ADVANCES IN ULTRA-PORTABLE FIELD FLUOROMETRY FOR DYE TRACING IN REMOTE KARST

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Abstract

Dye tracing is a powerful tool in karst hydrogeology, allowing to specify groundwater connections, drainage organization and groundwater flow characteristics in impenetrable places (underground rivers, flooded caves...). The use of in situ monitoring devices enables improved investigation quality and efficiency during field work. Autonomous field fluorimeters developed in the last decades now give reliable data for dye tracing with fluorescent tracers, with a limited investment on the field and limited human resources.

Nevertheless, the karst environment remains difficult to access and explore with scientific equipment. The size, weight, robustness and user-friendliness of the tool is determinant to improve the efficiency of field work and allow the acquisition of reliable data. In order to tackle this issue, we developed the Fluo-Green field fluorometer. This is a compact, extra-light and 2-in-1 field fluorometer (probe and data-logger) designed specifically for karst environment. The fluorometer allows the monitoring of fluorescein, turbidity, and water temperature with a user-defined resolution (1 minute to 1 day). An improved management of energy gives an extended lifetime that is useful for monitoring in remote locations. The compact device is especially useful to carry into the field and facilitates the monitoring of multiple sampling points.

Several dye traces in Belgian karst show the field performance of the Fluo-Green (precision, accuracy, resolution, lifetime...). Different karst environments were investigated using dye tracing: underground rivers, flooded caves, karst springs, vadose percolations. Those experiences illustrate the routine use of the Fluo-Green in various remote karst environments.

Introduction

Dye tracing by the mean of fluorescent dyes is widely used in hydrogeology and specifically in karst systems. This field methodology helps to refine groundwater connections, drainage organization and groundwater flow characteristics. The exploration of underground and impenetrable flow systems within karst networks can also benefit from this tool, in addition to scientific characterization of the karst media.

The measurement of dye concentration in groundwater can be performed with different methodologies. The most widely used techniques are the use of charcoal bags, manual or automatic water sampling and continuous monitoring using automatic field fluorimeters. This last technique has many advantages such as the automatic measurement, a better temporal resolution, precision and accuracy, no sample transportation or analysis, no

contamination of samples. Broadly speaking, it greatly improves hydrogeologic understanding, all the while saving time, human resources, and field efforts.

However, field work and scientific monitoring in karst environments are often difficult to implement. Access and progression in caves with scientific equipment may be challenging, especially in hydrologically active caves. For this reason, field equipment has to be compact and easy to use in variable cases of study, and replacement cost must not be prohibitive.

In order to deal with the challenge of cave dye tracing, this paper presents results from the Fluo-Green field fluorometer (Poulain, 2017; Poulain et al., 2017), which is a compact and user-friendly fluorometer that is designed for cave use. The main characteristics of the device are shortly presented as well as two examples of comparative field results.

Fluo-Green Characteristics

The Fluo-Green fluorometer combines a fluorescence-turbidity-temperature probe and a data-logger in one small submersible equipment (Figure 1). A 470 nm channel is used to measure the fluorescein as it is the most used fluorescent dye in karst hydrogeology (Benischke et al., 2007). An additional 625 nm channel is used to measure water turbidity in order to evaluate possible interference with the fluorescence signal. The controller manages the measurement sequence with a user-defined time step between 1 minute and 1 day. Six AA batteries give a lifetime of 8000 to 9000 sequences (30 days for a 5 minutes time step). The data are stored on an internal SD card that can be read with a computer.

The routine laboratory calibration is made using 1, 10, and 100 ppb solutions in a calibration bath and a computer. Standard resolution for fluorescein ranges between 0.06 and 0.09 ppb. The watertight casing is suitable for rivers, cave percolations and shallow karst pools. It has been successfully tested at -4 meter depth.

Field Performances in Belgian Karst

Field tests were performed to measure the performance of the fluorometer: lifetime, precision, accuracy, robustness. The main objective was to evaluate the ability of a simplified material to give reliable data that are consistent with the objectives and context of the trace (user expectations, financial resources...). Several

Figure 1. Schematic view and photograph of the Fluo-Green field fluorometer.

environments were tested, mainly in karst: underground rivers, springs, pools, and percolations. Two comparative traces are presented here: (1) the monitoring of a karst spring with Fluo-Green and automatic groundwater sampling, (2) the monitoring of a cave river with Fluo-Green and a GGUN filter fluorometer.

Figure 2 shows the location of the two study sites in the south Belgium karst. They are two classical sinkhole to resurgence systems with discharge around 50 liters/second at the sampling points.

The first dye trace was performed in order to compare the monitoring results between 3 Fluo-Green units and automatic groundwater sampling combined with

Properties	Value
Size	10x16x21cm
Weight	2.75 kg
Channels	470 and 625 nm Fluorescein and turbidity
Turbidity range	0.08 – 200 NTU
Time resolution	1 minute – 1 day
Fluorescein resolution	0.06 – 0.09 ppb
Saturation threshold	3000 ppb (theoretical)
Temperature resolution	0.06°C
Maximum depth	–4 meters
Battery lifetime	8000 measurements with 6xAA batteries

Table 1. Fluo-Green characteristics.

Figure 2. Location of the study sites in south Belgium karst.

laboratory analysis (Figure 3). The lab analysis were made at the University of Namur using an Agilent spectrofluorometer. The Fluo-Green time resolution was 5 minutes and the water sampling resolution was 1 hour during 48 hours. The Figure 3 shows the breakthrough curve of this trace. The Fluo-Green breakthrough curves show the same results, there are also in good fit with spectrofluorometer analysis. The precision (3 synchronous measurement) and accuracy (comparison with spectrofluorometer) are very satisfying. Daylight noise is observable in the Fluo-Green results and can be corrected with differential measurement and additional smoothing of the data. A daylight cover should be implemented for such surface measurements.

The second dye trace shows the comparison between a Fluo-Green fluorometer and a GGUN FL30 fluorometer (Schnegg, 2002). The monitoring was performed in a cave river. Figure 4 shows the results with a strong similitude between the two breakthrough curves. The small difference may be attributed to the calibration procedures. This is a promising result because no additional filters are used on the Fluo-Green, which could be a potential issue for an accurate measurement of fluorescent dye. Dye tracing during stable conditions of turbidity and natural fluorescence may be performed in a reliable way using the Fluo-Green.

Conclusions

The objectives of this tool development were: (1) to provide a compact fluorometer that is useful to carry and

Figure 3. Breakthrough curves comparison between Fluo-Green and spectrofluorometer analysis in karst spring groundwater samples.

Figure 4. Breakthrough curve comparison between *Fluo-Green* and a *GGUN FL30* filter fluorometer in the Rochefort cave river.

use even in the most challenging places (exploration, remote cave systems...), (2) simplify the material in order to limit the cost, size and user's handling and (3) ensure that the simplification affects in an acceptable way the precision, accuracy and field capabilities of the device. The tool should be adapted to the scientific issue and user's expectations. Thus, the *Fluo-Green* can be considered as an ultra-portable field fluorometer that is specifically suited for short-terms experiments, accessible for cavers and field researchers. So far, these objectives were reached but there is still a need for complementary experiences about field use, material durability and results in variable environments. Further improvements are expected as field results will bring new experience in the near future.

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