Flow characterization in fractured black marls by single well pulse injection tests (Alpes-de-Haute-Provence, France)

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ABSTRACT: Single well pulse injection tests have been carried out in the Draix ERB black marls (04, France) to investigate recharge processes in stable shale rocks and the role of water flow on marl breakdown. Cross hydrochemical and hydrological monitoring from 5 boreholes made it possible to improve our knowledge of spatial heterogeneity of the system. Hydraulic conductivities are very low in such material (10^{-7} to 10^{-6} m.s^{-1}) but macropore flow from limits between lithological units proved very efficient for water and mass transfer. Forthcoming elaboration of a functional scheme of these hydrological processes will aim at improving numerical modelling of deep groundwater flow in landslide systems.

1 INTRODUCTION

Black marls hillslopes in the French South Alps are prone to weathering processes and landslides generation (Antoine & al., 1995; Malet & al., 2003). Few studies have been carried out on flow processes in stable fractured marl rocks. Bedrock is usually covered in weathered material and soils which makes the investigation tricky and expensive. Yet knowing and quantifying flows conditions in fractured marl bedrock and the hydrological interaction with the overlying weathered material are important issues for understanding rainfall-induced landslides generation and motion.

In July 2007, a single well pulse injection test has been carried out in the Draix ERB black marls (04, France) by using artificial tracers, Fluorescein and bromide.

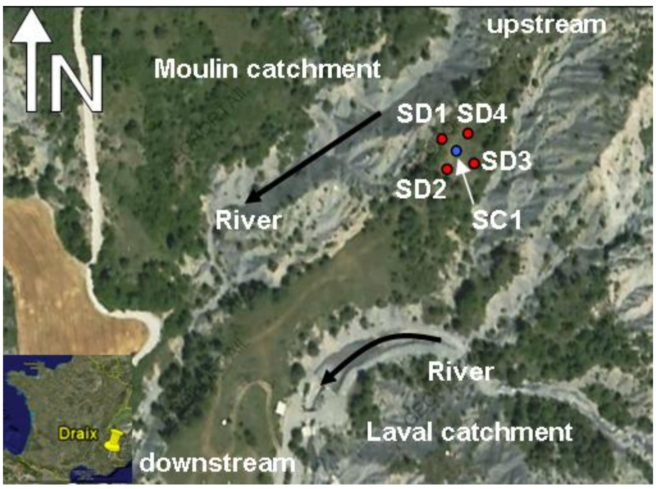

Figure 1. Localisation of the study site and the five wells.

2 SITE AND METHODS

2.1 Site description

The experimental plot is located in the Draix ERB black marls (Alpes de Haute Provence, France). It is a convex shaped watershed portion of 200 m^2 area. The elevation ranged from 880 m to 890 m NGF. The site is composed of a Pliocene colluvial argilo-calcareous material 2-6 m thick above the fractured marl bedrock. This topping enabled the bedrock to be protected from intense weathering. (Fig. 1)

2.2 Instrumentation

Five observation wells were installed in the shape of a cross. The well at the plot centre (SC1) is 20 m depth and the others (SD1, SD2, SD3 and SD4) are 25 m depth and 10 m apart from the centre well. A lugeon test was carried out in SC1 immediately after the drilling operation (LRPC d'Autun, 2007). The results showed that a discharge over 90 l.min^{-1} could be observed in the bedrock when high water pressure is applied (1MPa). Information about faults distribution and state (calcite filling level) has been provided from well logs and core samplings. 13 sedimentary units distributed over the bedrock (unit I), transition zone (unit II) corresponding to the weathered marls and colluviums topping (unit III) were defined from borehole diagraphy (Bondabou, 2007).

The observation wells SD1 to SD4 were instrumented with fluorimeters, electric conductivity sensors and water level sensors. Water samples and manually water level measurements were regularly made over the whole experiment period. The lower part of SC1 was isolated by packing off a 7-8 m thick section of the well.

2.3 Experimental procedure

On July 16th and 17th 2008, a known mass of tracers was added at the centre well (injection well) below the packer. Over the first day, the tracer used during experimentation (injection A) was fluorescein (packer at 12,5 m depth, injection mass: 23 g). Water was then injected at a low pressure (0.25 bars) during 13,5 h (2578 l). The second tracer test (injection B) started 11.5 hours after the end of the first experiment. A quantity of 1460 g of bromide (Br^-) was injected and the water pressure was between 1 and 2 bars (packer at 10,5 m depth). This experimentation lasted 7.83 hours (1451 l). Sampling rate was 15 min over the time of the experiment and varied from 2 h to 4 days over the remaining monitoring time (23/07/2008). Bromide was analysed in laboratory by liquid phase chromatography. The relative uncertainty including the measurement accuracy and the repeatability errors is less 3%. During the two injections SC1 water level was constant (883.81 m NGF).

3 RESULTS

3.1 Injection A

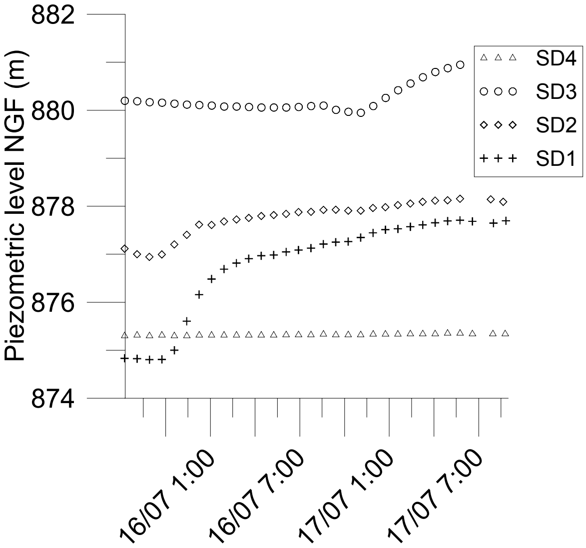

Figure 2. Piezometric levels during the injection A.

The hydrodynamic responses were very different from one piezometer to another. The first reaction was observed in well SD2 after 80 min of experiment. The hydraulic impact on SD1 and SD3 was observed 170 min and 13.5 hours after the start of the injection, respectively. The upstream well SD4 was the only one to remain unaffected. The steady state was not reached at the start of the second injection B as water levels in SD1, SD2 and SD3 were still increasing. The water level rose at a maximum of 2,5 m in SD1, 0,97 m in SD2 and 0,3 m in SD3.

The first results of the fluorescein tracing showed that the tracer was only observed in SD1 130 min after the start of the test. To date, calibration problems between the fluorimeter signal (mV) and laboratory analyses prevented any quantitative interpretation of the test.

3.2 Injection B

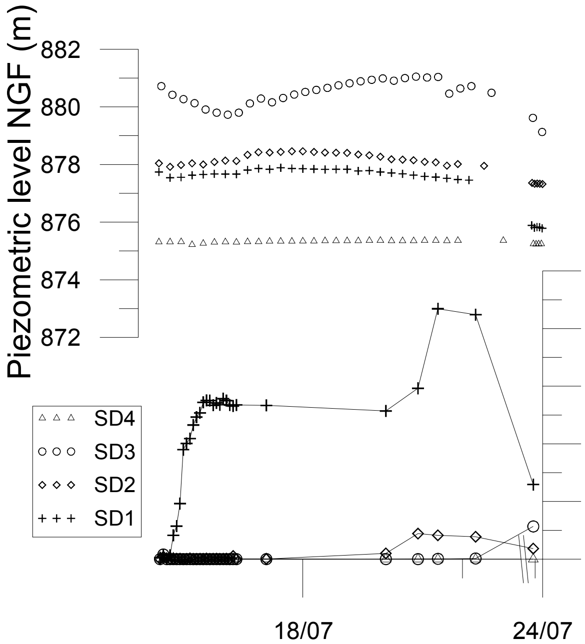

Figure 3. Piezometric levels and bromide concentration curves from the injection A start to 23/7/08.

Groundwater level variations were lower than for the injection A as a consequence of the water storage and progressive saturation of the material. Changes were similar in SD1 and SD2. In SD2, the water level decreased of 53 cm over the first 50 min of the experiment while in SD1 a decrease of 22 cm was observed in 70 min. This first stage was followed by a period of continuous rise with a maximum of + 52 cm and + 22 cm, 4 hours after the end of the experiment in SD2 and SD1 respectively. In SD3, the water level dropped of 1m over the first 7.83 hours of injection, then increased slowly up to a max of + 1m 3 days after. As for the injection test A, water level in SD4 did not change.

Unlike the results of injection A, the increase of water level was greater in SD2 than in SD1. It means that the solicited levels were different and the flow rates have changed.

In SD1, bromide was detected 60 min after the start of the test, whereas in SD2, the tracer was observed 11,75 hours after the end of injection.

The maximum concentration peak (217 $mg.l^{-1}$) was observed in SD1, 15 hours after the end of the experimentation.

In SD1, bromide concentration remained constant (between 133 and 139 $mg.l^{-1}$) over the last 4,5 hours before the end of injection. In SD2, bromide concentration was 20 $mg.l^{-1}$ over the 4 first hours after the detection of tracer. In SD3, bromide was observed 5 days after the experimentation with a concentration of 23 $mg.l^{-1}$.

These results illustrate the heterogeneity in the hydraulic properties of the material and show the role of preferential flow on the groundwater response in SD1.

4 INTERPRETATION

4.1 Transmissivity in SD1 and SD2 by Cooper-Jacob graphic method:

The piezometric variation during the injection A allowed calculating transmissivities in SD1 and SD2 using the Cooper-Jacob approximation (Cooper & Jacob, 1946):

$$s = \frac{Q}{4\pi T} \ln\left(\frac{2{,}25Tt}{r^2 S}\right)$$

$$T = \frac{2.303Q}{4\pi\Delta s} \tag{1}$$

where T = transmissivity ($m^{-2}.s^{-1}$) ; Q = injection rate ($m^3.s^{-1}$); s= drawdown (m), Δs = water level variation (m/log unity), t=time (s), r = well radius (m), S=specific yield.

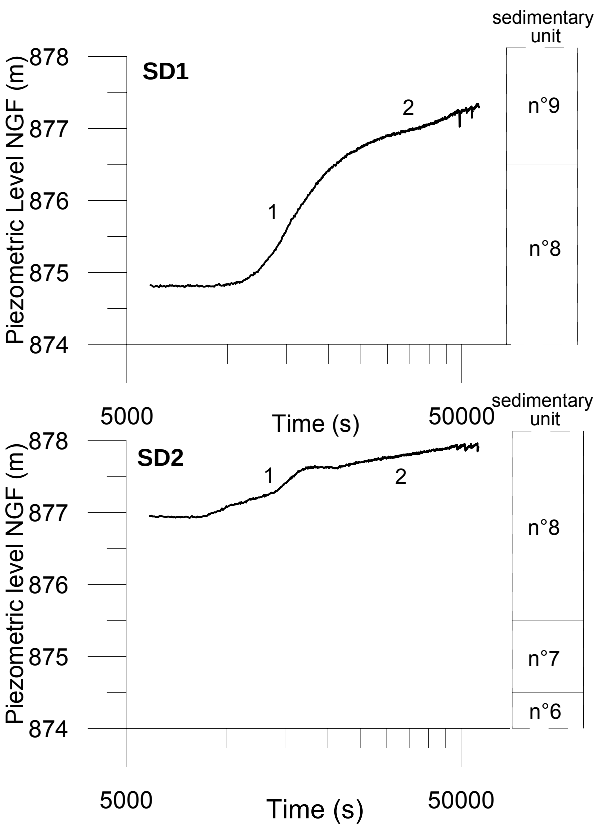

Figure 4. Variation of the piezometric level according to time log during injection A in SD1 and SD2. Numbers corresponds to the different gradients of the notable segments on the curve.

A plot of drawdown s' vs. log of t usually forms a straight line. T is calculated from the slope of the relation. In our case, several lines were observed as a consequence of areal variations in the hydraulic properties. Table 1 shows the transmissivity calculated from each segment of the plot.

Table 1. Transmissivities and permeabilities calculated for SD1 and SD2.

	SD1		SD2	
	T ($m^2.s^{-1}$)	K ($m.s^{-1}$)	T ($m^2.s^{-1}$)	K ($m.s^{-1}$)
1	$3.40.10^{-6}$	$1.95.10^{-7}$	$3.33.10^{-5}$	$1.71.10^{-6}$
2	$1.04.10^{-5}$	$5.77.10^{-7}$	$1.14.10^{-4}$	$5.77.10^{-6}$

On Figure 3, SD1 and SD2 curves had a first part with a slope less important than the second one. Respectively for SD1 and SD2, the transmissivities calculated were 3 and 3.5 times lower on the first parts of the curves, but in SD2 transmissivities were 10 times higher than in SD1.

In SD1, the piezometric level was ranged between sedimentary units 8 and 9, whereas in SD2, variations were in the unit 8. Sedimentary units 8 and 9 were at the interface between the bedrock (unit I) and the transition zone (unit II) with an important fracturation. For SD1 and SD2, the variations of the transmissivities were corresponded to a lithologic change, with a transmissivity lower for the unit I than for the unit II.

The horizontal slope visible on the figure 3 was corresponded to a permeable zone which could be interpreted as a zone with a high fracturation density.

These results were shown the role of the fracturation in the processes lateral flows and the spatial heterogeneity of the soil.

Discharge in SD1 and SD2 by Darcy's equation)
The discharges in SD1 and SD2 could be calculated with the Darcy's equation during injection B by using permeability computed in §4.1.

$$Q = Kai \tag{2}$$

where Q = discharge (m^3/s); K = permeability (m/s); a=cross sectional section area to flow (m²); i = piezometric gradient between SC1-SD1 or SC1-SD2.

Permeabilities values chosen are 5.1110^{-5} $m.s^{-1}$ for SD1 and 5.7710^{-6} $m.s^{-1}$ for SD2 because they correspond to the highest water level for injection A.

The discharges calculated are 6.810^{-4} l/min in SD1 and 9.710^{-2} l/min in SD2.

4.2 Bromide mass found in SD1 and SD2

With equation 3, bromide mass could be calculated in SD1 and SD2 between the 17/7/08 and the 23/7/08.

$$M = Q \,.\, \int C.dt \tag{2}$$

where M = bromide mass (mg); Q = discharge ($l.min^{-1}$); C = bromide concentration ($mg.l^{-1}$); dt = time since the start of the injection B (min).

Bromide mass found was 2 g and 4.2 g in SD1 and SD2 respectively. These values were very low compared to 1460 g of bromide injected. This result suggests that most tracer was transported according a dispersive way without taking preferential pathways.

The discharge through SD1 was lower than through SD2, although bromide has been detected earlier in SD1. Bromide concentrations measured in SD1 were higher than in the other piezometers. Consequently, the effective porosity was lower between SC1 and SD1 than between SC1 and SD2. (actual water velocity is higher).

5 CONCLUSION

The first results of this experimentation by injection have contributed to describe the nature of the water flows encountered in stable marl hillslopes. Lateral flows seem to be organized in the unit II, zone which was fractured. So in this context, the fracturation had an important role in the processes flows. The flows directions are not necessarily stressed by the topography, stratigraphy and schistosity. This result reveals the macroporous nature of the flow. These first data constitute a starting point for the fitting of the numerical modelling of the groundwater flows in stable marl hillslope.

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