FINDING THE MOST SUITABLE SLOPE STABILITY MODEL FOR THE ASSESSMENT OF THE IMPACT OF CLIMATE CHANGE FOR A LANDSLIDE NEAR BARCELONNETTE (SE-FRANCE)

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Abstract

Three slope models, relating rainfall to landslide activity, with different complexity, were tested on a landslide near Barcelonnette, South East France. The R-model relates single monthly precipitation to landslide activity. The RN-model relates monthly net precipitation to landslide activity, while the EPL-SLIDE model is a conceptual slope model simulating groundwater levels and linking them to slope stability. The models were tested against dating of eccentricities in the rings of trees, growing on the landslide, indicating periods of landslide activity in the period 1956-89. It appeared that the most simple R-model model, give the same model performance as the RN-model and the EPL-SLIDE model. The models were also applied in a climatic change scenario study. The RN-model turned out to be the best compromise between conceptual description and model robustness. This model is therefore considered best suitable for present studies of climatic change impact on landsliding.

Key words: landslide, climate change, slope stability models.

Riassunto

Determinazione del più idoneo modello di stabilità dei versanti per la valutazione dell'influenza di cambiamenti climatici relativamente ad una frana nei pressi di Barcelonnette (Francia sud-orientale). Tre modelli di stabilità dei versanti di diversa complessità, che correlano importi pluviometrici e attività di frana, sono stati testati su una frana nei pressi di Barcelonnette, Francia sud-orientale. Il modello R mette in relazione la precipitazione mensile con l'attività di frana. Il modello RN correla la precipitazione mensile netta all'attività di frana, mentre l'EPL-SLIDE è un modello concettuale che simula diversi livelli piezometrici e li correla con la stabilità dei versanti. I modelli sono stati testati per confronto con datazioni di eccentricità riscontrate in anelli di accrescimento di alberi localizzati su un accumulo di frana e indicanti fasi di attività nel periodo 1956-89. Il più semplice modello R fornisce gli stessi risultati dei modelli RN e EPL-SLIDE. I modelli sono anche stati applicati in uno studio di scenari di variazioni climatiche. Il modello RN è risultato il miglior compromesso tra descrizione concettuale e affidabilità del modello. Pertanto questo è da ritenersi il più idoneo per i presenti studi relativi all'influenza dei cambiamenti climatici sui movimenti franosi.

Parole chiave: frana, cambiamento climatico, modelli di stabilità dei versanti.

1. INTRODUCTION

In this study three slope models with different complexity were tested on the Boisivre landslide near Barcelonnette, South East France:

- R-model, relating landslide activity to gross precipitation without considering

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physical links;

- RN-model, relating landslide activity to net precipitation, based on field data;
- EPL-SLIDE, a conceptual slope model simulating groundwater levels and linking them to slope stability.

The models were tested against dating of eccentricities in the rings of trees growing on the landslide, indicating periods of landslide activity (Fig. 1). Subsequently they were fed with scenarios of precipitation and temperature.

2. R-Model

Single-monthly precipitation was poorly correlated to landslide activity (not shown). Fig. 2 shows the results for 8-month precipitation sums (threshold of 670 mm) over the period 1956-80. Discrepancies only occurred in 1974 and 1975, which were dry years while high tree ring eccentricity rates were found.

3. RN-Model

Monthly net precipitation was calculated from monthly precipitation and temperature, using a simple water balance model of the root zone:

$$R + M = AET + \Delta S + RN$$

where

R+M	=	liquid precipitation including snowmelt	[L/T]
AET	=	actual evapotranspiration from the root zone	[L/T]
ΔS	=	change of water storage in the root zone	[L/T]
RN	=	net precipitation or supply to perched groundwater table	[L/T].

Snowmelt (M) was simulated with a temperature-index formula (e.g. *Bergström*, 1976, *Martinec et al.*, 1983). Actual evapotranspiration (AET) was calculated according to *Thornthwaite & Mather* (1957), using potential evapotranspiration (PET) calculated from mean monthly temperature only, according to *Thornthwaite* (1948). Good results were obtained for the period 1956-80 with 3-month net precipitation sums, with a threshold of 270 mm (Fig. 3). Again, discrepancies only occurred in 1974 and 1975.

4. EPL-SLIDE

The hydrological component EPL uses net precipitation, geometrical and hydrological characteristics of the landslide for the calculation of a groundwater level.

The stability of the landslide was analysed with the simplified *Janbu* (1957) model implemented into the numerical model SLIDE (*De Vos*, 1990).

EPL is a lumped linear reservoir model, the principle behind which is the linear proportionality between water storage and discharge of the reservoir representing the landslide.

$$Q = S/K$$

where

S	=	storage	[L]
Q	=	discharge	[L/T]
k	=	discharge coefficient	[T]

Also $dS + (RN - Q)dt$, where RN is the input into the reservoir, [L/T]. The mean storage S(t) is converted to groundwater levels through division by a storage capacity factor

$$\varepsilon : GW(t) = S(t)/\varepsilon$$

The best fit over 1956-80, shown in Fig. 4 is slightly worse than the fits obtained with the other models.

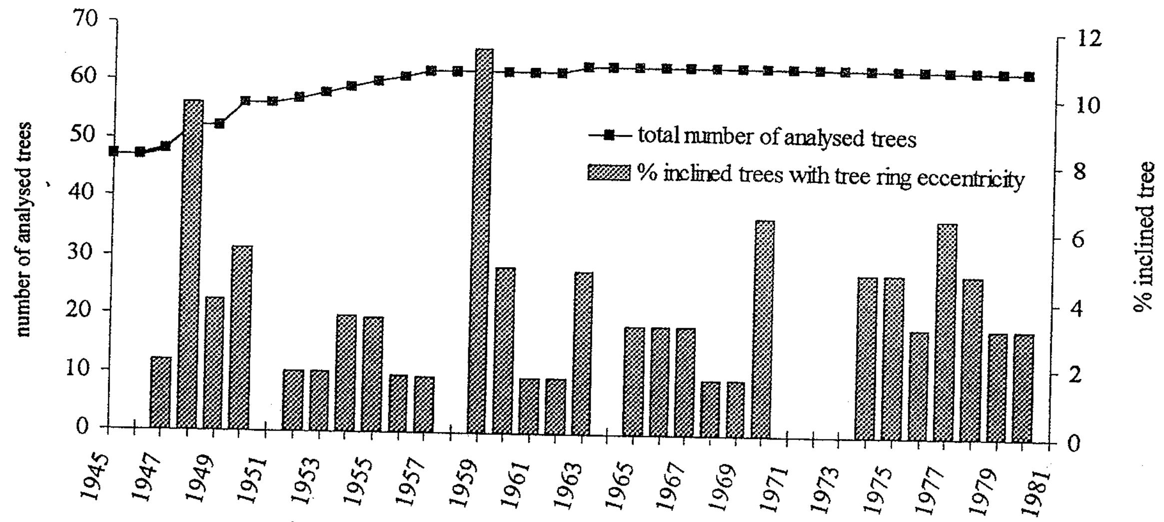

Fig. 1 - Temporal pattern of ring eccentricities of trees on the Boisivre landslide (after *Verhaagen*, 1988).

5. Frequency of landslide activity

The frequency of exceedance Φ of a precipitation or groundwater threshold is regarded as an adequate indicator for landslide activity on the present crude scale. Applying a regression according to *Gumbel* (1958) yields Φ-values of 0,45 year^{-1} (EPL-SLIDE), 0,27 (RN-model) and 0,25 (R-model) over the period 1960-89.

6. Discussion

The inclusion of additional parameters in

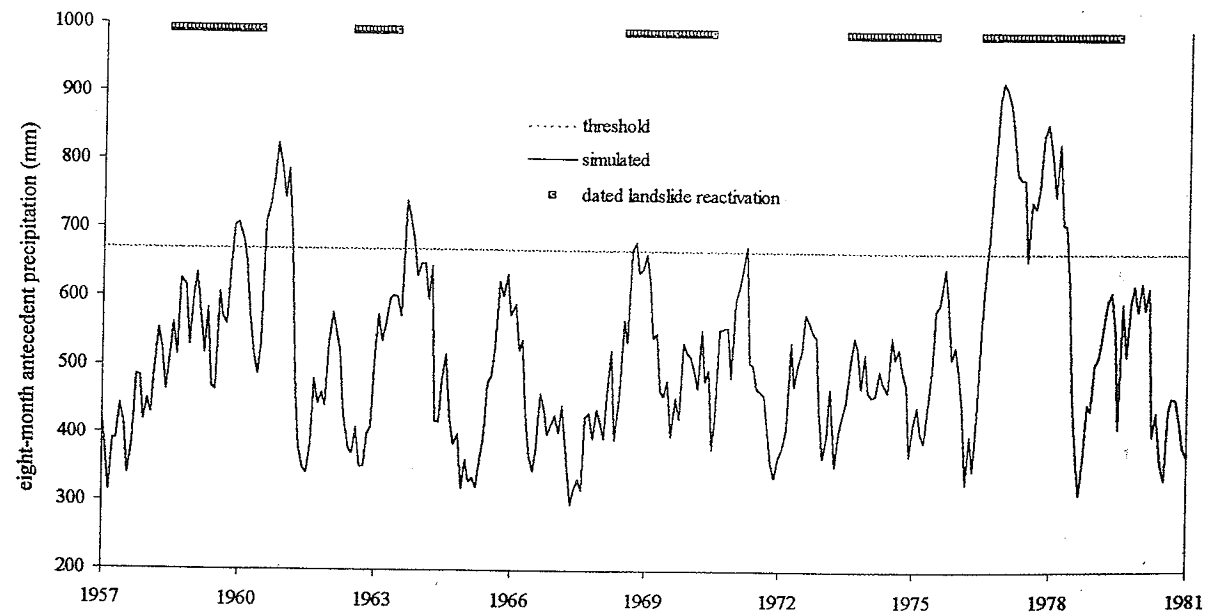

Fig. 2 - Eight-month gross Barcelonnette precipitation sums against dated periods of landslide activity.

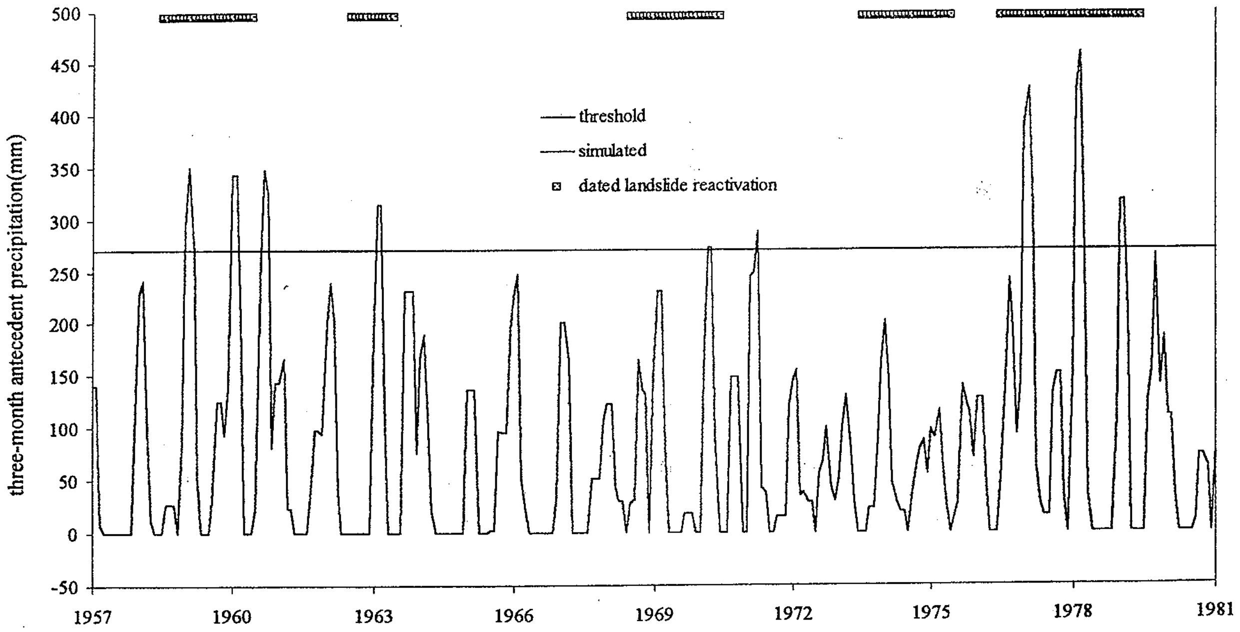

Fig. 3 - Three-month sums of net precipitation against dated periods of landslide activity.

the RN-model and EPL-SLIDE does not give rise to improved model results. A sensitivity analysis showed that Φ is most sensitive to ε and k, which are present in EPL-SLIDE only. For the RN-model and EPL-SLIDE, equally good results over the period 1956-80 could be obtained with two other, significantly different parameter settings (UNSTAB and STAB, not shown here).

On the other hand, the R-model does not take into account the effect of temperature on evapotranspiration and landslide activity, identified from field data by *Caris & Van Asch* (1991). This could have consequences if the model is applied to a climate scenario study in which also temperatures change.

7. Application of the models in a climate change scenario study

The landslide models were fed with temperature and precipitation scenarios derived by interpolation and statistical downscaling, respectively, from the ECHAM4/OPYC3 experiment by the Max Planck Institut für Meteorologie in Hamburg. The scenarios are shown in the German national report. They show a steady upward temperature trend, and a general decrease in precipitation, notably in autumn (SON). Each landslide model run yielded 1000 scenarios of landslide activity expressed in Φ values due to the existence of 1000 precipitation scenarios for each period. Φ values were calculated for running windows of 30 years, shifted at ten year intervals (Oct. 1869 - Sept. 1899, ..., Oct. 2069 - Sept. 2099). In this study, the 0,05-, 0,50- and 0,95-quantiles of the 1000 Φ-values are considered for each of these periods.

Fig. 5 shows the results of the scenario calculations with the three models using the BEST parameter configuration (0,50-quantile values). Towards the end of the scenario the R-model simulates a less pronounced decrease than the other two models.

The uncertainty of landslide activity, marked by the difference between the STAB and UNSTAB curves, is much larger for

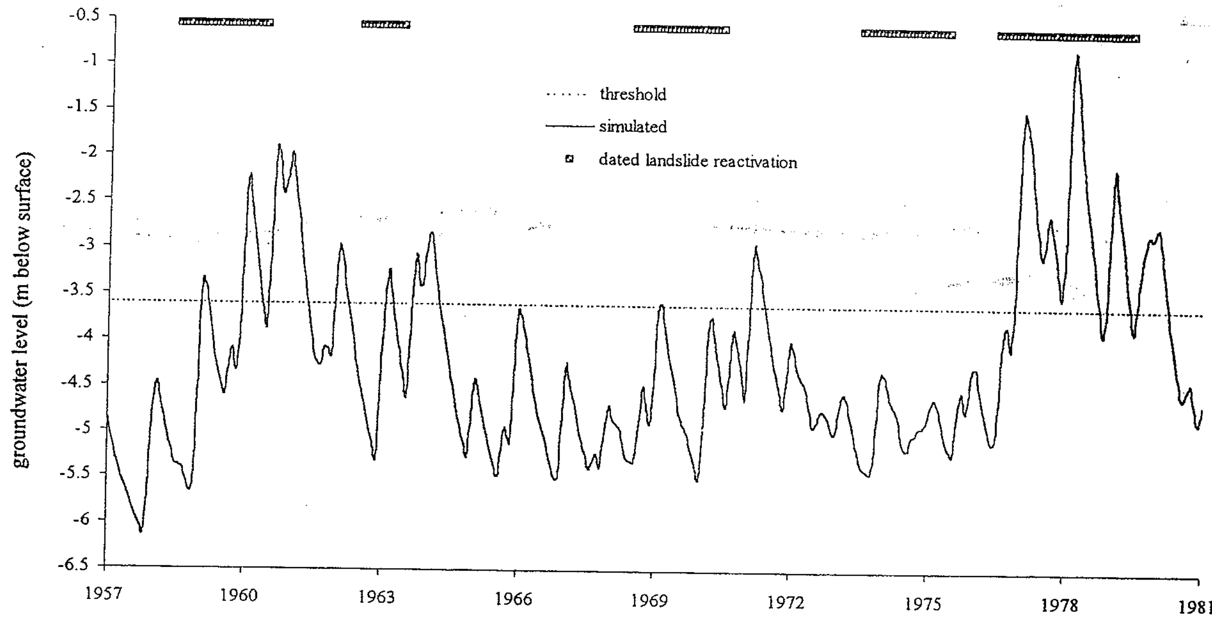

Fig. 4 - Groundwater levels simulated with EPL (best fit, or BEST), against dated periods of landslide activity.

EPL-SLIDE than for RN, in particular if not only the 0,50- but also the 0,05- and 0,95-quantiles are considered (Fig. 5). ε is a particularly tricky EPL-SLIDE parameter because it does not influence the simulated *absolute groundwater level* so much, but rather the *amplitude of fluctuations.* This means that for the present-day situation, the frequency of landslide activity is not influenced, but if the climate becomes drier,

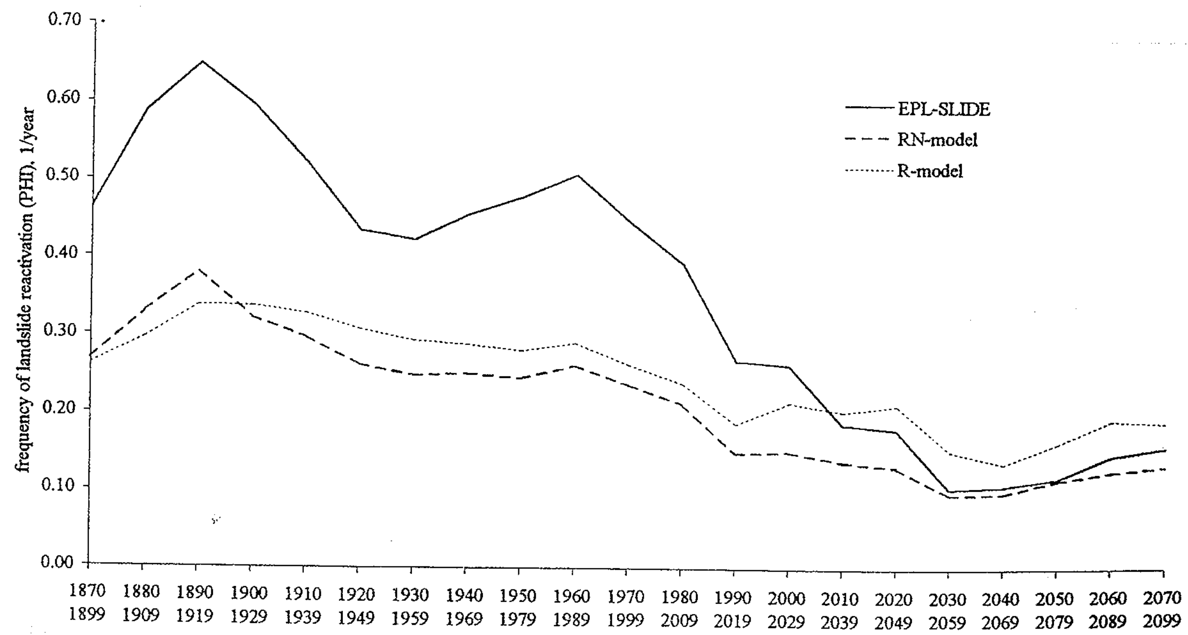

Fig. 5 - Scenario of frequency of landslide reactivation Φ, simulated with BEST parameter settings (median Φ values of the Monte Carlo simulation).

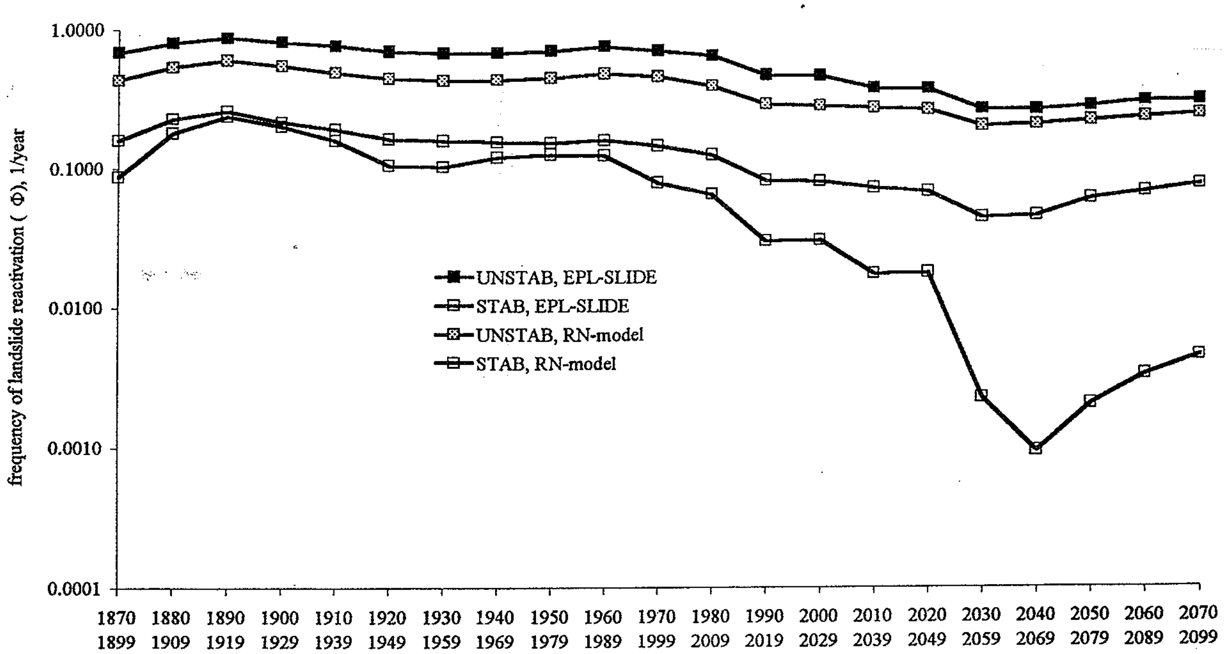

Fig. 6 - Uncertainty ranges of scenarios of Φ, defined by the 0,05- (STAB-) and 0,95-(UNSTAB-) quantiles (EPL-SLIDE and RN). Note the ^{10}log scale.

a general lowering of the groundwater has different consequences: a large ε means (large storage capacity) little fluctuation, while the opposite is true for a low ε. If the amplitude of fluctuations is high (low ε) compared to the overall decline, threshold exceedances still occur, albeit less often than in the present-day situation. If the amplitude is low (high ε) compared to the overall decrease, the threshold is hardly exceeded anymore. It is these situations that cause the extremely low Φ values in STAB.

8. CONCLUSION

The performance of the conceptual slope model EPL-SLIDE was devaluated by low-resolved test data. This devaluation pertained not so much to the accuracy of the model but rather to its uncertainty, and it turned out to have serious consequences in a climate change impact study. The problem could be (partly) solved by monitoring groundwater fluctuations, thus obtaining indications of ε. However, a better option might be to apply a simpler model. In regional studies in which much information has to be collected over a large area in a relatively short time, it is better to focus on regionalisation with a simple model, rather than to go into detail at one single site. Two such simple models were evaluated in this study. The fully empirical climatic threshold (R-model) discarded some essential processes and consequently yielded disputable scenario results. The semi-empirical net precipitation threshold (RN-model) turned out to be the best compromise between conceptual description and model robustness. This model is therefore considered best suitable for the presented study of climate change impact on landsliding.

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