

# Hydrograph separation of stormflow components in a small catchment (Strengbach, Vosges) using hydrological measurements, and chemical and isotopic tracers

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## 1. Introduction

Streamflow generation processes have been the subject of many previous studies in order to determine streamflow components in various catchments under different environmental conditions (e.g. Pinder and Jones, 1969; Pearce, 1990). Generally such studies use chemical tracers in a two or three-component mixing model for hydrograph separation, and are supposed to estimate the contributions from two or three reservoirs (surface runoff, sub-surface flow and groundwater) (Hooper *et al.*, 1990; Ogunkoya and Jenkins, 1993; Buzek *et al.*, 1995). Other studies have used water stable isotopes (<sup>2</sup>H, <sup>18</sup>O) to distinguish pre-event water from event water (as example : McDonnell *et al.*, 1990). Recently, some authors (Kennedy *et al.*, 1986; Wels *et al.*, 1991) have tentatively compared the results obtained using isotopic and chemical tracers.

Since the different tracers used in the above studies do not identify the same streamflow components, the present study has tentatively used simultaneously hydrological measurements, stable isotopes (<sup>18</sup>O, <sup>2</sup>H) and geochemical tracers. The aim was to investigate the origin of the water in a small catchment by identifying the temporal (pre-event and event water) and spatial components (contributing areas) to the total streamflow during a major storm event.

In this paper, hydrograph separation was performed in three different ways: (1) using hydrological measurements of the different tributaries to estimate the subcatchment contributions to the total streamflow; (2) using <sup>18</sup>O and <sup>2</sup>H to determine the proportion of event water; and (3) using dissolved organic carbon (DOC) and silica which have been selected among several other measured chemical tracers to identify the contributing areas.

## 2. Material and Methods

The Strengbach forested catchment (80 ha) at Aubure is located at the eastern side of the Vosges mountains (north-eastern France), 58 km south-west of Strasbourg (Probst *et al.*, 1990). It ranges from 883 m at the outlet to 1146 m at the top (Fig. 1). This catchment mainly lies on a base-poor granitic bedrock (the Brezouard granite). Soils are acidic, sandy and stony; brown acid and podzolic soils have developed on the south- and north-facing slopes respectively. In the valley bottom, a small saturated area with permanent hydromorphic conditions covers ~2 % of the basin area (Probst *et al.*, 1992). The catchment is completely forested: Norway spruce covers two-thirds of the catchment area (mainly as old trees), and mixed beech and silver fir take up the rest. The climate is temperate-oceanic-mountainous. The mean annual precipitation (1986-1989) is 1553 mm with 25 % falling as snow (Probst *et al.*, 1992). The mean annual discharge is 1051 mm; the highest flow period generally occurs during snowmelt (spring) and the lowest flow period is always in autumn (September-October).

During the storm event of 18 May 1994, bulk precipitation (PS) and throughfall (TF) have been collected regularly in PVC funnel collectors and in replicate 2 m long open gutters, respectively. Throughfall and zero tension soil solutions (SS) were collected in an old spruce stand. Stream discharge

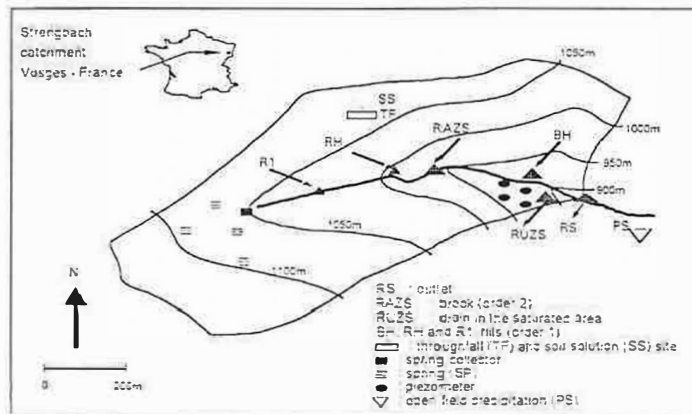


Figure 1: Map of the Strengbach basin and location of different sampling sites.

was monitored at a permanent gauging station (RS) equipped with an H-flume weir and at two non-permanent sites (RAZS and R1). Water samples were frequently and regularly taken simultaneously at the outlet (RS), along the main stream (RAZS, R1) and at the adjacent tributaries (BH, RH). The small saturated area has also been sampled using several piezometers and a gauging pipe (RUZS) (Fig.1). Samples were collected in polyethylene bottles and filtrated through a 0.45  $\mu\text{m}$  Millipore membrane. For pH, electrical conductivity, alkalinity, silica,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Cl}^-$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{NH}_4^+$  and dissolved organic carbon (DOC), classical analytical methods were used (Krempp, 1988). Oxygen-18 analysis were carried out by the standard  $\text{CO}_2$  equilibration method (Eipsten and Mayeda, 1953) and deuterium analysis by reduction of water to hydrogen over zinc at 540°C following a standard method (Coleman *et al.*, 1982). Results are expressed in per mil (‰) difference relative to the standard mean ocean water (SMOW) as defined by (Craig, 1961). Deuterium analyses have been normalized according to the V-SMOW-SLAP scale (Gonfiantini, 1978).

For both chemical and isotopic tracers, the hydrograph separation was performed using a classical two-component mixing model (Pinder and Jones, 1969). This approach assumes that the mixing of the fluxes coming from different sources is conservative and that there is no chemical interaction between the different components. In the model, equations could be solved at each step of the hydrograph separation by using the concentrations and the discharges measured in the different components.

### 3. Results and discussion

#### 3.1. Hydrology

At the outlet of the Strengbach catchment, the hydrograph generated by the storm event of 18 May 1994 (40 mm in 19 hours) is characterized by two peaks of discharge (35 l/s and 28 l/s) in response to two successive rainfall events (respectively 26 mm and 14 mm). Figure 2 represents the hydrographs of the main stream (RS, RAZS and R1) and of the different tributaries (BH, RH and RUZS), and the corresponding hctograph. In Fig. 2, it can be seen that the discharge measured at the pipe of the saturated area (RUZS) reaches its maximum during the first peak of the total streamflow. Whereas RAZS which controls the upper subcatchment presents its maximum discharge during the second peak of the hydrograph. However, the water table measurements in the piezometers of the saturated area indicate an increase of water height during the second period of the storm event which means that the contribution of the deep flow increases. During the first part of the event, the surface flow was important in the saturated area.

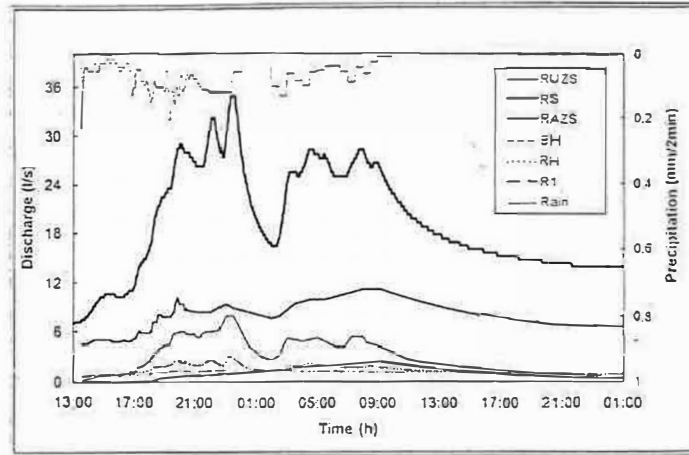


Figure 2: Hydrographs of the stream at the outlet (RS) and of the different tributaries, and corresponding hyetograph during the storm event of 18 May 1994.

For the whole event, the hydrological measurements indicate that the amount of water supplied by the upper subcatchment RAZS represents 40% of the total streamflow with a specific discharge of 3.5 l/s/km<sup>2</sup>. The downstream subcatchment (between RAZS and RS) contributes the remaining 60% with a specific discharge of 5.7 l/s/km<sup>2</sup>. However on the whole, the hydrological budget indicates that about 40% of the total streamflow could not be gauged because of uncontrollable drainage areas.

This hydrological approach allows determination of the geographical origins of the streamflow but it must be coupled with chemical and isotopic tracers to determine the contribution, in space and in time, of the different reservoirs.

### 3.2. Isotopic tracers

The isotopic signatures of the rainfall-runoff event show that the initial oxygen-18 content in streamwater (-9.43 ‰) is nearly identical to that of groundwater (-9.49 ‰), considering the uncertainty (Fig. 3). During the event, the temporal variation of oxygen-18 content measured at the outlet (RS) is low but significant compared to that observed in the open-field precipitation. The isotopic content of the streamwater is fluctuating around the mean  $\delta^{18}\text{O}$  of spring water and returns to the initial value during the recession period. This temporal evolution of  $\delta^{18}\text{O}$  measured in streamwater is mainly due to a contribution of event water (rainfall). However, these results show that only a very small amount of rainfall contributes directly to the storm runoff.

The temporal isotopic variation of event rainfall may complicate the choice of appropriate signature for hydrograph separation. So, the event water composition has been derived using the incremental weighted mean method in order to integrate the temporal variability of  $\delta^{18}\text{O}$  in rainfall (McDonnell *et al.*, 1990). The hydrograph separation (Fig. 4) takes into account two distinct rainfall events and a constant pre-event isotopic composition supposed to be equal to that of the mean spring water content which is relatively constant.

The hydrograph separation indicates that pre-event water is the major component for this event. The instantaneous event contributions are not very important, ranging from a minimum value of 2 % at the beginning of the stormflow to a maximum value of 12 % at the main peak flow. The determination of the total event contribution for the entire stormflow period is around 277 m<sup>3</sup> ± 51 m<sup>3</sup>. The area contributing new water determined from the isotopic separation is 0.87 ha ± 0.16 ha. This result suggests that the contributing areas calculated by the isotopic method could represent the saturated areas located in the vicinity of the main stream (1.06 ha before the stormflow). Thus, for this event, it is suggested that nearly all the precipitation on the surface of the saturated areas have contributed to the stormflow.

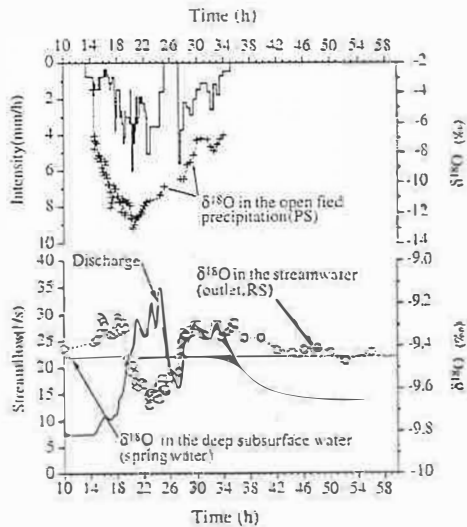


Figure 3: Rainfall intensity and stream discharge at the outlet. Rainfall and streamwater isotopic variations ( $\delta^{18}O$ ) during the storm event of 18 May 1994.

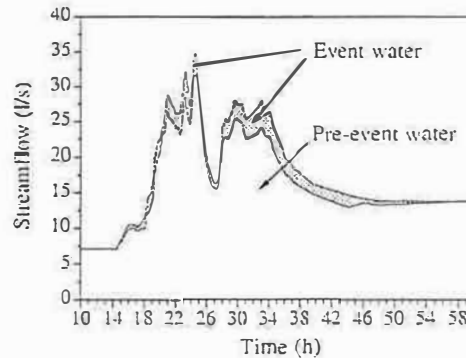


Figure 4: Hydrograph separation performed using isotopic tracer ( $\delta^{18}O$ ).

### 3.3. Chemical tracers

During the storm event, the rainwater is slightly acidic (pH = 5.1), very diluted and dominated by ammonium, protons, sulfate and nitrate. Concentrations decrease during the first part of the event. During the second part, concentrations were higher (particularly for acid compounds). Throughfall is more acidic (pH = 4.6) and more concentrated than open-field precipitation. Streamwater is circumneutral (pH between 6 and 6.7); calcium and sulfate dominate the chemical composition as previously observed in this catchment (Probst *et al.*, 1990).

According to their concentration behaviour with respect to discharge variations in the mainstream and in the adjacent tributaries, four groups of chemical parameters could be identified during the storm event:

- parameters for which the concentrations are highly diluted with increasing discharge at all sampling stations (conductivity,  $SO_4$ , Cl, Na, Ca, Mg and silica);
- elements for which the concentrations are weakly diluted (K, pH and alkalinity);
- dissolved organic carbon (DOC) for which the concentration increases with discharge for all sampling stations; and
- $NO_3$  which is diluted during the first flow and concentrated in the second part of the storm event.

The linear mixing diagram between DOC and silica (Fig. 5) exhibits the contribution of two obvious end-members to the total streamflow discharge: one is characterized by low silica concentrations and high DOC contents and the other by high silica concentrations and low DOC contents. The first one corresponds to waters draining the upper layers of the saturated area (RUZS pattern) and the second corresponds to waters draining deep layers of the hillslopes (spring water pattern). It is important to note that, as confirmed by mixing diagrams using other major elements, the soil solution (SS), the open-field rain water (PS) and the throughfall (TF) are not on the mixing line. Consequently, they contribute only very weakly to the chemical composition of the stream water.

Because of their clearly identified origin and of the good relationship between concentration and discharge, hydrograph separation was performed using DOC (Fig. 6) and silica. We identified two contributing areas; the hillslopes and the saturated areas. During this storm event, the main water contribution to the total stream discharge is supplied by the hillslope (75% of total stream flow).

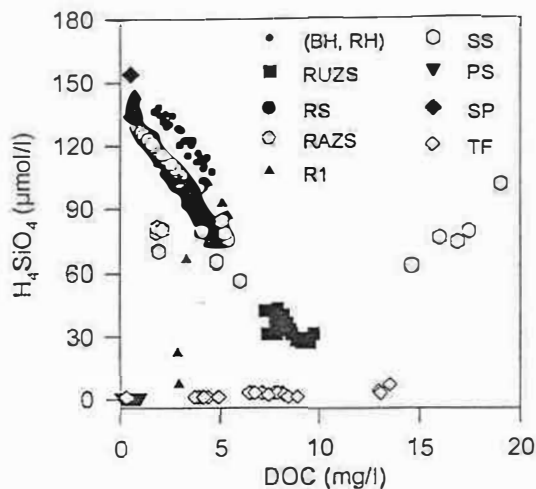


Figure 5: Mixing diagram between DOC and silica in various sampling sites during the storm event of 18 May 1994.

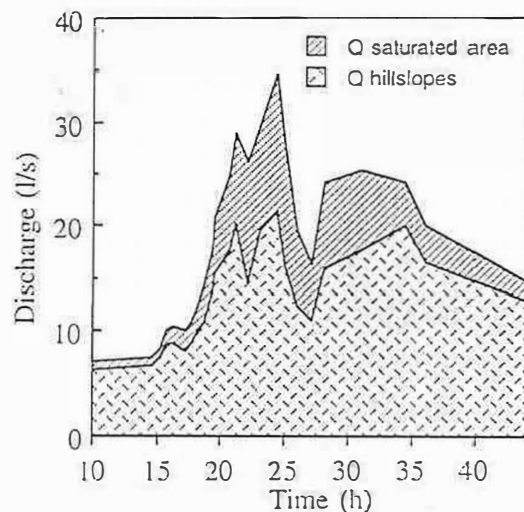


Figure 6: Hydrograph separation using DOC as a chemical tracer.

Nevertheless, this contribution is slightly lower during the first period (70%) than during the second one (77%). The results obtained using DOC and silica as geochemical tracers are very close and are consistent with those obtained using isotopic tracers. We consider that the major part of the hillslope contribution is dominated by pre-event water.

#### 4. Conclusion

Contrary to many comparable studies where event waters were found to highly influence stream water composition, the hydrograph separation of a main storm in the small Strengbach catchment presents a different pattern of results.

The hydrological measurements indicate a major contribution of the upper subcatchment (upstream source area) to total stream flow. The isotopic tracers ( $^{18}\text{O}$ ,  $^2\text{H}$ ) point out that the direct influence of rain water on streamwater is very low (2% to 10%). Among several measured chemical elements, silica and DOC appeared to be the more efficient tracers to identify contributing areas. Streamflow hydrochemistry is highly controlled by a mixing of two contributing areas; the hillslope (75%) and the saturated area (25%). The simultaneous use of geochemical and isotopic tracers shows that pre-event water draining hillslopes was the main contribution to total streamflow.

This approach combining hydrological, geochemical and isotopic measurements is recommended for streamflow component separation in other case studies.

#### 5. Acknowledgments

This work has been carried out within the DBT II « Fleuves et Erosion » research program supported by the INSU/CNRS. The authors are also grateful to all participants in the field and in the laboratory for their contribution which allows this study to progress in good conditions.

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