Role of hydrological process in landslide occurrence: Villerville-Cricqueboeuf landslides (Normandy coast, France)

C. Lissak & O. Maquaire
UMR 6554 CNRS, LEGT- Geophen, University of Caen Basse-Normandie, Caen, France

J.-P. Malet
CNRS UMR 7516, School and Observatory of Earth Sciences, University of Strasbourg, Strasbourg, France

ABSTRACT: In Normandy, along the Calvados coast, the 12 km long Pays d'Auge section is periodically affected by rotational and translational landslides. In January 1982, major landslides (3m high scarp) have caused several damages to property. In this paper, we focus our attention on the relationship between precipitation and groundwater fluctuations linked to Villerville–Cricqueboeuf landslide crises. Through these preliminary results coming from comparative analysis of twenty years of survey we have reached first insight in the groundwater level threshold for these landslides and have got a better understanding of the internal coastal slope behaviour.

1 INTRODUCTION

The Calvados coastal slopes are frequently affected by landslides for several centuries particularly at the Pays d'Auge coast (Fig. 1). These two actives landslides (Varnes 1978) called Cirque des Graves near Villerville and Fosses du Macre near Cricqueboeuf are slow moving landslides but reactivated by spectacular crises (Maquaire 2000). In the Cirque des Graves landslide, the first time failure occurred the 10/11 January 1982. Several houses have been partially or totally destroyed and the departmental road has been cut at different points (Flageollet & Helluin 1987). After this first major event, three crises occurred in February 1988, January 1995 and March 2001. These reactivations caused different damages and the extension of the active zone (Maquaire 2000). All reactivations occurred in winter after freezing and heavy rainfall period.

Therefore, the field survey focus, since 1984 on the hydrological characteristics of the landslide to understand the hazard process. A field monitoring network was set up initially in 1984 but only completed in 2007.

Climate forcing is known as one of the major landslide triggers (van Asch, 1999) and this paper aims to illustrate the relationship between climatic conditions - groundwater changes - displacements but specific threshold cannot be defined yet.
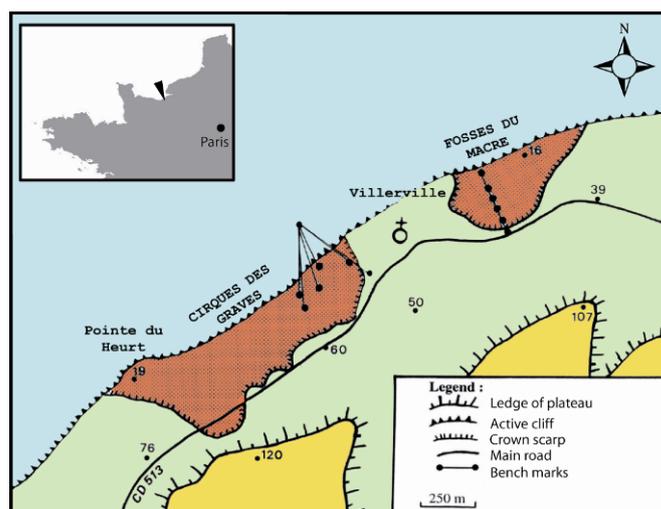
Figure 1. Map of Villerville-Cricqueboeuf landslides. Geographical setting

Both study areas (Villervile-Cricqueboeuf) are located on the Pays d'Auge plateau which is bordered by very high cliffs (up to 140 m). The geologic structure and topography are heterogeneous. The main scarps of these rotational and translational landslides are several meters height, defined in Cenomanian chalk resting on Albian glauconic sand (Fig. 2). At the toe, the scarp is more gentle and relatively straight (Maquaire 1990, Flageollet & Helluin 1987).

Both unstable zones are characterized by superficial material composed of blocks, debris of chalk, flints and loess (Fig. 2).
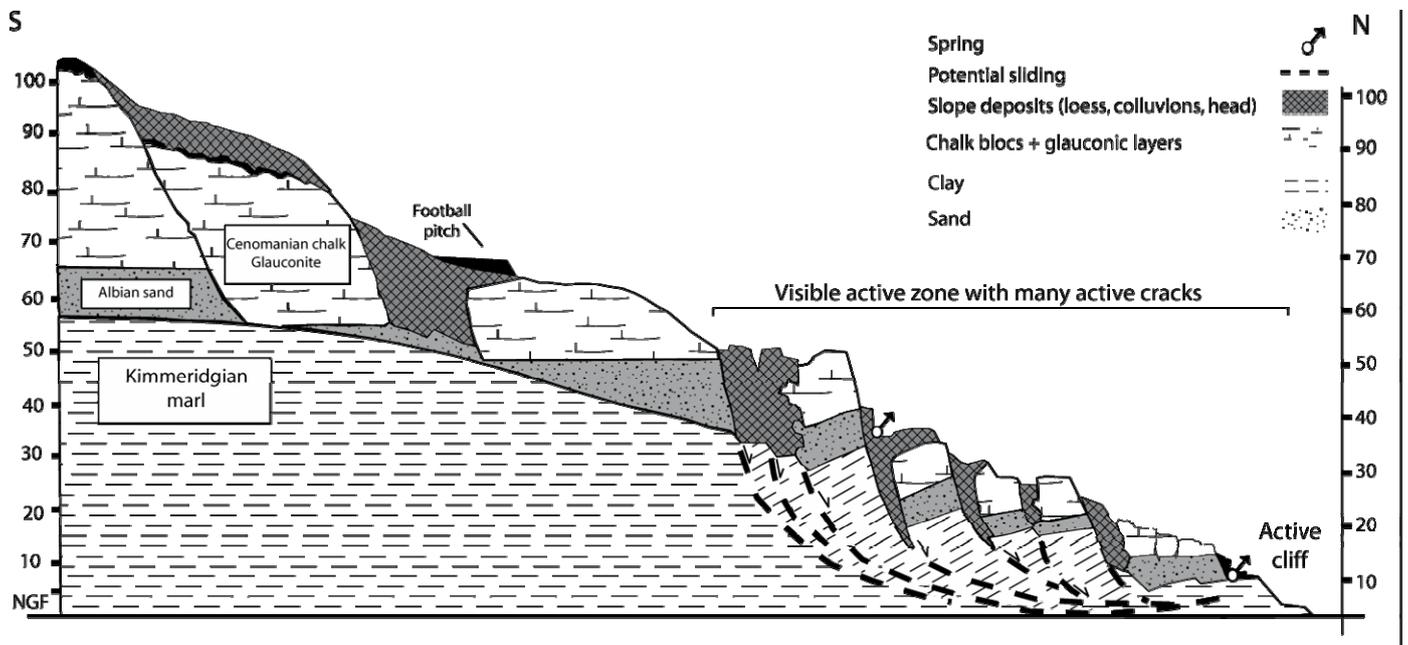
Figure 2. Geological profile show different parts of the landslide (Location in Fig. 3).

The slope morphology and the geologic structure increase landslide susceptibility. Frequent water resurgences and springs along the slope could be explained by a complex and dispersed underground network of deep water tables and subsurface water tables. The groundwater system discharges into the sea which and in such contribute to the slope erosion. The role of sea erosion on the slope instability is an important factor but not studied in this paper. Normandy is characterized by an oceanic climate with an annual precipitation which varies from 600 to 1150 mm with an average of 870 mm (period 1949-2007).

2 MONITORING AND METHODS

The 1982's first time failure introduced studies to the rotational and translational landslide mechanisms of this area. In 1984 a first field monitoring system has been installed.

To analyse hydro-climatic conditions of displacements, the actual network (Fig. 3) is constituted by eighteen cemented ground benchmarks to evaluate surface displacements, three inclinometers, twenty-one wells and ten piezometers in order to analyze landslide kinematic and groundwater level variations.

Four piezometers are equipped with automatic water level recorders. Also the pore pressure and the climatic data will be recorded continuous.

Only the surficial displacements are measured with discrete intervals (1 time per month) and have been interrupted several years until January 2008.
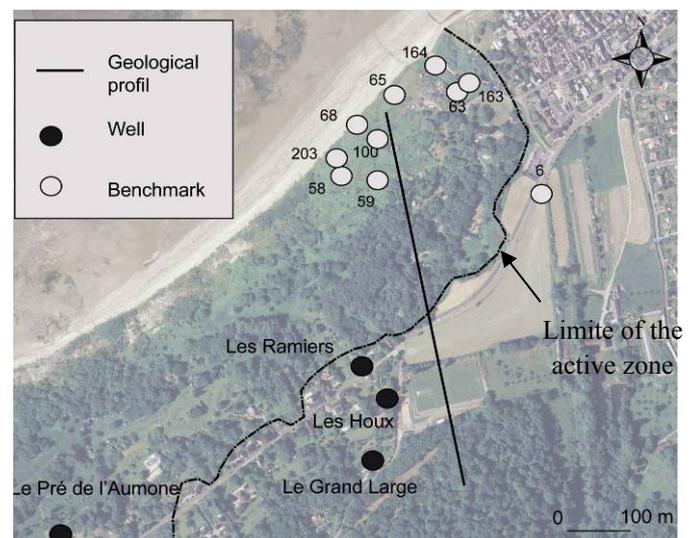
Figure 3. Part of monitoring survey at Villerville Landslide.

3 RESULTS

4.1 Piezometry - Precipitation

Figures 4 to 6 present groundwater variations and field pluviometry since 1974. We can see that Danestal piezometer, which is located 17 kilometers from the landslide area, has similar behaviour as the local wells in and close to the landslide area. The groundwater fluctuations are correlated with high effective rainfall here Precipitations minus Evapotranspiration (P-ETP). Figure 4 shows the correlation between water table elevations and landslide reactivation. All important events are linked to groundwater rise. We can also define a first approach for a groundwater level threshold.
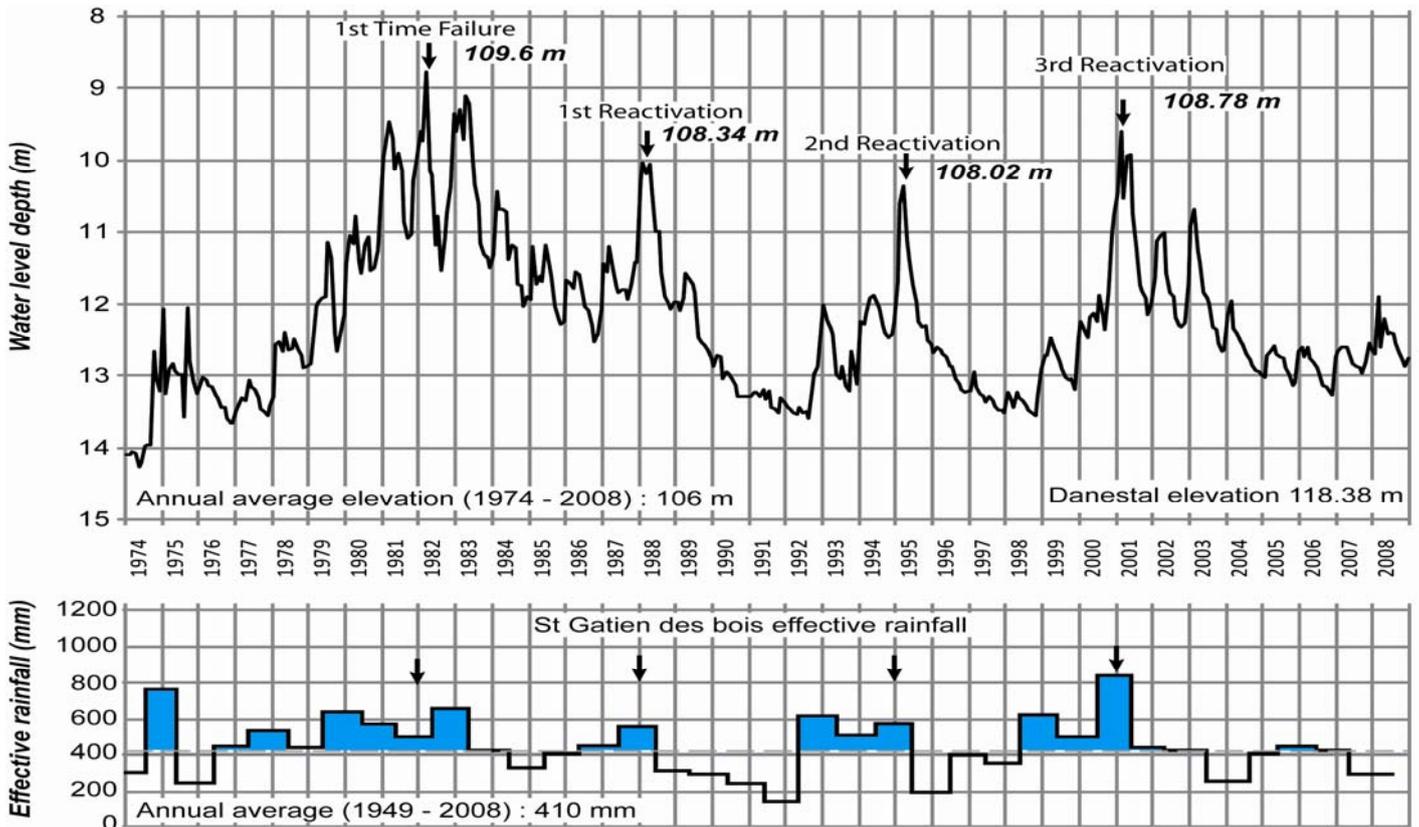
Figure 4. Danestal piezometers fluctuation 1974 – 2008 (BRGM data). And effective rainfall St Gatien station 1974-2008/ Hydrological year July-June (Météo France).

.

Figure 4 shows the correlation between water table elevations and landslide reactivation. The four crises are linked to groundwater rise. We can also define a first groundwater level threshold (108-109 m asl.).

The annual level is around 12 m depth; for the first time failure, in January 1982, the groundwater table reached the highest and exceptional level ever known (4 m higher than the annual average). The following reactivations (1988, 1995 and 2001) needed lower groundwater level rises (3 m). A statistical analysis was used to evaluate the groundwater tendency for 30 years and distinguish the recharge and discharge periods (every 4 years). The recharge periods are linked to landlside acceleration periods (Fig. 4).
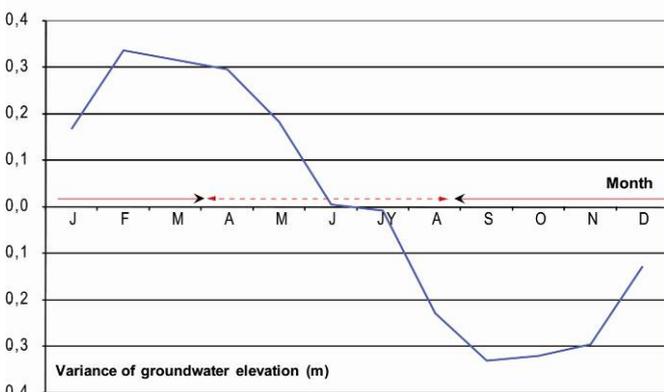
Figure 5. Groundwater behaviour standard cycle in Pays d'Auge.
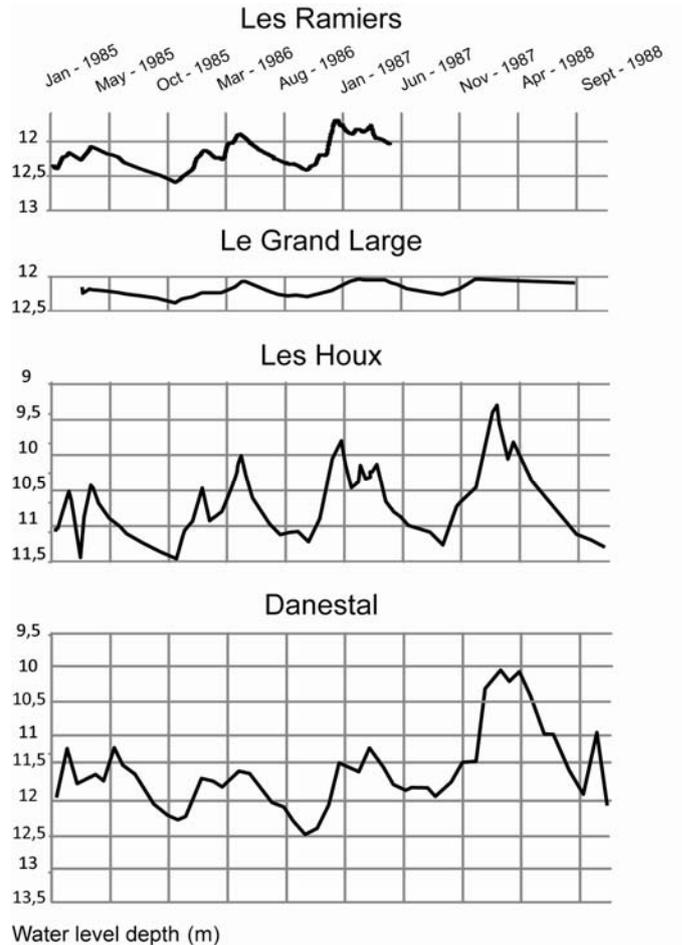
Figure 6. Comparative piezometry in wells at 4 locations (1985-1988).

The annual groundwater behaviour can be defined by an annual standard cycle and be divided into two steps (Fig. 5): a clear water level rise from September to March, and a water level decrease from March to September (Dupont et al. 2008). The groundwater level rise is in close relation with prolonged rainy periods and groundwater recessions correspond to the summer seasons with generally water deficits (Maquaire 1997).

Relationship between piezometry and precipitation are known and established with positive effective rainfall (P-ETP) (Fig. 7) and with exceeding rainfall (effective rainfall minus active storage of the soil). At first, we have considered a theoretical soil active storage of 100 mm to calculate the water budget and to estimate the pluviometric exceeding that feed directly the groundwater. Next we will evaluate the real infiltration conditions (Tacher 2005) to evaluate these threshold values.

The figure 7 shows that the correlation between water tables fluctuations and precipitations is better with effective rainfall (circles) than total rainfall (squares) but to estimate threshold value we need to know precisely the rainfall water needed by the soil and run-off. Although at different locations (Danestal, Le Ramier) the groundwater level fluctuations in all observation points react on the same moment but the amplitude variations are completely different for each one of them (Fig. 6). For example, on the field area, the water table variations of the well "Les Houx" are more important (2 m versus 80 cm) and shorter than "Le grand Large" fluctuations. These adjustments are linked to the aquifer characteristics and the internal structure of the slope. The groundwater level rise lags behind the rainfall event because of damping character of the unsaturated soil; infiltration and percolation (Bogaard, 2001, Bogaard & van Asch 2002). The water table response depends on the depth of the groundwater and on the cumulated rainfall. Subsurface groundwater tables are more reactive than the deep water tables. The water table in "Les Ramiers" increases around six days after beginning of the rainfall (Maquaire, 1990).
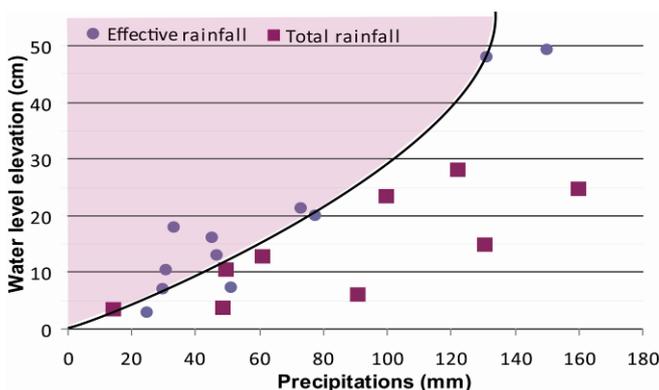
Figure 7. Relation between precipitations (total, effective) and water level elevation at 'Les Ramiers'.
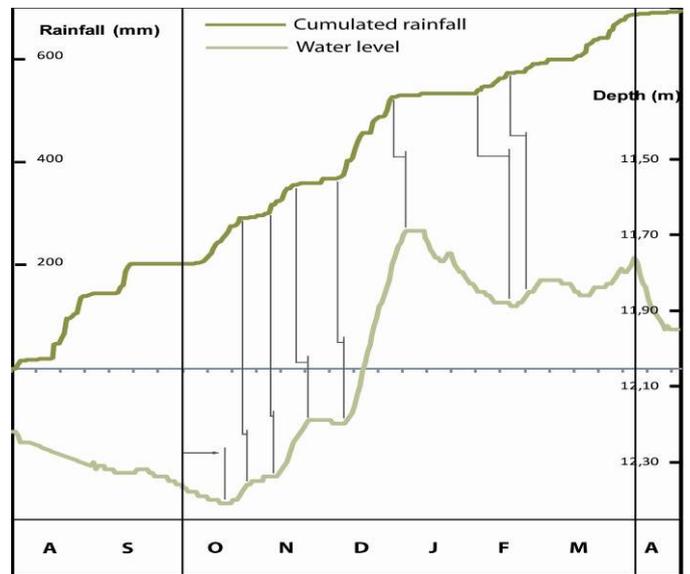
Figure 8. Les Ramiers' cumulated rainfall and groundwater variations (1986-1987).

We can evaluate pluviometric thresholds needed to increase the groundwater level with the figure 8 that shows the connection between groundwater level rising and rainfall. For 70 mm rainfall, the groundwater level increases 10 cm. This rise is only possible if the pluviometric threshold is exceeded. During drainage periods with a limited rainfall, the water level quickly stabilizes and decreases.

4.2 Piezometry –Rainfall – Displacement

As other landslides like La Frasse landslide (Noverraz 1990), displacements amplitude and occurrence depends on seasons and climatic conditions (Maquaire, 1990). Suspended or very slow-moving landslides can be reactivated in periods of heavy rainfall and are characterized by phases of acceleration and deceleration. This kind of behaviour has been observed in slow-moving earth-flow (Lateltin & Bonnard, 1995) or in rotational and translational landslides (Corominas et al., 1999).

Horizontal and vertical surface displacements were measured using standard tacheometry together with the directions of these displacements. Annual rainfall, groundwater rise and cumulated displacements of benchmarks are clearly correlated (Fig. 9). The 2001 event is clearly visible and related to the important rainfall peak. On the contrary there are limited displacements in the dry years (2004, 2005) because of a low rainfall amount. The landslide kinematic follows the seasonal trend: with acceleration in winter and early spring and deceleration during the drainage periods (Malet et al., 2004, 2003). The March 2001 event occurred when the precipitations in the years 2000 and 2001 were exceeding the long-term average values (134 mm in January 2001 versus a 60 mm monthly average and 137 mm versus 28 mm monthly average in March 2001).

Along the year, we can say that displacements are heterogeneous. The most active zone is at the lower

part of the slope, (benchmarks n° 68, 203, 58, (Fig. 3). Displacement is higher at the slope toe and decrease to upstream and to the east flank. As expected, point n°68 located near the long-shore has moved around 4 m since 1985 (vertical displacement) contrary to points 63, near the east flank or 59 (upstream) which are affected by lower displacements. Recession by sea erosion could not explain spatial variability and temporal distribution of displacements but it is one of triggering factors.
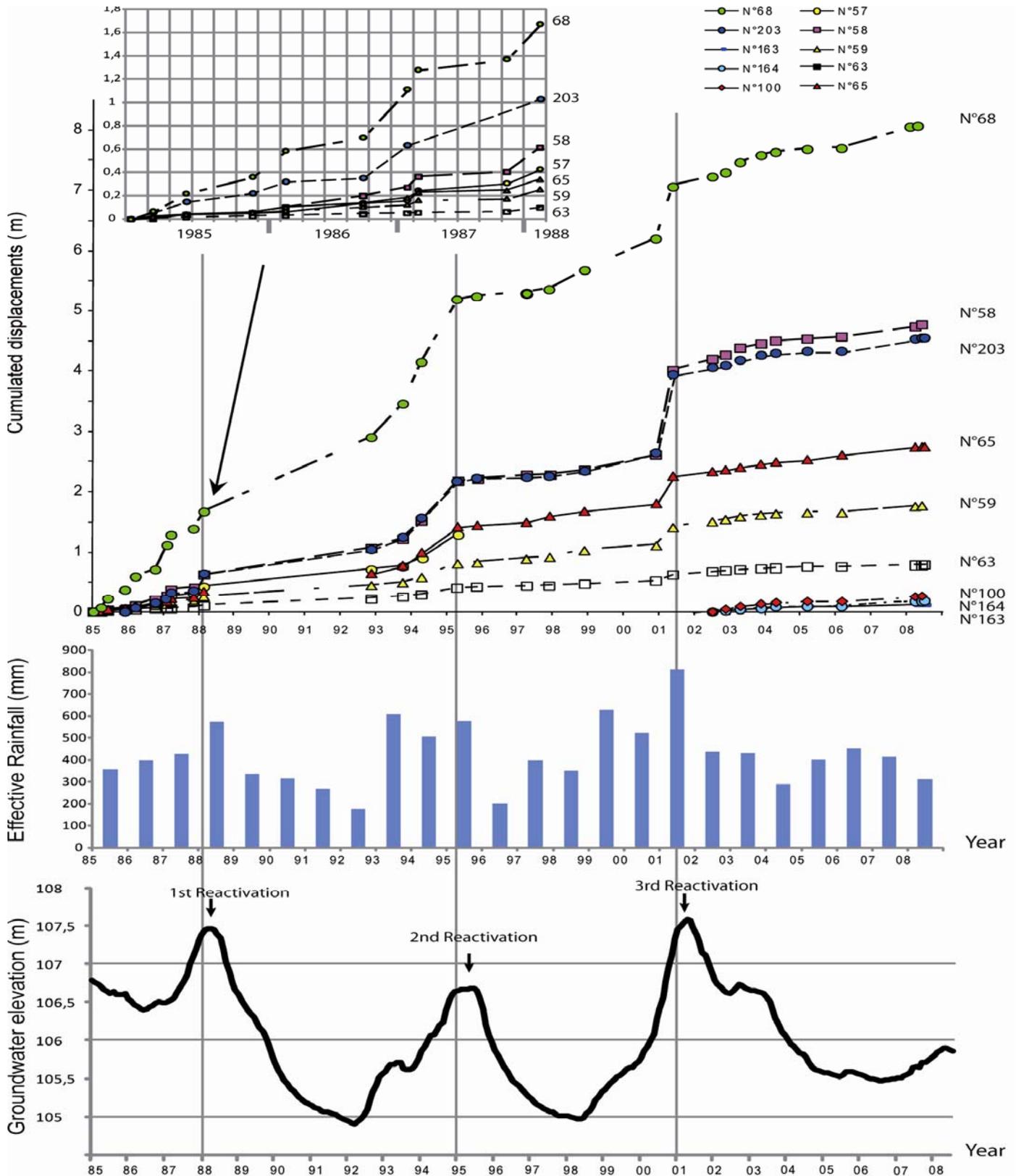
Figure 9. Cumulated displacements Villerville Camping 1985-2008, effective rainfall and Danestal groundwater level at the same period.

4 CONCLUSION AND DISCUSSION

The historical comparison of hydrological events confirms the temporal variability of the mass landslides and an indubitable correlation between rainfall, groundwater and displacement. These movements are defined by characteristic parameters: such as temporal variability linked to a long rainy period and a regional groundwater recharge period. All triggering factors play a role at different geographical and temporal scales, that why all parameters have to be studied at different scale. In terms of risk prevention we have to put forward the most important parameters acting on the slope instability. Cricqueboeuf landslides, outside exceptional crises, evolve with continuous slow displacements particularly in winter season occurring important damages. In this context the field survey is now completed (since January 2008) by monthly and permanently displacements recorders. Add to tacheometer method, displacements are registered with DGPS and with the installation of new benchmarks to cover the majoritiy of the landslide. Water level is for several points permanently registered by electronic data recorder and linked to meteorological data with local pluviometers. We try to determine water evolution by quantitative approach in order to analyze landslide movement frequency in response to rainfall events to evaluate precisely triggering thresholds and to determine precursor signs for alert system.

REFERENCES

Bogaard T.A., 2001. *Analysis of hydrological processes in unstable clayey slopes*. Doctoral thesis, Netherlands Geographical Studies, Amsterdam/Utrecht KNAG/Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht: 287.

Bogaard T.H., Van Asch Th. W. J, 2002. The role of the soil moisture balance in the unsaturated zone on movement and stability of the Beline landslide, France. *Earth Surface Processes and Landforms*. 27: 1177-1188.

Corominas J., Moya J., Ledema A., Rius J., Gili J.A., Lloret A., 1999. Monitoring of the Vallcebre landslide Eastern Pyrenees, Spain. In *Proceeding International Symposium on Slope Stability Engineering*. Matsuyama, Japan. 2: 1239-1244.

Dupont N., Planchon O. & Cador J-.M., & Delahaye D. & Douvinet J., 2008. Types de circulations atmosphériques et de crises hydrologiques dans le nord-ouest de la France - Approches croisées des risques liés au climat. In *Climat et risques : changements d'approches* (Coll. Sciences du risque et du danger). dir. LAMARRE Denis.

Flageollet J.-C. & Helluin E., 1986. Morphological investigations in the sliding areas along coast of Pays d'Auge, near Villerville, Normandy, France. *International Geomorphology*. (1): 447-486, Gardiner V, Wiley J. and Sons Ltd.

Flageollet J.-C. & al. 2000. The 3-D structure of the Super-Sauze earthflow: a first stage towards modeling its behaviour. *Physics and Chemistry of the Earth,* 25: 785-791.

Lateltin O., Bonnard Ch., 1995. Reactivation of the Falli- Hölli landslide in the Prealps of Freiburg, Switzerland. *Landslide News* (9): 18-21.

Malet J.-P., Maquaire O. 2003. Black marl earthflows mobility and long-term seasonal dynamic in southeastern France. In Picarelli L. (eds), *Proceeding of the International Conference on Fast Slope Movements: Prediction and Prevention for Risk Mitigation.* Patron Editor Bologna: 333-340.

Malet J.-P., Maquaire O. 2004. Hydrological behaviour of earthflows developed in clay-shales: investigation, concept and modeling. In Picarelli, L. (eds), *The Occurrence and Mechanisms of Flows in Natural Slopes and Earthfills.* Patron Editor, Bologna: 175-193.

Maquaire O. 1990, *Les mouvements de terrain de la côte du Calvados, Recherche et prévention* Document BRGM n°197, Eds BRGM : 431.

Maquaire O. 2000. Effects of groundwater on the Villerville-Cricqueboeuf landslide. Sixteen years ofsurvey (Calvados, France), In Bromhead, Ed., Dixon N., Ibsen M.L. (eds), *Landslide in Reasearch, Theory and Practice. Proc. 8th Int. Symp. On landslides* (2), Cardiff, Wales, T. Telford, London: 1005-1010

Noverraz F., Parriaux A. 1990. Evolution compare des conditions hydrologiques et des mouvements du glissement de la Frasse (Alpes suisses occidentals), *Hydrology in Mountainous Regions. - Artificial Reservoirs; Water and Slopes* no. 194 (Proceedings of two Lausanne Symposia, August 1990). IAHS Publisher: 355-364

Tacher L., Bonnard, Ch., Laloui, L. & Parriaux, A. 2005. Modelling the behaviour of a large landslide with respect to hydrogeological and geomechanical parameter heterogeneity. *Landslides* (2). No 1: 3-14.

Varnes, D.J.1978. Slope movement Types and Processes. In special report 1976: *Landslide Analysis and Control.* In Schuster R.L., Krizek R.J; (esd), Transport research board, National research : 11-33.

van Asch Th. W.J., Buma J.T. 1996. Modelling groundwater fluctuations and the frequency of movement of landslide In tht Terres Noires region of Barcelonette (France), *Earth Surface Processes and landforms* (522): 131-141.

van Asch Th.W.J., Buma J.T., van Beek L.P.H. 1999. A view on some hydrology triggering systems in landslides, *Geormophology* (30): 25–32.