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WATER ELECTRICAL CONDUCTIVITY - WATERFLOW RELATIONSHIP AS A HANDY WAY TO DEFINE FLOW DISCHARGE COMPONENTS AND CATCHMENT INITIAL SOIL WATER CONTENT.

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1. INTRODUCTION

A good knowledge of the hydrogeological behaviour on a given zone is required to precise the origin of water supplying streamflow during flood periods. This knowledge becomes more and more often necessary in our regions where one tries to better understand the impact of human activities, in particular agricultural practices, on the environment. Watercatchment characterization must provide means to separate the different components of the hydrogram : base flow, hypodermic flow and surface runoff. This splitting in different components is of the highest importance as water quality and its pollution level will totaly differ wether they come from the soil or stay at the surface.

2. OBJECTIVES

Our deficient knowledge of the environment and its complexity leads to propose the use of adapted methods in this particular context.
The use of indices and indicators matches particularly well for this purpose. The objectives of this paper are:
- to precise the groundwater role during flood periods;
- to better understand the Rainfall (RR) - streamflow discharge(Q) relationship by using water electrical conductivity (EC) of the stream as an indicator of the water saturation status of the watercatchment.
Study site (see figure 1.)

3. STUDY SITE

The study site, called « bassin du Ruisseau de la Fontaine » is located in South East of Belgium and has a size of 32.4 ha. Land occupation is a mixture of agriculture and forest. Mean annual rainfall reaches 1050 mm and mean air temperature is 8.5°C. Soils are equaly represented by loamy sand and sandy loam. Mean spring flow for a three years period is 3 l/s. The same value is observed at the outlet with extreme values ranging from 0.8 l/s to 20 l/s.
The groundwater is superficial (2 to 3 meters depth on average) laying mainly in the sinemurian calcareous sand and standstone and in a smaller part in sandy and loamy alluvions in the downward of the basin.

4. MATERIAL AND METHODS

Streamflow data at the outlet are measured every 30 minutes during a 30 weeks continuous period from November 89 to April 90. Electrical conductivity (EC) of stream water is taken at the same time step and in the same place.
The method consists in analysing and explaining the relationship between Q and EC as a function of time by the light of hydrological measurements : rainfall, groundwater depth, spring flow and air, soil and water temperature.

The basin has been equipped with
> an automatic complete weather station,
> a 19 piezometers network with one (P14) equipped with a pressure sensor connected to a datalogger.
> two waterflow stations located at the spring and at the outlet, this last one beeing connected to a data logger recording EC, waterflow and water temperature at a 30'time step. When available a data logger was also placed near the spring (see figure 1.).

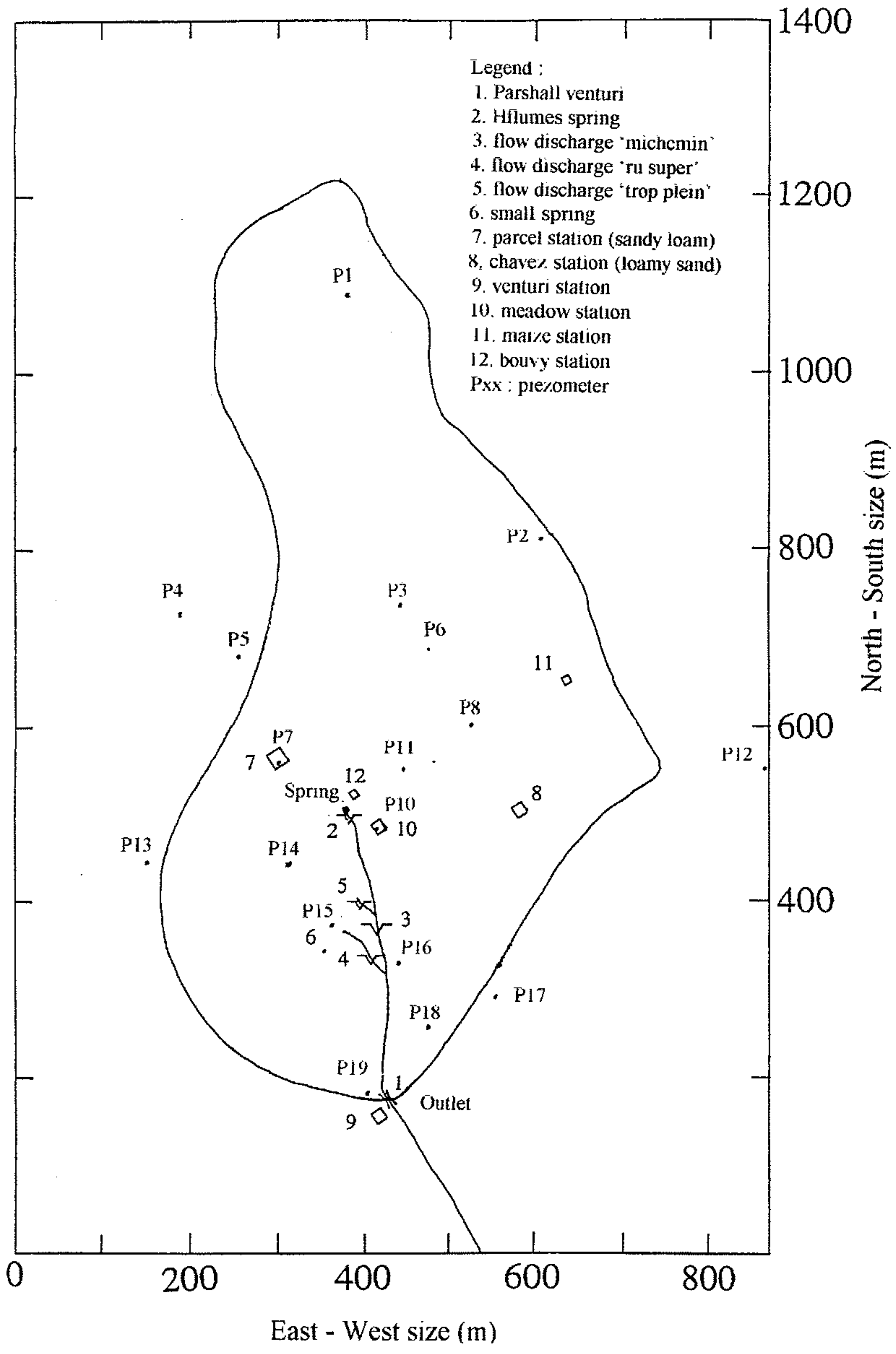

Figure 1 : Map of the study site with its equipment and the location of the equipment

5. RESULTS

From 15 November 89 to 25 April 90, systematic measurements campain recorded all the flood episods. Figures 2a and b show, for example, month February with the main parameters observed in the basin

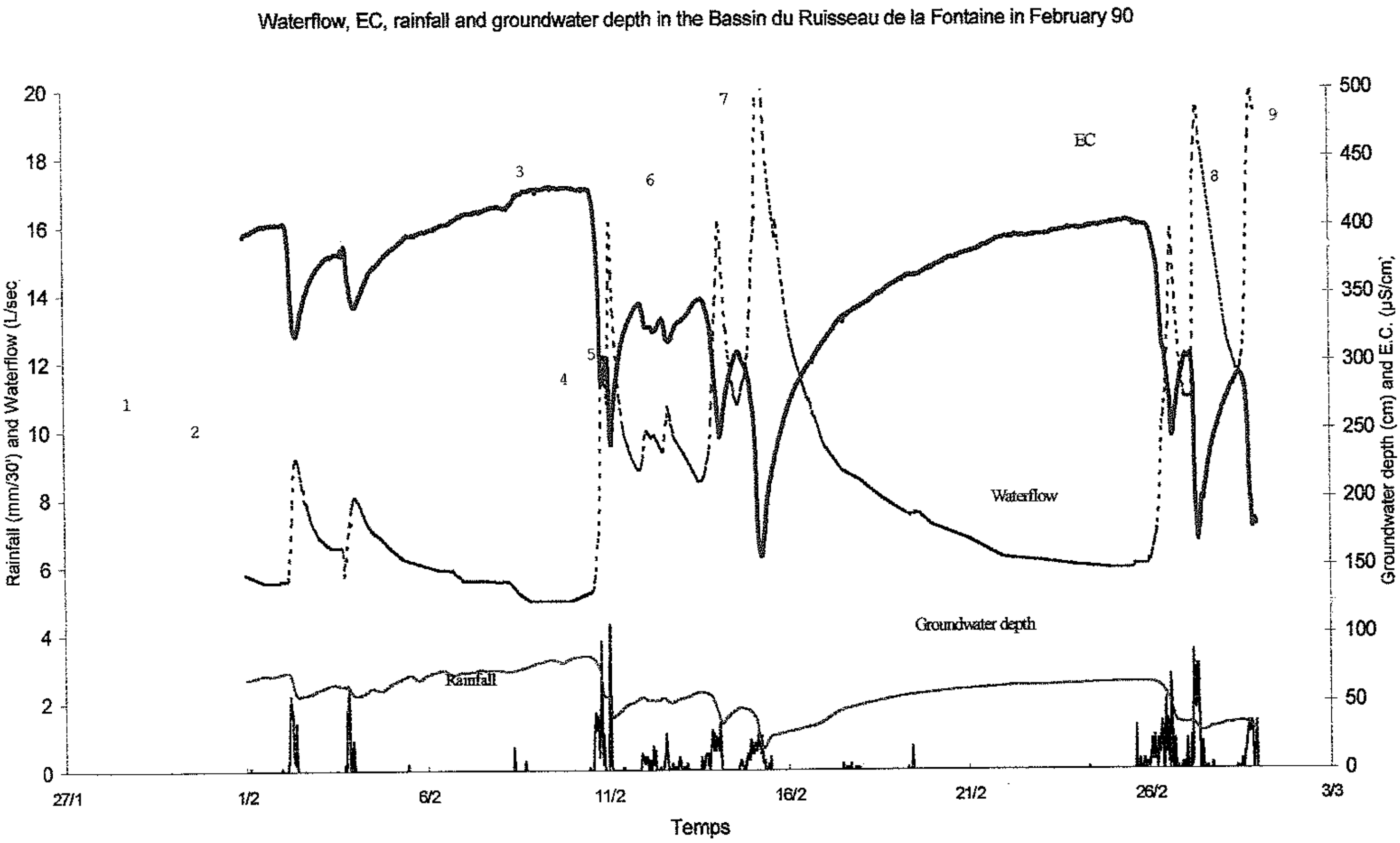

Figure 2a : Waterflow, EC, Rainfall and groundwater depth in Bassin du Ruisseau de la Fontaine (February 90).

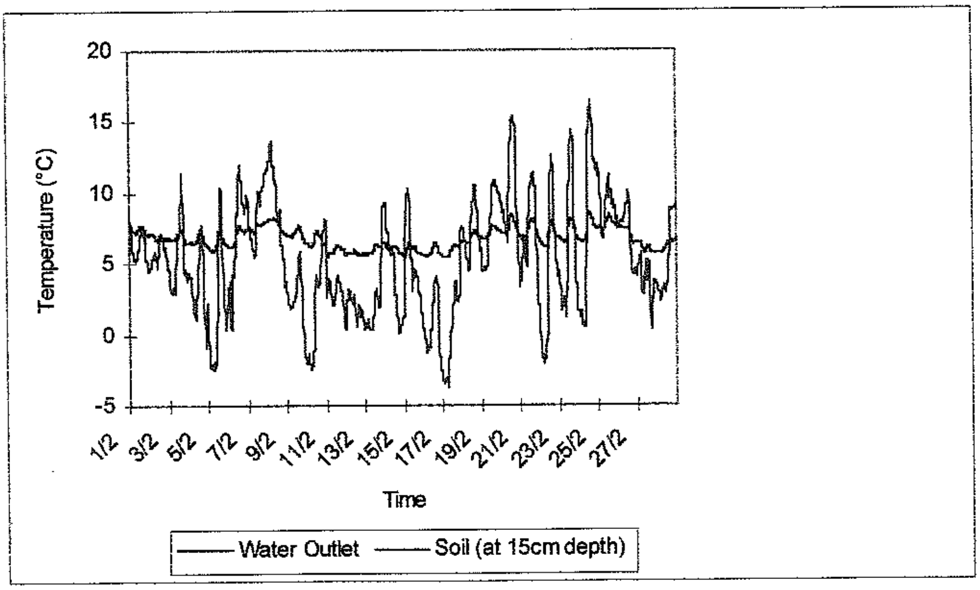

Figure 2b : Temperature of the water outlet and in the first soil layer (15 cm) in February 90.

6. ANALYSIS

Indications, measurements and observations related to the origin of the streamflow water are counted and analysed in order to highlight the role of groundwater in the flood hydrogram.

- Surface runoff looks negligeable. No visual indication of erosion was observed except on compacted soils roads.
- A same rainfall volume produces much different discharges as it can be seen on 11 and 15th February, for example (figure 2a).
- During January, February and March, a high correlation ($R^2 > 90$ %) exists between groundwater depth and the streamflow. The quality of this relationship falls down for the first 2 months and can be explained by the following :

. in December the watertable reaches the surface preventing groundwater to go higher and this, of course, disrupts the linearity of the relationship between groundwater depth (H) and streamflow.

. the H-Q relationship is actually changing during this period. The shape of the aquifer changes, some parts of the basin needing more time to accumulate water and contribute to the water supply of the stream.

. a simple rough model using temperatures of the water at the spring, at the outlet and at the soil surface linked to the waterflow at outlet also shows a high domination of groundwater in the streamflow supply (fig 3).

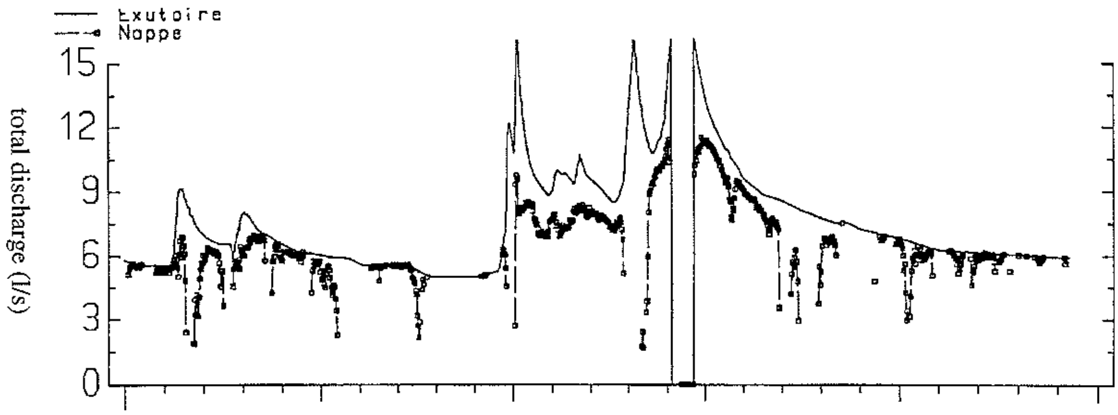

Figure 3 : Simulation of the groundwater components in comparison with the total discharge -February 90

7.ANALYSIS OF THE EC-Q RELATIONSHIP

The above classical approaches show that the main water input during floods comes from the aquifer. This last approach (use of the EC-Q relationship) is an other way to confirm this point. But used with the others it can be more precise in explaining the process of input change in time.

The EC-Q relationship shows a reduction of Q when EC increases (see Figure 4). It looks like a dilution curve where 2 liquids of different concentrations are mixed together in variable proportions. The Q-EC relationship correlation value is always higher than that of the Q-H one what is a new argument in favour of a groundwater input. A high surface runoff would never have such regular behaviour (proven by the high correlation coefficient). If it was the case, water concentration at the outlet would change sensibly according to rainfall size and intensity events. This has never been observed in our experiment.

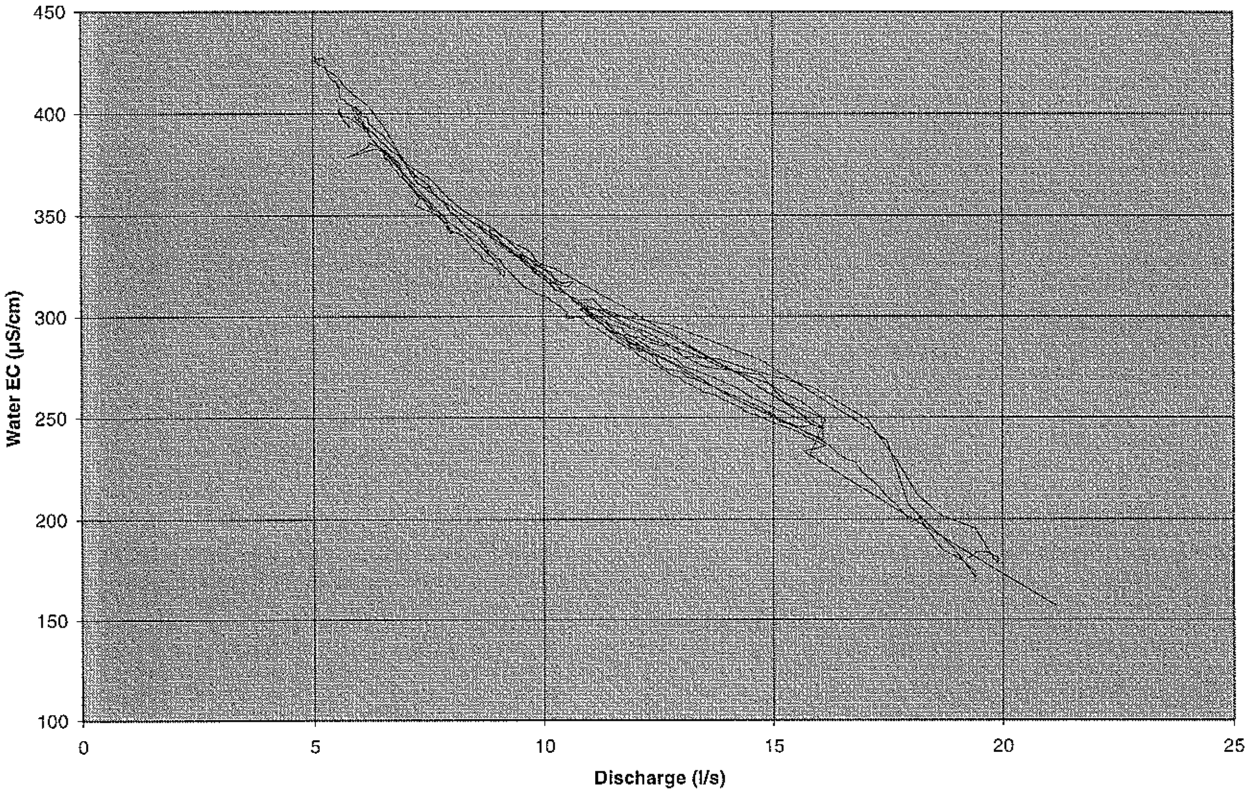

Figure 4 : EC-Q relationship in February 90

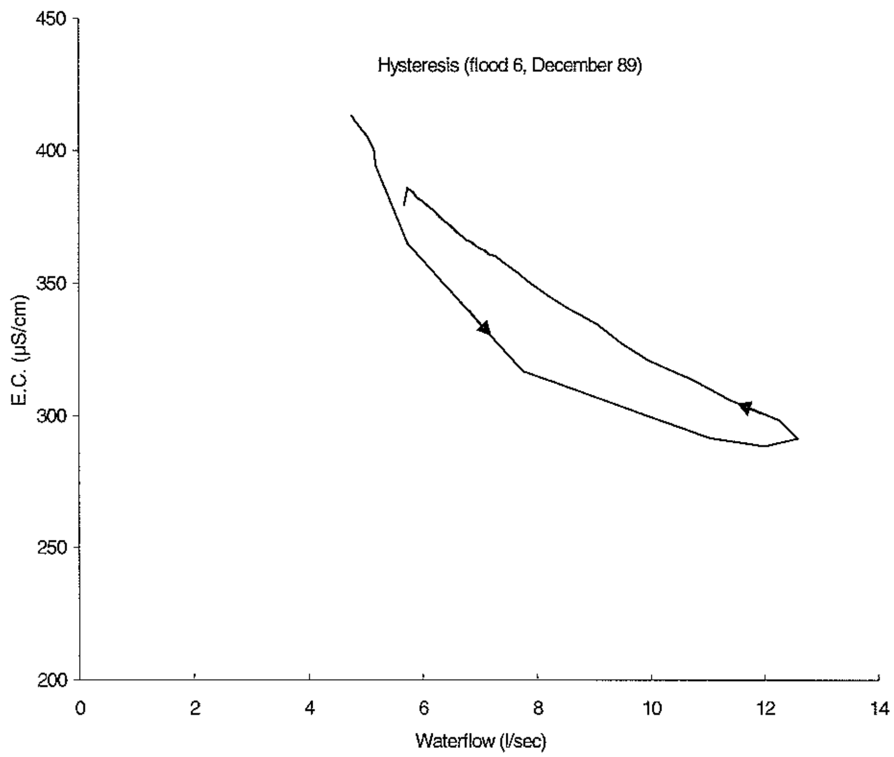

Figure 5 : E.C.-Q hysteresis : an example of anticlockwise

A more precise analysis of the EC-Q relationship underline an hysteresis phenomenon (figure 5). This phenomenon is already known. But what is not often known is the hysteresis changes of direction after some episodes (table 1). In the beginning, it turns anticlockwise, ie during the rise of the flood, water concentration is higher than during the falling part of the flood. This change of direction is gradual, the distance between the two arms of the hysteresis reducing slowly until cancellation. Then, the phenomenon go further by reversing the two arms and produces a clockwise hysteresis. At that time the concentration of the water flood is higher during the falling part of the hydrogram. The dilution factor occuring during rainfall with weakly concentrated atmospheric input can be an explanation for the anticlokwise hysteresis but not for the clockwise one. Moreover, an unexpected phenomenon also occurs when analysing short heavy rainfall episodes : the slope of the EC-Q curve increases or decreases undifferently according to the period of the year. This means that a rain event might increase the concentration of the water and this is not compatible with the very weak salts concentrations in rain water. The explanation based on a mixture of rain water (or surface water having an equivalent concentration) with groundwater is not satisfactory and must be replaced by an other one where groundwater depth variation in the downward part of the basin intervenes quasi exclusively as water supplier during floods.

Table 1 : Listing of floods analysed during this experiment

Date de la crue	*Waterflow range (L/sec)*	*Sens de l'hystérèse*	*Remarques*
1.11 0h00-2.11 19h30	2.1-4.1	anticlockwise	
2.11 20h00-3.11 19h00	2.7-3.9	anticlockwise	
4.11 16h00-6.11 18h00	2.4-4.3	anticlockwise	
12.12 10h30-14.12 0h30	1.9-2.5	anticlockwise	very small flood
14.12 0h30-14.12 14h30	2.1-2.2	anticlockwise	very small flood
14.12 15h00-15.12 7h00	2.1-3.8	anticlockwise	
15.12 9h00-16.12 0h00	2.8-7.6	anticlockwise	
16.12 0h30-16.12 21h30	4.7-11.2	anticlockwise	
16.12 21h30-17.12 18h00	5-12.6	anticlockwise	
17.12 18h30-18.12 17h30	4.5-7.2	no hysteresis	
18.12 18h00-19.12 11h30	3.9-4.9	clockwise	small rain
19.12 12h00-20.12 21h00	4.5-17.7	anticlockwise	
20.12 21h30-22.12 4h30	6-15.7	anticlockwise	
22.12 5h00-23.12 16h00	6-17	anticlockwise	
23.12 16h30-31.12 23h00	4.5-13	clockwise	
15.1 12h30-19.1 23h00	3.2-3.8	no hysteresis	
23.1 14h30-25.14h30	4-19.5	no hysteresis	
25.1 5h00-30.1 5h00	8-22	clockwise	
30.1 5h30-31.1 23h30	6.2-6.8	clockwise	
2.2 3h30-3.2 17h00	5.5-9	no hysteresis	
3.2 18h00-8.2 9h00	6-8	no hysteresis	
10.2 14h00-11.2 21h30	5-16	clockwise	
11.2 22h00-12.2 13h30	8.8-10	clockwise	
12.2 14h00-12.2 13h00	8.5-10.7	clockwise	
13.2 13h30-14.2 15h30	8.5-16	clockwise	
14.2 16h00-25.2 14h30	9-21	clockwise	
25.2 15h00-27.2 3h00	6-16	clockwise	
27.2-3h30-28.2 11h00	11-20	clockwise	
28.2 12h00-2.3 10h00	10-20	clockwise	
2.3 10h30-3.3 10h00	11.4-12.3	clockwise	very small flood
20.3 1h30-22.3 16h00	5.2-5.6	no hysteresis	very small flood
15.4 12h00-16.4. 18h00.	3.5-6	anticlockwise	

8. SCENARIO PROPOSAL :

During the first floods, water from the vadose zone brings a high salts concentration to the aquifer. Floods after floods, groundwater level increases due to phenomenons mentionned by Beven (1987) : translatory flow, capillary fringe effect, overland flow. At a given time, water close to the bank of the stream and water from the downward part of the basin start to drain (See Figure 6). Close to the surface, high pressure gradients emphasized by capillary fringe rise produce high discharges, and maybe also a short gradient inversion that may limit the supplying zone to the region close to the bank. With groundwater rising up, there is a dilution of the groundwater concentration as it has been observed on the field. Water EC in the aquifer increases with depth. The salts supply from the soil only slow down the groundwater concentration increase with depth. Moreover as the level of the aquifer rises, the contributing zone of the basin acting on the flow will also grow up lateraly and the first contributing zones rapidly reduce their salts discharge becoming leached and this also reduces the salts water concentration. During the falling part of the hydrogram, water supplying the stream comes from a larger zone of the fully saturated bottom of the basin with a much lower gradient. During the first floods, the top of the groundwater might have been charged with a concentrated water coming from the unsaturated zone. Consequently, the falling part of the flood is situated above the rising one. When floods follow rapidly, the soil becomes soon unable to provide the same quantity of ions as just after a drought period. At that time, floods after floods, the range between the two arms of the hysteresis will reduce, soil water being unable to modify as sensibly as before the groundwater quality. If this process go further, soil water is so much diluted that the hysteresis reverse. By this process, the two types of hysteresis might be explained

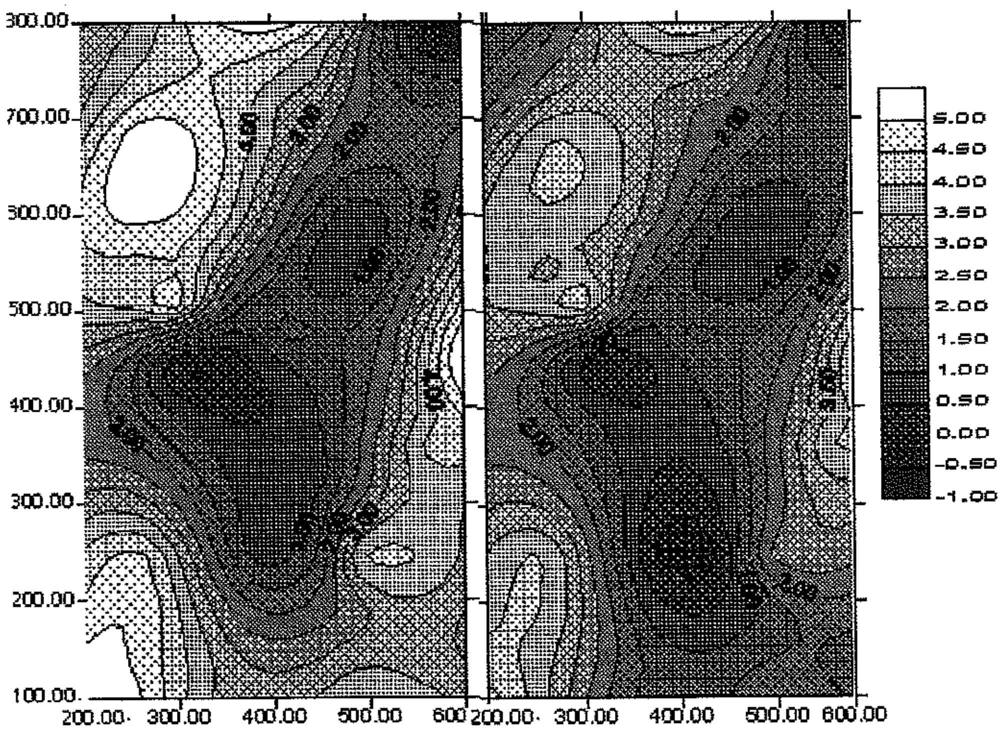

Figure 6 : size of the vadose zone (m) for two equivalent discharge flow in december 89 (left) and february 90 (right) in the downward part of the basin.

9. CONCLUSIONS

The analyse of the relationship between water Electrical Conductivity (EC) – and discharge (Q) can be used at any period of the year (not possible with temperature tracer). It gives a lot of information on the origin of water supplying the river. In the studied catchment, the direction of the hysteresis and, in a less extent, its slope and its amplitude are original indicators of the soil water status of the basin, at least in the initial phase of stormflow events. They permit to refute with certainty some hypotheses on the origin of water and to support some others. Up to now, these indicators provide some qualitative interpretations. But in environmental sciences as well as in hydrology, given the scarcity of information with regard to the studied system complexity, this kind of cheap and easy to use approach can not be disregarded. Researches on other sites and methodologies integrating this qualitative type of information are recommended.