ASSESSMENT OF THE RELATIONSHIP BETWEEN STREAM FLOW AND BASE FLOW: PATTERNS, ANALYSIS, APPLICATIONS

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ABSTRACT. **– Assessment of the relationship between stream flow and base flow: patterns, analysis, applications.** Base flow indices for low land area from North-Eastern part of Romania are compared, which were calculated with six different separation methods: the local minimum method (LMM), Talaksen filter, Chapman filter, recursive digital filter (RDF) WHAT model and the Ekchardt filter. All filter-based methods indicate a slight increase in BFI values throughout the study period (1981-2013), in agreement with an increase in precipitation levels in the area over the past decades. The correlation matrix between the different values obtained for the BFI indicates that the most appropriate methods for the study area are the Chapman filter and the Eckhardt filter (r=0.98). Both methods suggest the identification of parameters *a* and *BFImax*, which, when adjusted for the lowland area of North-Eastern Romania (a=0.925, BFImax=0.7-0.8), indicate that, in the area in question, BFI values exceed 0.5.). This indicates the need for a careful reevaluation of the region from a hydrological point of view, one that takes into account the changes in land use and the numerous hydro-technical works of the past decades.

Keywords: BFI, empirical methods, filter based methods, lowland area

1. INTRODUCTION

The ratio between base flow and stream flow is an important issue in analyzing and assessing the water resources of a river basin. The lack of direct data from measurements reflected in the development of graphical models of the base flow (Nash, 1966; Anderson and Burt, 1980) or mathematical (James and Thompson, 1970; Lyne and Hollick 1979; Nathan and McMahon 1990), to identify the underground intake. Since 1980 Britain's Institute of Hydrology introduces the concept of base flow index (BFI) defined as the ratio of the sum of the base flow and sum of the stream flow:

$$BFI = \sum_{i=1}^{n} Qb / \sum_{i=1}^{n} Qi$$

where: unde: Q_b is the sum of the base flow and Qi is the sum of the stream flow.

It is later followed by a number of methodologies that led to the development of computing and mathematical models like BFLOW (Arnold et al., 1995), HYSEP (Sloto and Crouse, 1996), PART (Rutledge, 1998), UKIH (Piggott et al., 2005), WHAT (Lim et al., 2005), Eckhardt (2005, 2008, 2012).

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Identifying the applicability of such a model in Romania is more than necessary given that studies related to the assessment base flow are descriptive (Diaconu, 1971, Ujvari, 1972, Badea et al., 1983). In recent decades identifying sources of supply was the subject of classical works that approached the methodology of splitting the flow hydrograph (Sorocovschi, 1996) or applied new methods of separation of water supply taking into account the local climatic and geological conditions (Minea, 2012).

2. DATA SOURCES

In the application for the evaluation of the identified patterns of stream flow and base flow was used data from gauging stations located in Moldavian Plain managed bu Prut-Bârlad Water Administration between 1981 and 2013. (Table 1). For the results to be more accurate were analyzed only gauging stations where leakage rivers is under natural conditions and in the basins supply upstream were not performed hydraulic works at large scale (reservoirs, catchments of water or derivatives rivers).

Table 1. ***Gauge stations and drainage basins characteristics***

No.	River	Gauge station	Distance to confluence (km)	Surface (km^2)	Medium altitude (m)	Average precipitation (mm)	Average flow (m^3/s)	Max. flow (m^3/s)	Min. flow (m^3/s)
1	Volovă	Manoleasa	7.0	214	178	502.1	0.455	69.0	0.001
2	Buhai	Pădureni	8,0	54,2	165	592.5	0.171	96.0	0.001
3	Jijia	Dorohoi	267	238	262	592.5	0.668	170.0	0.005
4	Sitna	Cătămărăşti	46,5	173	202	557.2	0.424	77.0	0.001
5	Miletin	Nicolae Balcescu	46.0	220	202	641.0	0.470	226.0	0.001
6	Bahlui	Vama cu Tabla	92.0	46	345	527.5	0.239	55.5	0.001
7	Magura	Carjoaia	11.0	39	315	525.5	0.080	83.1	0.001
8	Bahlue	Targu Frumos	23.5	68	252	491.4	0.187	95.0	0.001

*the valeus are corelated with the data obtained by Prut-Bârlad Water Administration

Moldavian Plain geological matrix consists in Sarmatian sedimentary deposits (clay, marl and sand) and quaternary deposits which has generated a relief with altitudes between 35 and 400 m. Quaternary loess clays is presented as an alluvial-colluvial deposits couverture, with 12-23 m thick deposited over pre-quaternary deposits eroded by the river Prut tributary river network (Dragomir, 2009). Geographical position, outside the Carpathian area creates a temperate climate with continental shades, where average annual temperatures vary between 8.5 and 9,5^{0}C and rainfall totals between 450 and 650 mm/year (Croitoru, Minea, 2014).

The climatic conditions favor the frequent occurrence of periods of dryness and drought (Minea, 2010) which on the rivers flow appear between late July and

early October. Prolonged periods without precipitation are often more than 5 consecutive days, and sometimes over 10 consecutive days, causing that in the rivers flow, the underground supply to prevail over the surface supply and in general equation of flow Qi=Qb.

3. METHODOLOGY

To identify the most realible applied to cliamtic and geological conditions from the model aplicat lowland area from the north-eastern part of Romania was used several assessment models of BFI based on two methods: empirical methods based on hydrograph separation and filter based methods.

Hydrograph separation method it is the most applied method used in romanian hydrology. The results were correlated with climatic and geological condition of the drainage basin analyzed. For eastern part of Romania, Harjoabă, et al. (1997) calculates a BFI 0.68, for Moldavian Subcapathians and a BFI between 0.53 and 0.60, for Moldavian Plateau (Harjoaba, Amariucai, 1998).

Aplications of filter based methods involves the use of parameters identified by the statistical analysis of the data string. Of the models based on algorithms, in this paper was used local minimum method (LMM) used by Sloto and Crouse (1996), tooked over by Talaksen and van Lannen (2004) as emphirical methods based on daily flow hydrograph separation method. Within filter based methods was used Champan filter (1991), modified in in recursive digital filter (RDF) by using one parameter algorithm (Chapman and Maxwell, 1996), WHAT model (Lim et al., 2005) and Ekchardt filter (2008).

Initially the algorithm proposed by (1991 modified by Chapman and Maxwell, in 1996) turn to account just one parameter recession constant *k*:

$$Qbi=\frac{k}{2-k}Q_{bi-1}+\frac{1-k}{2-k}Qi$$

Later models, like WHAT model (which is based on an algorithm proposed by Ekchardt, in 2005) resumed and simplified in Ekchardt filter (2008) use a formula to calculate the base flow as:

$$Qb_i=\frac{(1-BFImax)aQb_{i-1}+(1-a)BFImaxQ_i}{1-aBFImax}$$

where: Qb_i is baseflow at time *i*, *BFImax* – base flow index maximum, *a* is a recesion constant and Q_i is total streamflow at time *i*. Eckhardt (2005) suggests that the coefficient values used for BFImax coefficient (non-measurable parameter) can be between 0.70 and 0.80 for rivers with permanent drainage, which developed their catchment areas on permeable rocks. For rivers developed on areas with permeable rocks are proposed BFI values between 0.40 to 0.50 max, and for mountain rivers, built on impermeable hard rock BFI max can be between 0.20 and 0 25.

The filter parameter *a* can be analyzed on the basis of average daily flows taking into account the relationship: $Q_{i-3}>Q_{i-2}>Q_{i-1}>Q_i>Q_{i+1}>Q_{i+1}$, where Qi is taken into account if there are at least 5 days with recession period. The *a* parameter values are determined by linear regression analysis based on the relationship $Q_{i+1}=f(Q_i)$, taking into account only the recession period. After Nathan and McMahon (1990), this parameter values generally fall between 0.9–0.95. For geological conditions in the north-eastern part of Romania the *a* parameter value was set at 0,925 (Minea et al., 2014).

4. RESULTS AND DISCUSSIONS

Applying the different methods used in assessing BFI showed that certain algorithms proposed by (1991) and Ekchardt (2008) give the best results in geographical conditions of the Moldavian Plain. Using local minimum method (LMM) very high values of BFI are obtained (over 0.75) which does not reflect the climate and geology realities of the area. The standard deviation values for this method do not exceed 0.15, and the coefficient of variation are over peste 0.22. Even if the average values of the precipitation amounts are reduced (in some places under 450 mm) the BFI not exceed 0.75, given that there is an increasing trend of precipitation in recent decades their (Croitoru, Minea, 2014).

Table 2. ***BFI results for different methods***

River/Gauge station Methods	Volovăț	Buhai	Jijia	Sitna	Miletin	Bahlui	Magura	Bahluet
LMM	0.74	0.80	0.75	0.82	0.79	0.75	0.81	0.8
Talaksen and van Lannen (2004)	0.59	0.55	0.58	0.55	0.57	0.55	0.58	0.58
Chapman filter (Chapman, 1991)	0.51	0.52	0.57	0.57	0.58	0.52	0.57	0.59
RDF (Chapman, Maxwell, 1996)	0.56	0.55	0.55	0.58	0.56	0.56	0.55	0.58
WHAT model	0.58	0.58	0.58	0.63	0.60	0.59	0.63	0.62
Ekchardt filter (Ekchardt, 2008)	0.56	0.55	0.57	0.58	0.56	0.56	0.56	0.58

The variations in atmospheric input are highlighted by WHAT model and Talaksen and van Lannen methods. The driest year (as were those in 1982, 1985, 1990, 1997, 2000 and 2007) are are visible through these methods with values of BFI over 0.70. In rainy years the BFI values according to these methods fall under 0.4 (Fig. 1). Champan filter and Eckhardt filter (with values of BFI often similar) tend to attenuate the variations induced by climatic conditions and to highlight the contribution in multiannual cycles of the base flow related to local geological characteristics and system convergence between groundwater and surface runoff. All filter based methods shows at all gauging stations for the analyzed period a

slight increase of BFI values in acording with increase in precipitation in this area in recent decades (Dumitrescu et al., 2014).

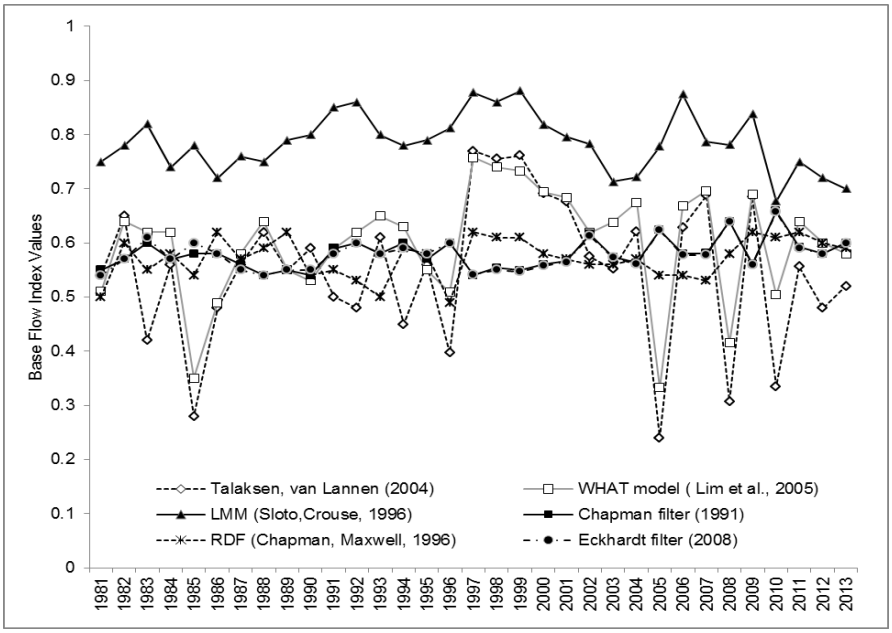

Fig. 1. ***BFI values variation between 1981-2013 using different methods in Moldavian Plain***

Ekchardt (2008) suggest that there can be no real assessment base flow without being checked at least through other direct methods, as would be the tracer measurements. But considering the fact that the use of algorithms attenuates the peaks of base flow, conditioned by the intake of water from excess rainfall, reflected in the production of flood-basin, it can be considered that the data obtained by filter based methods are closer to reality (Figure 2). The correlation matrix between the different values of BFI obtained show that the best methods can be applied in this area are Chapman filter and Eckhardt filter (r=0.98). Both methods aim to identifying calculation parameters like *a* and BFI max which adjusted for this area (a=0.925, BFImax=0.7-0.8) indicates that the values of BFI exceeding 0.5.

If we take into account highly variable hydrological conditions during the year, and that over 35% of the river has a temporary drain (Minea, 2012), the BFI values according to the algorithm proposed by Eckhardt (2012) are the following:

- for basins developed on porous aquifer with perennial stream, asuming values for a=0.925 and BFI max=0.7, the values of BFI=0.55.

- for basins developed on porous aquifer, but with ephemeral stream, asuming values for a=0.925 and BFI max=0.5, the values of BFI=0.50.

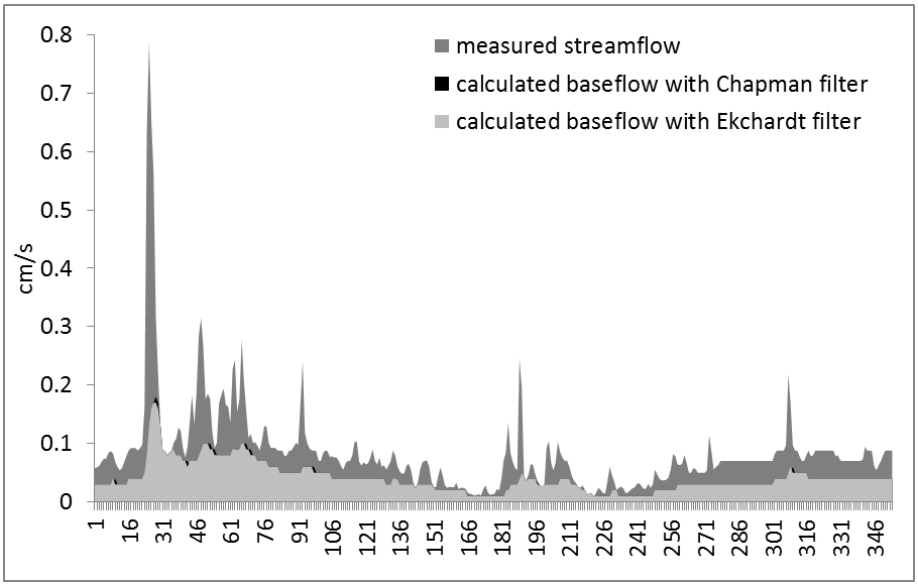

Fig. 2. ***Comparition between measured stremflow and calculated baseflow with Chapman and Ekchardt filters at the H.S. Targu Frumos (Bahluet)***

5. CONCLUSIONS

Statistical modeling of BFI shows that the base flow in the stream flow for rivers that drain lowland area from north-eastern part of Romania is over 50%. These values are higher than the estimated values in studies in the years 70'-80 ', when base flow was considered as provide 15-35% of the total flow. The most realible models for this area is Chapman filter and Ekchardt filter, considering adjustment of statistical parameters depending on local climatic and geological conditions. The values of BFI obtained (over 0.5) suggest a careful reassessment of hydrological balances for the region, considering how land use changes and numerous hydraulic works carried out in recent decades.

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