Quantitative analysis of preferential flow during small scale infiltration tests on an active mudslide, Super-Sauze, South French Alps

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ABSTRACT: Precipitation is one of the major landslide triggers and rainfall patterns control temporal behaviour of landslides. Although the importance of fast preferential infiltration is recognized in literature, its quantification remains difficult. Three infiltration experiments were carried out in the black marls mudslide of Super-Sauze in the Southern Alps of France. The aim of the experiments was to study the hydrological system within three morphologically different parts of the landslide. Special attention was given to characterise preferential infiltration patterns (through the fissure system). Infiltration processes and travel time distribution were monitored with hydrological observations and hydrochemical tracers (Br^- and Cl^-). Furthermore, high temporal and spatial resolution 2D electrical resistivity tomography (ERT) was used to derive a detailed subsurface image of the soil and hydrological dynamics.

1 INTRODUCTION

Precipitation is one of the major landslide triggers. Rainfall patterns control temporal behaviour of landslides and their displacement dynamics. To make progress in mountain hydrogeomorphological hazard analyses, it is necessary to quantify the groundwater recharge processes and in particular take into account preferential infiltration of rainfall (Savage et al., 2003; Coe et al., 2004). Although the importance of fast preferred infiltration (for example through the fissures) is recognized in literature, its quantification remains difficult.

This paper presents the results obtained during small scale infiltration experiments that aimed to study and quantify the role of preferential flow in highly heterogeneous mudslide of Super-Sauze, in Southern French Alps.

2 SITE DESCRIPTION

The Super-Sauze mudslide has developed on the South slope of the Barcelonnette basin (Southern Alps, in France) in an enclosed marly torrential basin gullied by badlands. The landslide is located between 2105 (crown) and 1740 m (toe of the flow). It covers 0.17 km^2 with average slope of 25° (Fig. 1). The total volume of the landslide is approximately 750.000 m^3 and the velocities vary from 0.01 to 0.4 $m.day^{-1}$ (Malet et al. 2005). The Super-Sauze mudslide consists of strongly heterogeneous clayey material, reworked blocks of marl at various stages of weathering, clasts of all sizes immersed in a silty-clay matrix (Malet et al., 2003).

There is very limited vegetation cover over the whole area. The exception is the more stable part on the Western side of the landslide, where some shrubs grow.

3 METHODOLOGY

Three 1x1 m^2 infiltration experiments were carried out, between 20 and 25 July 2008, in the black marls mudslide of Super-Sauze. For the experiment plots of 1x1m dimensions were selected to represents morphologically different parts of the landslide (Table 1). For each plot two periods of 7-8 hours artificial rain was applied with the use of rain simulator, which consists of a pomp, a pipe system for water transport and a nozzle with known characteristics (drop size, spray angle and spray pattern).

The rain was applied in time blocks of 15 min rain and 15 min break with average intensity of approximately 50 $mm.h^{-1}$. In order to protect the experiment from wind disturbances and to minimize evaporation the rainfall infiltration area was covered with a tent (figure 2). Manual and automated measurements of the groundwater level were done to monitor local hydrological response of the area. At each plot, 4 piezometers were installed: one in the middle of the plot, 2 in the direction of expected (sub-) surface water movement and one uphill from the plot as a reference (Fig. 3).

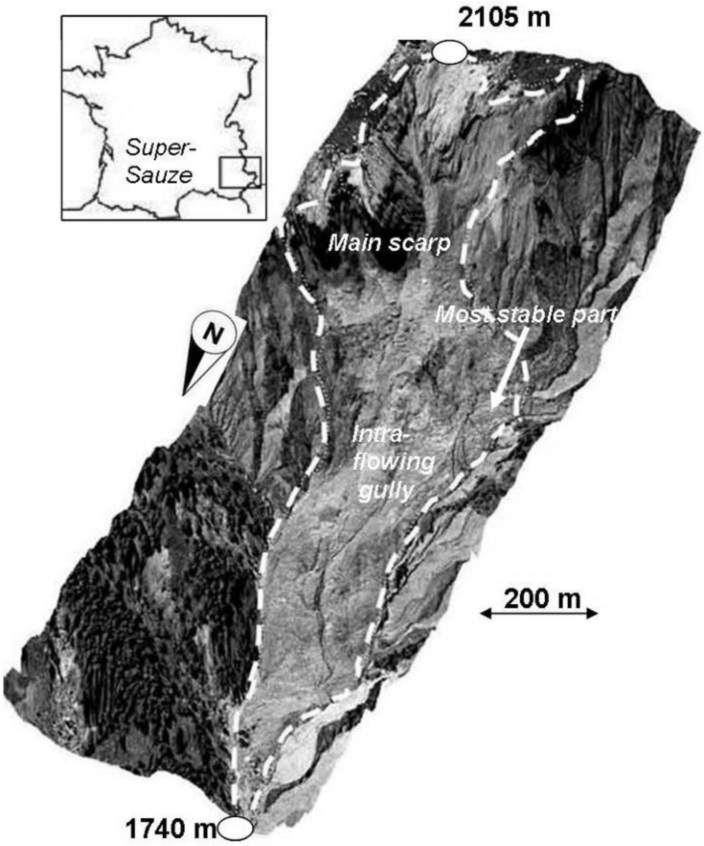

Figure 1. Super-Sauze mudslide morphology characteristics.

Piezometers were installed by using of open PVC standpipes (50 cm filters). Filters were carved in manually and covered with standard filter protection and surrounded by filter sand closed with granular bentonite. The depth of the piezometers is different at each area and depends on local hydromorphological conditions:

- within plot "A" all piezometers were installed at around 2 m depth;
- within plot "B" depth of the piezometers was determine by presence of rocks in the soil and its vary from 3 to 1.30 m;
- within plot "C" depth of the piezometers is around 1m due to the shallow ground water level.

Moreover, the chemical tracers (Br^- during the first day of experiment and Cl^- during the second day of experiment) were applied with artificial rain water to trace infiltration processes and to determine the travel time distribution. The water sampling was done manually, every hour from the piezometers and analyzed in the laboratory.

Furthermore, high-resolution 2D electrical resistivity tomography (ERT) was used to derive a detailed subsurface image of soil and ground water dynamics in the cross-section of each plot. The infiltration experiment was monitored by measuring the electrical resistivity variation in dipole-dipole configuration. The cross-section followed the local slope direction. Electrode spacing was 0.5 meter, the total length 12 m and the acquisition was carried out every 2 hours.

Figure 2. Preparation of infiltration experiment plots.

Table 1. Basic characteristic of the infiltration plots.

	Plot A	Plot B	Plot C
Location	Just below main scarp	Western part of landslide, most stable part	Deposit area of the mudslide, active area
Material	Dry reworked marls with limited degree of weathering	Dense black marls with big stones	Mudslide deposit
Fissures	Big, undulating, filled with material perpendicular to the slope direction	No visible fissures	Big, undulating fissures, partly filled with material, wet, various direction

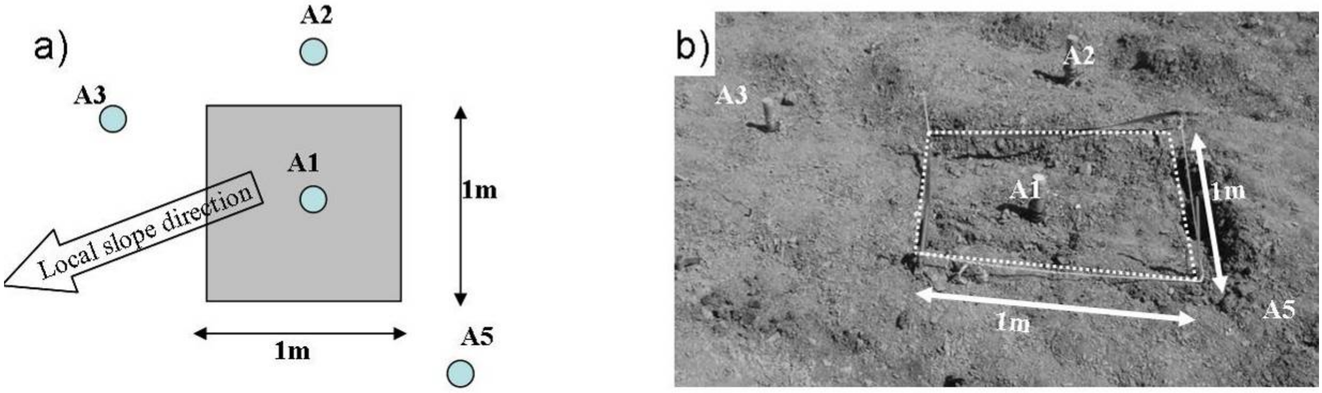

Figure 3. Installation of piezometers (A1-A5) within plot A.

4 ANALYSIS OF INFILTRATION EXPERIMENT

Within each plot different hydrological response was observed. Table 2 shows measured components of the water balances for each plot.

Within plot "A" neither surface nor subsurface runoff was observed. Ground water level fluctuation in piezometer A1 during the first rain period shows very fast vertical movement of water (Fig. 4 a). The significant rise of the piezometric water level during 15 minutes of rain is followed by fast drop of water level in the 15 minutes break time. Hence, infiltration capacity of experimental $1m^2$ is more than 50 $mm.h^{-1}$ (which is applied rain intensity).

The mixing process is very clear on plot "A". The Br^- concentration changes with time show that there is pre-event water in the system that can readily move and "dilute" the infiltrating rain water. This high capacity of water remobilization indicates that water is stored not only in the matrix but also has to be stored in macropores (e.g. fissures). After the rain infiltration experiment concentration of the Br^- stayed at a high level which confirms that water is temporarily stored in the fissures. Within 4 hours after the end of the experiment the system comes back to its initial condition. This clearly shows that within plot "A" hydrological processes are strongly influenced by the system of deep fissures that drains the water out of the experiment area.

The area "B" is generally wet and there is significant amount of antecedent water in the system. The Br^- concentration is relatively constant during the first rain experiment (Fig. 4b) and remains constant during the second period of rain (with chloride as a tracer). Also the Cl^- concentration remains high long after the second experiment. This means that there is limited contribution of pre-event water but relatively high capacity of storage and restitution by fissures of short residence time waters. The low concentration of the tracer in the ground water is the effect of the properties of the medium (lower hydraulic conductivity and higher dispersivity compared to plots "A" and "C"). Hence, the tracer reactivity is smoother (damped and delayed).

On the contrary of the dynamics of plot A, the infiltration capacity of the "B" area is limited. More than 60% of rain water leaves the system as a surface runoff (table 2). Moreover, during the entire experiment ponding was observed within the 1 m^2 area. It can be concluded that infiltration rate of this area is less than 15 $mm.h^{-1}$. The ground water responses show similar temporal behaviour as the application scheme of the artificial rainfall, block of 15 minutes. Generally, a ground water level rise is observed, and the hydrological system is not back to its initial condition within 12h after the experiment.

Table 2. Basic components of water balance for each infiltration plot.

	Plot A		Plot B		Plot C	
	Rain 1 (7h)	Rain 2 (8h)	Rain 1 (7h)	Rain 2 (7h)	Rain 1 (7h)	Rain 2 (8h)
Rain volume and intensity	351 l ~50 $mm.h^{-1}$	395 l ~50 $mm.h^{-1}$	343 l ~47$mm.h^{-1}$	362 l ~51 $mm.h^{-1}$	443 l ~62$mm.h^{-1}$	529 l ~62 $mm.h^{-1}$
Surface runoff	No surface runoff		224 l ~32$mm.h^{-1}$	226 l ~32.3 $mm.h^{-1}$	No surface runoff	
Subsurface runoff	No subsurface runoff observed within experiment area		No subsurface runoff observed		185.8 l	303 l

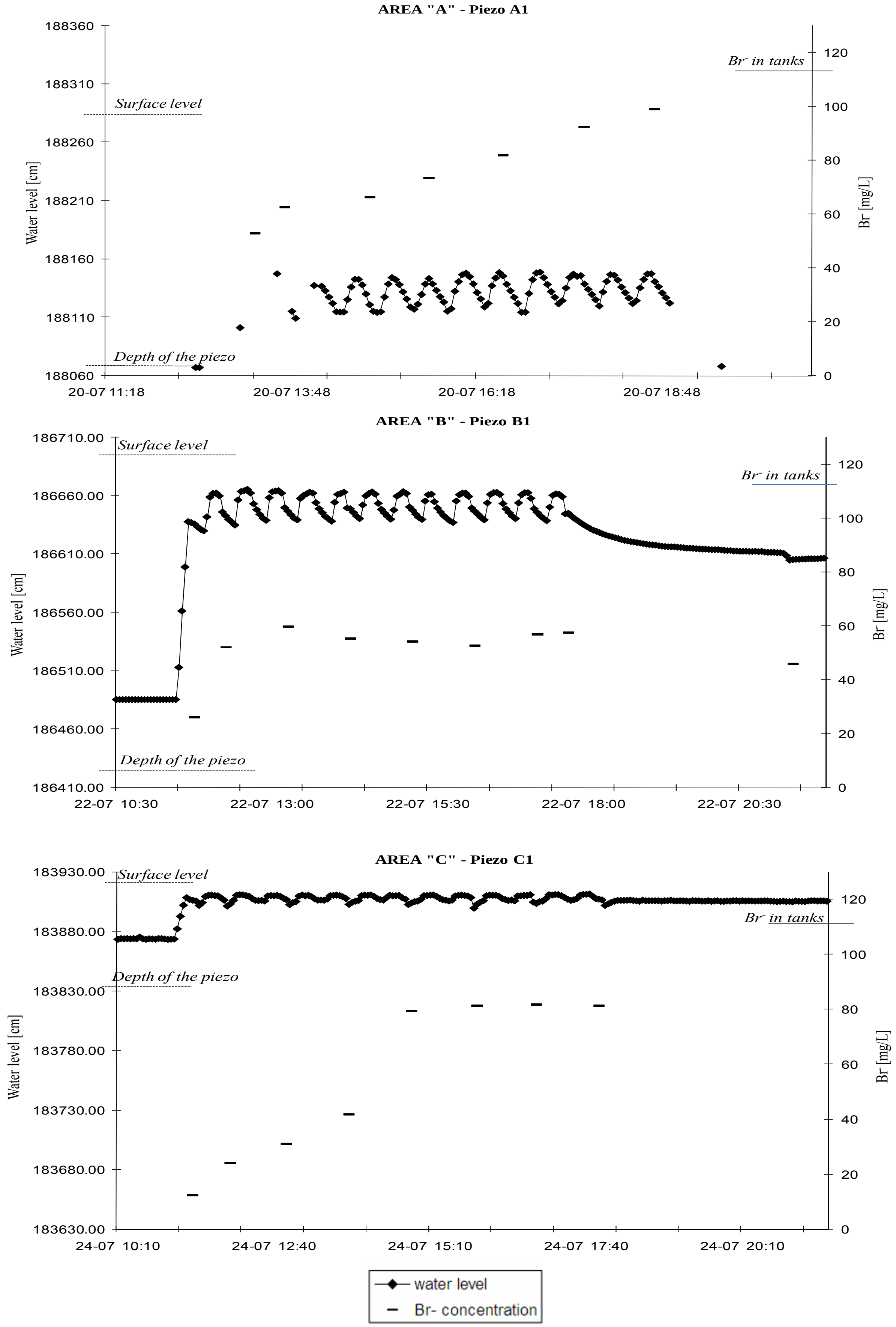

Figure 4. Ground water responses in the piezometers A1, B1 and C1 during first rain period and corresponding Br^- concentrations.

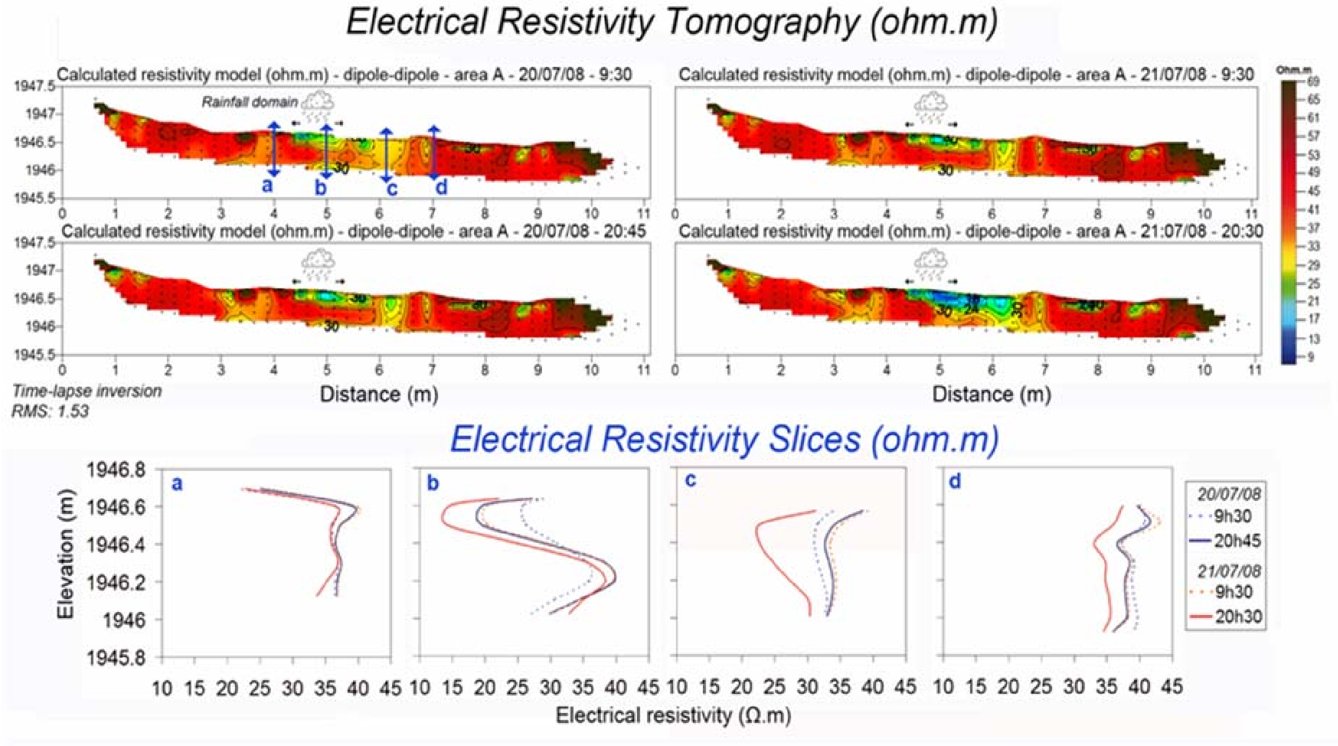

Figure 5. Electrical resistivity tomography results for the area “A” (Ponton, 2008).

This indicates that plot “B” represents matrix-like infiltration behaviour.We conclude that there is limited fissure system present in this area. Plot “C” is located on a mudslide deposit area with shallow ground water level (35-55 cm below the surface). The Br^- concentration rises quickly and stays high (Fig. 4c). During the second day of experiment, when Chloride is applied, concentration of Br^- drops fast while Cl^- concentrations remain high. It shows that limited confined reservoir (fissures system with poor relation with its near environment) is completely filled over the first rainfall simulation and is poorly drained. When the second rainfall starts, the new water replaces almost entirely the previous waters (Br^- near zero and Cl^- max). Thus, in this case the “old” water is stored in matrix around but can not be mobilized.

The presence of a wide open fissures system (up to 5-6 cm) influences infiltrating water distribution. Water is drained out of the experimental area through this system and transported to a small stream at 2 m distance from the plot. Subsurface runoff is around 50% of the applied rainfall. The infiltration capacity of the area is difficult to estimate.

Hydrological and hydrochemical observation were compared with ERT measurements. Figure 5 shows the contrast (in term of resistivity) between the volume of ground influenced by the artificial rain and the surrounding ground. During two days of infiltration experiment a front of low resistivity was developed laterally (in a layer thickness approx. 0.3 m). Additionally, during the second day of the experiment, vertical (up to 0.5-0.6 m) development can be observed.

The resistivity variations can be related to the variations of soil water content. Decrease in resistivity in the first soil layer (30cm) corresponds to increase of the water storage in this layer. Development of the low resistivity zone can be associated to the lateral and vertical migration of a front of infiltration and thus highlight the hydrological processes of preferential flow.

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