A Downhole Fluorometer for Tracer Tests in 3" Boreholes

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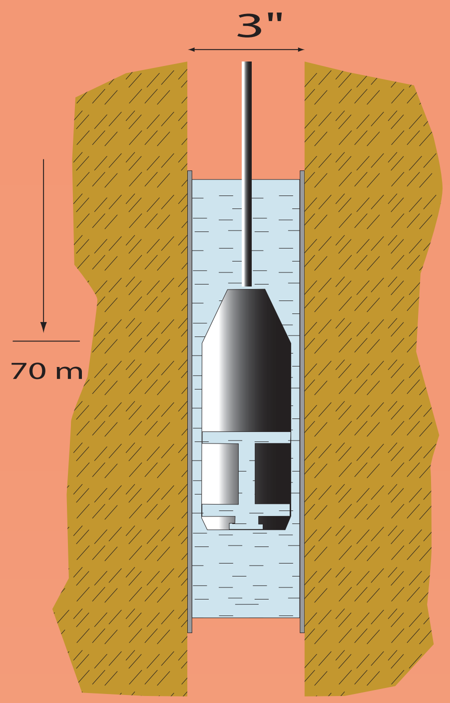


Fig. 1:
Fluorometer setup in a borehole. The system has been tested successfully under a water pressure corresponding to a depth of 80 m.

Fig. 2:
Downhole fluorometer FL10, showing lateral inlet/outlet holes.
Sonde diameter: 74 mm
Height: 200 mm

We describe here the principle and characteristics of a field fluorometer that was designed to provide automatic monitoring of tracer concentrations. Its shape and size allows its use downhole in boreholes with diameters of 3-inches and more to depths up to 70 meters (Fig 1) . A double-excitation, double-detection optical scheme permits simultaneous concentration measurements of two different dye tracers and water turbidity. The optical filter set is selected for the dye tracer pair described in Table 1, consisting of dyes with different optical properties. Thanks to a favourable separation of their characteristics in the visible spectrum, two tracers can be used simultaneously at two different injection sites. The instrument can measure the response of both dyes even when there is an overlap of the two tracing curves. Real-time measurement of the turbidity in the range of 0.02 to 400 nephelometric units is also of great interest.

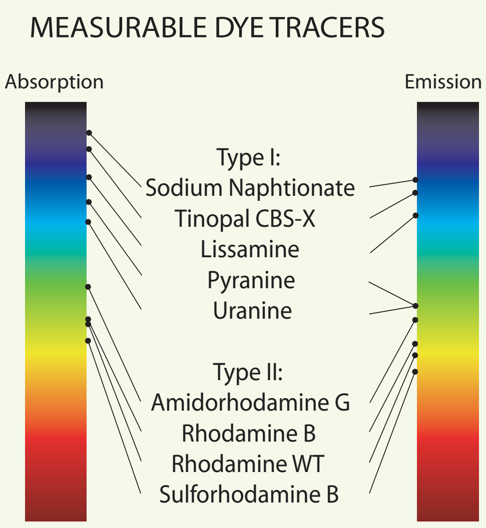
A flow-through field fluorometer can be used in water of various origins and chemistry to measure very small dye concentrations. We started down this path by first designing an automatic, inexpensive device, with the idea of replacing mechanical sampling systems because of their inherent disadvantages.

Recently, we have revised the design using smaller optical parts allowing us to drastically reduce the size of the fluorometer so that it can go down 3" boreholes. A related advantage was that tracer tests could be performed under sub-zero temperature conditions since the water no longer needs to be brought to the surface, but can be directly analysed with the fluorometer in place at the required formation depth.

The principal objective in the design of a new field fluorometer is to replace outdated and frequently impractical mechanical sampling systems. Three advantages favouring the use of field fluorometers are:

- Unlike mechanical water samplers, fluorometers have no moving parts, and therefore do not wear out. No pump is needed.
- The signal sensor is always completely immersed removing the risk of freezing and ambient air change affects on the measurements.
- Unattended measurements with a high sampling frequency can extend over weeks instead of the daily or hourly sampling and the related 24- to 48-bottle limitation that frequently limits mechanical device measurement programs.

The fluorometer probe (Fig. 2) connects to a water-resistant datalogger through a signal cable that can be up to 100 m long. The datalogger waterproof housing contains one or two rechargeable batteries providing the capacity for 2 to 4 weeks of unattended recording and the digital circuitry. The data is written to a rugged PCMCIA memory card with PC-interface compatibility. Other characteristics are in Table 1.

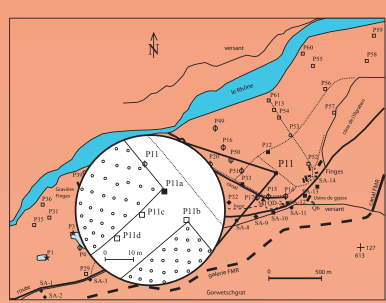


The double-excitation, double-detection optical scheme permits simultaneous concentration measurements of two dye tracers of different type (Type I and II).

Table 1:
List and spectral characteristics of dye tracers usable with the fluorometer.

Characteristics:

- **Usable tracers** : uranine, sulforhodamine B, amidorhodamine G, Rhodamine WT, naphtionate, Tinopal CBS-X, Lissamine, Pyranine, others.
- **Number of channels** : 4, including turbidity measurement 0.02 - 400 NTU
- **Sensitivity** : ~ 500 mV per 10-7 g/ml typical for uranine
- **Detection threshold** : 2 x 10-11 g/ml (uranine)
- **Signal noise** : 0.1 mV
- **Measuring intervals** : 10 seconds and 4 minutes. Other rates can be achieved.
- **Capacity of memory card** : 5123 x 6 samples (on SRAM 64kB PCMCIA)
- **Recording time** : 14 to 28 days (with 1 or 2 batteries)
- **ADC conversion dynamics** : 16 bits unipolar
- **Data storage / transfer** : on PC memory card / direct connect. via serial port
- **Power supply** : 12 Volt
- **Battery capacity** : 7 to 14 Ah
- **Stand-by consumption** : 5 mA with lamp off / 50 mA on. 700 mA for UV dyes
- **Weight (in working order)** : probe: 2 kg cable: 2.5 kg datalogger (1 battery): 6 kg
- Windows 95 /NT software tools.

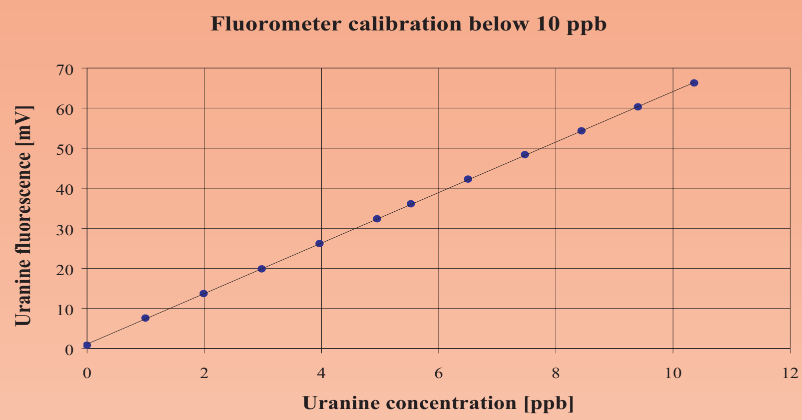


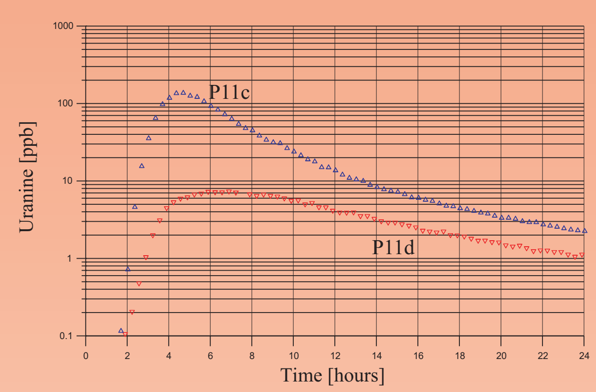
Tracer separation

It is often useful to inject different tracers from two locations during the same tracer test, for example to locate different pathways flowing to a spring or pumping well. By using different tracers at each injection site, the tracer data for each channel (u, s) are obtained subsequently, by processing the signals of the two receiving channels with the equation set

$$[u] = \frac{c_{22}x_1 - c_{12}x_2}{c_{11}c_{22} - c_{12}c_2} \qquad [s] = \frac{c_{11}x_2 - c_{21}x_1}{c_{11}c_{22} - c_{12}c_2}$$

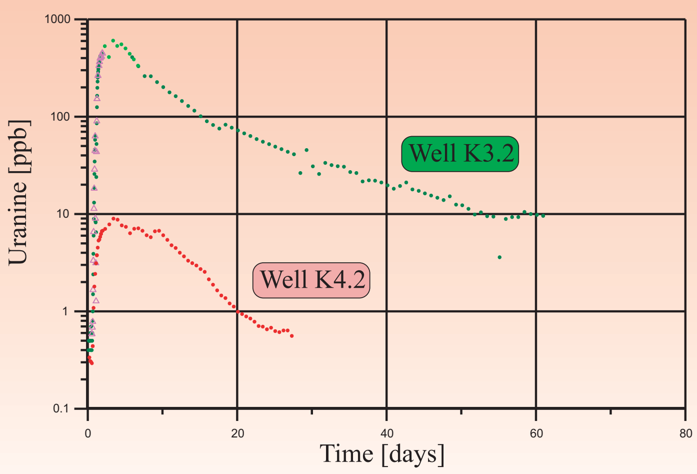
Two coefficients, c11 and c12 correspond to an excitation signal from source 1 of the uranine and sulforhodamine at a given concentration. Coefficients c21 and c22 correspond to source 2. The values x1, x2 are the voltages measured on the photodetectors. Using other fluorescent tracers is possible. However, to ensure good spectral separation, the optical filters must be chosen carefully, so that the denominator in the two equations does not vanish which would produce instabilities.



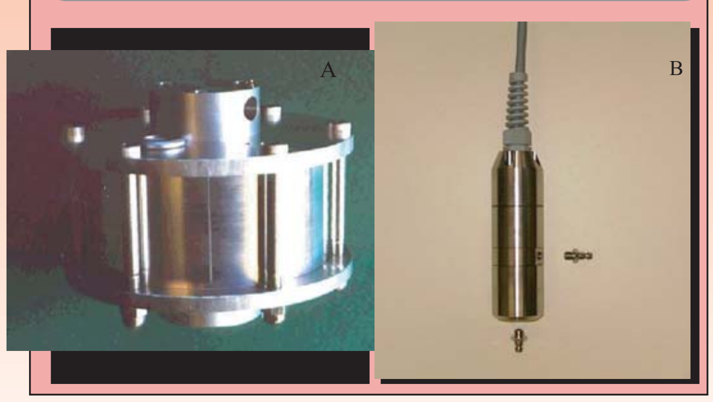


Tracer test carried out in the Rhone river aquifer (see map above). Upstream well P11c is equipped with a surface fluorometer with a pump flowing uranine. Well P11d has a downhole instrument with a pump circulating flow in the well. Only each fifth point is shown.

Tracer test carried out in the Swiss Molasse Plateau. A surface fluorometer monitors uranine at the injection well (K3.2), whereas a downhole instrument records the tracer concentration at a distant well (K4.2). Triangles denote concentration check carried out with an auxiliary fluorometer. Light green dots are obtained with the low gain input. Only each 300th point is displayed.



Other current developments:
A. Fluorometer for surface waters
B. Prototype for downhole probe with 2" diameter



Conclusion

The borehole fluorometer is a versatile, economical instrument. It makes the field work of the hydrogeologist easier. Compared to mechanical samplers, it has the advantages of first, dramatically reduced surveillance and maintenance, and second, greater versatility for longer term, more rapid and even real time data acquisition, observation and transmission over the net. With enhanced time resolution, this tool can now assist identifying the nature and extent of hydrogeological heterogeneity that previously was not possible. The results of tracer experiments can be seen 'as they happen' and used immediately. Finally, laboratory delay and expense, other than for confirmation samples, are dramatically reduced.