Civil and Environmental Science Journal
Vol. II, No. 02, pp. 128-134, 2019

Calibration of surface runoff parameters with the hydrologic tank model using recursive digital filter and master recession curve

N Suryoputro[1], Suhardjono[2], W Soetopo[2], E Suhartanto[2]

[1]Department of Civil Engineering, Universitas Negeri Malang, Malang, 65145, Indonesia
[2]Water Resources Engineering Department, Universitas Brawijaya, Malang, 65145, Indonesia

nugrohosuryoputro@gmail.com

Received 16-08-2019; revised 31-08-2019; accepted 28-09-2019

Abstract. There are two basic methods to calibrate the hydrological model: (1) the trial and error procedure; (2) the automatic calibration. The problem in the calibration method is the determination of the initial value of the parameters. This poses a problem for beginner model users. This paper presents the calibration results of surface runoff parameters in the hydrological tank model using recursive digital filter method and the master recession curve. The results indicate that the Recursive Digital Filter as a surface runoff separation method can be used for the initial approach to calibrate the tank model parameters.

Keywords: Calibration, hydrological tank model, recursive digital filter, master recession curve

1. Introduction

The calibration of rainfall-runoff model parameters is an interesting issue for hydrological model researchers. Some procedures and parameters can be determined directly by analysing physical data or experiments, while other procedures are performed by determining parameters based on changes in physical and climatological factors in a place [1].

The hydrological tank model is a conceptual rainfall-runoff (CRR) model developed by Sugawara and Funiyuki in 1956 [2]. There are three objectives when calibrating the conceptual hydrological model: 1) Reproduction of the hydrograph model approaching the observational hydrograph at each point of the river system, 2) The model parameters should function properly, representing the process of natural physical components, 3) There should be a realistic variation of parameter values from one location to another within a river area and with a location across the river in adjacent watershed.

There are two basic methods to calibrate the hydrological model [1]. The first method is the trial and error procedure where the experience and knowledge of the model user about the effect of parameter changes on the model outcome are needed to control the model parameters. The second method is automatic calibration. In this method, various computer algorithms are used to achieve the best model output approaching the observed value.

Based on the above description, it can be concluded that the model calibration should be performed under several conditions: 1) the initial parameters of the model should be realistic in representing the processes and physical elements of nature, 2) the initial parameter values should be inputted before they are estimated using trial and error or automatically to get the optimal value. To determine a realistic initial value, it takes model users' experience and knowledge. This poses a problem for beginner model users. In this research, the initial values of the top tank model parameters were determined based on the physical factors of infiltration in a watershed and surface runoff hydrograph. Determination of parameters in the top tank with physical approach was as a binding parameter for calibration in the subsequent tanks. The calibration process was done in two stages. The first stage was the calibration of the top tank model only, while the second stage was the calibration by combining all tank models. In this research, the tank models used were in a vertical series arrangement, and there were four of them.

To analyse the surface runoff from river hydrograph, two methods of baseflow separation were used in this study and compared with the output of the top tank model. The baseflow separation methods used were: 1) Recursive Digital Filter (RDF) and 2) master recession curve (master RC) [3].

2. Material and Methods

2.1. Research Materials and Study Area

The research was conducted in a sub-watershed of Kali Bango in Malang district; the watershed has an area of 239.71 Km^2. Infiltration measurements were conducted in January to March 2017. The soil samples were analysed at the Soil Physics Laboratory, in the Department of Soil Science, Faculty of Agriculture, Universitas Brawijaya.

2.2. Model and Method Description

2.2.1. Tank Model. The hydrological tank model is a conceptual rainfall-runoff model. This model consists of a series of linear tanks arranged in series or parallel with the outlet holes on the sides and bottom of the tank. The tank model relates the discharge as a function of the influence of precipitation, evaporation, and water storage in the soil at the previous time so that the conceptual model developed is non-linear deterministic. The tank model simulates the watershed by replacing a number of storages with a series of tanks. The tank model parameters are grouped into two types: 1) parameters of outlet coefficient on the sides and the bottom of the tank, 2) parameters soil water storage.

The total outflow from the outlet on the (Q) side of each tank is considered as the accumulation of water flow from the system in the watershed and the equation is as follows:

$$Q(t) = Qa1(t) + Qa2(t) + Qb(t) + Qc(t) + Qd \quad (1)$$

The equation of water balance in the tank model

$$d/dt\, H(t) = P(t) - Q(t) \quad (2)$$

Where P denotes the rainfall (mm/day), E denotes the evapotranspiration (mm/day), Q is the total runoff (mm/day), H is the height of water storage (mm), and t is the time (day). At the initial time (t=1), the initial height of water storage in tank A (Ha (1)), tank B (Hb (1)), tank C (Hc (1)) and tank D (Hd (1)) was determined. For the next step (t+1), the storage in each tank was updated as follows:

$$Ha_{(t+1)} = Ha_{(t)} + P_{(t)} - Qa1_{(t)} - Qa2_{(t)} - Ia_{(t)} \quad (3)$$

$$Hb_{(t+1)} = Hb_{(t)} + Ia_{(t)} - Qb_{(t)} - Ib_{(t)} \quad (4)$$

$$Hc_{(t+1)} = Hc_{(t)} + Ib_{(t)} - Qc_{(t)} - Ic_{(t)} \quad (5)$$

$$Hd_{(t+1)} = Hd_{(t)} + Ic_{(t)} - Qd_{(t)} \quad (6)$$

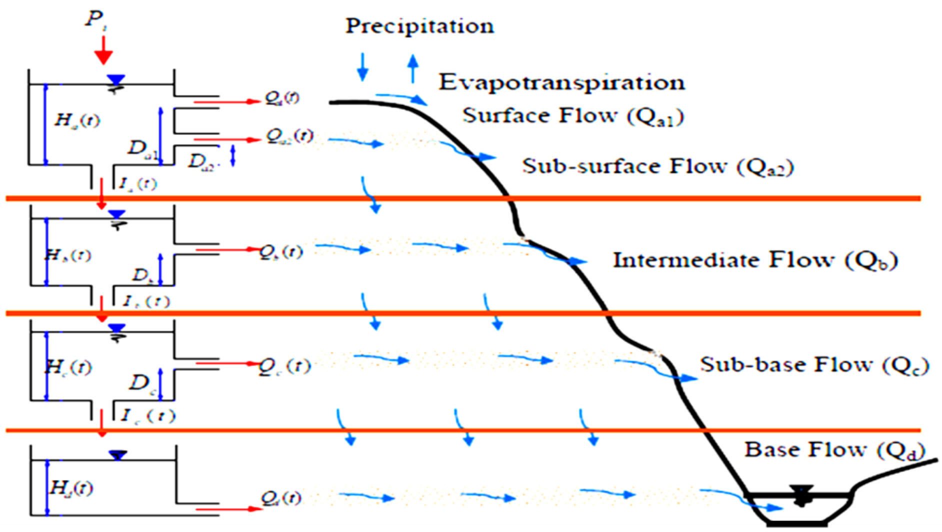


Figure 1. Schematic plan of tank model

2.2.2. Recursive Digital Filter (RDF) method. Many hydrograph separation techniques are used to identify different flow components of total flow. These components are thought to represent the flow systems in a watershed, generally representing surface flow, intermediate flow, and groundwater flow. The use of the digital filter method is more suitable for the separation of the baseflow from the hydrograph of continuous flow over a long period of time.

Digital filter is a method of hydrograph separation by using a numerical algorithm (digital filter) to separate river hydrograph into high-frequency component (direct run) and low frequency (baseflow). There are currently various models and computer programmes for estimating baseflow, one of which is HydroOffice. It is based on the Recursive Digital Filter (RDF) method, which uses 6 RDF methods (table 1).

Table 1. RDF filter for analysing baseflow

No	Filter Name	Filter Equation	Reference
1	One parameter algorithm	$q_{b(i)} = \frac{k}{2-k}\, q_{b(i-1)} + \frac{1-k}{2-k} q_{(i)}$	(Chapman and Maxwell, 1996)
2	Boughton two-parameter algorithm	$q_{b(i)} = \frac{k}{1+c} \cdot q_{b(i-1)} + \frac{C}{1+C} (q_{(i)} + \alpha_q q_{(i-1)}$	(Boughton,1993; Chapman and Maxwell, 1996)
3	IHACRES three-parameter algorithm	$q_{b(i)} = \frac{k}{1+C}\, q_{b(i-1)} + \frac{C}{1+C} (q_{(i)} + \alpha_q q_{(i-1)})$	(Jakeman and Hombarger, 1993)
4	Lyne and Hollick algorithm	$q_{f(i)} = \propto q_{f(i-1)} + (q_{(i)} - q_{(i-1)}) \frac{1+\propto}{2}$	(Lyne and Hollick, 1979; Nathan and McMahon, 1990)
5	Chapman algorithm	$q_{f(i)} = \frac{3\alpha - 1}{3-\alpha}\, q_{f(i-1)} + \frac{2}{3-\alpha} (q_{(i)} - \alpha q_{(i-1)})$	(Chapman, 1991)
6	EWMA	$q_{b(i)} = \alpha q_{(i)} + (1-\propto) q_{b(i-1)}$	(Thularam and Ilahee, 2008)

Source: [3]

Description:
q(i): the original streamflow on the ith day, qb(i): the original baseflow on the ith day, qb(i-1): the baseflow before the ith day, qf(i): the direct runoff on the ith day, k: the filter parameter given by the recession constant, α: filter parameter, C: a parameter that allows the shape of the separation to be altered, i: daily time interval

2.2.3. Master Recession Curve (master RC) Method. Malik [4] has developed a technique of hydrograph separation using the interactive solution of several linear and exponential equating members. This method uses the parameters from a set of simple linear and exponential equations. The exponential equation is described by Q0 as the initial streamflow and α as the recession coefficient, while the linear equation is described by Q0 as the initial discharge and β as the recession coefficient.

The main idea of this method is based on a simple understanding of the reality of the hydrological system that the same streamflow should reflect the same water saturation (piezometric) level in the system. The principles of hydrograph separation based on the master recession curve are shown in Figure 2, where each streamflow on the right side of the figure corresponds to the value of a particular recession curve. The figure also shows how each streamflow value can be divided into several sub-regimes, depending on its position on the master recession curve. However, understanding of the hydrologic system (the same streamflow reflects the same water saturation or piezometric level in the watershed/aquifer) is a crude simplificati.

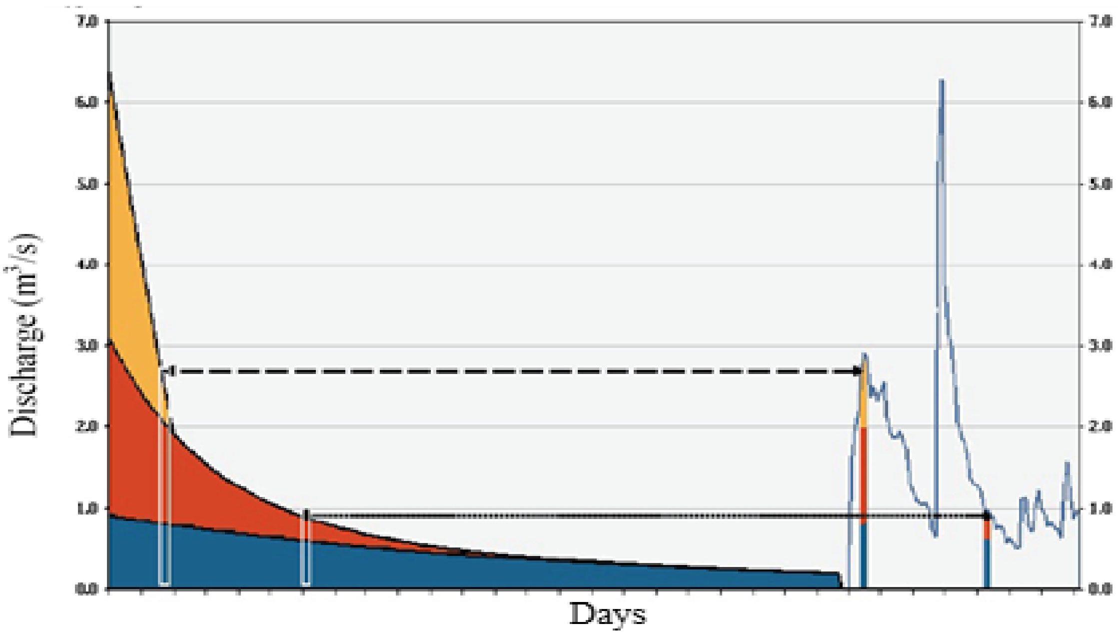


Figure 2. Principles of hydrograph separation based on the master RC [3]

3. Results and Discussion

3.1. Results

3.1.1. Infiltration coefficient. The coefficient of infiltration was analysed by referring to the largest coefficient of infiltration i.e. forest. Based on the slope of land and soil texture, the coefficient value of water flow in the forest was (C) = 0.25, so the infiltration coefficient for the forest was 0.75. The value of infiltration coefficient for other land uses in the watershed was determined by using the comparison of infiltration rate between forest and other land uses and it was multiplied by the forest infiltration coefficient of 0.75 (table 2).

Table 2. Infiltration coefficients of the tank model in Bango watershed

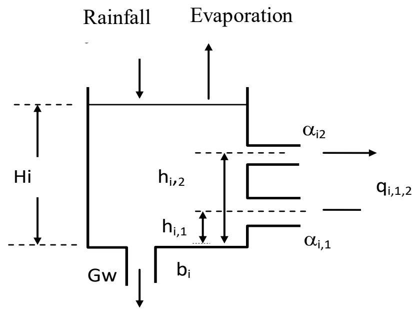
Land Use	Land Area (Km^2)	Percentage	Infiltration Coeff. (not units)
(not units)Housing	44.43	19%	0.12
Plantation	124.00	52%	0.28
Rice Field	49.35	21%	0.01
Forest	21.93	9%	0.75
Total	239.71	100%	

The average infiltration coefficient tank model of Bango Watershed = 0.24

3.1.2. Parameter values and calibration of tank model. The calibration of tank model parameters for the Bango watershed can be seen in table 3 and Figure 3. The optimisation results of the tank model parameters showed the Nash-Sutcliffe Coefficient value of 0.22.

Table 3. Tank model parameters

Parameter	tank-1	tank-2	tank-3	tank-4
Hi	0.13	600	1600	2599
hi,2	55.06	0.00	0.00	0.00
αi,2	0.27	0.00	0.00	0.00
hi,1	4.89	15.04	30.02	0.00
αi,1	0.25	0.00	0.00	0.01
bi	0.23	0.11	0.05	0.00



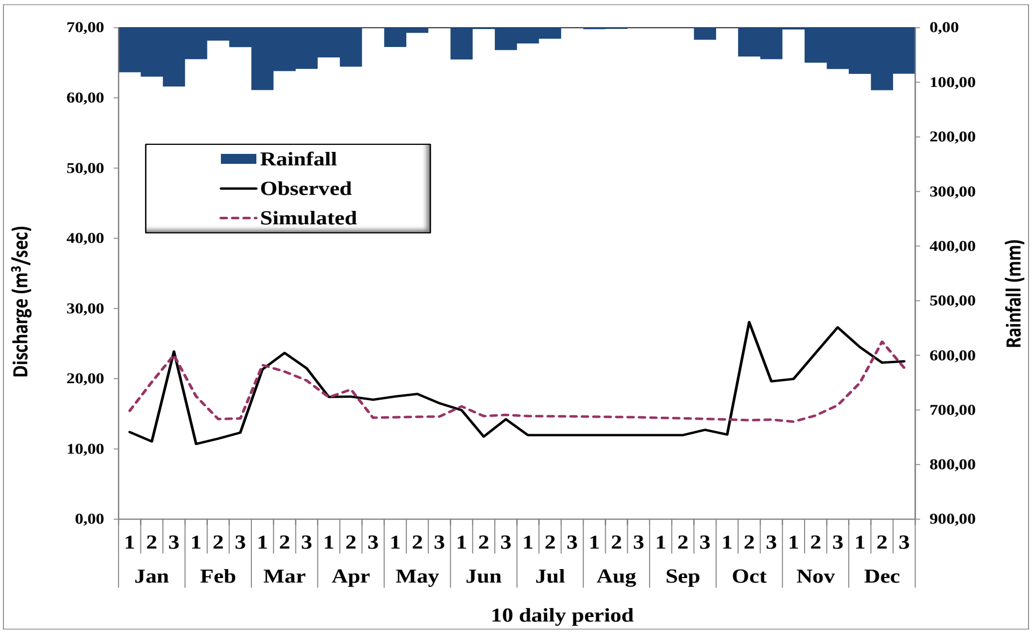


Figure 3. Results of tank model calibration compared to observation discharge

3.1.3. Surface runoff from tank model, RDF, and master RC. The separation of flow by tank model, RDF, and master RC method can be seen in Figure 4.

3.2. Discussion

As shown in Figure 5, the difference between the surface runoff resulting from the tank model and that of the master RC analysis is quite far. In other words, the master RC method cannot be used as a preliminary approach to direct runoff parameter calibration in the hydrological tank model.

Based the comparison between the surface runoff resulting from the tank model and that of the RDF analysis, it can be seen that the difference is quite good (Figure 6). In other words, the RDF method can be used as a preliminary approach to direct runoff parameter calibration in the hydrological tank model. The value of runoff coefficient is almost similar to the research conducted by researchers [5, 6, 7], where the runoff coefficient is one-tenth and located between 0.0 - 1.0.

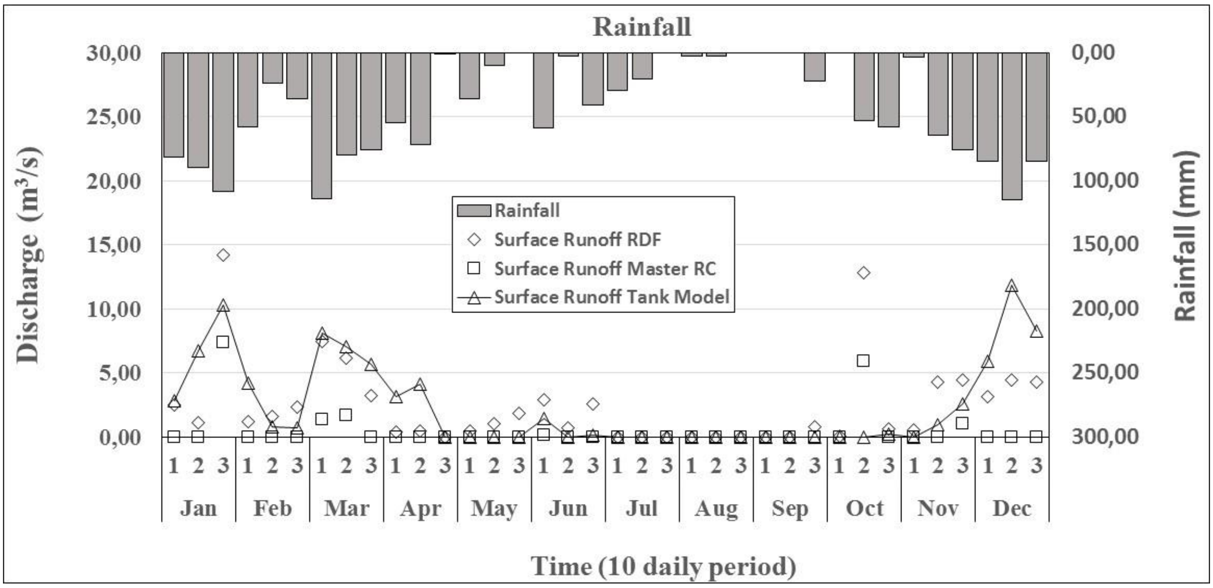


Figure 4. Surface runoff from tank model, master RC, and RDF

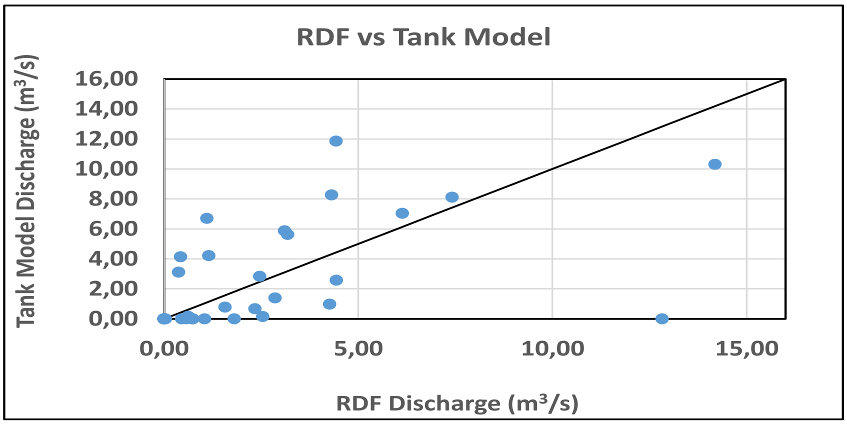


Figure 5. Comparison of tank model discharge to master RC discharge

Indarto [8] has conducted RDF research in East Java, Indonesia using 6 RDF methods (One-parameter, Boughton two parameters, Chapman, Ihacres, Lyne & Hollick, and EWMA filters) for the separation of base flow. The study shows that all RDF methods can be used, however, three algorithms (Ihacres, Lyne & Hollick, and EWMA filters) perform better than others methods. The result also shows the setting of parameters values from calibrated watershed is transferable to other adjacent watersheds. Furthermore, most watersheds on these regions are considered influenced by strong contribution of baseflow both for rainy and dry seasons.

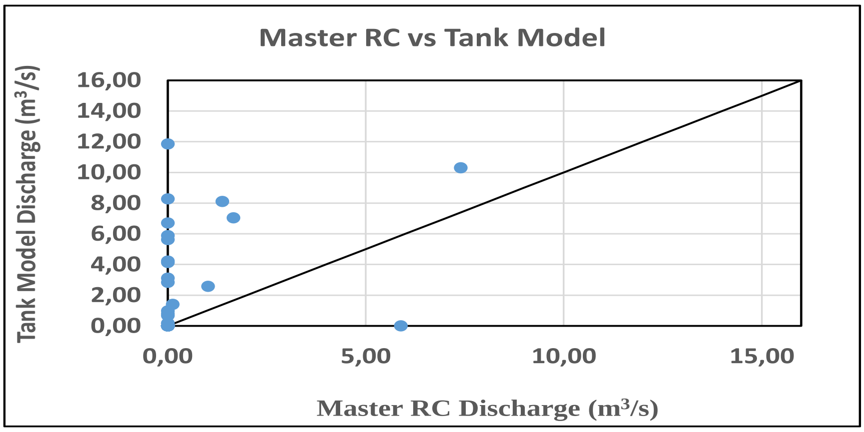


Figure 6. Comparison of tank model discharge to RDF discharge

Interpretation of streamflow variations in terms of catchment characteristics has been a major theme in hydrology for many years in order to improve catchment and stream management. Two of the main tools for this task are baseflow separation and recession analysis [9, 10, 11, 12]. Baseflow separation aims to separate streamflow into two components (quickflow and baseflow), where quickflow is direct runoff following rainfall, and baseflow is delayed streamflow during periods without rain. Recession analysis aims to model the decrease of streamflow during rainless periods to extract parameters descriptive of water storage in the catchment. The problem in the recession analysis is the determination of the starting point of recession in hydrograph, this will lead to misleading results. Different analyzes of the recession curves also show that the general consensus has not yet been reached on how best to analyze recessions in river flows [13]. The consequences of these problems cause the inaccuracy of flow recession curve results.

4. Conclusions

From the analysis results of the two methods of surface runoff separation, it can be concluded that the RDF method can be used for the initial approach to calibrate the tank model parameters. This can speed up and simplify the use of the tank model.

References

[1] Anderson E 2002 *Calibration of conceptual hydrologic models for use in river forecasting* (http://www. nws.noaa.gov, visited 17 June 2017)
[2] Sugawara M and Fuyuki M 1956 *A Method of Revision of River Discharge by Means of a Rainfall Model* (Collection of Research Papers about Forecasting Hydrologic variables)
[3] Gregor M and Malík P 2012 *FlowComp 2.0 User's Manual. Hydro Office* (Bratislava)
[4] Malík P 2010 *Podzemná voda* **16**(1) 113-124
[5] Ngoci T A, Chinh L V, Hiramatsu K and Harada M 2011 *J. Fac. Agr* **56** (2), 335–341
[6] Sulianto and Setiono E 2012 *Jurnal Teknik Industri* **13** 85–92
[7] Surya R A, Purwanto M Y J, Sapei A and Widiatmaka 2014 *J Environment and Earth Science* **4**(14) 107-117
[8] Indarto, Ratnaningsih A, and Wahyuningsih S 2017 *ARPN Journal of Engineering and Applied Sciences* **12**(12) 3772- 3778
[9] Hall F R 1968 *Water Resour. Res*. **4** 975–983
[10] Brutsaert W, and Nieber J L 1977 *Water Resour. Res* **13** 637–643
[11] Tallaksen L M 1995 *J. Hydrol.* **165**, 349–370
[12] Smakhtin V U 2001 *J. Hydrol.* **240** 147–186
[13] Stewart M K 2015 *Hydrol. Earth Syst. Sci.* **19** 2587–2603