

V. BRUŠKOVÁ

ASSESSMENT OF THE BASE FLOW IN THE UPPER PART OF TORYSA RIVER CATCHMENT

VALÉRIA BRUŠKOVÁ

Department of Land and Water Resources Management,
Faculty of Civil Engineering, Slovak University of
Technology, Slovakia, e-mail: brusкова@svf.stuba.sk.

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ABSTRACT

The purpose of this paper is to assess the base flow in the upper part of the Torysa River catchment in two gauging stations (No. 8710 – Nižné Repaše, Torysa River; No. 8750 – Brezovica, Torysa River). The base flow is the portion of the stream flow that is derived from natural storage (e.g., groundwater outflow and the draining of large lakes and swamps or other sources outside the net rainfall that creates surface runoff). The separation of the base flow from the discharge records is an important issue in hydrology. Knowledge of discharge regimes is one way to understand the stream flow process in a catchment. There are lots of methods for assessing base flow, including Base Flow Index method (BFI). This method performs a separation of the base flow from the total stream flow to calculate the Base Flow Index. It is written as a Visual Basic Application using Excel.

KEY WORDS

- base flow,
- base flow index,
- discharge,
- hydrological drought

1. INTRODUCTION

Groundwater system is a complex dynamic system characterized by nonstationary input (recharge), output (base flow), and response (groundwater levels). The base flow is important, but it is a difficult assessing part of the total stream flow. It is not attributable to direct runoff from precipitation or melting snow; but it is usually sustained by groundwater. Calculated values of base flow can be helpful by assessing the wettest and driest period. There are lots of methods for its selection, for example base flow separation from stream flow hydrograph, statistical methods based on minimal stream flow, flow duration curve analysis, Base Flow Index...

The aim of this paper was to assess the base flow in the upper part of Torysa River catchment by Base Flow Index method.

2. BFI PROGRAM

The Base Flow Index (BFI) method was developed during a low – flow studies in the UK (Institute of Hydrology, 1980). The index gives a ratio of the base flow to the total flow calculated from a hydrographic smoothing and separation procedure using daily discharges. The BFI is thus considered a measure of the river's runoff which is derived from stored sources and, as a general catchment descriptor, has found many areas of application, including low flow estimation and groundwater recharge assessment.

The BFI is closely related to other low – flow indices and is frequently used as a variable for estimating low – flow indices at an ungauged site. The relationships between the index and catchment descriptors have been derived for different hydrogeological regimes



and used to estimate BFI, and hence flow indices, at an ungauged site (Institute of Hydrology, 1980).

The base flow separation is performed on time series of daily mean flows. The minima of 5-day non-overlapping consecutive periods are calculated, and the turning points in this sequence of minima are identified. The turning points, defined as points that belong to the base flow separation line, are connected to obtain the base flow hydrograph.

The base flow separation can not start on the first day of the record and similarly can not finish on the last day. The starting and ending dates of the base flow hydrograph must therefore be used in calculating the volume of flow beneath the base flow hydrograph. For the same reason, the BFI is sensitive to missing data, as the loss of only one day may result in several days of data being omitted from the base flow separation. Interpolation can be used to fill in missing periods, providing these are of short duration.

It is generally recommended that the base flow separation be computed for the entire period of record. The BFI can then be calculated as the ratio of the volume of the base flow to the volume of the total flow for the whole period. Annual BFIs can also be estimated with the separation computed using the entire period of record, thus avoiding the loss of some days at the start and end of each year. A period of the recorded BFI can in this case be derived as the mean of the annual BFIs (Institute of Hydrology, 1980).

Calculation of BFI

Calculation of BFI is result of several steps and it is illustrated in Table 1 (Hisdal et al., 2004). The daily flows Q ($m^3 \cdot s^{-1}$) are divided into non-overlapping blocks of five days (Column 1 and 2). From this block is selected minima value (Q_{min}) of daily flows (Column 3). If central minima value (in between surrounding minima values) is ≤ 0.9 , than it is used for plotting base flow separation line and assigns to each day a base flow value Q_b , by linear interpolation between selected central values.

Next step calculates the water volume (V_{base}) beneath base flow hydrograph between the first and last date of interest. The volume (m^3) is simply derived as the sum of the daily base flow values times the timespan in second per day.

Calculating of corresponding volume water beneath the recorded hydrograph (V_{total})

The volume (m^3) is obtained by summing the daily flow values between the first and the last dates inclusive.

Calculating of BFI (V_{base}/V_{total})

The BFI for the whole stream flow series, calculated as:

$$BFI = \frac{\sum_i b_i}{\sum_i d_i}$$

with: b_i – base flow values that are part of the selected season
 d_i – total stream flow values that are part of the selected season

Table 1 Calculation of the base flow separation line from time series of daily flows; non-overlapping 5-day blocks are separated with dotted lines and turning points are marked bold

1. Date	2. Daily flow Q ($m^3 \cdot s^{-1}$)	3. Q_{min} ($m^3 \cdot s^{-1}$)	4. $0.9Q_{min}$ ($m^3 \cdot s^{-1}$)	5. Base flow Q_b ($m^3 \cdot s^{-1}$)
1.1.1995	0.109			
2.1.1995	0.063			
3.1.1995	0.043			
4.1.1995	0.039	0.039	0.0387	
5.1.1995	0.229			
6.1.1995	0.186			
7.1.1995	0.116			
8.1.1995	0.111			
9.1.1995	0.095	0.095	0.0855	
10.1.1995	0.123			
11.1.1995	0.178			
12.1.1995	0.091			
13.1.1995	0.076			
14.1.1995	0.073			
15.1.1995	0.062	0.062	0.0558	
16.1.1995	0.054	0.054	0.0486	0.054
17.1.1995	1.060			0.0560
18.1.1995	0.856			0.0580
19.1.1995	1.050			0.0600
20.1.1995	1.340			0.062
21.1.1995	1.640			0.064
22.1.1995	1.350			0.0670
23.1.1995	0.559			0.0690
24.1.1995	0.255	0.255	0.2295	0.0710
25.1.1995	0.644			0.073
26.1.1995	0.793			0.075
27.1.1995	0.896			0.0770
28.1.1995	0.631			0.0790
29.1.1995	1.000			0.0810
30.1.1995	0.492	0.492	0.4428	0.083
31.1.1995	0.377			0.085
1.2.1995	1.670			0.0870
2.2.1995	0.448			0.0900
3.2.1995	0.237			0.0920
4.2.1995	0.163	0.163	0.147	0.094
5.2.1995	0.123			0.096
6.2.1995	0.102			0.0980
7.2.1995	0.100	0.10	0.09	0.1000
8.2.1995	0.151			0.1070
9.2.1995	0.178			0.1150



Mean of annual BFIs: This field displays the mean of the annual BFIs, which are displayed under “Result: Annual values”:

$$\text{Mean of annual BFIs} = \frac{\sum BFI_a}{n}$$

with: BFI_a – annual or seasonal BFI where a denotes the year/season
 n – total number of years/seasons (Morawietz, 2004).

the Torysa River is classified as a river in the Odra group, where the main water source is melting snow; however, rain prevails as a water source with a maximum amount of rain in the spring months (April-May).

The average maximums of water content are very important attributes of this area, depending on the snow melt, especially in March. A slightly increased level of water content occurs in summer, which is caused by heavy rains (July-August). A considerable decrease in the water content level occurs in late summer and the beginning of Autumn, followed by an increase in discharges resulting from Autumn rains.

3. DESCRIPTION OF THE UPPER PART OF TORYSA RIVER CATCHMENT

The Torysa River is the biggest river in the area of Šarišské vrchovina. It originates in the Levočské vrchy mountains at an altitude of 1140m above sea level (a.s.l.) below the Škapová peak (Fig. 1). According to Lvovič’s classification (Duba 1968),

4. RESULTS

For assessing the base flow in the upper part of the Torysa river catchment, data from two gauging stations was used:

1. No. 8710 – Nižné Repaše, Torysa River,
2. No. 8750 – Brezovica, Torysa River.

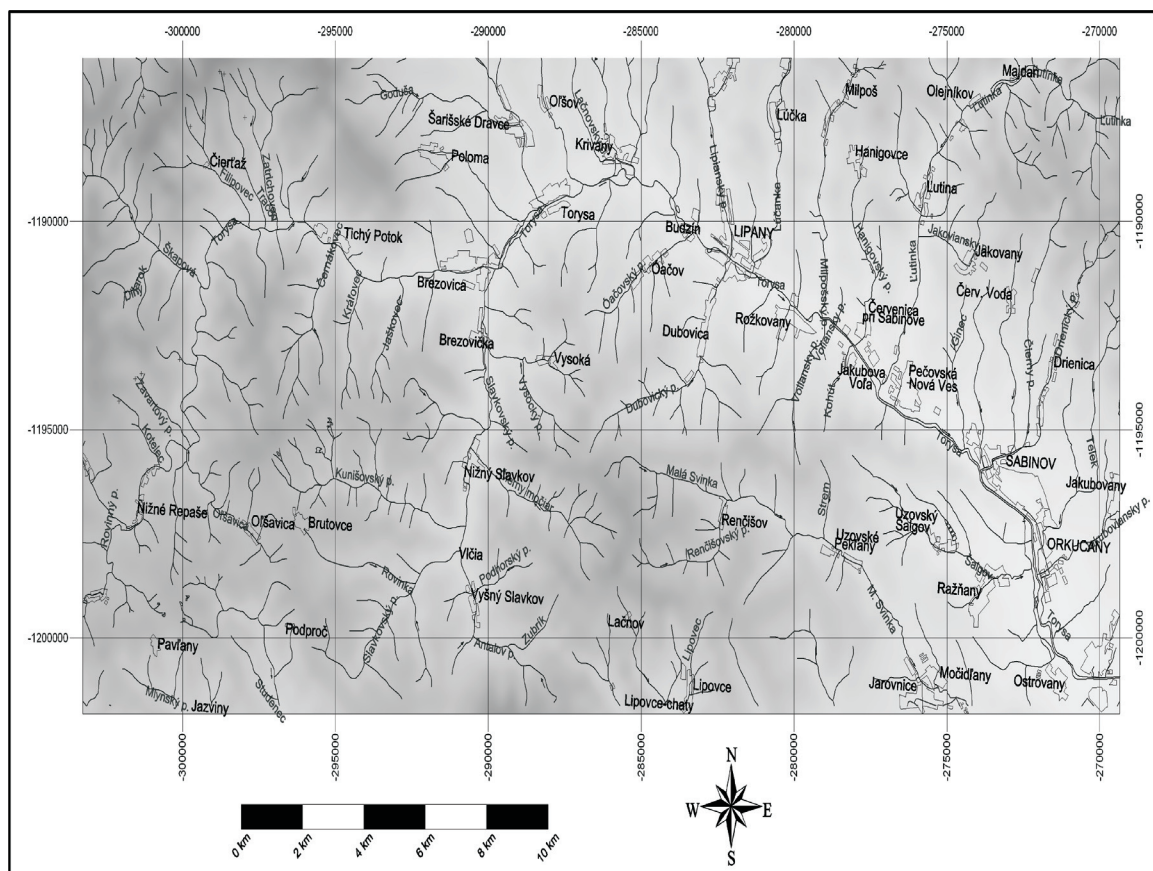


Fig. 1. General situation of the area (Brušková, 2006)



Table 2 *Input data*

Series Information		Season Information	
Start of entire series:	1.1.1975	Season start day:	1
Start of base flow line:	9.1.1975	Season start month:	11
End of base flow line:	22.12.2004	Season end day:	31
End of entire series:	31.12.2004	Season end month:	10
		Year shift during season:	yes

Table 3 *Results: Whole series*

BFI	0.546
Mean of annual BFIs	0.555

Input data is time series from 1.1.1975 to 31.12.2004, but the base flow is calculated for hydrological years 1976 – 2004. A graph of the base flow separation shows us the total stream flow (input data) and the calculated base flow values (Fig. 2, 3, 4, 5).

The aim was to describe a specific period using the BFI for an individual gauging station. If we calculate the minimal, maximal and mean base flows, then we can assess a specific period.

Gauging Station No. 8710 – Nižné Repaše, Torysa River

Discharges from the Nižné Repaše gauging station are natural,

because the site has no abstractions. In Table 2 we can see some information about the input data. The results of the whole series are displayed in Table 3. The BFI results and base flow values for individual years are displayed in Table 4. The value for the long-term base flow is $0.145 \text{ m}^3 \cdot \text{s}^{-1}$.

The hydrological year 1982 was the driest from all the rated years. The value of the base flow is $0.065 \text{ m}^3 \cdot \text{s}^{-1}$ (Fig. 2). The second driest hydrological year was 1993. The base flow value is $0.071 \text{ m}^3 \cdot \text{s}^{-1}$. The mean base flow is conserved in total flow with 49% in this year (1982).

Conversely, the wettest year was the hydrological year 2000. The value of the base flow is $0.238 \text{ m}^3 \cdot \text{s}^{-1}$ (Fig. 3). The mean base flow is conserved in total flow with 60% in this year.

According to Balco (1990), we can use for assessing of dry period in groundwater long-term mean base flow value. The value of this threshold level (Q_{tb}) is $0.145 \text{ m}^3 \cdot \text{s}^{-1}$ in gauging station No. 8710. The

Table 4 *Result of annual values BFI and base flow*

Year	BFI	Base flow ($\text{m}^3 \cdot \text{s}^{-1}$)	Lost Days	Year	BFI	Base flow ($\text{m}^3 \cdot \text{s}^{-1}$)	Lost Days
1975	0.596	-	69	1991	0.593	0.130	0
1976	0.640	0.215	0	1992	0.603	0.145	0
1977	0.592	0.193	0	1993	0.655	0.071	0
1978	0.614	0.164	0	1994	0.516	0.123	0
1979	0.555	0.123	0	1995	0.522	0.153	0
1980	0.440	0.174	0	1996	0.606	0.181	0
1981	0.633	0.134	0	1997	0.529	0.174	0
1982	0.484	0.065	0	1998	0.530	0.122	0
1983	0.445	0.107	0	1999	0.621	0.138	0
1984	0.479	0.126	0	2000	0.605	0.238	0
1985	0.555	0.206	0	2001	0.455	0.170	0
1986	0.682	0.140	0	2002	0.494	0.126	0
1987	0.513	0.083	0	2003	0.619	0.144	0
1988	0.632	0.124	0	2004	0.389	0.121	0
1989	0.437	0.162	0	2005	0.632	-	313
1990	0.528	0.100	0	-	-	-	-

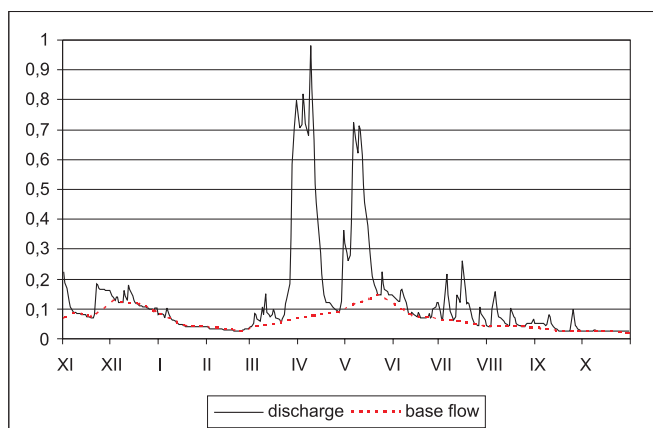


Fig. 2. Base flow in the driest hydrological year 1982

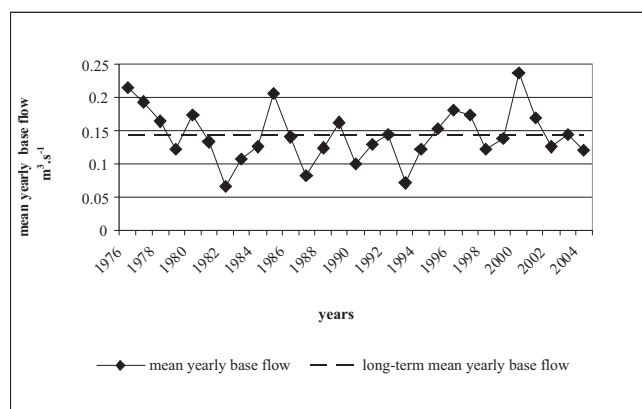


Fig. 4. Separation of dry periods

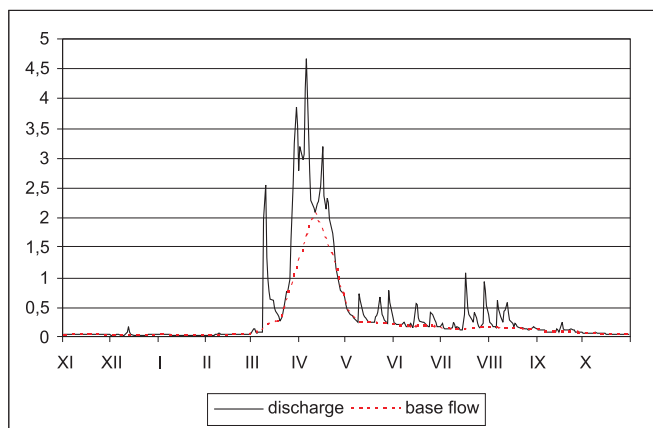


Fig. 3. Base flow in the wettest hydrological year 2000

Table 5 Input data

Series Information		Season Information	
Start of entire series:	1.1.1975	Season start day:	1
Start of base flow line:	15.1.1975	Season start month:	11
End of base flow line:	22.12.2004	Season end day:	31
End of entire series:	31.12.2004	Season end month:	10
		Year shift during season:	yes

Table 6 Results: Whole series

BFI	0.532
Mean of annual BFIs	0.537

dry periods are illustrated on the figure 4. Dry years are under the threshold level. Dry hydrological years are 1979, from 1981 to 1984, 1986 to 1989, 1990 to 1994, 1998, 1999 and 2002 to 2004. Drought started in hydrological year 1979 at the first time. This phenomenon takes 5 years in this gauging station from 1990 to 1994. The dry years was 18 from total record.

Gauging station No. 8750 – Brezovica, Torysa River

The discharge in this gauging station is impacted by abstractions. This site has a lot of groundwater abstractions. Affected data for the assessment of the base flow was used. Some information about the input data, series information, season information and results of the annual BFI values and base flow is in the tables below (Tables 5, 6, 7). The long-term base flow is $0.816 \text{ m}^3 \cdot \text{s}^{-1}$.

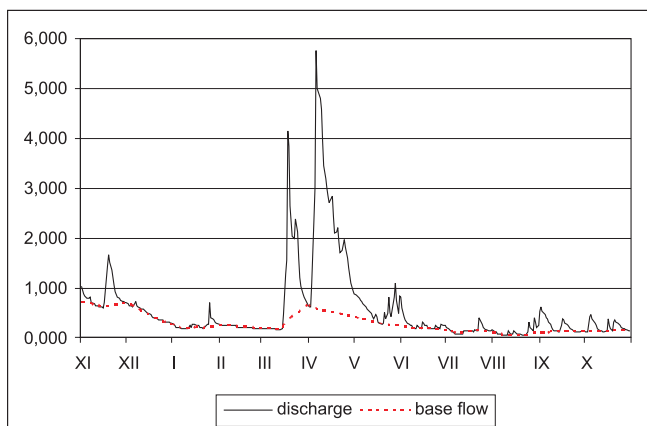


Fig. 5 Base flow in the driest hydrological year 1993

Table 7 Result of annual values BFI and base flow

Year	BFI	Base flow (m ³ .s-1)	Lost Days	Year	BFI	Base flow (m ³ .s-1)	Lost Days
1975	0.539	-	75	1991	0.518	0.558	0
1976	0.480	0.924	0	1992	0.586	0.796	0
1977	0.547	1.340	0	1993	0.470	0.272	0
1978	0.597	1.446	0	1994	0.533	0.597	0
1979	0.620	1.039	0	1995	0.553	0.889	0
1980	0.477	1.176	0	1996	0.612	0.796	0
1981	0.679	0.969	0	1997	0.562	1.048	0
1982	0.537	0.515	0	1998	0.598	0.934	0
1983	0.563	0.817	0	1999	0.527	0.869	0
1984	0.532	0.717	0	2000	0.503	0.861	0
1985	0.504	1.345	0	2001	0.418	0.839	0
1986	0.709	0.721	0	2002	0.469	0.528	0
1987	0.351	0.363	0	2003	0.577	0.596	0
1988	0.496	0.503	0	2004	0.371	0.504	0
1989	0.476	1.082	0	2005	0.639	-	313
1990	0.590	0.588	0	-	-	-	-

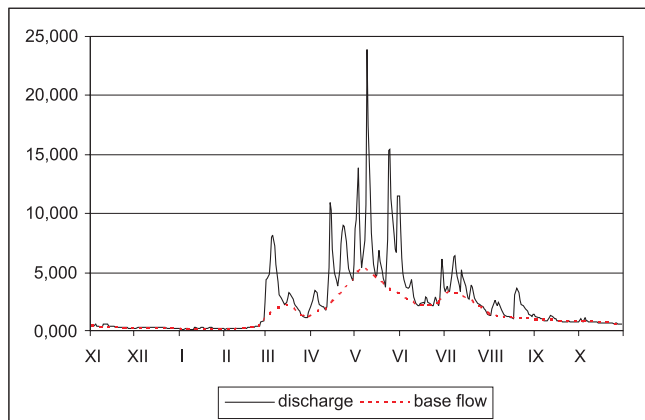


Fig. 6. Base flow in the wettest hydrological year 1978

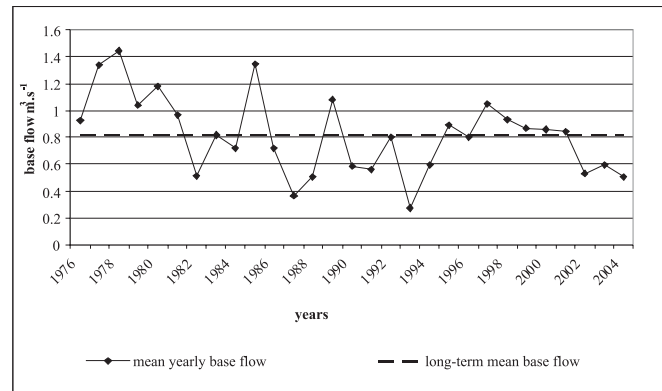


Fig. 7. Separation of dry periods

The driest year from all the rated years was the hydrological year 1993. The mean base flow is conserved in total flow with 47% in this year. The value of the base flow is 0.272 m³.s⁻¹ (Fig. 5). The second driest year was the hydrological year 1987. The base flow value is 0.363 m³.s⁻¹. The mean base flow is conserved in total flow with 35% in this year.

In figure 6 we can see the wettest hydrological year at the Brezovica gauging station, i. e., the hydrological year 1978. The base flow

value is 1.446 m³.s⁻¹. On this year the mean base flow is conserved in total flow with 60%. The second wettest year was the hydrological year 1985. The base flow value is 1.345 m³.s⁻¹. The mean base flow is conserved in total flow with 51% in this year.

The value of the threshold level (Q_{th}) is 0.816 m³.s⁻¹. The dry periods are displayed on the figure 7 (gauging station No. 8750). Dry hydrological years are from 1982 to 1986 to 1988, 1990 to 1994, 1996, and 2002 to 2004.

Drought started later (hydrological year 1982) in this gauging station than in the station No. 8710 (hydrological year 1979) at the first time. This phenomenon takes 7 years in this gauging station from 1990 to 1996. The dry years was 18 from total record.

5. CONCLUSION

Input data for the BFI program are available and do not need any additional data. The data processing is very practical, simple and not time-consuming. This method can be used for various rivers. The reliability of the results depends on the accuracy of the input data and on the program algorithm.

The resulting base flow values from these gauging stations are impacted by climate variability and anthropogenic activities. This

program can be generally used for determining hydrological droughts (surface water drought and groundwater drought). According to Balco (1990), we can use the long-term values of the base flow as a threshold level and then we can determine hydrological droughts in general. Hydrological drought takes longer in gauging station Brezovica (No. 8750) than Nižné Repaše (No. 8710) because this phenomenon is affected not only with climate but by human activity (abstractions) too in No. 8750. Drought is affected only climate in No. 8710.

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