proceedings of the
9th Conference on Limestone Hydrogeology

actes du
9ème Congrès d'hydrogéologie en pays calcaire

Université de Franche-Comté - Université de Neuchâtel

Besançon, France
September 1-3, 2011

H2 KARST
Hydrology & Hydrogeology
of the Karst

Stream gauging by dilution of fluorescent tracers and state of the art of the EDF hydroclimatological observation network

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Abstract

EDF (Electricité de France) currently runs a hydrological network centred on the mountainous massifs. This network allows operational surveillance of snow, rain and stream flow rates with the aim of anticipating the flow rate at hydroelectric plants. For information 50% hydrometric and 60% pluviometric EDF-monitored stations are located at an altitude above 600m. This article shows the status of the EDF mountainous network more particularly related to the stream gauging by dilution of fluorescent dye tracers.

Résumé

EDF exploite un réseau de points d'observations hydrologiques très centré sur les massifs montagneux. Ce réseau permet une surveillance opérationnelle de la neige, la pluie et des débits dans une optique de prévision de débits aux ouvrages hydroélectriques. A titre indicatif, on peut rappeler que 50% des stations d'hydrométrie et 60% des stations pluviométriques gérées par EDF sont situées à une altitude supérieure à 600m. Cet article propose un état des lieux du réseau de montagne EDF plus particulièrement axé sur la stratégie d'observation des débits par dilution de traceurs fluorescents.

1. Introduction

Like every European countries after World War II electrical energy needs of France were huge. Electricité de France (EDF), the national company born in 1946 from the nationalization law of 1450 French companies was in charge of accompanying the national effort in supplying electrical power to the nation.

In 2011 the EDF hydroclimatological network comprises as many as 800 stations scattered on the mountainous massifs (PERRET *et al.*, 2011, Fig. 1).

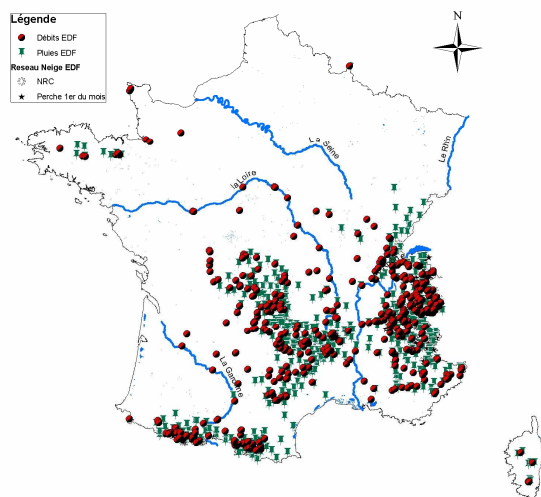Réseau hydroclimatologique EDF DTG au 31/12/2010

Fig. 1: Map of the EDF observation network

Stream gauging by tracer dilution is funded on the law of conservation of the mass. The method has been extensively used for a long time. Sensitivity improvement was achieved by better selection of the injected substance. At the origin, sodium chloride was employed. Later, the chloride salt was replaced by the dichromate salt. But the injected mass could still be very large, and this tracer was no longer environmentally acceptable. The use of fluorescent dye tracers was a decisive breakthrough since the injected mass could be reduced by a factor of 5000 (1g fluoresceine is equivalent to 5kg NaCl in terms of signal to noise ratio).

Two equivalent methods are used: the continuous and the global injection methods. In the first one, a concentrated tracer solution is injected at a constant flow rate. The calculated stream flow rate is inversely proportional to the tracer concentration in the stream. In the second method, a finite mass of tracer is quickly poured into the stream. At sufficient distance downstream, large enough to allow for perfect mixing of the tracer, an instrument (field fluorometer) is set to measure the tracer concentration at an elevated sampling rate (1 to 5s).

The stream flow rate Q is calculated as the tracer mass VC_1 divided by the surface of the breakthrough curve, where V is the injected tracer solution of concentration C_1 and C_2 is the instantaneous tracer concentration in the stream. The integration is done over the entire curve from time 0 to T:

$$Q = \frac{VC_1}{\int_0^T C_2 . dt} \qquad (1)$$

The continuous method can calculate the stream flow with only one concentration measurement. A sample can be collected and its concentration measured in the laboratory. The global method requires fast real-time measurement of the concentration. However, the continuous injection needs a special vessel, the Mariotte's bottle that supplies the stream with a constant flow of concentrated solution. This tool is cumbersome and heavy, unfit for transportation in mountainous areas. In addition, some local field laboratory operations are necessary. In this respect the global method is straightforward and more appropriate in difficult environmental conditions. This is probably the best method in terms of quality-price ratio in stream flow measurements (gauging). This technique is the most effective for gauging boisterous flows, such as can be found in mountainous areas. A field fluorometer (Fig. 2) is used for the real-time measurement of the tracer concentration (SCHNEGG, 2003). This is the same instrument in use for tracer tests. Since only one tracer is injected, only one (of the four) optics is set to work. But a high sampling rate is mandatory since the tracer plume can be as short as one minute. The next section explains how to make the most out of the global injection method.

Fig. 2: Field fluorometers (L: 2" downhole, R: surface waters) and a data logger with flash card and battery.

2. Results

The field fluorometer measures the tracer concentration at two-second interval some hundreds of meters downstream. For optimal precision we carry out a local calibration a few minutes prior to injecting the tracer. The fluorometer is switched on and immersed during 2 minutes in a bucket (Fig. 3) filled with exactly 4.950L of fresh stream water added with the content of a small bottle prepared in advance in the laboratory (50mL of rhodamine WT at a concentration of 10ppm). The concentration of this calibrating solution is exactly 100ppb.

This method allows for discarding all possible influences on the tracer, such as variations of the water chemistry, temperature, turbidity, pH and possible presence of bleaching chemicals (such as dissolved chlorine).

The large water volume prevents a quick warm-up, although the temperature is measured by the fluorometer and taken into account for correcting its effect on the fluorescence. We observe that simultaneous measurements at the same site produce results within as small as 0.2% variation.

Fig. 3: Rapid calibration with local water

Note that virtually any dye tracer can be employed. However sodium fluoresceine (uranine) is not advisable under high sunshine conditions. Naphtionate (and some others such as amino G acid) has the appealing property of being invisible. But usually, this is not a serious concern since the method gives very good results with a plume peaking at only 10ppb, which is below the sensitivity of human eye even with a bright tracer such as sodium fluoresceine.

At EDF the choice of rhodamine WT is based on a long practice. It is an excellent compromise between stability to UV light, sorption by the soil, sensitivity, eco-toxicity and price (YORKSHIRE CHEMICALS 2003).

Without stopping the data sampling, the fluorometer is then installed in the stream (Fig. 4). The background signal is recorded during a few minutes. Note that this background signal can be particularly high at the excitation wavelength used for naphtionate, due to the possible presence of DOC. For sodium fluoresceine or rhodamine WT, this level is usually below 1 ppb. Since the background is subtracted from the tracer signal, the only requirement is that the background signal remains stable during the measurement.

Fig. 4: Setup of the field fluorometers into the stream

The tracer is injected a reasonable distance upstream (Fig. 5). The success of the method relies on the perfect concentration homogeneity over a cross-section of the stream at the measuring point.

Fig. 5: Upstream injection of the tracer

Water concentration at the fluorometer is monitored in real-time. The value is displayed on the data logger or graphically plotted on a screen. Peak concentration in excess of 10ppb is not recommended because the water coloring becomes visible. In addition, higher concentration is useless since the smallest detectable variation is 0.1ppb, insuring high signal to noise ratio. When the tracer signal has returned back to its starting value, the acquisition is stopped, and the data downloaded and displayed on a personal computer running the dedicated program. Three segments of the breakthrough curve are selected in turn with two cursors: The background signal, the calibration mark, the entire breakthrough curve (Fig. 6, *last page*).

If the tracer can be suspected of being absorbed by water-driven solid particles, or chemically degraded, a forth data segment is measured with the fluorometer installed again in

the bucket before stopping the acquisition. The average of the two calibration measurements is used for the final calibration.

The program calculates the flow rate by applying the formula of the global method given in this paper. The error bar is computed as the sum of the volumetric errors from the vessel used for preparing the injection and calibration volumes. If the curve was not given enough time to return to zero, the program suggests extrapolating the missing tailing with a decreasing exponential function.

The local calibration of the fluorometer with water freshly taken from the stream is the key to the accuracy of the method. Note that the fluorometer is periodically calibrated in the laboratory with a series of standards (10ppb and 100ppb), but this operation is not critical. The response of the fluorometer to the concentration of tracer has about 15% non-linearity. Relying only on this laboratory calibration would lead to large flow rate errors (>20%), not because of the non-linearity, but due to the environmental factors (temperature difference, water quality, etc.) and the incredible variations of the tracer quality (50%) depending on the manufacturer. The local calibration is based on one concentration only (10ppb to 100ppb). It allows the fine adjustment of the vertical scale. One concentration is sufficient since the shape of the curve does not vary with the factors listed above. The only condition that really matters is that the injected tracer is also used for the local calibration.

3. Conclusions

The hydroclimatological network of EDF includes 320 gauging sites. The mastery of the gauging method based on the dilution of a fluorescent tracer is an effective tool for improving the knowledge of the mountainous hydrology. Using the global method with a field fluorometer is opportune in this respect. Suppressing all laboratory activities is an appreciable progress since the method does not make use of any specialized equipment. The direct access to the gauging results is a great advantage. In case of doubt, the operation can be repeated immediately, by varying sensitive parameters such as the distance of injection. EDF DTG

hopes that the method will allow a large number of hydrometric teams to carry out stream gauging.

After five years of EDF practice with the global method (and therefore with the fluorometer), the main source of error seems to be related with the quality of the mixing of the tracer into the stream water. More work must be done in this respect. Figure 7 shows the distribution of results compared with reference gauging. For newcomers to stream gauging it is advisable to start from the beginning with long distances between injection and sampling points.

The method is easily prone to telemetry (GPRS or SMS).

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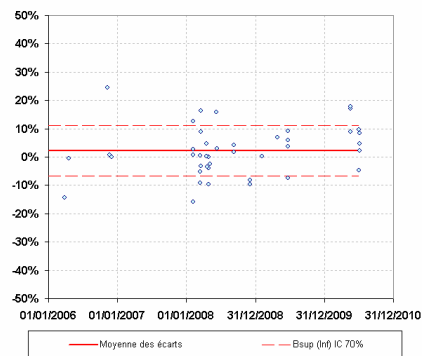
Fig. 7: Flow rate differences between the global method and a reference

References

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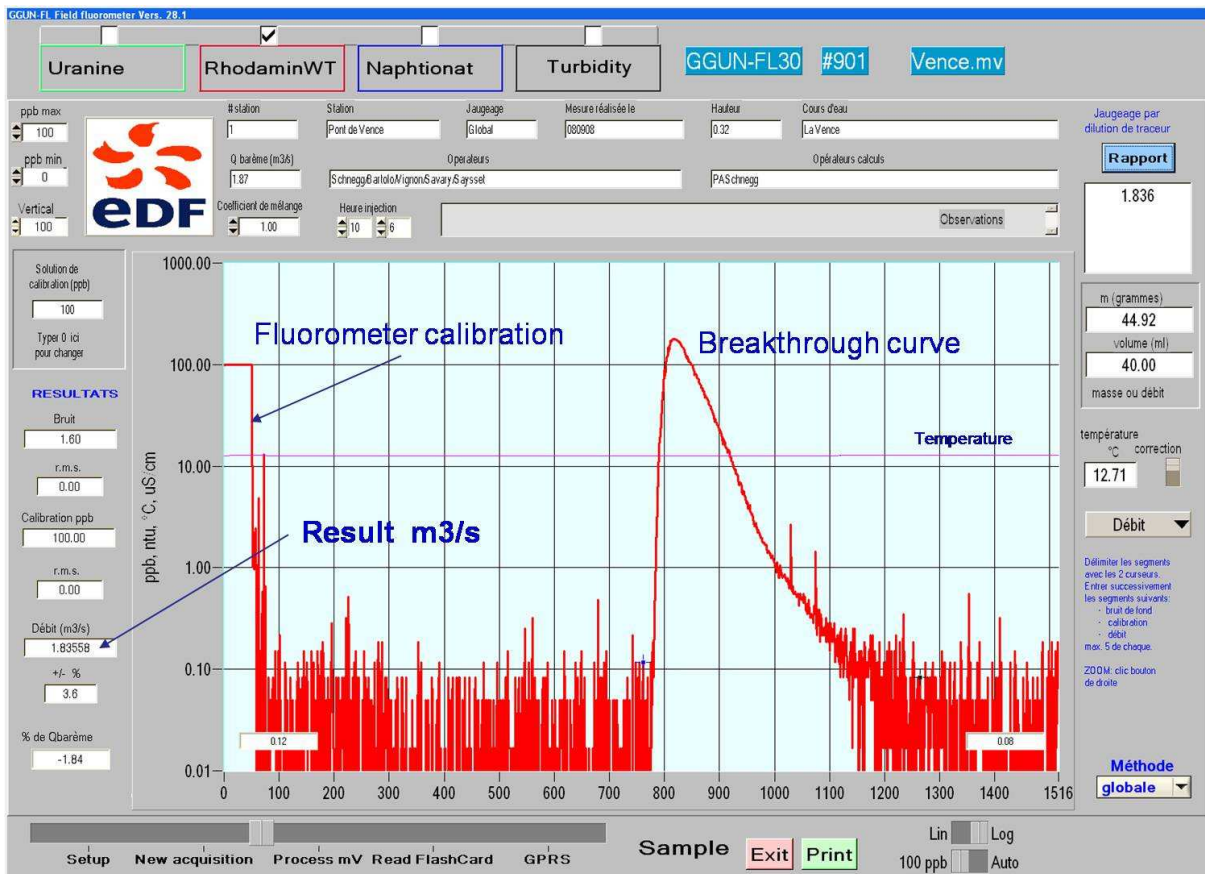YORKSHIRE CHEMICALS 2003., Fiche de sécurité du produit.

Fig. 6: Screenshot after data processing of a stream gauging with the global method using rhodamine WT as tracer. Sampling rate is two seconds. Three segments provide :

1) baseline (samples 100 to 780, no tracer in water),
2) calibration step at 100ppb and
3) breakthrough curve (logarithmic scale).

After selecting these three segments with the cursors, the resulting flow rate is computed with formula given in this paper, then displayed. The error bar is calculated from the sum of the volumetric errors from the vessels used for preparing the injection and calibration volumes.