 1400 to the overlap between the two reference periods addressed and the subsequent expression of the differences between them. Time series from Czech hydrometeorological institute were used for the mentioned analyzes (hereinafter only abbreviated as CHMI).

Characteristics of selected water gauging stations are given in Tab. 1. The specified elevation (above sea level) is defined as the zero line of a depth gauge at water gauging station (gauge zero level). Basin area (catchment area in km$^2$) is derived from GIS. The Strážnice station has the largest catchment area and the Kyjov station has the smallest catchment area. The characteristics of mean discharge $Q_a$ (meaning long-term mean discharge), the annual rainfall amounts (meaning the average amount of rainfall per catchment area) and the mean annual runoff (mm) are derived for the current reference period 1981–2010. The runoff coefficient is then determined as the ratio the runoff height to the amount of rainfall.

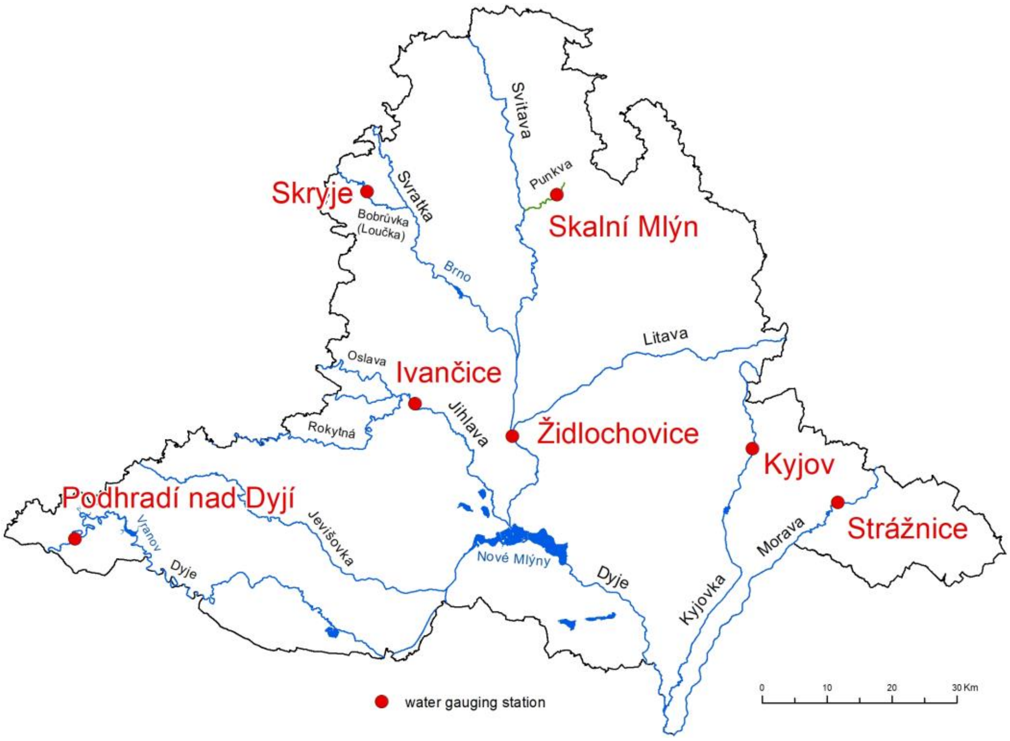


*Fig. 1. Location of selected water gauging stations in the South Moravian Region.*

**Table 1. Characteristics of selected water gauging stations in the South Moravian Region**

| Gauging station | River | Elevation [m a. s. l.] | Basin area [km$^2$] | Mean discharge $Q_a$ [m$^3$ s$^{-1}$] | Annual Rainfall amounts [mm] | Mean Annual Runoff [mm] | Runoff coefficient |
|---|---|---|---|---|---|---|---|
| Strážnice | Morava | 163.3 | 9144.83 | 59.33 | 718 | 205 | 0.29 |
| Podhradí nad Dyjí | Dyje | 348.4 | 1755.49 | 8.81 | 652 | 158 | 0.24 |
| Skryje | Bobrůvka | 310.1 | 222.01 | 1.45 | 687 | 206 | 0.30 |
| Židlochovice | Svratka | 177.9 | 3938.12 | 15.05 | 649 | 121 | 0.19 |
| Skalní Mlýn | Punkva | 342.5 | 154.17 | 0.93 | 644 | 191 | 0.30 |
| Ivančice | Jihlava | 194.0 | 2679.98 | 10.39 | 614 | 122 | 0.20 |
| Kyjov | Kyjovka | 185.9 | 117.49 | 0.26 | 621 | 68 | 0.11 |

The Kyjov station has the lowest value of the runoff coefficient, which is caused by a large loss of run-off water from rainfall.

### *Processing of time series and evaluation of a series of M-day discharges*

For the sake of clarity and to provide an overview of flow frequency in the given years, flow frequency data were displayed graphically in mean annual discharges with indication of reference periods. The comparison of the series of M-day discharges will be displayed in tabular form. For the subsequent evaluation of the differences in the long-term mean discharge and the series of M-day discharges in water gauging stations between the currently used (1981–2010) and the newly designed reference period (1991–2020) determined according to the formula of Chegodaev (1).

$$p=\frac{m-0,3}{n+0,4} \qquad (1)$$

where

$m$ – is the order of the given value in the time series, which is arranged in descending order (ie in the first place is the highest value of mean daily discharge in 30 years),

$n$ – is the number of values in the time series (in 30 years it is almost 10 960 values mean daily discharges).

Chegodaev's formula is used to calculate the probability of exceedance because we work with time series of mean daily discharges, which are almost always a sample from the basic statistical set, for which we do not know all the values that could probably occur in a given time series. Thus, the last value of the series does not have a probability of occurrence of 1 or 100 %, but has a lower probability of exceedance (Němec, 1964).

From the displayed flow duration curve (FDC) it is then possible to derive a discharge value for a given probability. So, for example, to express a 355-day discharge, we derive a value from the flow duration curve with a probability of occurrence of 97%. The value of the long-term mean discharge is then calculated as the arithmetic average of all mean daily discharges over 30 years. Evaluation of N-year discharges is not the aim of this concept.

To analyze the trend in the time series used, the method of a mass curve of mean daily discharges is used, where the trends of discharges over a period 40 years can be clearly displayed. The method of the mass curve consists in first converting the time series of mean daily discharges (according to Kaňok, 1999) into a cumulative form. The cumulative series is determined by successive addition of individual values, so that the last value of the cumulative series has the value of the sum of all values of mean daily discharges. By converting this cumulative series into a relative series by gradually dividing the individual values with the value of the sum of all daily discharges. For each value of the cumulative series, its share in the whole series is created as a percentage. We will convert this relative series of daily discharges into a graphical form with the interpolation of the trend line. From this graph, it is then possible to clearly derive how the daily discharges behaved over 40 years in terms of deviations (breaks) from the trend line.

**Results**

***Morava River Basin***

In the case of the Morava river basin in the South Moravian Region, the evaluated mean daily discharges from the Strážnice water gauging station for the last 40 years were used. The Strážnice station has a catchment area of 9145 km$^2$ and is located in the flat depression Dolnomoravský úval, where extensive outflows into floodplain forests occur at higher flows.

The graphical representation of the mean annual discharges shows the period of minimum flows 1989 to 1993, which contrasts sharply with the following period 1995 to 2002, when the mean annual discharges remained above 60 m$^3$ s$^{-1}$ (see Fig. 2). Above all, it is worth mentioning the extensive regional floods in July 1997, when discharges of more than a century occurred occurred in the Morava river basin. If we focus on the subnormal period of flow frequencies (when discharges fell on average below 50 m$^3$ s$^{-1}$), then from 1980 to 1990 there were several, but it was compensated by abnormally water years above 60 m$^3$ s$^{-1}$. In the period of the last 10 years (2010 to 2020), however, these compensations did not occur; on the contrary, in the years 2017–2019 the annual discharges fell below 30 m$^3$ s$^{-1}$. An example is the mean daily discharge in the Moravia river in Strážnice from 20 August 2018, which was only 3.2 m$^3$ s$^{-1}$ (see Fig. 4), which is below the level of even the lowest value of 364-day discharge in both solved reference periods of series of M-daily discharges. These facts were then reflected in a decrease in the long-term mean discharge ($Q_a$) in Strážnice by 8%, in minimum discharges by up to 15%, which is evident from Table 2.

From the analysis of the trend in the time series by the mass curve method, it was found that the mean daily discharges in the 80's are balanced around the trend line. From the 1990s onwards, there were first declines in the minimum flows, which were offset by increases between 1997 and 2014. Since 2015, the trend has been significantly declining (see Fig. 3).

***Dyje River Basin***

On the example of the Podhradí nad Dyjí water gauging station over the last 40 years, periods with maximum and minimum annual discharges are evident (see Fig. 5). Significant decreases in annual flows at the turn of the 1980s and 1990s and also between 2016 and 2019 are most noticeable here. Here the flows fell to lows, when the mean annual discharge fell significantly below 4 m$^3$ s$^{-1}$ (in mean daily discharges, especially in August 2018, flows decreased to historical lows). Maximum discharges occurred during major flood events in 1985–1988, 1996, 2002–2006, 2009–2010 and also in 2013.

In addition, compared to the reference period 1981–2010, the newly proposed period 1991–2020 includes a longer

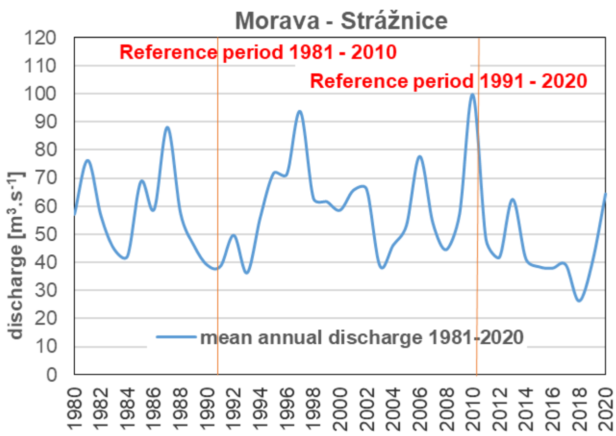


*Fig. 2. Mean annual discharges in the water gauging station Strážnice (Morava) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

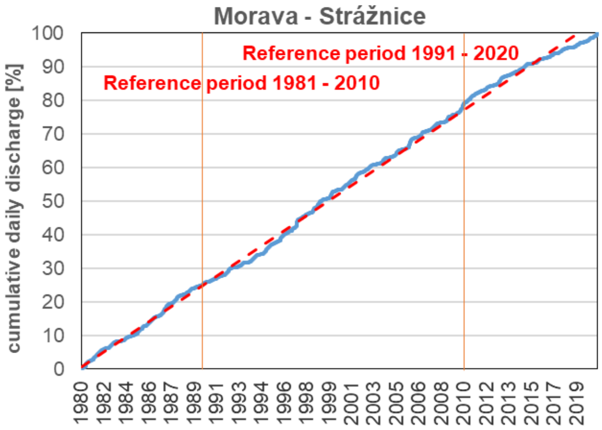


*Fig. 3. Mass curve of mean daily discharges in the water gauging station Strážnice (Morava) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

**Table 2. Comparison of series of M-day discharges for the current and proposed reference period in the water gauging station Strážnice (Morava)**

| | M-day discharges [$m^3 s^{-1}$] | | Difference [%] |
|---|---|---|---|
| | 1981–2010 | 1991–2020 | |
| $Q_a$ | 59.3 | 54.7 | -8 |
| $Q_{30d}$ | 135 | 124 | -8 |
| $Q_{60d}$ | 93.1 | 85.9 | -8 |
| $Q_{90d}$ | 72.6 | 66.2 | -9 |
| $Q_{120d}$ | 57.7 | 53.7 | -7 |
| $Q_{150d}$ | 47.5 | 44.4 | -7 |
| $Q_{180d}$ | 39.6 | 36.7 | -7 |
| $Q_{210d}$ | 33.5 | 31.0 | -8 |
| $Q_{240d}$ | 28.1 | 25.4 | -9 |
| $Q_{270d}$ | 23.3 | 20.8 | -11 |
| $Q_{300d}$ | 18.5 | 16.6 | -10 |
| $Q_{330d}$ | 14.1 | 12.6 | -11 |
| $Q_{355d}$ | 9.10 | 8.00 | -12 |
| $Q_{364d}$ | 5.30 | 4.49 | -15 |

*Fig. 4. The water level of Morava river in the Strážnice water gauging station on 20 August 2018 at a time when only about 3 $m^3 s^{-1}$ flowed here.*

period with the occurrence of minimum flows (2014–2019) than in the previous case (here only in 1983/84 and 1989/90). In this case, we do not consider the overlapping period 1991–2010. From the results of the comparison of the series of M-day discharges for both periods (see Table 3.) it is clear that the long-term mean discharge for the period 1991–2020 will be 11% lower than for the previous period. The minimum values in a number of M-day discharges will be lower by up to 45% (364-day discharge) precisely due to the already mentioned decreases in flows in the years 2016 to 2018 (mean daily discharges often fell below 0.5 $m^3\ s^{-1}$).

From the analysis of the trend in time series by the mass curve method, it was found that the daily discharges compared to the Strážnice station in the period 1987–90 have an upward trend. Since the 1990s, there have been falls to the minimum discharges, which have been offset by increases between 2009 and 2014. Since 2015, the trend has been declining significantly (see Fig. 6).

***Svratka River Basin***

Svratka is one of the most important watercourses in the region. It flows through the built-up area of the city of Brno and is the waterfront tributary to the Nové Mlýny reservoir system. In addition to the water meter station directly on Svratka (Židlochovice), a water meter station on a significant tributary of the Svratka – Bobrůvka (Skryje) was used for water analysis. This more or less unaffected station was chosen both because it drains a significant part of the runoff from the adjacent Vysočina Region, but also because the flows in the period 2016–2018 dropped very significantly to the values of historical lows. According to data from hydrometric measurements of CHMI staff, only 20 $l\ s^{-1}$ was measured here on 21 August 2018, which is, according to available records, the lowest measured instantaneous discharge in the history of this water gauging station. Thus, when we compare the reference period, it is clear that the years 1980 to 1987 were more watery in the first period, and only then at the turn of the 80s and 90s there was a significant decrease in annual flows below 1 $m^3\ s^{-1}$ (see Fig. 7). In contrast, the years 2010 to 2019 in the newly proposed reference period were below normal in terms of flow frequency. The long-term mean discharge for the period 1991–2020 will therefore be 9% lower than for the previous period and in minimum daily discharges there will be a decrease of up to 39% due to historical significant low water levels (see Table 4).

From the analysis of the trend in the time series by the mass curve method, it was found that the daily discharges in the period 1981–1986 and 1997–2000 are essentially balanced around the trend line. Between 1991 and 1996, there were decreases to minimum flows. To the upward trend then between 2009–2014. Since 2015, the trend is declining (see Fig. 8).

The Židlochovice water gauging station, which also includes the Svitava, Bobrava and Litava river basins, was used to evaluate changes in flow frequencies over 40 years directly at Svratka. From the course of the mean annual discharges, it is quite clear that the new reference period 1991–2020 will include significantly lower flow frequencies than in the current period 1981–2010 (see Fig. 9). This is mainly due to significant drops in flow frequencies in the period 2016–2018.

While in the years 1980–1990 the mean annual discharges reached over 20 $m^3\ s^{-1}$, in the years 2011–2020 this did not happen at all and the annual discharges reached the maximum level of the long-term mean discharge ($Q_a$). From the results of the comparison of the series of M-day discharges (Table 4.) for both periods, it is clear that the long-term mean discharge for the period 1991–2020 will be 7% lower than for the previous period.

From the analysis of the trend in the time series by the mass curve method, it was found that the daily discharges in the period 1981–1986 and 1997–2009 are essentially balanced around the trend line. In other periods, the graphic representation is very similar to the Skryje station (see Fig. 10). The minimum values in the series of M-day discharges will be lower by up to 17% (364-day discharge) due to the already mentioned decreases in daily discharges in the years 2016 to 2018. It is clear that the occurrence of historically significant minimum discharges also affected the supply of large reservoirs in the Svratka river basin, which kept runoff at the necessary minimums so that they themselves had enough water for their own management.

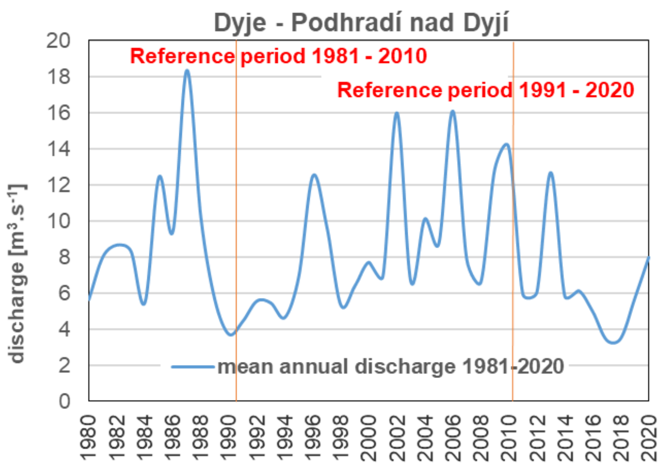


*Fig. 5. Mean annual discharges in the water gauging station Podhradí nad Dyjí (Dyje) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

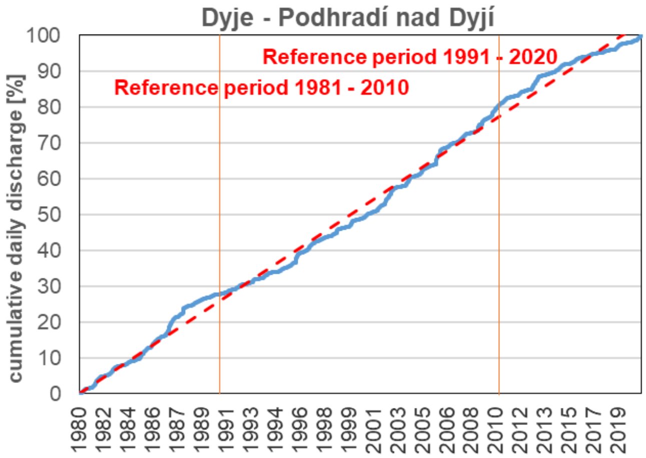


*Fig. 6. Mass curve of mean daily discharges in the water gauging station Podhradí nad Dyjí (Dyje) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

**Table 3. Comparison of series of M-day discharges for the current and proposed reference period in the water gauging station Podhradí nad Dyjí (Dyje)**

| | **M-day discharges** [m³ s⁻¹] | | **Difference** [%] |
|---|---|---|---|
| | 1981–2010 | 1991–2020 | |
| $Q_a$ | 8.81 | 7.86 | -11 |
| $Q_{30d}$ | 20.2 | 18.5 | -8 |
| $Q_{60d}$ | 12.7 | 11.5 | -9 |
| $Q_{90d}$ | 9.25 | 8.40 | -9 |
| $Q_{120d}$ | 7.39 | 6.68 | -10 |
| $Q_{150d}$ | 6.05 | 5.42 | -10 |
| $Q_{180d}$ | 5.07 | 4.50 | -11 |
| $Q_{210d}$ | 4.30 | 3.78 | -12 |
| $Q_{240d}$ | 3.68 | 3.21 | -13 |
| $Q_{270d}$ | 3.11 | 2.73 | -12 |
| $Q_{300d}$ | 2.57 | 2.27 | -11 |
| $Q_{330d}$ | 1.97 | 1.72 | -13 |
| $Q_{355d}$ | 1.30 | 1.05 | -19 |
| $Q_{364d}$ | 0.80 | 0.437 | -45 |

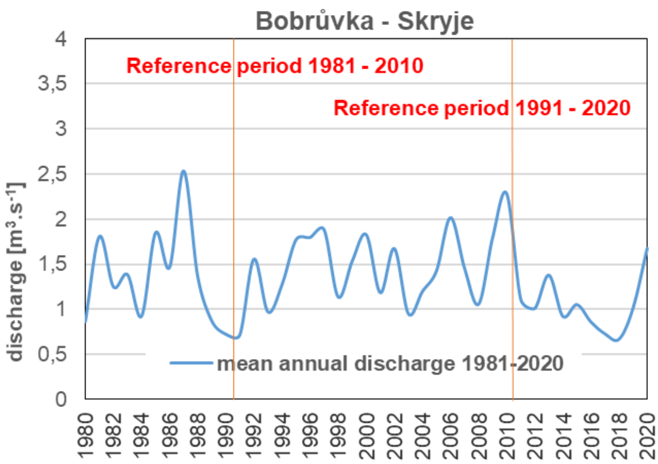


*Fig. 7. Mean annual discharges in the water gauging station Skryje (Bobrůvka) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

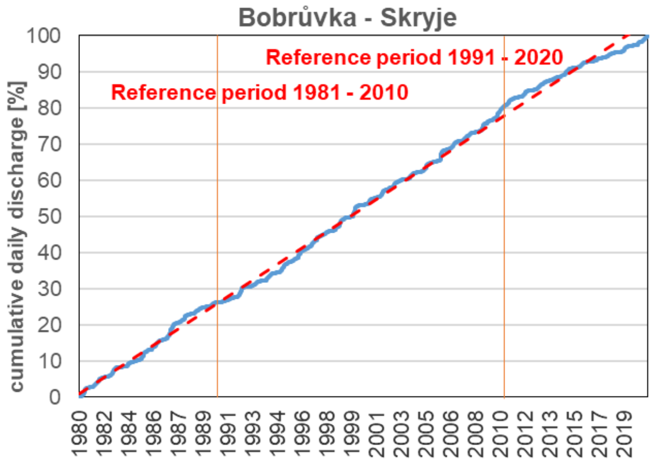


*Fig. 8. Mass curve of mean daily discharges in the water gauging station Podhradí nad Dyjí (Dyje) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

**Table 4. Comparison of series of M-day discharges for the current and proposed reference period in the water gauging station Skryje (Bobrůvka)**

| | M-day discharges [m$^3$ s$^{-1}$] | | Difference [%] |
|---|---|---|---|
| | 1981–2010 | 1991–2020 | |
| $Q_a$ | 1.45 | 1.32 | -9 |
| $Q_{30d}$ | 3.50 | 3.20 | -8 |
| $Q_{60d}$ | 2.20 | 2.02 | -8 |
| $Q_{90d}$ | 1.60 | 1.49 | -7 |
| $Q_{120d}$ | 1.24 | 1.17 | -6 |
| $Q_{150d}$ | 0.985 | 0.943 | -4 |
| $Q_{180d}$ | 0.809 | 0.782 | -3 |
| $Q_{210d}$ | 0.686 | 0.660 | -4 |
| $Q_{240d}$ | 0.575 | 0.540 | -6 |
| $Q_{270d}$ | 0.480 | 0.432 | -10 |
| $Q_{300d}$ | 0.391 | 0.347 | -11 |
| $Q_{330d}$ | 0.300 | 0.262 | -13 |
| $Q_{355d}$ | 0.203 | 0.156 | -23 |
| $Q_{364d}$ | 0.118 | 0.072 | -39 |

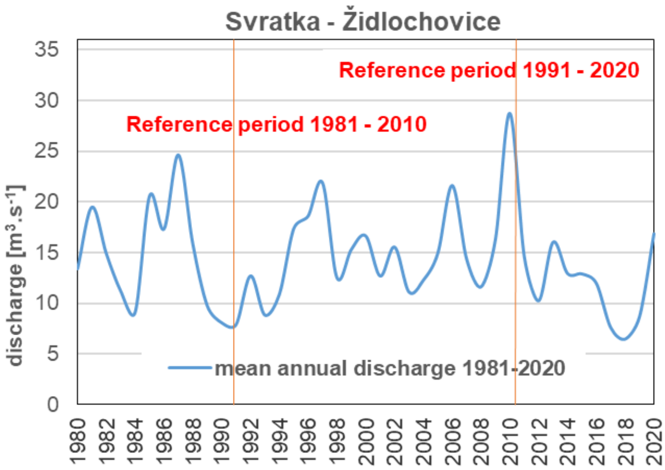


*Fig. 9. Mean annual discharges in the water gauging station Židlochovice (Svratka) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

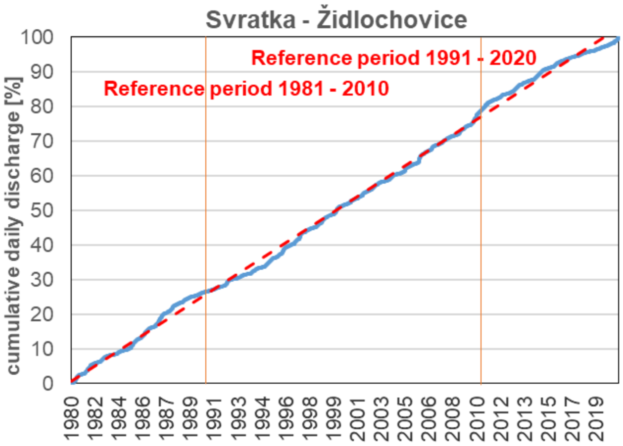


*Fig. 10. Mass curve of mean daily discharges in the water gauging station Židlochovice (Svratka) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

**Table 5. Comparison of series of M-day discharges for the current and proposed reference period in the water gauging station Židlochovice (Svratka)**

| | M-day discharges [m$^3$ s$^{-1}$] | | Difference |
|---|---|---|---|
| | 1981–2010 | 1991–2020 | [%] |
| $Q_a$ | 15.1 | 14.0 | -7 |
| $Q_{30d}$ | 30.7 | 27.9 | -9 |
| $Q_{60d}$ | 21.5 | 19.5 | -9 |
| $Q_{90d}$ | 17.0 | 15.6 | -8 |
| $Q_{120d}$ | 13.9 | 13.0 | -6 |
| $Q_{150d}$ | 11.9 | 11.4 | -4 |
| $Q_{180d}$ | 10.5 | 10.1 | -4 |
| $Q_{210d}$ | 9.37 | 9.15 | -2 |
| $Q_{240d}$ | 8.38 | 8.23 | -2 |
| $Q_{270d}$ | 7.50 | 7.42 | -1 |
| $Q_{300d}$ | 6.72 | 6.62 | -1 |
| $Q_{330d}$ | 5.85 | 5.70 | -3 |
| $Q_{355d}$ | 4.45 | 4.32 | -3 |
| $Q_{364d}$ | 3.68 | 3.06 | -17 |

***Moravian Karst***

The hydrological regime in the Moravian Karst is very specific and that is why it was included in the evaluation of differences in flow frequencies between the two reference periods.

For the purpose of evaluating flow frequency over 40 years, the Skalní Mlýn water gauging station on the Punkva watercourse was selected, which is located below an extensive cave system. Data from this station can provide us with a partial overview of how the cave systems of the Moravian Karst affect the runoff of rainwater in surface waters. According to the graphical expression of annual discharges over 40 years (see Fig. 11), it is clear that, similarly to the Svratka river basin, the years 1980 to 1987 are evident here, which were more favorable to higher discharges, and only then decrease of annual discharges up to 0.5 m$^3$ s$^{-1}$. The years 2010 to 2019 in the newly proposed reference period were below normal in terms of flow frequency, the long-term normal was exceeded only in 2013. In 2017 and 2018, the mean annual discharge decreased to 0.3 m$^3$ s$^{-1}$, which was the lowest decrease in 40 years. In the mean daily discharges in the station, the minimum values appeared from 28 to 31 August 2018, when there was a decrease to only 75 l s$^{-1}$ (below the level of 364-day discharge), which was also confirmed by hydrometric measurements. During this hydrometric measurement on August 29, 2018, 75 l s$^{-1}$ was measured at the lowest value since 1928. It is also interesting to delay the occurrence of historical minimum discharges in this station for the period from 28 to 31 August 2018 compared to all mentioned stations where minimal discharges occurred most often from 12 to 24 August 2018, which could be caused by the influence of the cave system of the Moravian Karst. The above-mentioned facts were subsequently reflected in a decrease in the long-term mean discharge ($Q_a$) between periods by 11%. In minimal discharges in the reference period 1991–2010, this is a decrease of up to 21% (see Table 6). The analysis of the trend in the time series by the mass curve method shows smaller declines around the years 1984–1985. Compared to other stations, there is a much smaller trend to lower discharges in the 1990s. The most significant is clearly the declining trend since 2015 (see Fig. 12).

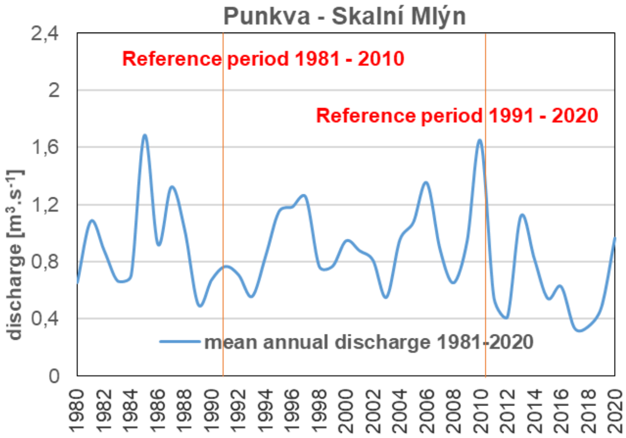


*Fig. 11. Mean annual discharges in the water gauging station Skalní Mlýn (Punkva) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

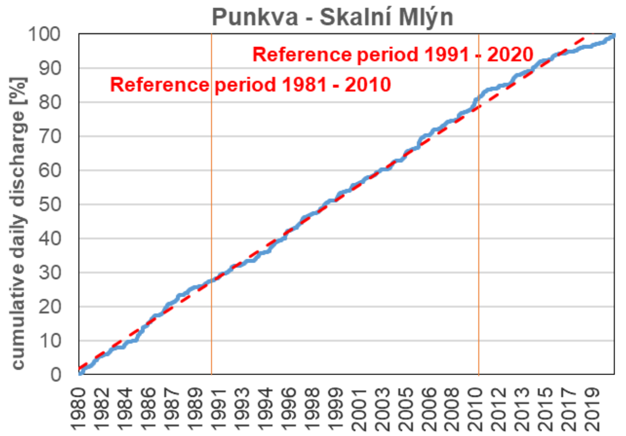


*Fig. 12. Mass curve of mean daily discharges in the water gauging station Skalní Mlýn (Punkva) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

**Table 6. Comparison of series of M-day discharges for the current and proposed reference period in the water gauging station Skalní Mlýn (Punkva)**

| | M-day discharges [m$^3$ s$^{-1}$] | | Difference |
|---|---|---|---|
| | 1981–2010 | 1991–2020 | [%] |
| $Q_a$ | 0.933 | 0.827 | -11 |
| $Q_{30d}$ | 2.28 | 2.00 | -12 |
| $Q_{60d}$ | 1.40 | 1.25 | -11 |
| $Q_{90d}$ | 0.990 | 0.884 | -11 |
| $Q_{120d}$ | 0.733 | 0.649 | -12 |
| $Q_{150d}$ | 0.557 | 0.503 | -10 |
| $Q_{180d}$ | 0.456 | 0.398 | -13 |
| $Q_{210d}$ | 0.366 | 0.321 | -12 |
| $Q_{240d}$ | 0.306 | 0.259 | -15 |
| $Q_{270d}$ | 0.252 | 0.210 | -17 |
| $Q_{300d}$ | 0.200 | 0.175 | -13 |
| $Q_{330d}$ | 0.165 | 0.146 | -11 |
| $Q_{355d}$ | 0.129 | 0.114 | -12 |
| $Q_{364d}$ | 0.105 | 0.083 | -21 |

***Jihlava River Basin***

The Ivančice water gauging station was chosen to assess the flow frenquency of the Jihlava river basin. The Ivančice station is located below a very important confluence junction of the Jihlava, Oslava and Rokytná watercourses. In this station, which already has an area of 2680 km$^2$, a water flowing practically from half of the Vysočina Region flows.

A significant influence on the river Jihlava is the system of reservoirs Dalešice – Mohelno in close proximity to the nuclear power plant Dukovany. The outflow from these reservoirs stabilizes the fluctuations and fall of the flow frequency to the minimum discharges, which is clearly evident from the table (Tab. 7), where there was a significant decrease in long-term mean discharge $Q_a$ between periods by 12%, but the difference in 364-day discharge remained unchanged. The decrease in the long-term mean discharges and other data between the periods in Table 6 is due, as in the previous case, to the period 1980–1989 with the occurrence of higher discharges (e.g. floods in May 1985), which does not occur within the reference period 1991–2020. Instead, it is significantly below normal in the newly proposed period, only in 2013 and 2020 are annual discharges at least at the level of normal. Other years are below normal, the largest decreases are recorded in 2017 and 2018 (see Fig. 13).

From the analysis of the trend in the time series by the mass curve method, it was found that the daily discharges around 1988–1989 and 2010–2014 have an upward trend. Between 1992 and 1996, there were decreases to minimum flows. Since 2016, the trend is declining (see Fig. 14).

***Kyjovka River Basin***

Kyjovka (referred to in the older maps as Stupava) is an example of a watercourse, where the occurrence of hydrological drought in the period 2016–2018 caused

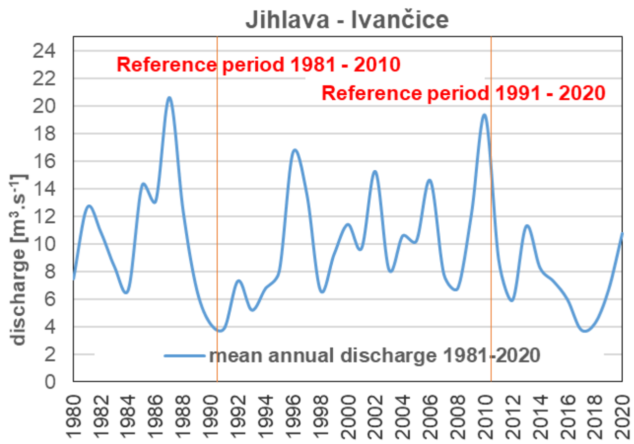


*Fig. 13. Mean annual discharges in the water gauging station Ivančice (Jihlava) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

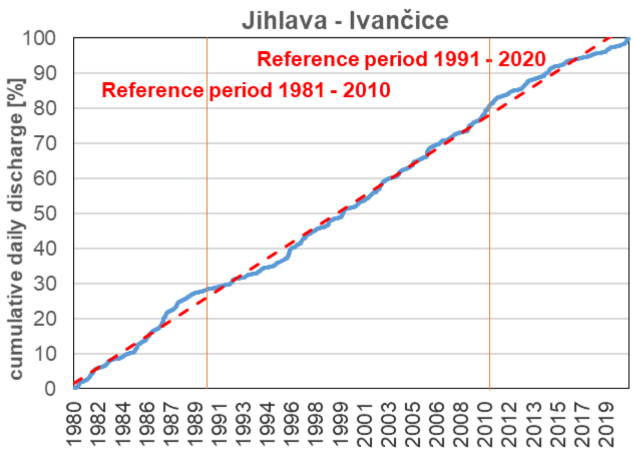


*Fig. 14. Mass curve of mean daily discharges in the water gauging station Ivančice (Jihlava) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

significant differences in minimum flows between reference periods. The Kyjov water gauging station was chosen for the evaluation of flow frequencies. The Koryčany water reservoir is located in the upper part of the Kyjovka catchment area, but with the growing area of the catchment area, its influence on the water stability in Kyjovka is weakening. In addition, in the last 5 years, the dam of the reservoir has been undergoing reconstruction, so it operated for most of the year in the inflow-outflow regime, which means that the Koryčany reservoir could not sufficiently improve the flow frequency in Kyjovka. As can be seen from the graphical and tabular expression of flow frequencies at the Kyjov station, the difference in long-term mean discharge between periods by 6%, but in the minimal discharges (364-day discharge) is over 60 (see Fig. 15 and Tab. 8).

Significant increases in the period 1980–1984, 1987–1990 and 2009–2014 can be identified from the graphical expression of daily discharges trends. Significant downward trends are in the period 1991-1997 and since 2016 (see Fig. 16).

**Table 7. Comparison of series of M-day discharges for the current and proposed reference period in the water gauging station Ivančice (Jihlava)**

| | M-day discharges [m$^3$ s$^{-1}$[ | | Difference [%] |
|---|---|---|---|
| | 1981–2010 | 1991–2020 | |
| $Q_a$ | 10.4 | 9.15 | -12 |
| $Q_{30d}$ | 24.6 | 19.9 | -19 |
| $Q_{60d}$ | 14.6 | 13.1 | -10 |
| $Q_{90d}$ | 11.1 | 10.2 | -8 |
| $Q_{120d}$ | 9.25 | 8.45 | -9 |
| $Q_{150d}$ | 7.98 | 7.18 | -10 |
| $Q_{180d}$ | 7.00 | 6.10 | -13 |
| $Q_{210d}$ | 6.13 | 5.17 | -16 |
| $Q_{240d}$ | 5.34 | 4.49 | -16 |
| $Q_{270d}$ | 4.52 | 3.84 | -15 |
| $Q_{300d}$ | 3.78 | 3.28 | -13 |
| $Q_{330d}$ | 3.09 | 2.90 | -6 |
| $Q_{355d}$ | 2.50 | 2.39 | -4 |
| $Q_{364d}$ | 1.60 | 1.60 | 0 |

**Table 8. Comparison of series of M-day discharges for the current and proposed reference period in the water gauging station Kyjov (Kyjovka)**

| | M-day discharges [m$^3$ s$^{-1}$] | | Difference [%] |
|---|---|---|---|
| | 1981–2010 | 1991–2020 | |
| $Q_a$ | 0.255 | 0.240 | -6 |
| $Q_{30d}$ | 0.493 | 0.479 | -3 |
| $Q_{60d}$ | 0.329 | 0.321 | -2 |
| $Q_{90d}$ | 0.262 | 0.254 | -3 |
| $Q_{120d}$ | 0.220 | 0.209 | -5 |
| $Q_{150d}$ | 0.190 | 0.176 | -7 |
| $Q_{180d}$ | 0.170 | 0.156 | -8 |
| $Q_{210d}$ | 0.151 | 0.139 | -8 |
| $Q_{240d}$ | 0.137 | 0.121 | -12 |
| $Q_{270d}$ | 0.120 | 0.103 | -14 |
| $Q_{300d}$ | 0.105 | 0.086 | -18 |
| $Q_{330d}$ | 0.088 | 0.068 | -23 |
| $Q_{355d}$ | 0.065 | 0.039 | -40 |
| $Q_{364d}$ | 0.040 | 0.015 | -62 |

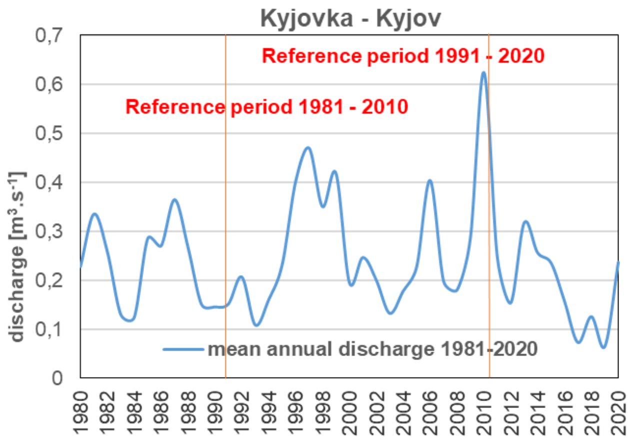


*Fig. 15. Mean annual discharges in the water gauging station Kyjov (Kyjovka) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

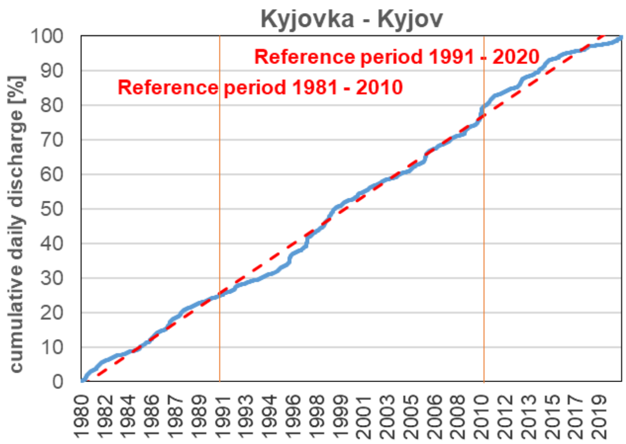


*Fig. 16. Mass curve of mean daily discharges in the water gauging station Kyjov (Kyjovka) for the period from November 1980 to October 2020 with indication of reference periods. Source of used data: CHMI.*

**Conclusion**

Based on the above results, it is clear that the dry period 2015 to 2020 had a significant role in the flow frequencies of watercourses in the South Moravian Region than the dry period in the 1990s. The average flow frequencies for the period 1981–1991, which are included in the still valid reference period 1981–2010, were more favorable than the average flow frequencies in the period 2011–2020, which are included in the newly proposed reference period 1991–2020. This difference affects the decrease in long-term mean discharge ($Q_a$) and other data within M-day discharges. The effect of the dry season is noticeable in all selected water gauging stations, e.g. in the Strážnice station (Morava) there is a noticeable decrease in the long-term mean discharge between periods by 8%. The most significant decrease is evident in the quantiles around the 300-day to 364-day discharge, which represent the minimum flows in a given watercourse (up to 15%).

The most significant decrease in the long-term mean discharge in the newly proposed reference period from the evaluated water gauging stations will be evident in the Ivančice station (Jihlava) by 12%, as the more watery 80s will fall out of the 1991–2020 reference period (e.g. floods in May 1985). On the contrary, the smallest decrease from the evaluated stations will be evident in the station Kyjov (Kyjovka) by 6%. In minimal flows, however, the situation is exactly the opposite. The value of the 364-day flow in the new period will be unchanged in Ivančice (this is most likely due to the stabilization of fluctuations and the prevention of water drop to minimum flows due to manipulations at the outflow from the Dalešice – Mohelno reservoir system). In Kyjov, however, there will be a noticeable decrease of up to 62%, which is the largest difference between the periods of all evaluated stations. On average, of all evaluated stations, this is a decrease in the long-term average flow by 9%, in the minima it is a decrease of 28% in the period 1991–2020.

Furthermore, from the data of water gauging stations, e.g. from the Svratka river basin, it is clear that the occurrence of historically significant minimum flows also affected the supply of large water reservoirs, which kept runoff at the necessary minimums so that they themselves had enough water for their own management. The Skalní Mlýn water gauging station (Punkva) in the Moravian Karst was also evaluated for interest. There is a noticeable decrease between periods in the long-term mean discharge (by 11%). In addition, a hydrometric measurement was performed in the station profile (August 2018), where, according to available data, the historically lowest flow since 1928 was measured. where minimal flows occurred most often from 12 to 24 August 2018, which could be caused by the influence of the cave system of the Moravian Karst.

The above-mentioned analyzes of the trend of mean daily discharges confirmed the above. The results support the conclusions describing the differences between the two reference periods. Above all, there is a significant dry period in all stations since 2015–16, where a significant declining trend in daily discharges is evident. These conclusions are evident from various other outputs of the author of this paper. For example, the Evaluation of Minimum Discharges on Watercourses in the South Moravian Region for the period 2015–2018 (Coufal, 2019) or the same for the last 10 years (Coufal, 2020) can be mentioned. The problem with the dry season is also evident in other parts of the Czech Republic, for example in the Vysočina Region (Coufal et al., 2018).

The results and conclusions will serve for practical use in applied hydrology, e.g. as a basis for determining the minimum residual flows in water management and other other purposes in providing standard hydrological data of surface waters according to ČSN 75 1400.

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