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# The examination of the performances of methods used in separating the total stream flow in different rivers

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In this study, the performances of methods of flow separation into the surface flow and base flow of the total stream flow in rivers with different hydraulic features have been examined. For this purpose, daily mean stream flow data of Büyük Melen and Aksu Rivers which are in the same watershed but with different features (average flow value, catchment area, mean elevation) have been separated as surface flow and base flow with the use of Digital Filtering Method (DFM) and United Kingdom Institute of Hydrology Method (UKIH). The recession coefficient in DFM has been used as $\alpha = 0.830$; and the number of elements for the groups formed to determine the turning points of flow data in UKIH has been used as $N = 5$. The study has revealed that the results of surface and base flows obtained by both flow separation methods show similarity in all rivers in an acceptable level; and the surface flow values agree better ($R^2 > 0{,}76$) compared to base flow values ($R^2 > 0.63$). However, it has been seen that as long as the total flow values decrease, the surface flow results for both methods come closer to each other; but the results of base flow get differentiated. This situation has been clearly seen in the results of surface ($R^2 > 0.89$) and base ($R^2 > 0.63$) flows belonging to Aksu River which has lower values of flow when compared to the ones of Büyük Melen River.

*Keywords*: separation of flow, surface flow, base flow, DFM, UKIH

## 1. Introduction

The success of plans made for the management of water resources depends on acknowledgement of the amount and quality of available water. A detailed analysis of water flow is required in environmental issues such as determination of the amount of water to be taken from and discharged into rivers, design of water discharge structures, natural treatment system effectiveness, basin hydrology and non-point pollutant sources, acidification or salinity of water resources. Therefore, in the field of hydrology studies for the correct determination of hydrograph components have been carried out for years and suitable methods have been developed.

Although studies of flow separation started with field studies and observations such as usage of hydrochemical tracers and environmental isotopes, due to the breadth of field of study, expensive methods and inapplicable on specific basins, hydrograph based methods became popular.

Some common hydrograph separation methods are manual graphical approaches (Linsley et al., 1975), automated separation tecniques (Sloto and Crouse, 1996; Lim et al., 2005), artificial intelligence tecniques (Corzo and Slomatine, 2007), hydrochemical tracer-based tecniques (Ladouche et al., 2001; Mul et al., 2008), digital filtering method (Lyne and Hollick, 1979; Nathan and McMahon, 1990; Eckhardt, 2005), smoothed minima approach and its derivations (IH, 1980; Piggot et al., 2005; Aksoy et al, 2008; 2009, Koskelo et al., 2012).

Although there are various techniques used in hydrograph separation, the most suggested methods are filtering methods which are based on filtering observed flow data and also can be used practically due to computer programmes and obtained results able to repeat.

In this study, the success of the usability of Digital Filtering Method (DFM) and United Kingdom Institute of Hydrology Method (UKIH) in the rivers that are in the same watershed but have different features (average flow value, catchment area, mean elevation); and which have been seen to have given more accurate results when compared to the other methods in the separation of daily mean flow to its components as surface and base flows has been examined.

## 2. Material and methods

In this study, DFM proposed by Nathan and McMahon (1990) and UKIH proposed by Pidgott et al. (2005) were used as separation methods which are the most accepted methods to separate long term continuous stream flow data into surface flow and base flow components. Selected two methods were applied to the average daily stream flow data by using codes written in MATLAB version 7.9.0.529 (R2009b) programme and surface flow and base flow were determined.

Daily average stream flow data of stream flow gauging stations (SGS) 1302 and 1340 along Büyük Melen River, and 1339 along Aksu River belonging to EIE (The Electrical Power Resources, Survey and Development Administration) of Turkey were used (Tab. 1). Büyük Melen and Aksu Rivers are located in Melen Watershed in Western Black Sea Region of Turkey (Fig. 1). Melen Watershed has been used since 2010 as the source of inter-basin water transfer to solve the water scarcity of Istanbul which is one of the most populated metropolitan of the world. It is expected that drinking water demand of Greater Istanbul till year 2040 will be met by this resource (Ertürk et al., 2007).

*Table 1. Streamflow gauging stations used in the study and their general features.*

| SGS Number | Name of SGS | Coordinates of SGS | | Approximate elevation (m) | Area of precipitation (km$^2$) | Average flow value (m$^3$/s) | Period of observation |
|---|---|---|---|---|---|---|---|
| | | East | North | | | | |
| 1302 | Büyük Melen | 30° 59’ 04” | 40° 51’ 28” | 115 | 1988 | 36.35 | 1981-2010 |
| 1339 | Aksu | 30° 55’ 13” | 40° 42’ 55” | 634 | 105.2 | 3.83 | 1981-2010 |
| 1340 | Büyük Melen | 30° 57’ 20” | 40° 58’ 58” | 23 | 2174 | 48.89 | 1981-2010 |

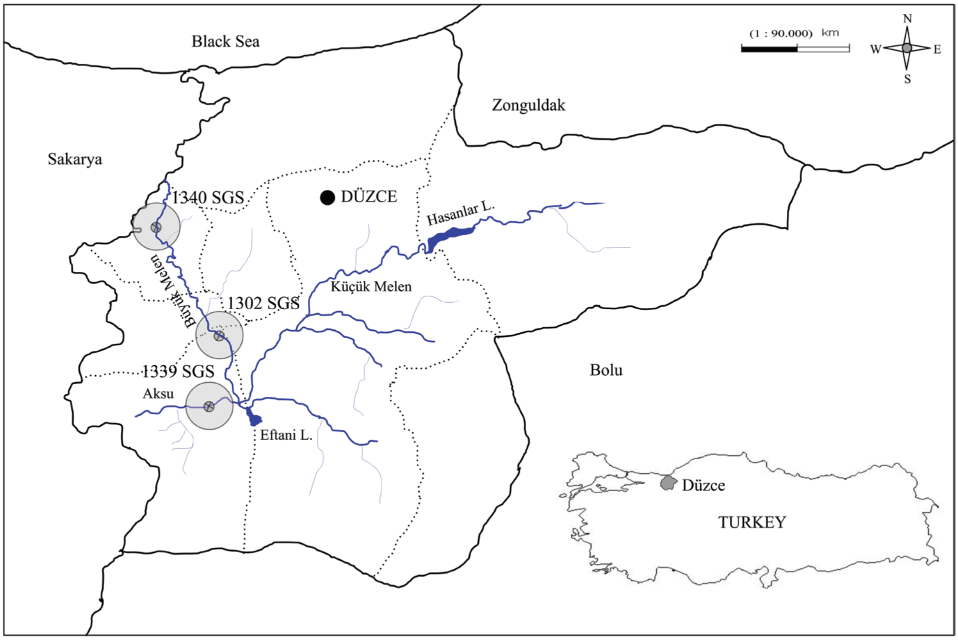


**Figure 1.** Study area and stream flow gauging stations (SGS) (1302, 1340, 1339).

## *2.1. Digital filtering method (DFM)*

DFM is an algorithm which is used in order to calculate base flow assuming that total stream flow of river is separated into surface flow and base flow (Nathan and McMahon, 1990; Chapman, 1999; Echardt, 2005). There are many revised versions of filter equations used in separation of total stream flow as base flow and surface flow.

In this study the version of DFM which was revised by Chapman and Maxwell (1996) was used as shown by eq. (1). The reason for choosing this filtering equation is that it is more useful when surface flow is greater from or equal to base flow. After base flow is determined with filtering process, surface flow is calculated by using equation (2). In eqs. (1) and (2), $b_k$ is base flow, $y_k$ is total stream flow, $s_k$ is surface flow and $a$ is recession coefficient.

$$b_k = \frac{\propto}{2-\propto} \cdot b_{k-1} + \frac{1-\propto}{2-\propto} \cdot y_k \tag{1}$$

$$s_k = y_k - b_k \tag{2}$$

The ideal range given in the literature for recession coefficient is 0.9–0.95. However it is noted in various studies that different recession coefficients also give good results (Echardt, 2008).

In this study, the recession coefficient was found as $a = 0.830$ in the filtering process in which total flow is separated as surface flow and base flow. Steps of DFM which was used as first method are given in Fig. 2a.

### *2.2. United Kingdom Institute of Hydrology method (UKIH)*

This method which was developed by the United Kingdom Institute of Hydrology by using data of rivers with continuous flow is basically based on the identification and interpolation of turning points. The turning points indicate the days and corresponding values of stream flow, where the observed flow is assumed to be entirely base flow (Piggott et al., 2005). In this study long-term flow data are used. Flow values were separated in non- overlapping, sequential groups in order to determine turning points. Number of elements of these groups was shown with $N$ and was determined as five. A data series was formed within group with minimums in the groups ($y_i$, $i = 1, 2, 3, 4, \ldots$) and turning points were determined by comparison with equation (3) (Institute of Hydrology, 1980; Tallaksen, 1987; Hisdal et al., 2003; Aksoy et al., 2009).

$$0.9\, y_i \leq \min\,(y_{i-1}\,,\, y_{i+1}). \tag{3}$$

Sequential turning points were united with a line, and base flow values were calculated with the rest of days. It was seen that calculated base flows surpass total flow or determined as negative on some days. In cases where base flow surpasses total flow, total flow was equalised to base flow, while for negative values it was taken as zero. Such cases are also found in literature (Aksoy et al., 2008).

The success of the used methods (DFM, UKIH) in separating the stream flow to its components for all observational stations has been determined by compar-

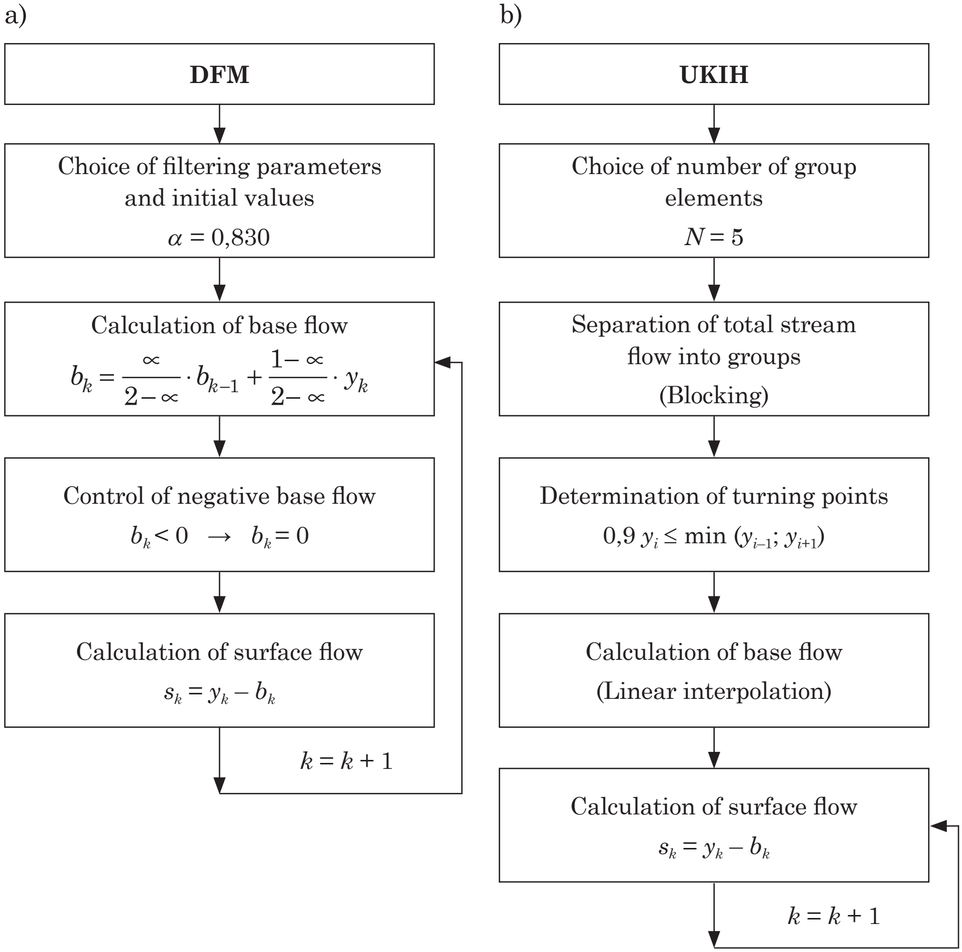


**Figure 2.** Flow-chart of methods used in the study: (*a*) digital filtering method (DFM) and (*b*) United Kingdom Institute of Hydrology method (UKIH).

ing the results of surface flow, base flow and Base Flow Index (*BFI*) which has been calculated with eq. (4) (Aksoy et al., 2009; Nejadhashemi et al., 2009; Koskelo et al., 2012).

$$BFI = \frac{\int_{t1}^{t2} Q_{base}(t)\,\mathrm{d}t}{\int_{t1}^{t2} Q_{total}(t)\,\mathrm{d}t} \tag{4}$$

For the obtained results mean absolute error (*MAE*) and root mean square error (*RMSE*) were calculated, and linear regression method ($R^2$) was applied (eqs. 5–9) (Dogan et al., 2010).

$$R^2 = \frac{Q_{f_0} - Q_f}{Q_f}, \tag{5}$$

$$Q_{f_0} = \sum_{i=1}^{n} (Q_{fi(A)} - Q_{f(mean)})^2, \tag{6}$$

$$Q_f = \sum_{i=1}^{n} (Q_{fi(A)} - Q_{fi(B)})^2. \tag{7}$$

where $Q_{fi(A)}$ and $Q_{fi(B)}$ are DFM, UKIH flow values respectively and $Q_{f(mean)}$ is the mean DFM flow values. The mean absolute error (*MAE*) and root mean square error (*RMSE*) are defined as

$$MAE = \frac{1}{N} \sum_{i=1}^{n} \left| Q_{fi(A)} - Q_{fi(B)} \right|, \tag{8}$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{n} (Q_{fi(A)} - Q_{fi(B)})^2}\ . \tag{9}$$

## 3. Results and discussion

It is possible to determine the surface flow and base flow by only using the data of stream flow. According to the literature the models developed for this purpose give good results (Arnold and Allen, 1999; Larocque et al., 2010). In addition, the most significant issue to be paid attention in the processes of separating the flow into components is to test the accuracy of the methods. The generally accepted idea for the purpose of testing the prediction ability of the used methods is to compare the results of the methods with one another (Nahan and McMohan, 1990; Aksoy et al., 2009; Nejadhashemi et al., 2009; Welderufael and Woyessa, 2010). Therefore, in this study the results obtained by separation of daily mean flow of Büyük Melen and Aksu rivers that are in the same watershed, but have different magnitude and hydraulic features into surface flow and base flow have been statistically examined (Tab. 2) and results of both methods compared (Tab. 3). When the statistical values of surface flow and base flow given in Tab. 2 are evaluated, the mean values of surface flow and base flow obtained with DFM have been found to be so close to each other at the three stream flow gauging stations (SGSs). The values of mean base flow are higher than those of surface flow for the UKIH results. The standard deviations of the results of surface flow have been found to be higher than the mean values of the surface flow. As it can be understood from the high difference between the maximum and minimum values, this situa-

*Table 2. Some statistical values of surface flow and base flow.*

| | Digital filtering method | | | | | | United Kingdom Institute of Hydrology method | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Surface Flow | | | Base Flow | | | Surface Flow | | | Base Flow | | |
| | 1302 | 1339 | 1340 | 1302 | 1339 | 1340 | 1302 | 1339 | 1340 | 1302 | 1339 | 1340 |
| $X_{mean}$ | 17.50 | 1.86 | 23.99 | 17.47 | 1.85 | 23.95 | 11.09 | 1.87 | 15.63 | 23.86 | 2.14 | 32.31 |
| $X_{max}$ | 344.2 | 62.58 | 496.8 | 170.3 | 18.07 | 229.84 | 438 | 72.62 | 72.62 | 136 | 12.5 | 12.5 |
| $X_{min}$ | 0 | 0 | 0 | 1.09 | 0.05 | 1.184 | 0 | 0 | 0 | 1.86 | 0.06 | 0.06 |
| *Sd* | 20.27 | 2.68 | 28.76 | 16.1 | 1.87 | 22.04 | 21.88 | 3.30 | 32.62 | 21.01 | 1.81 | 27.95 |

*Table 3. The statistical comparison of the results of surface flow, base flow and BFI.*

| | Surface flow (DFM-UKIH) | | | Base flow (DFM-UKIH) | | | *BFI* (DFM-UKIH) | | |
|---|---|---|---|---|---|---|---|---|---|
| Station Number | *MAE* | *RMSE* | $R^2$ | *MAE* | *RMSE* | $R^2$ | *MAE* | *RMSE* | $R^2$ |
| 1302 | 8.29 | 12.36 | 0.76 | 8.28 | 12.32 | 0.75 | 0.27 | 0.30 | 0.78 |
| 1339 | 0.76 | 1.20 | 0.89 | 0.72 | 1.18 | 0.63 | 0.29 | 0.34 | 0.71 |
| 1340 | 11.46 | 17.38 | 0.78 | 11.42 | 17.34 | 0.7 | 0.27 | 0.32 | 0.79 |

tion arises from the feeding of precipitation on the total river flow by turning into surface flow, especially in the periods with so much rain. On the other hand, the average total flow values are close to the base flow values and this indicates that the rivers are mostly fed by the base flow (Tabs. 1 and 2).

The statistical comparison of the results of the surface flow and base flow for the both methods in all stations has been presented in Tab. 3. It can be understood from the results in Tab. 3 that *MAE* and *RMSE* values of surface flow and base flow are so close to each other in all stations. The stations 1302 and 1340 have higher *MAE* and *RMSE* values when compared to the station 1339. This is due to the high flow values for stations 1302 and 1340. When the determination coefficients ($R^2$) are evaluated, it is seen that the surface flow ($R^2 > 0.76$) values of DFM and UKIH methods have closer results when compared to those for the base flow ($R^2 > 0.63$). In addition, as the total values of flow decrease, the surface flow results for both methods are closer to each other, while the results for the base flow are different. This can be seen from the results of surface flow ($R^2 = 0.89$) and base flow ($R^2 = 0.63$) for the station 1339 that has lower values of flow when compared to stations 1302 and 1340.

*BFI*, which is calculated as a ratio of the volume of base flow and volume of total flow, is suggested in many studies as an important index used in compari-

*Table 4. Some statistical values of Base Flow Indexes.*

| | Digital filtering method | | | United Kingdom Institute of Hydrology method | | |
|---|---|---|---|---|---|---|
| | 1302 | 1339 | 1340 | 1302 | 1339 | 1340 |
| $X_{mean}$ | 0.52 | 0.52 | 0.52 | 0.768 | 0.73 | 0.76 |
| $X_{max}$ | 1 | 1 | 1 | 1 | 1 | 1 |
| $X_{min}$ | 0.162 | 1.62 | 0.17 | 0.03 | 0.02 | 0.02 |
| *Sd* | 0.09 | 0.103 | 0.09 | 0.216 | 0.245 | 0.218 |

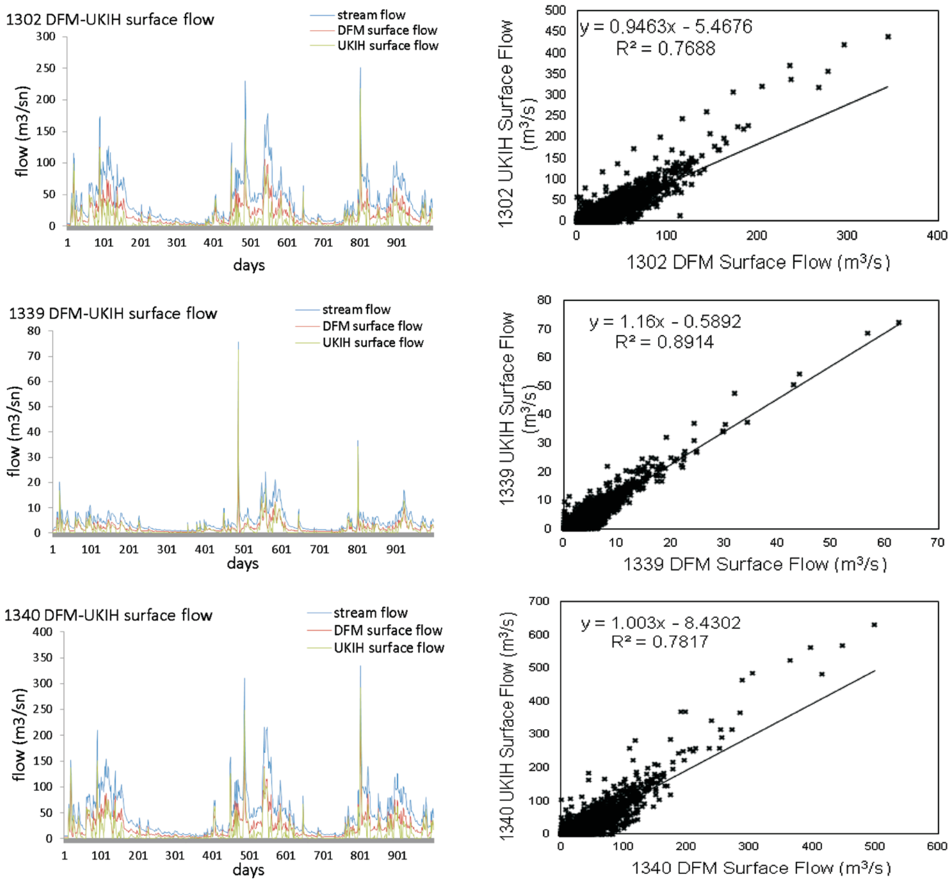


**Figure 3.** Graphics and scatter diagrams of surface flow separated with DFM and UKIH.

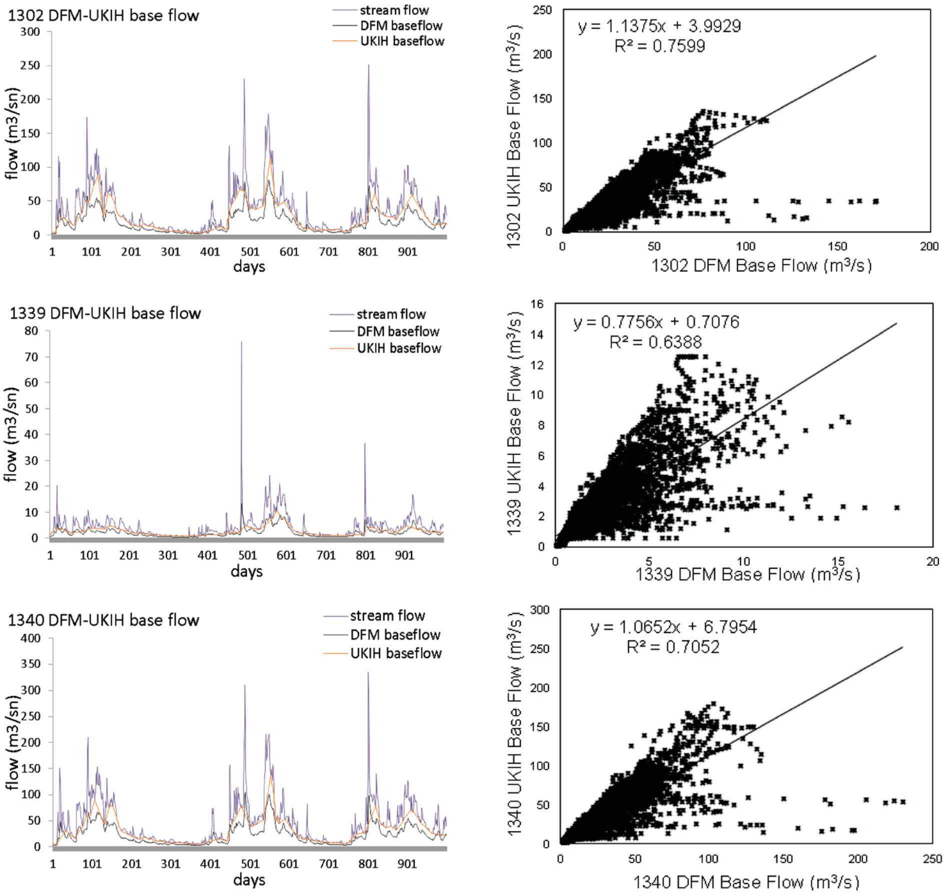


**Figure 4.** Graphics and scatter diagrams of base flow separated with DFM and UKIH.

son of separation models (Mazvimavi et al., 2004; Aksoy et al., 2008). In order to compare methods used in the study, *BFI* value for each method was calculated and statistical information about results are presented in Tabs. 3 and 4. Standard deviation of *BFI* values is low for both methods. When mean and median values of *BFI* are analysed, it is seen that more than half of total flow is composed of base flow. Maximum values show that total flow is totally composed of base flow in some cases (Tab. 4). In addition, similarly to the results obtained from the comparison of flow values, *BFI* values obtained by DFM and UKIH methods are the closest ($R^2 = 0.79$) for the station 1340 in which the total flow is high. As the total flow decreases, results started to get more distant. These differences are acceptable for the results of the base flow for DFM and UKIH ($R^2 > 0.71$), while as the total flow decreases, the results start to differentiate.

Hydrographs consisting of total stream flow, surface flow and base flow values and the graphics of scattering are given in Figs. 3 and 4. For the purpose of preventing the complication possible to occur as a result of the excessive data and enabling a better understanding of the results, a flow value for 100 days in hydrographs and all of the results in the graphics of scattering have been used. When the flow hydrographs are examined, it is clearly seen that in all flow observation stations, especially surface flow proceeds in accordance with the increases and decreases of the total flow. In addition, surface flow values determined by DFM gave the peaks closest to the total flow's peaks associated with the heavy precipitation periods in the hydrographs.

Scatter-plots reveal that surface flow values in all stations show more similarity when compared to the base flow (Figs. 3 and 4). In addition, acceptable differences in the base flows determined by the two different methods occurred especially in the base flow values for the station 1339 having low flow value ($R^2 = 0.63$). This situation results from the fact that the base flow which is separated with the method of UKIH is higher than the values of base flow determined with the DFM. Similar results are also reported in the literature addressing to methods DFM and UKIH methods (Eckhardt 2008; Aksoy et al., 2009).

## 4. Conclusions

Separation of total stream flow into its components using experimental methods and field studies is quite difficult and expensive. Therefore, mathematical models are more preferred for flow separation. Additionally, it is important to know the performance of the used flow separation methods in rivers with different magnitude and features. Therefore, the performance of DFM and UKIH methods, which are among the existing flow separation methods used the most frequently in the literature, has been examined for Büyük Melen River and Aksu River which are in the same watershed. The obtained results have revealed that the surface flow and base flow determined with both methods are similar, that is, the difference are acceptable. The surface flow for both rivers has are more similar to each other compared to the base flow. Additionally, the base flow results for both methods differ significantly, especially for the Aksu river which is characterised with the low total flow. The results obtained by this study can be useful for the long- and short-term management and planning of the associated with this wathershed which is the water source of the region and which is important for inter-basin water transfer.

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SAŽETAK

## Ispitivanje svojstava metoda korištenih za razdvajanje ukupnog vodnog protoka u različitim rijekama

*Bülent Şengörür, Cemile Dede i Emrah Doğan*

U ovom radu su ispitivana svojstva metoda razdvajanja protoka u površinski protok i pridneni protok ukupnog vodnog protoka u rijekama s različitim hidrauličkim profilima. U tu svrhu, podaci srednjeg dnevnog vodnog protoka rijeka Büyük Melen i Aksu, koje pripadaju istom slivu, ali s vrlo različitim odrednicama (prosječni protok, površina sliva, srednja visina) radvojeni su na površinski protok i pridneni pritok korištenjem metode digitalnog filtriranja (DFM) i metode Instituta za hidrologiju Ujedinjenog Kraljevstva (UKIH). Za koeficijent recesije u DFM-u korištena je vrijednost $\alpha = 0.830$. U UKIH metodi je korišteno 5 elementa ($N = 5$) za određivanje točke preokreta u protocima. U radu je pokazano da površinski i pridneni protoci dobiveni pomoću obje metode razdvajanja vodnog protoka pokazuju sličnost u svim rijekama na prihvatljivoj razini, te da se podaci površinskog protoka slažu bolje ($R^2 > 0{,}76$) od onih s pridnenim vrijednostima protoka ($R^2 > 0.63$). Međutim, vidljivo je da se, dokle god vrijednosti ukupnog protoka rastu, rezultati površinskog protoka određeni objema metodama približavaju, dok se rezultati pridnenih protoka sve više razlikuju. Ova je situacija jasno vidljiva u rezultatima površinskih ($R^2 > 0.89$) i pridnenih ($R^2 > 0.63$) protoka rijeke Aksu, koje imaju niže vrijednosti protoka u usporedbi s onima rijeke Büyük Melen.

*Ključne riječi*: odvajanje protoka, površinski protok, pridneni protok, DFM, UKIH

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