Field fluorometer and injection device for gauging streams with fast variations

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I INTRODUCTION

When it is desired to measure the temporal evolution of the flow of a river in torrential, kinematic methods (reel, electromagnetic current meter) are not appropriate, because of turbulent flow types. Dynamic for their methods (weirs, calibrated items) require fixed installations whose costs do not generally fall into the budgets allocated. The method of choice is the chemical gauging or dilution method. It involves injecting a known amount of chemical and continuously measuring the concentration in the water downstream of the injection point. The substance may be ionic in nature (salt). Its concentration is then deduced from the increase in the electrical conductivity of the water. But usually a fluorescent tracer is used as the sensitivity of the measuring device (the fluorometer) is much higher. Indeed, for equivalent signal to noise ratio, 1 gram of uranine is equivalent to 5 kg of salt.

To study the temporal variation of a stream flow, we repeat the measurement at regular intervals. For this purpose, we developed a mechanical injection system based on the rain gauge bucket. This device periodically delivers a constant mass of tracer at a concentrated solution. A suitable distance from the injection site, we set a field fluorometer. At the end of work, successive measurements of the concentration of tracer are used to calculate the temporal evolution of the flow of the water.

II THE PRINCIPLE OF THE METHOD BY DILUTION

Flow measurement by means of the dilution method is based on the conservation of the mass of tracer which passes through any profile of the stream. There is a prerequisite for correct result: the homogeneity of the tracer concentration on a profile at the measurement location. A torrential flow promotes rapid mixing of the concentrated solution. A laminar flow, as observed in a channel, is not favorable. But in all cases, the operator must estimate the sufficient distance to be observed between the injection and measurement in order to perfectly meet this homogeneity requirement.

The calculation of the flow of the water uses the following information:

- Mass m of injected tracer (grams).
- Corrected tracer concentration $c(t)$ (grams/L) measured by the fluorometer along the time.

The flow rate (L/s) is obtained by (1) where t_1 and t_2 indicate any two times (in seconds) before the arrival of the plume and after full pass:

$$Q = \frac{m}{\int_{t1}^{t2} c(t)dt} \tag{1}$$

To estimate and take into account a potential level of noise c_0 of water (turbidity, traces of fluorescent substances) we must arrange a measurement interval before the first injection of tracer. The effective concentration of the tracer is $c(t)=c_m(t) - c_0$ where $c_m(t)$ is the measured concentration. The detailed procedure has been described in recent account reports [Schnegg et al, 2011]. It also emphasizes the importance of a local calibration of the fluorometer, using a standard prepared with the product to be injected and the water from the stream. This procedure removes multiple factors that may distort the original calibration: batch of tracer, temperature and water pH, turbidity, chlorine, etc.

III THE MEASURING EQUIPMENT

The measuring equipment consists of two devices:

- The tipping bucket, mounted on the injection site,
- The field fluorometer placed in the stream at a distance providing a perfect mixing of the tracer.

III.1 TIPPING BUCKET

The tipping bucket (Fig. 1) is a completely mechanical device, operating under the effect of the weight of the injection solution. It is supplied by a reservoir containing the solution of tracer to be injected. The tank (capacity of 2 L in this application) is placed on the protective enclosure of the device (Fig. 2), so that the liquid can flow by gravity. To maintain a constant flow and achieve a regular frequency of injection, this tank is a Mariotte bottle. A flexible tube leads the solution to the center of the system, from where it flows into one of the buckets. A tap allows flow adjustment.

The liquid fills the bucket which, when full, switches instantly in the inclined collector within the enclosure protection. The flow is driven through the axial bore provided with a flexible hose, which discharges the liquid in the stream. It is then the opposite bucket that fills and so on. The volume of liquid which triggers the tilting can be adjusted by stops located under the collector. This implementation allows for a maximum volume of 110 mL of solution per bucket.

The acrylic enclosure provides effective protection against the wind, preventing premature tilting. The leveling is necessary to ensure the symmetry of the mechanism. It is difficult to avoid a slight asymmetry in the left and right volumes. This does however not affect the accuracy of injected masses, since the device can be calibrated. To do this, we simply intercept the first two doses in a graduated cylinder. It is likely that this realization would be too small (currently: 3 kg), or unstable, for use in a rain storm or strong wind. Under these conditions, we simply suggest the use of a protective enclosure covering everything.

The major source of variation in tracer mass (or volume of solution) is caused by the imperfect drain troughs, and the collector terminal of the pipe, i.e. all the parts in contact with the solution. Fig. 2 shows the residual solution on the collector. One consequence is that the first round has a slight deficit of mass. It is therefore necessary to make one or two cycles to reach a steady state where the liquid residues remain more or less constant. This phase takes place just before the calibration described above. A significant improvement was obtained by depositing a hydrophobic film on the contact surfaces (silicone spray).

The flow (sometimes dropwise, if the injection interval is long) may also cause an early tilting under the effect of the impact of a drop. We avoid this problem by extending the end tube (syringe needle) with a wool wire, through which the solution flows smoothly.

Figure 1. Tipping bucket. The capacity of a bucket is 110 ml.

Figure 2. Enclosure protection against the wind. A Mariotte bottle delivers the tracer solution at a constant rate.

To quantify the variability of the amount of tracer, we measured during a day successive tilt volumes (Fig. 3). We note that the error on the mass of tracer injected (Table 1, 0.5%) does not contribute significantly to the total absolute error of the global gauging method (4%). As the driving principle is the balance of torque between the two trays, a temporal variation of density of the solution under the

effect of a change in temperature may affect the volume of fluid injected. Therefore, it is advisable to use the apparatus and the injection solution only when the equilibrium temperature has been reached.

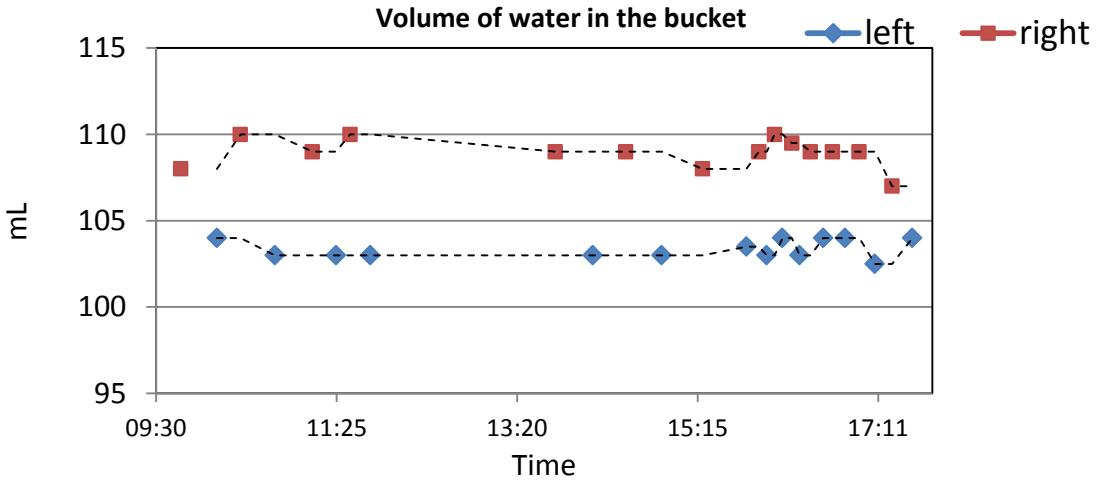

Figure 3. Measurement of the tilting volume. Solution provided by a Mariotte bottle. At the end of the test, the flow was deliberately increased.

	Left side	**Right side**
Mean	103,4	109,0
Std. deviation	0,5	0,8
Mean deviation	0,5	0,6

Table 1. Mean tilting volumes of the tipping bucket. Units : mL

III.2 FIELD FLUOROMETER

The measurement of tracer concentration in the stream is provided by a field fluorometer of type GGUN-FL30 (Fig. 4), developed at the University of Neuchatel [Schnegg and Doerfliger 1997] [Schnegg and Bossy, 2001]. The probe is placed on the bottom of the stream or hanging (Fig. 5).

Figure 4. GGUN-FL30 Field fluorometer probe. 160mm diameter.

Figure 5. Immersion in water. Mass of the probe: 7.5 kg

Water naturally passes through the optical cell of the probe (quartz tube). The fluorescence of the tracer is excited periodically (2 second intervals) by a light source and detected at 90 ° through properly selected optical filters. The detection limit of uranine is close to 0.02 µg/L (or ppb). The typical noise level of the water is 0.5µg/L.

Depending on the circumstances, other fluorescent substances can be used. Rhodamine WT has a higher resistance to bleaching by sunlight, but at equal signal, it uses eight times more. If the coloration of the river must be avoided, sodium naphthionate can also be used.

The probe is connected to a measurement box by a cable. The tracer concentration is recorded on a flash memory card. It can also be read on a liquid crystal display. This reading is of great interest because it ensures that the passage of the tracer is complete before the arrival of the next plume.

IV TEST MEASUREMENT

To illustrate the operation of the system, a gauging of a few hours was performed on a diversion channel of the river Areuse, 1200 meters from its mouth in Lake Neuchatel. The fluorometer was installed on the bed of the cemented canal, 50 cm from the edge. The injection site was located 430 meters upstream. On the upper half of the journey, the rugged configuration of the river has provided the right mixing of tracer.

The tipping bucket was installed on one side of the channel (Fig. 2). It was fed by a Mariotte bottle containing 2 liters of solution (uranine to 10 g/L). Some filling / emptying cycles were made before the actual measurement to establish a steady state for the residual liquid. These preliminaries also verified the amount of liquid delivered by the two buckets (100 and 107 mL for the left and right buckets). It goes without saying that the solution has not been released to the river, to avoid compromising future blank measurement. The flow of the Mariotte bottle was set at about 10 mL / minute, to ensure an injection every 10 minutes (which turned out to be a little too fast in this case).

After the last injection of tracer, the probe is immersed in a bucket containing a solution of 100 µg/L prepared on site with canal water (4950 mL of water containing 50 ml of a solution of 10 mg/L prepared in the laboratory from the injection solution). This saves a calibration step following concentration measurements. One calibration concentration is enough. Indeed, although the response of the fluorometer is slightly non-linear (approx. 10%), the probe is periodically calibrated in the laboratory with solutions of 1 at 100 µg/L, which allows to calculate the non-linearity. We found that all the calibration points lie on a straight line in a log-log graph of variables. The transformation of the signal (mV) in µg/L depends only on a multiplicative factor, the one obtained by the simple local calibration.

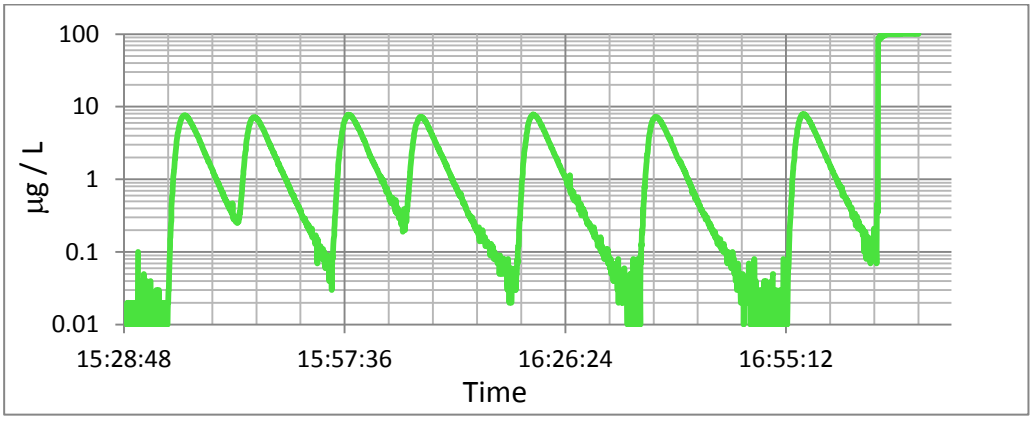

Figure 6. Concentration of the tracer (uranine) vs. time, measured 430 meters downstream of the injection. The signal / noise ratio obtained with 1 g of uranine is nearby 200 and provides low measurement error. The 100 µg/L plateau was obtained by immersing the sensor in a calibration solution prepared on site with canal water.

The flow rate of the water over time is calculated using (1) for each peak taking into account the volume of each bucket measured before injection into the channel. The results are summarized in Tab. 2. There was unfortunately no local parallel measurement of the flow, but we have verified that the flow of Areuse river at the junction of the canal remained constant during the gauging (ref. Swiss National Hydrological Service, 3003 Berne).

Plume timing		Calculated flow [m^3/s]	
Left side	**Right side**	**Left side**	**Right side**
-	15:36:44	-	0,737
15:45:48	15:58:06	0,710	0,716
16:07:36	16:22:12	0,706	0,707
16:38:10	16:57:36	0,708	0,705
Standard deviation = 0,011			

Tableau 2. Results of the gauging

It is likely that the first step is slightly biased upward because the decrease of tracer was stopped prematurely by the arrival of the second plume. If the first result is removed, the standard deviation drops to 0.004. It is of the same magnitude as the standard deviation of the injected. It also confirms that the relative error of a gauging whose injected mass is precisely known does not exceed 0.1%. The absolute error is related to the volume of the various operations necessary for the preparation of the calibration solution, some 4%.

V CONCLUSIONS

The combination of a tipping bucket and a field fluorometer allows for rapid series of measurements of the flow rate. No action is required as long as some solution remains in the tank. This example shows that a dose of 1g (100 mL) is sufficient to obtain a good signal / noise ratio in a stream with less than 1 m3 / s. We can estimate that the same device could be validly used to assess more powerful rivers, probably up to 10 m^3/s, injecting a commercial uranine solution to 100 g/ L. This concentration is also the value not to be exceeded during injection into a stream in order not to jeopardize the survival of microorganisms. But very quickly, the peak concentration reaches its equilibrium value between 5 and 50 μg/L, well below the standards.

Since the concentrations measured by the fluorometer are stored in the data logger, it is perfectly possible to transmit the results of each injection in real time on the internet by GPRS or on a mobile phone by SMS. It is only to retransmit the integral of the concentration between the first measurement and the successive returns to baseline, and not all of the measures (1800 per hour), a very small amount of data.

VI REFERENCES

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