Suppl. Geogr. Fis. Dinam. Quat.
III, T. 3 (1999), 189-192

FOURTH INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY - Italy 1997
Round Table: «Geomorphological Hazards: a European Strategy»

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THE CEC ENVIRONMENT PROGRAMME PROJECT «THE TEMPORAL STABILITY AND ACTIVITY OF LANDSLIDES IN EUROPE WITH RESPECT TO CLIMATIC CHANGE» (TESLEC)

INTRODUCTION

The CEC Environment Programme project «The temporal stability and activity of landslides in Europe with respect to climatic change» (TESLEC, contract no. EV5V-CT94-0454) was a research project which investigated the interrelationship between landslide, climate and time.

The project started working in July 1994 as a co-operation network of scientific institutes from six member states of the European Community. These are:

- Universität Heidelberg, Germany (UHEI.GEO) (project co-ordinator: Prof. Dr. R. Dikau, project manager: Dr. L. Schrott)
- Université Louis Pasteur Strasbourg, France (ULPS. CERG) (principle contractor: Prof. J-C. Flageollet)
- Consiglio Nationale Ricerche Roges di Rende, Italy (CNR.IRPIM) (principle contractor: Dr. M. Sorriso-Valvo
- Universidad de Cantabria, Spain (UCANT.DCIT) (principle contractor: Dr. J. R. Díaz de Terán)
- Universiteit Utrecht, The Netherlands (RUUTR.VFG) (principle contractor: Dr. Th. W.J. van Asch)
- King's College London, United Kingdom (KCOLL.DG) (principle contractor: Prof. D. Brunsden)

The project finished in June 1996. This paper is based on the final project report which was published in Dikau & *alii* (1996). Furthermore, the main project results will be published by Schrott & Pasuto (1999).

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COMPLETED TASKS AND DISCUSSION

The following discussion summarizes the main completed research tasks of the project and the main research contributions, problems and future research directions.

The TESLEC project was established to investigate the interrelationship between landslide, climate and time. The research interest was concentrated on three main objectives:

1) The development of criteria for the recognition of landslides including the publication of the manual landslide recognition;

2) The reconstruction of past distributions of landslide incidence related to the change of various climate parameters;

3) The development of qualitative landslide evolution models and a hydrological and slope stability modelling framework for the prediction of landslide activity in a changing climate evolved at test sites.

The first deliverable of the project was to prepare and to edit the manual «Landslide Recognition» which presents the main characteristics of different landslide types in Europe. The book assists in the education of landslide recognition with the aim of helping the reader to distinguish different landslide types in the field. The manual summarizes different classification systems for landslides and also summarizes the description of diagnostic features of each landslide category for potential and relict circumstances. The book is a considerable international achievement and was published by Dikau, Brunsden, Schrott & Ibsen (1996).

The second objective of the TESLEC project was the investigation of past distributions of landslide incidence and their relationship to climate change parameters. This included the understanding of the nature of climatically controlled landslide distribution in space and time and the behaviour of individual landslides.

One prerequisite to reconstruct landslide distributions in time is the direct or indirect dating of material exposed or removed by a landslide process. In a previous European project, EPOCH (The temporal occurrence and forecasting of landslides in the European Comunity, contract number: 900025 (1991-93) (Casale & *alii*, 1994; Soldati, 1996) classical dating methods like ^{14}C, dendrochronology or lichenometry were described and applied. In the TESLEC project the new techniques like Accelerator Mass Spectrometry (AMS), Thermally Ionised Mass Spectrometry (TIMS), laser fusion, and methods like Optically Stimulated Luminescence (OSL), alpha recoil track dating were discussed in their potential to date landslides. The project discussed and considered the possibilities and limitations of theses techniques and methods for different parts of the landslide body and the exposed scarps. Especially surface exposure dating of *in situ* produced cosmogenic nuclides and OSL-dating are recommended as new methods for dating past landslide events. However, the project also states, that most of the described new techniques and methods have currently no widespread application in landslide research.

If the past landslide event has been dated there is, however, no complete certainty on whether this landslide has been triggered by the climatic conditions present at the time of failure or by other causes. Therefore, the project delivered a critical discussion of the frequency and activity of holocene landslides in western European countries in terms of the relationship between landslide event and climate. The group stated that the establishment of a holocene slope instability history is difficult because of the low number of dated landslides available. Landslide series, therefore, should be taken with caution as they may be only partly representative of the climatic conditions of the studied region. This is especially caused by the lack of data and by the fact that often a landslide can only be indirectly dated as for example fluvial terraces developed on the landslide mass or peat bogs located at the landslide surface. Despite these uncertainties, the new results of the TESLEC project show that it appears that climatically generated landslide activities have not been homogenously distributed all over Europe. Cool phases such as the Younger Dryas and the Little Ice Age are characterized by an increase in landslide activity in most European countries. This is consistent with what was found by other researchers in European mountain areas. Wet and warm periods seem not to affect Europe homogenously. During the early Atlantic and Sub-Atlantic (wet periods) in Northern and Central Europe landslide reactivation is very significant. An increase in landslide activity in the late Atlantic and Sub-Atlantic in the Mediterranean region and no reactivations in Northern Europe were observed. Based on the problems described it is clear that the increase of landslide activity is not homogenously across Europe and can be explained by local factors such as the increase in mean annual precipitation (Eastern Pyrenees), an increase in the mean annual temperature that causes the melt of permafrost ice (Alps), the effect of sea level rise and storms responsible for coastal erosion and retreat (Southern Britain).

A further task of the project was the climatic and dynamic influences from dated landslides. The central question to be asked was whether or not a dated landslide carries a climatic signal. There may be many possible interpretations of each landslide occurrence not all of which involve climate. It is important to consider that the time of climate influence may range from the nature of a climate experienced by the landslide, e. g. the effective precipitation available in a humid tropical or a cold periglacial climate, to an alteration of the weathering, erosion, deposition, rainfall or water regimes by climate variability. Therefore, it is usually not possible to assess accurately the climatic cause of an individual slide unless there is independant cooperative information, e. g. a direct observation of a wet winter or a high magnitude storm. A further important question is if landsliding can be correlated with sunspot activity. There are results from Russian scientists which show similar periodicities to those discovered in the EPOCH and TESLEC projects at the south coast of Britain and Northern Europe.

The causal factors of landslides include climate, geomorphological processes, and ground conditions which are considered as preparatory and triggering effects. Special emphasize lies on the temporal change of intrinsic characteristics of the slope by weathering or hydration. Rainfall plays the essential role in triggering landslides in changing the ground conditions of a slope. At the present level of knowledge no agreement has yet been reached about the identification of pluviometric thresholds above which landslides are triggered. Despite clear uncertainties on the relationships of the process-trigger-ground conditions it can be stated, that beside the mean annual rainfall, the cumulative effective rainfall over weeks, months and years as well as the antecedent maximum rainfalls, especially 1 to 3 days, should be considered in more detail for prediction modelling of landslides.

A further task of the TESLEC project was related to the differences between a first time trigger of a landslide and a landslide reactivation. It became evident that there is a high complexity of combinations of long and short-term climatic factors which trigger a first time or reactivate a landslide. There are situations where no clear climatic signal can be found because events may occur after dry months preceded or not by abundant annual rainfall. The complexity of the relationships between climate and landsliding seems to make it difficult to establish «universal laws» for Europe. It seems possible to establish rainfall trigger indices for different European regions including the landslide type, the status of reactivation, the seasonality and the initial degree of the slope stability. The TESLEC summary report also discusses other factors than precipitation as principal trigger for landsliding. These factors are natural (earthquakes, combination of earthquakes with long-lasting rainfall, sea erosion) and human-induced (quarrying, brine mining, changing of natural systems and sediment jeux, changing landuse).

The analysis of rainfall-landslide relationships which are based on historical landslide data shows clear correlations between antecedent precipitation and landslide events if enough landslide and rainfall data are available. In numerous European regions, however, historical records are difficult to obtain and are too incomplete to carry out detailed statistical analysis. A further problem is that different landslide types show different movement patterns under the same climatic condition. Therefore, in order to reconstruct in a reliable way changes in landslide frequencies as a response to changes in precipitation patterns, more detailed investigations pertaining to one region are needed. These investigations must be focused on soil mechanical and hydrological factors of different landslide types. Combined hydrological/equilibrium models can be assessed for different landslide types which can deliver critical precipitation thresholds. From these results two research conceptions can be drawn. Firstly, these models can be used to obtain climatic signal from landslide frequencies in the past and climatic scenarios can be constructed which explain the change in landslide frequencies in the past. Secondly, deterministic hydrological and slope stability models can be used to evaluate the stability of landslide test sites and to assess future climate change impacts which was the third objective of the TESLEC project. To achieve this the project had to evaluate the available hydrological and slope stability models and climate change scenarios based on general circulation models (GCM). In the TESLEC project this work was focused on the qualitative assessment of deterministic modelling requirements.

The hydrological models evaluated included GWFLUCT, HILLFLOW, HYWASOR, MODFLOW, SEEP/W, SWMS-2D and TANK. The evaluation of the slope stability models included static and dynamic models, where as the static models imply a close relationship between the onset of the landslide movement and rising groundwater level. The dynamic models predict different landslide behaviours as groundwater levels continue to rise after the initial reactivation.

Based on these different models the modelling framework of the TESLEC project has been carried out. There are various ways of modelling slope behaviour according to the different types of landslide events described in objective one. The project decided to use the simplest form of landslide events, the translational slab slide with a shallow planar shear surface for analysis with the available models. For this the test sites Alverà in Cortina d'Ampezzo (Dolomites, Italian Alps), Riou Bourdoux in the Barcelonnette basin (French Alps) and the Roughs landslide complex (Southern Britain) were selected. These test sites had relevant data which were available for the TESLEC projet to calibrate and validate the modelling framework. The sites were chosen to represent different climates, locations and landslide types across Europe. Additionally, the Lago Sackung was discussed in terms of the serious problems to model complex and deep seated landslide types.

From the hydrological and slope stability modelling the following conclusions can be drawn: Physically-based models are operative and are clearly capable of producing useful results. However, these models had been developed for simple shallow landslides where the data requirements were quite small. For large landslides with multiple layers or permeability differences, or for locations with multiple hydrological regimes it is difficult to replicate the observed field data. These results could be simulated by reducing the complexity of the model from two to one dimension. Therefore, simple conceptual models (e.g. GWFLUCT) currently seem to be the best modelling alternative. Fracture flow and vegetational influences have been negleted in many studies, although they may have an important influence in the landslide process. Future studies should draw more attention to these aspects.

Currently available general hydrological models have two disadvantages in modelling the activity of landslides: they require data in a spatial resolution that often cannot be provided, and they fail to cope with landslide specific processes like fracture flow. Future models must be able to consider not only these effects but also incorporate sudden changes in permeability, complex topography and large landslide volumes.

Concerning the combination of climate change modelling by GCMs and slope hydrology/stability models for an assessment of climate change impacts on landslide activity, it is shown that GCM results have to be downscaled by appropriate techniques in order to derive local scale climate scenarios. The evaluation of downscaling techniques show that empirical-statistical approaches are more appropriate than nested dynamical climate models. These techniques include a linear regression model with a canonical correlation analysis, an analog approach and an analog approach with rainfall generator which are suitable in landslide research. In the TESLEC project an empirical-statistical downscaling technique was applied in two study sites (Cortina d'Ampezzo, Dolomites, Italy and Barcelonette, French Alps) using monthly winter precipitation. While for the Alverà landslide in Cortina d'Ampezzo the statistical relationship is too weak for a predictive task, the case study of the Riou Bourdoux landslide in Barcelonette revealed many problems concerning the performance of the different seasons and decreasing amplitudes due to the downscaling procedure. This shows that the links between climate modelling and impact modelling are still in a developing stage. One of the results is that hydrological and slope stability models using GCM data produce only probabilistic statements. As a first effort the presented approach for linked modelling of future landslide activity is promising because it shows that a quantification of climate change impact is feasible. However, the case study carried out shows only for monthly time steps useful results while most slope hydrology / stability models use daily data resolutions. Therefore, further developments must be concentrated on the development of daily climate change scenarios on a local scale.

In relation to considerations of the three-dimensional nature of the landslide phenomena it is stated, that insufficient attention has been given to the meaning of retrogressive processes and to the interaction effect of landslide units locked together in a complex area. In the future, as three-dimensional slope stability models are constructed it will be necessary to take following conclusions into consideration:

- the three dimensional shape of the natural topography, the structural ground water and the shear surface control, the application of stress, the mobilisation of resistance and the availability of three-dimensional weakness patterns;
- the internal structural behaviour of the sytem in which complex self-loading and unloading effects occur such as undrained loading, kinematic waves etc.;
- the existing pattern of shear surfaces and landslide debris which will control the way a slope will unravel when the landslide is reactivated.

It is therefore very important to determine whether the three-dimensional pattern and analysis is for a single first time slide, first-time retrogression at the head of an existing slide or reactivation of a whole complex.

Based on these conclusions it is felt that the TESLEC project has provided a very clear research direction for the future.

REFERENCES

DIKAU R., BRUNSDEN D., SCHROTT L. & IBSEN M. (1996) - *Landslide Recognition*. Wiley, Chichester.

DIKAU R., SCHROTT L., DEHN M., HENNRICH K. & RASEMANN S. (1996) - *The Temporal Stability and Activity of Landslides in Europe with Respect to Climatic Change (TESLEC)*, Final Report Part I and II, European Community CEC Environment Program Contract No. EV5V-CT940454.

CASALE R., FANTECHI R. & FLAGEOLLET J.C. (1994) - *The temporal occurrence and forecasting of landslides in the European Community*, Final Report Vol. I and II, Commission of the European Community Programme EPOCH Contract No. 90 0025.

SCHROTT L. & PASUTO A. (1999) - *New developments in mass movement research in Europe - Temporal Stability and Activity of Landslides in Europe with Respect to Climatic Change (TESLEC)*. Geomorphology (in print).

SOLDATI M. (1996) - *Landslides in the European Union*. Geomorphology, 15, Elsevier, Amsterdam.