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Hydrograph separation using high frequency chemical information

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1. Objective

✓ This work examines a methodology for hydrograph separation based on high frequency water quality data. The hypothesis behind the work is that, at small time scales, data can be considered as the result of the mixing of two water sources (base flow and runoff), and that provided baseflow can be identified by a "classical" numerical separation procedure, the concentration of each source can be characterized by linear regression

$$C(t) = C_{1j} \frac{Q_b(t)}{Q(t)} + C_{2j} \frac{Q_e(t)}{Q(t)}$$

with :
- $C(t)$: Stream water concentration for the time step t (mg/L)
- $Q_e(t)$: Quickflow for the time step t (m^3/s)
- $Q_b(t)$: Baseflow for the time step t (m^3/s)
- $Q(t)$: Total flow for the time step t (m^3/s)
- C_{1j} : Representative daily parameter of the concentration from baseflow (mg/L)
- C_{2j} : Representative daily parameter of the concentration from quick response runoff (mg/L)

Figure 1: Classical hydrograph separation

✓ An iterative process is proposed as follow :

Assume a value for the parameter of the hydrograph separation algorithm → Process with hydrograph separation (several algorithms) → Evaluate the composition of water sources by regression → Assess the coherence of estimated water sources composition

2. Hydrograph separation methods

✓ We used 4 Recursive Digital Filter methods to separate baseflow and quickflow (Table 1)

✓ The four methods were adapted to be dependent on a single parameter τ which conditions the recession constant α

$$\alpha_\tau = exp\left(-\frac{\Delta t}{\tau}\right)$$

- Δt : time step (h)
- τ : characteristic drainage timescale (h),

Table 1: Summary of hydrograph separation methods used for the study

Baseflow method	Algorithm	Particular descriptors
Linear Reservoir (LR) [1]	$Q_b(t + 1 + T) = \alpha_\tau Q_b(t) + \beta Q(t) + \omega Q(t + 1)$	$\beta = \tau(1 - \alpha_\tau) - \alpha_\tau$; $\omega = 1 - \tau(1 - \alpha_\tau)$; T = 0 (Lag time)
Lyne – Hollick (LH) [2]	$f(t) = \alpha_\tau f(t - 1) + \frac{(1 + \alpha_\tau)}{2}(Q(t) - Q(t - 1))$	f(t) = quickflow; $Q_b(t) = Q(t) - f(t)$
Chapman – Maxwell (CM) [3]	$Q_b(t) = \frac{\alpha_\tau}{2 - \alpha_\tau} Q_b(t - 1) + \frac{1 - \alpha_\tau}{2 - \alpha_\tau} Q(t)$	
Eckhardt (EC) [4]	$Q_b(t) = \frac{(1 - BFI_{max})\alpha_\tau Q_b(t-1) + (1 - \alpha_\tau)BFI_{max}Q(t)}{1 - \alpha_\tau BFI_{max}}$	BFI_{max} = 0.80 (perennial stream with porous aquifer [4])

4. Results : Selection of parameter τ and sensibility of the methods

➤ Each RDF method present one possible solution for the characteristic drainage timescale, whatever the ion selected, except for Nitrates.

➤ LR and LH method, with chemical calibration give similar characteristic drainage timescale than the Master Recession Curve method (MRC). MRC is a referential hydrological method to calibrate the τ [6]. LR and LH do not have the same sensibility to the τ parameter than CM and EC methods.

Table 3: Optimal values for τ found from the Pareto front with IIQRC$_{1j}$ and IIQRC$_{2j}$ values, α values and BFI values corresponding for each ions (Note that BFI is the ratio between the sum of the base flows with respect to the total flows)

| baseflow method	ion	IIQRC1	IIQRC2	τ (h)	α	BFI	baseflow method	ion	IIQRC1	IIQRC2	τ (h)	α	BFI
LR	Chloride	0.57	1.05	230	0.998	0.74	CM	Chloride	2.02	1.71	2000	1.000	0.44
	Sulfate	0.74	1.25	230	0.998	0.74		Sulfate	2.05	1.05	2000	1.000	0.44
	Magnesium	0.44	0.88	230	0.998	0.74		Magnesium	2.27	1.26	2000	1.000	0.44
	Sodium	0.46	1.13	230	0.998	0.74		Sodium	2.61	1.55	2000	1.000	0.44
	Nitrate	0.37	0.80	81	0.994	0.81		Nitrate	1.67	1.52	480	0.999	0.47
	Calcium	0.42	0.85	250	0.998	0.74		Calcium	1.21	1.22	760	0.999	0.47
LH	Chloride	0.57	1.05	230	0.998	0.74	EC	Chloride	0.62	1.69	660	0.999	0.70
	Sulfate	0.74	1.25	230	0.998	0.74		Sulfate	0.88	1.39	970	0.999	0.68
	Magnesium	0.44	0.88	230	0.998	0.74		Magnesium	0.46	1.21	950	0.999	0.68
	Sodium	0.46	1.13	230	0.998	0.74		Sodium	0.58	1.59	660	0.999	0.70
	Nitrate	0.37	0.80	81	0.994	0.81		Nitrate	0.44	1.37	660	0.999	0.70
	Calcium	0.42	0.85	250	0.998	0.74		Calcium	0.44	1.19	660	0.999	0.70
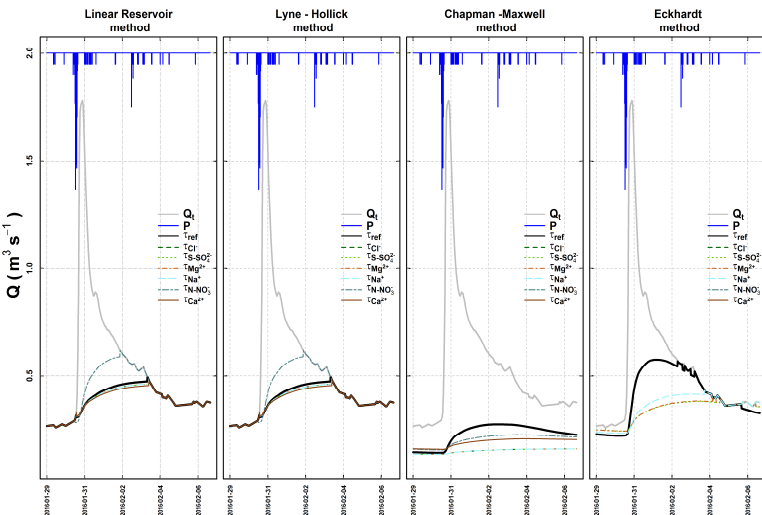
Figure 4: Comparison of the baseflow calculated from the optimal τ (table 3; orange fill) and the τ calculated from the Master Recession Curve method)[4] [6] (black line, calculated with daily mean values of streamflow, source: http://data.datacite.org/10.17180/OBS.ORACLE) for the 4 recursive digital filtering base flow methods.

3. Materiel et Method

3.1. Study Zone

ORACLE/BVRE Orgeval CZO, 42 years of water quality monitoring

Daily water quality monitoring
- ● Rain water quality
- ▲ River water quality
- ★ Piezometers

Sub-hourly CRITEX water quality monitoring
★ River -Lab

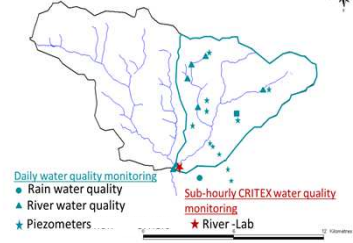Figure 2: Orgeval catchment with its corresponding sub-catchments (source: Irstea-Antony)

Table 2: Summary of the mean values, min and max of the chemical elements studied from the high frequency measurements

item	Unit	Avenelles Catchment		
		Mean	Min	Max
chloride	mg/L	32.00	4.00	40.00
sulfate	Smg/L	20.00	4.00	32.00
magnesium	mg/L	9.00	3.00	11.00
sodium	mg/L	13.00	3.00	17.00
nitrates	N mg/L	12.00	7.00	18.00
calcium	mg/L	121.00	57.00	168.00
rainfall	mm/30min	0.05	0.00	17.07
flow	m^3/s	0.27	0.03	12.20

✓ Avenelles catchment (46 km^2)

✓ High-frequency measurements from River Lab [5] (approximately every 30 minutes) from June 2015 to July 2017

✓ Six chemical elements measured (Table 2)

3.2. Methodology

✓ 4 methods were used to separate baseflow, with a τ ranging from 0 to 10 000 h,

✓ To resolve the mixing equation we used a simple linear regression with high frequency measurements at daily time step (i.e. 48 daily points and 780 couple of values for all the period)

✓ Because of the primary hypothesis of concentration mass balance of the two sources, we looked for the stability of C_{1j} and C_{2j}, measured using IIQR (relative inter-quantile index) and Pareto front between IIQRC$_{1j}$ and IIQRC$_{2j}$

$$IIQR(C) = \frac{C_{0.99} - C_{0.01}}{C_{0.50}}$$

- $C_{0.99}$: quantile 99 of C_{1j}/C_{2j} (mg/L)
- $C_{0.01}$: quantile 1 of C_{1j}/C_{2j}(mg/L)
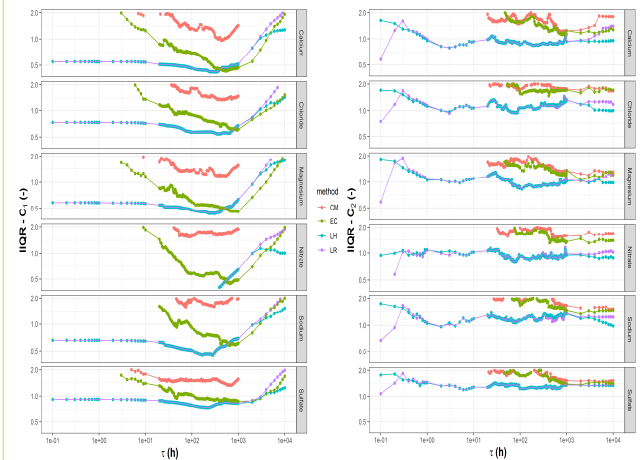- $C_{0.50}$: median of C_{1j}/C_{2j} (mg/L)

Figure 3: Values of IIQR vs τ (hours) for C_{1j} and C_{2j} for the 4 baseflow separation method (LR, LH, CM and EC)

5. Conclusions & Perspectives

➤ Hydrograph separation generally assumes that two main sources contribute to the discharge. It assumes also that a constant value of τ can be used for estimation of baseflow and quickflow.

➤ The hypothesis of a conservative mass balance (C_{1j} and C_{2j} stable) was validated by the LR and LH methods, except for nitrates. Whatever the ion, an unique τ parameter can be used for each method.

➤ The CM and EC method, were significantly different than LR, LH and RMC methods.

➤ The behavior of Nitrates is more complex: anthropogenic effect (fertilizers) and biogeochemical cycle.

6. References

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