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Can quantitative hydrological models benefit from water quality measurements? Revisiting the baseflow separation issue

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José Manuel Tunqui Neira, Gaëlle Tallec, Vazken Andréassian, Jean-Marie Mouchel. Can quantitative hydrological models benefit from water quality measurements? Revisiting the baseflow separation issue. IAHS-AISH Scientific Assembly, May 2022, Montpellier, France. hal-04497605

HAL Id: hal-04497605

<https://hal.science/hal-04497605v1>

Submitted on 10 Mar 2024

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Hydrograph separation, an age-old issue : Hydrograph separation is the oldest age topic in hydrology¹. The Recursive Digital Filter (RDF)² is one of the most used methods, which requires the calibration of at least one parameter, the filter parameter (α_τ) (Eq. 1) or the hydrological recession time constant (τ) (Eq.2).

$$\text{Eq. 1} \quad Q_{b(t)} = \min \left[\alpha_\tau \cdot Q_{b(t)} + \frac{1 - \alpha_\tau}{2} \cdot (Q_{(t+1)} + Q_{(t)}); Q_{(t)} \right]$$

$$\text{Eq. 2} \quad \alpha_\tau = \exp\left(\frac{-\Delta t}{\tau}\right)$$

$Q(t)$: total streamflow at time t
 $Q_b(t)$: baseflow at time t (computed using a RDF method with a parameter α_τ)
 α_τ : filter parameter of the RDF method
 τ : the hydrological recession time constant of the RDF method

A combined model: To inform hydrograph separation with high-frequency chemical concentrations measurements, we propose to calibrate the τ constant of the RDF, *via* a mixing equation based on the concept of mass balance. The RDF method for the hydrograph separation and a power law model, with a Box Cox transformation³ are combining in a classical mixing model⁴, which takes into account the concentration from the baseflow and that of the quickflow (Eq.3).

$$\text{Eq. 3} \quad C = \underbrace{\left(a_b + b_b Q^{\frac{1}{n}}\right)^n}_{C_b} \frac{Q_b}{Q} + \underbrace{\left(a_q + b_q Q^{\frac{1}{n}}\right)^n}_{C_q} \frac{Q_q}{Q}$$

$Q_b(t)$: baseflow at time t (computed using a RDF method with a parameter α_τ)
 $Q_q(t)$: quickflow at time t ($Q_q(t) = Q(t) - Q_b(t)$)
 C_b : Representative daily parameter of the concentration from the baseflow (mg/L)
 C_q : Representative daily parameter of the concentration from the quickflow (mg/L).

A multi-objective calibration: The combined mixing model⁵ parameters (n , couple (a , b) and τ) are fit with a rather long series of high frequency chlorides measurements on the Orgeval Research Catchment⁷, which captures a wide range of hydrological conditions. The n is fixed for each water quality parameter with a linear regression between flow and concentration to which a Box-cox transformation has been applied³. The couple (a and b) are fit with a multi-objective method⁶. A large number of (a , b) pairs and of τ value were explored, each yielding a series of simulated concentrations that can be compared with the observed concentrations with bounded Nash–Sutcliffe efficiency⁸ (Eq.4 and 5). Because low concentrations are underestimated and high loads overestimated, a multi-objective calibration was used ($NSEB_{comb}$, Eq.6)⁶. Figure 1 shows the $NSEB_{comb}$ for each τ value tested.

$$\text{Eq. 4} \quad NSE = 1 - \frac{\sum_t (X_{obs}^t - X_{sim}^t)^2}{\sum_t (X_{obs}^t - \bar{X}_{obs})^2} \quad \text{Eq. 5} \quad NSEB = \frac{NSE}{2 - NSE}$$

$$\text{Eq. 6} \quad NSEB_{comb} = \frac{NSEB_{load} + NSEB_{conc}}{2}$$

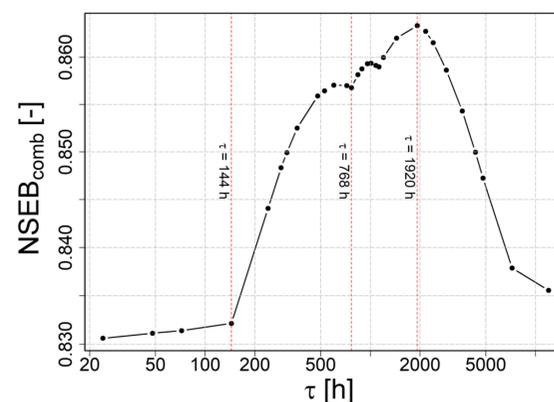


Figure 1 : $NSEB_{comb}$ obtained for the τ values tested (144 h, value proposed by Nathan and McMahon (1992)⁹; 768 h, value used in Tunqui Neira et al. (2020)⁴; 1920 h, value obtained with the highest $NSEB_{comb}$).

High-frequency chemical concentrations measurements a benefit for hydrograph separation : The optimal $NSEB_{comb}$ ($\tau = 1920h$) allows us to obtain the lowest standardized root-mean-square error ($sRMSE$) value in the two time periods studied (i.e. calibration (June 2015 to July 2017) and validation (August 2017 to December 2019) (see Table 1) and to improve the performance of the simulation of the chloride concentrations during rainfall events (see Table 2 and Figure 2).

τ	a_b	b_b	a_q	b_q	n	$NSEB_{comb}$	$sRMSE(\%)$	
							Calibration	Validation
144h	3.7	-0.9	3.3	-0.8	3	0.832	6.1	19.6
768h	3.6	-0.7	3.3	-0.8	3	0.856	5.3	19.6
1920h	3.6	-0.7	3.5	-0.9	3	0.863	5.2	19.5

Table 1 : Calibration and validation results of the combined model. Results for three τ parameters (144 h, value proposed by Nathan and McMahon (1992)⁹; 768 h, value used in Tunqui Neira et al. (2020)⁴; 1920 h, value obtained with the highest $NSEB_{comb}$).

τ	$sRMSE(\%)$		
	Nov-15	Feb-16	Mar-16
144h	6.2	6.1	5.1
768h	6.4	5.6	4.9
1920h	4.7	5.2	4.1

Table 2 : $sRMSE$ for three hydrological events and three τ parameters tested (144 h, value proposed by Nathan and McMahon (1992)⁹; 768 h, value used in Tunqui Neira et al. (2020)⁴; 1920 h, value obtained with the highest $NSEB_{comb}$).

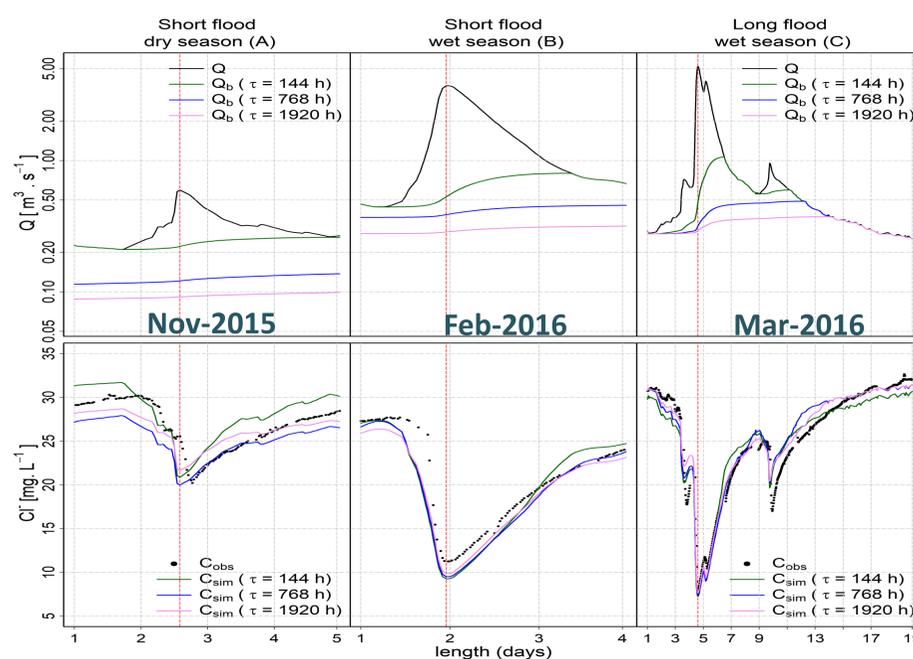


Figure 2 : Hydrograph separation and simulated concentration vs observed concentration in three rainfall events. Comparison of the three τ parameters (144 h, value proposed by Nathan and McMahon (1992)⁹; 768 h, value used in Tunqui Neira et al. (2020)⁴; 1920 h, value obtained with the highest $NSEB_{comb}$).