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INFILTRATION BETWEEN GR5J MODELLING IN THE OUED N'CHEF WATERSHED AND WATER BALANCE CALCULATION OF MEFFROUCH DAM (TAFNA, NORTH-WEST ALGERIAN)

L'INFILTRATION ENTRE MODELISATION PAR GR5J DU BASSIN VERSANT D'OUED N'CHEF ET CALCUL DU BILAN HYDRIQUE DU BARRAGE DE MEFFROUCH (TAFNA, NORD-OUEST ALGERIEN)

CHERKI K.

Hydraulic Department, Faculty of Technology, Tlemcen University, Algeria

Khadidja_cherki@yahoo.fr

ABSTRACT

The knowledge of the infiltrated water amount after a flood is very important to avoid an over-exploitation of the groundwater aquifer. This data, which is also used to calculate the water balance of a reservoir dam, is very difficult to determine.

The goal of the article is the exploitation of the infiltrated water quantity calculated by the daily five parameters hydrological model GR5J, to fill the lack of data concerning the infiltration variable in the computation of the water balance of Meffrouch dam. The latter is located at the outlet of Oued N'chef watershed situated in north western Algeria with the feature particularity of having a karstic aquifer. The GR5J model was selected after that the modelling by GR4J (not presented here) was unsuccessful. The results of the GR5J simulation are very satisfactory with a NASH criterion above 80%. The model shows that most of the precipitation infiltrates, the equivalent of 62%; the exchanges are about 31% and only 7% for the runoff.

The water balance calculation of the Meffrouch dam was based on the Gûntner (2002) formula whose results seem to be consistent with the infiltration values calculated by GR5J.

Keywords: Infiltration, water balance, GR5J model, Meffrouch dam, karstic aquifer.

RESUME

La connaissance de la quantité d'eau infiltrée après une crue est très importante pour éviter une surexploitation de l'aquifère souterrain. Cette donnée qui sert aussi au calcul du bilan hydrique d’un barrage réservoir est très difficile à déterminer. L’objectif de l'article est l'exploitation de la quantité d'eau infiltrée calculée par le modèle hydrologique Génie Rural journalier à cinq paramètres GR5J, pour combler au manque de données concernant la variable de l’infiltration dans le calcul du bilan hydrique du barrage de Meffrouch. Ce dernier est implanté à l’exutoire du bassin versant d’Oued N’chef situé au Nord-Ouest d’Algérie avec comme particularité son aquifère karstique. Le modèle GR5J a été choisi après que la modélisation par GR4J (non présentée ici) ait échoué. Les résultats de la simulation par GR5J sont très satisfaisants avec un critère de NASH supérieur à 80%. Le modèle ressort que la plus grande partie des précipitations (62%) s’infiltrent, 31% pour les échanges et 7% seulement pour le ruissellement.

Le calcul du bilan hydrique du barrage de Meffrouch s’est basé sur la formule de Gûntner (2002) dont les résultats semblent être cohérents avec les valeurs de l’infiltration calculées par GR5J.

Mots-clés : Infiltration, Bilan hydrique, Modèle GR5J, Barrage de Meffrouch, Aquifère Karstique.

INTRODUCTION

The northern Algeria presents a semi-arid climate, characterized by a strong rainfall irregularity, which has a significant impact on the groundwater development. The study basin is located in the North-West of Algeria, marked by a karstic aquifer that has been used during drought period by drilling several boreholes.

The flow in the Oued N'chef watershed is regulated by the Meffrouch dam with a capacity of 15 Hm^3. The dam water was intended for irrigation and drinking water supply in the region of Tlemcen, but it has been only used for the drinking water because of the drought that’s the region suffered from. In January 1991, the dam was dry, it reaches 1 Hm^3 in January 1993 and 0.31 Hm^3 in October

2002 (Touati, 2005). This situation lasted until 2008 with a completely dry reservoir in this year. So, following to the violent floods of 2009, the dam has reached the level of 13.87 Hm^3 in May 2009 (Boumaaza, 2012).

The computation of the water balance of a reservoir dam which is no other than a water management is often faced to the lack of the infiltration data. This latter is difficult to evaluate or measure accurately (Wulan et al., 2013).

There are several empirical models to estimates infiltration such as Green and Ampt (1911), Kostiakov (1932), Horton (1938), Holtan (1961), etc. On the other side there are conceptual models which rely much less on empiricism: they identify the internal relations of the system and can be global or discretized (Cherif et al. 2004). Among these models are GR (Génie Rural) designed at different time steps (annual, monthly, daily and hourly). These models have been used in several watersheds around the world, we quote for example, Amoussou et al. (2014) and Kamagate et al. (2017) in Africa, De Lavenne et al. (2016) in France, Pagano et al. (2010) in Australia, Salavati et al. (2015) in the United States , etc. They have been also applied in Algeria by Kabouya (1990), Kabouya and Michel (1991) on over sixty watersheds belonging to the Northern part of Algeria on a monthly and annual step.

Still in Algeria, Benkaci ali and Dechemi (2004) used the three-parameter daily model (GR3J) in their work. Bakreti (2014) applied the GR4J model in semi distributed scale on the Tafna watershed for a sensitivity analysis of the model and the parameters obtained to judge the adaptability of the model to watersheds with little instrumentation and spatial heterogeneity.

The model selected in this work is the daily five-parameter 'Génie Rural' (GR5J) model. The choice is based on the parsimony of the model and the low number free parameters. The main objective is therefore the estimation of the water balance of the Meffrouch dam taking into account the results of the infiltrated water quantity calculated by the GR5J model.

MATERIALS AND METHOD

Situation of the study watershed

The Oued N'chef catchment area is 90 km^2. It is the smallest watershed of the Tafna basin located in north-western Algeria (Figure 1).

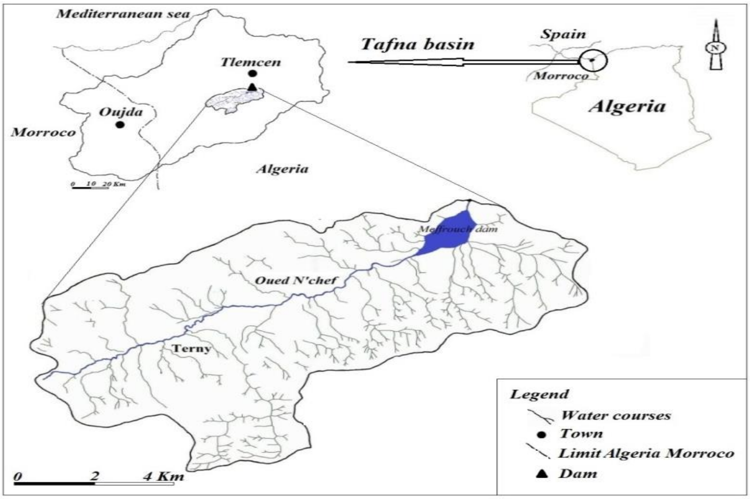

Figure 1 : Situation of the Oued N'chef basin

The main wadi that drains the basin is Oued N'chef, it originates in the mountains of Tlemcen at an altitude more than 1100 m. At this altitude, the basin is practically well watered (Meddi and Hubert, 2003). The average annual rainfall as precipitations and snow is in the order of 572.16 mm for the period from 1977 to 2013. In general, there is a rainy period from November to April

and a dry period from June to September where rains are almost non-existent. The most watered season is winter compared to autumn and spring.

The average annual temperature at Meffrouch Dam Station is about 16.7 ° C, and the vegetation is much reduced in the lake perimeter.

Hydrogeology

The special characteristic of Oued N'chef Basin is that it has a karstic formation, it is estimated that the karst is 67% of the overall field of the basin (Khaldi 2005). Based on the geological report established by Gevin (1948) during the geological study in preparation for the construction of the Meffrouch dam, the region is characterized by the presence of a complex network of faults. The scale of lands encountered in the Meffrouch zone extends from the Sequanian (J5) with faulty permeability to Cretaceous (C) with generally low permeability (Table 1).

Table 1 : The main facies and their gross morphological features of Oued N'chef basin (from Gevin 1948)

Depth (m)	Stages or systems	Facies	Permeability
70 to 80 m	Cretaceous (C)	Limestones	Low
80 m	Upper Kimmeridgian (J^{6c})	Limestones	Middle
100 to 110 m		Upper Dolomites	High
120 to130 m	Middle Kimmeridgian (J^{6b})	Limestones Beds	Very low
200 m	Lower Kimmeridgian (J^{6a})	Lower Dolomites	Very high
300 m	Sequanian (J^{5})	Sandstones limestones	Faulted vis-à-vis dolomites

The two large permeable formations (J^{6a}) and (J^{6c}) constitute the main aquifer reservoirs while the two Cretaceous and Middle Kimmeridjian formations can give rise to small sources. The most significant source in terms of underground reserve is a source of overflow called Ain Meharas, it originates in the valley of Oued Meffrouch. The latter is a continuation of Oued N'chef of the study basin, just after the Meffrouch dam.

Description of GR5J

The five parameter daily model GR5J (Le Moine et al., 2007) is an improvement of the four parameter daily model GR4J (Perrin et al., 2003). A fifth parameter has been introduced in the groundwater exchanges function called by Le Moine et al. (2007), the Intercatchment Grounwater Flow (IGF).

Therefore, the GR5J model is a global reservoir model composed of five parameters to be stalled: the capacity of production store X1 (mm), the underground exchange function X2 (mm), the capacity of routing store X3 routing (mm), the time base of unit hydrograph X4 (days), and threshold for change in F sign X5 (Figure 2).

The IGF formula is as follows:

$$F(X_2, X_5) = X_2\left(\frac{R}{X_3} - X_5\right) \tag{1}$$

Where, R is the current level of the routing reservoir.

The model requires little input data which are precipitations and evapotranspiration at a daily scale. Observed discharges values are used in calibration phase.

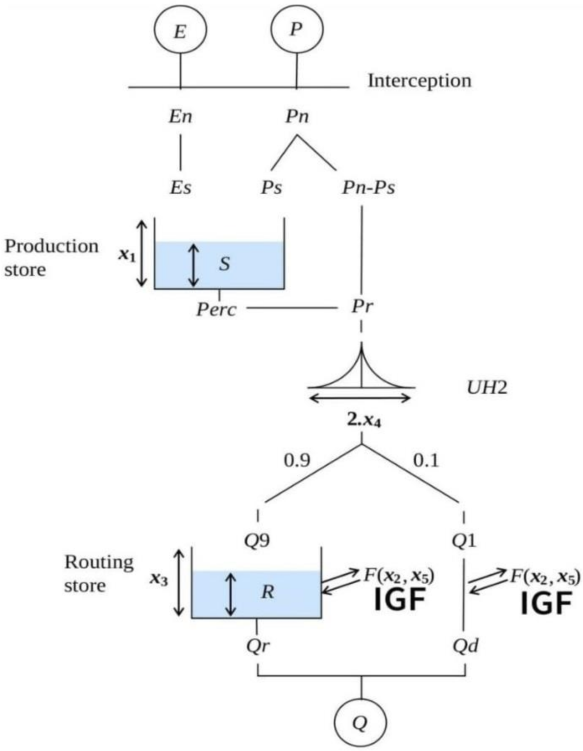

Figure 2 : Schematic of GR5J model (Le Moine et al. 2007). Source: EGU General Assembly (De Lavenne et al. 2016b)

Precipitations and discharges

Rrainfall and hydrometric data are collected from the Meffrouch Dam Station (X: 135.75 and Y: 179.7). The period collected starts from 1984 till 2013 but

the dam was empty for the most of this period as a result of drought. Given that the goal is to calculate the water balance of Meffrouch dam, it is obvious that the retained period coincides with the return of rainfall.

The dam began to fill from 2008, where significant rainfall was recorded throughout the month of December with very variable daily discharges from 4.5 $m^3 s^{-1}$ to 165.4 $m^3 s^{-1}$. This is why the chosen period spread from 2008 to 2013.

Precipitations are characterized by great variability, the coefficient of variation is very important, about 0.62. Therefore, precipitations in November for example whose the average value is 134.82 mm have shown quite wide variations during this period from 46 mm to 377.20 mm. Note that, July is the driest month with extreme values of 0 mm to 4 mm.

Temperature and Potential Evapotranspiration (PE)

In general, the PE follows the same trends as the temperature. It is too high in the summer and reaches its maximum in July; it decreases more and more in winter to reach its minimum in December and January. The average annual temperature at Meffrouch dam station is 16.7 °C. The study region is characterized by temperatures changing, the winters are very cold where it snows frequently and the summers are hot and dry.

The PE computation here is based on the Oudin et al. (2005) formula (2) that is specifically designed for GR models:

$$PE = \frac{R_e}{\lambda\,\rho}\frac{T_a}{100} \qquad if \qquad T_a + 5 > 0$$
$$\mathrm{PE} = 0 \qquad \text{Otherwise} \tag{2}$$

Where *PE* is the rate of potential evapotranspiration (mm day^{-1}), *Re* is extraterrestrial radiation (MJ m^{-2} day^{-1}), λ is the latent heat flux in (MJ kg^{-1}), ρ is the density of water (kg m^{-3}) and *Ta* is mean daily air temperature (°C), derived from long-term average.

The extraterrestrial radiation (Re) as defined by Allen et al. (1998) is the solar radiation received at the top of the earth's atmosphere on a horizontal surface. The formula (3) estimates the extraterrestrial radiation for each day of the year for different latitudes.

$$\mathrm{Re} = \frac{24(60)}{\pi}\mathrm{G_{sc}}\mathrm{d_r}[\omega_s \sin\varphi \sin\delta + \cos\varphi\cos\delta\sin\omega_s] \tag{3}$$

Where Re is the extraterrestrial radiation [MJ m^{-2} day^{-1}], G_{sc} is the solar constant (G_{sc} = 0.0820 MJ m^{-2} min^{-1}), d_r is the inverse relative distance Earth-Sun calculated by:

$$d_r = 1 + 0.033\ \cos\left(\frac{2\pi}{365}J\right) \tag{4}$$

Where J represents the number of the day in the year between 1 (1 January) and 365 or 366 (31 December), ω_s is the solar decimation [rad] calculated by:

$$\omega_s = arc\cos(-\tan\varphi\tan\delta) \tag{5}$$

Where φ is the latitude [rad], and δ is the solar decimation [rad] calculated by:

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J \times 1.39\right)1 + 0{,}033\ \cos\left(\frac{2\pi}{365}J\right) \tag{6}$$

Calibration, validation and performance of the model

The procedure used to control the performance of the model highly recommended is the Split Sample Test whose hierarchical scheme was presented by Klemes (1986). The dataset should be split into two equal parts. Each of the two parts should be used in turn for calibration and validation. The parameters obtained after calibration on one sub-period are applied on the other sub-period and vice versa. The goal is that the control should be done for the whole data.

Evaluation of the model's performance is done according to the NASH criterion (Nash and Sutcliffe, 1970), widely used in hydrology and whose formulation is as follows:

$$NASH = \left[1 - \frac{\sum_{t-1}^{n}\left(Q_{obs}(t) - Q_{sim}(t)\right)}{\sum_{t-1}^{n}((Q_{obs}(t) - \overline{Q_{obs}}))2}\right] \times 100 \tag{7}$$

Where $Q_{obs}(t)$ is the observed discharge at time t, $Q_{sim}(t)$ is the simulated discharge at time t and $\bar{Q}_{obs}$ is the mean of the observed discharge for the validation period.

The criterion takes values from minus infinite to 100%, more the NASH criterion is closer to 100%, more the model is performant. The value of 100% means a perfect adjustment.

Water balance of Meffrouch dam

Water balance computation of Meffrouch dam for the period (2008 – 2013) is based on Güntner (2002) formula (8). The author's work focused on large-scale hydrological modeling in the semi-arid north east of Brazil. In the area he studied, there exists a wide range of dam’s types of different scales. According to him, the daily water balance of a dam is as follows:

$$V_t = V_{t-1} + (Q_{in} - U) - Q_{out} + \left(P - E_{pot}\right) \times A - R_b \tag{8}$$

Where V_t is the storage volume at time step (t), (V_{t-1}) is the storage volume at time step (t-1), Q_{in} is the inflow to reservoir, U is the withdrawal water, Q_{out} is the outflow from reservoir, P is the sub basin precipitation, E_{pot} is the potential evaporation, A is the waterbody surface area and R_b is the infiltration losses to bedrock.

In Oued N’chef basin, the only unknown variable is infiltration, so the calculation is based on the results obtained by the GR5J model.

RESULTS AND DISCUSSION

The simulation period for the daily time step for the Oued N'chef watershed extends from 01/01/2008 to 31/12/2013, it is divided into two similar periods, one for calibration and the other for validation.

Sub period 1: 01/01/2008 - 31/12/2010,

Sub period 2: 01/01/2011 - 31/12/2013.

The results are shown in table 2, figure 3 and figure 4.

Table 2 : Calibration and validation of GR5J model in Oued N'chef watershed

Parameters	*Calibration*					*NASH* Criterion (%)
	X1	X2	X3	X4	X5	
Sub period 1	5.1	2.8	5.3	-0.6	3.7	81.9
Sub period 2	4.4	2.0	5.4	-0.7	3.9	92
Validation						
Sub period 1	4.4	2.0	5.4	-0.7	3.9	76.6
Sub period 2	5.1	2.8	5.3	-0.6	3.7	80.2

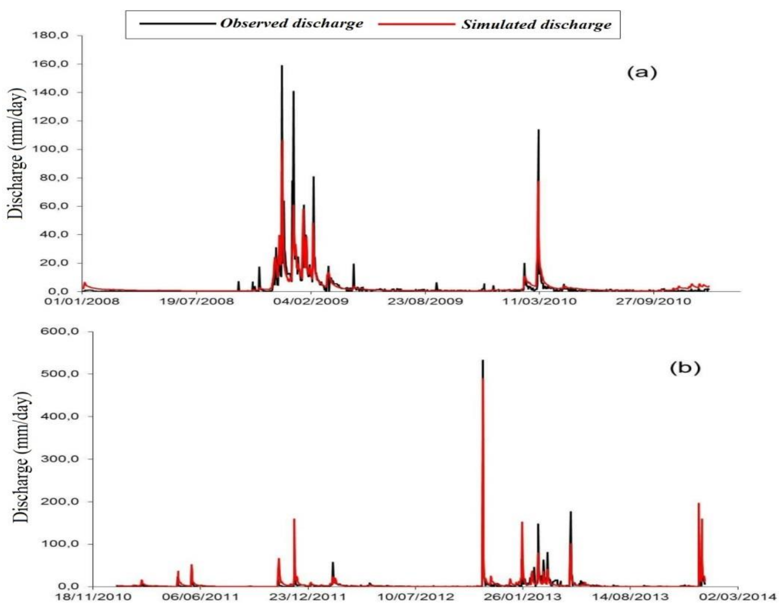

Figure 3 : Calibration of GR5J model implemented on Oued N'chef basin for sub period 1(a) and sub period 2 (b)

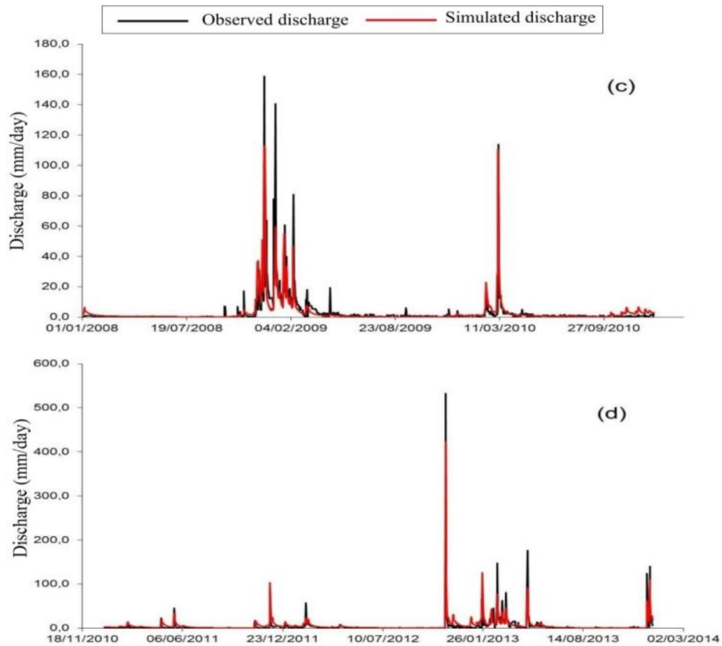

Figure 4 : Validation of GR5J model implemented on Oued N'chef basin for sub period 1 (c) and sub period 2 (d)

The calibration phase has yielded good results for the two sub periods with a NASH criterion greater than 80%. The performance degraded a little in the validation phase without losing its efficiency.

Graphically, it appears in the sub period 1 that the validation phase is better than calibration phase contrary to the NASH criterion results (Figure 4 (c)). This may be due to the well simulation by the model in low flow conditions as reported by Pushpalatha (2013).

According to the results obtained by the GR5J model, most of the precipitation infiltrates (62%), a result that is consistent with the measured values shown in figure 5, where the distance between the two curves (precipitations - runoff) reveals that the soil storage capacity is very important enhanced by the nature of the soil highly karstified and faulted.

The figure 5 shows a low flow that starts in November to reach the maximum in January and becomes almost zero during the summer, period characterized by a high evapotranspiration. The model estimates this runoff approximatively by

7%. The exchanges are about 31% which are in form of water gain as the underground exchange function X2 is positive according to the GR5J model.

The infiltration results are used as input data in the water balance formula (8). It should be noted that water balance takes negative values in the dry season; these outliers have been taken as zero. The results are presented in figure 6:

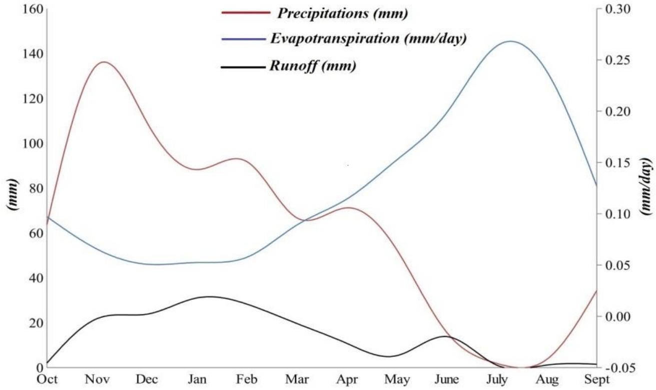

Figure 5 : Measured monthly avarage precipitation – PE – Runoff of Oued N'chef basin from 2008 to 2013.

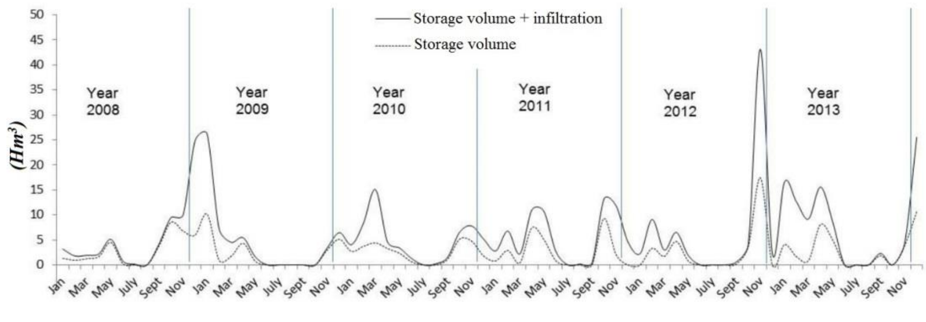

Figure 6 : Graphical representation of water balance and infiltration of Meffrouch dam

The figure 6 shows the evolution of two curves, one represents the storage volume for each month and the second one the storage volume before subtracting the infiltration values, for the period (2008 - 2013) in a monthly scale. It reveals that the volume of water in the Meffrouch Dam changes according to the seasons, the reservoir fills up in winter following the heavy rainfall and empties during the dry season accentuated by evaporation and infiltration.

On the other hand, the figure shows that infiltration is directly related to the floods intensity. The high values of the infiltration in 2009 and 2012 are due to the very violent floods experienced by the region in these years. Without forgetting that the strongly karstified underground of the Oued N’chef basin fosters infiltration. Seasonally, there is infiltration in winter, and it is relatively low in the summer, a hypothetical contrast highlighted by Ukata et al. (2015).

CONCLUSION

The article was about a test to fill the lack of infiltration data for the calculation of the water balance of Meffrouch dam located in the Oued N'chef basin outlet. The choice of this basin was made especially for the particularity of the karstic underground which is an impressive reservoir. The use of the GR5J model came after the GR4J model gave poor results. It seems that the added parameter X5 takes better into account the aquifer - soil relationship of Oued N'chef watershed. The values of the infiltrated flow obtained by GR5J were injected into the Guntner (2002) formula on a daily scale to calculate the water balance of Meffrouch dam. For more visibility, the results were plotted in monthly scale. The changes in the yield curves showed a seasonal evolution of the dam volume which fills up in winter and empties in summer. It seems that the values of infiltration calculated by GR5J fit well with the calculation of the water balance by the Guntner (2002) formula. It would be interesting to try this method in a basin with recorded infiltration values to judge the effectiveness of the calculation.

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