SECTION 3 :

DETAILED REPORT OF ASSISTANT CONTRACTOR FOR THIRD ANNUAL REPORT (1 March 2002- 28 February 2003)

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Section 3.1: Objectives of the Reporting Period (1/3/02-28/2/03)

The works and objectives for the last year of the Project are listed below.

1) Field data trying to characterise geologically the occurrence of the debris flows observed and the prone rockfall areas. Consideration of more detail observations of biotic factors (vegetation and land use).

2) Applying the regional models for predicting areas of debris flows in the Benasque valley trying to deep into more detailed geological and biological conditions. We will try to apply the WP1 and WP2 methodologies.

3) Applying the Milan team regional model (WP2) for predicting rockfall areas in the Benasque valley.

4) More detail studies in Sahún Catchment: Improve the thematic maps (geomorphology, vegetation and land use) at 1:5000 scale. Poll the population of Sahún and close villages and collect information from the town halls about historical debris avalanches.

5) Running the Padua team local model (WP3) on the Sahún fan area.

6) For doing 3) and 5) activities, it is planned the assistance to the training courses of the Damocles Project to be celebrated in Padua and Milan.

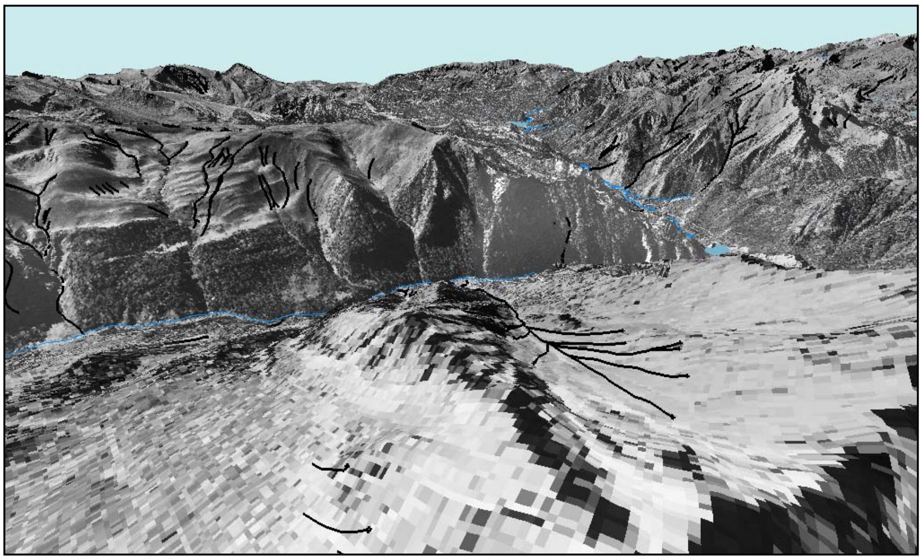
Section 3.2: Methodology and Scientific Achievements Related to Work Packages

3.2.1 WP1 Development of functional relationships for rapid slope failures.

Some field works have been carried out to improve our knowledge about the areas were the debris flows occur, and to try to characterise the magnitude of these flows. Some precisions about the moment when these events began to take place have been done trying to date some recent faults in relationship with the last postglacial period. Some samples of carbon (charcoal) have been picked up in some trenches dug near *Sackungen* faults and have been sent to a laboratory.

An updated 3D debris flow cartography has been done from 3D topographic maps, orthophotos and aerial photos of different dates (see example below). The number of mapped hillslope debris flows has increased from 188 (in the first survey) to 545 up to now (all of them in slope quaternary deposits: talus and moraines). Gullies where canalised debris flows occur have been mapped as well. We have identified a total of 71 up to now. In this new cartography, every debris flow has information about the starting point, track and stopping point and as far as they are into a 3D space, they provide information about heights, gradients and real distances.

Rockfall source areas and rockfall blocks have been mapped to prepare data for the application of the University of Milano-Bicocca and CNR from Perugia rockfall model in the framework of WP2.



Partial view of the 3D debris flow cartography

3.2.2 WP2 Development of a GIS hazard assessment technology

Knowing the characteristics of the debris flows and rock falls within our study area, we have tried to follow the gis hazard assessment methodology of some of the Damocles teams in applying some models that have been developed at regional and local scales.

As End-Users of the Damocles Project, this is an important goal for us that has to do with the WP5 objectives as it was planned at the beginning of the Project but we are referring in this paragraph and the following because of the maps obtained.

For doing this preliminary natural hazard assessment, an integration with the *Instituto Pirenaico de Ecología* team was necessary (see Regional analysis of debris flows) as well as with others work-packages teams: WP2, University of Milan Biccoca and CNR of Perugia (see Regional analysis of rockfalls) and WP3, for the application of a local impact model of debris-flows (referred in the next paragraph 3.2.3).

To complete our geologic and geomorphologic field knowledge, it has been necessary to get some complementary information of our study area, as for example: vegetation and land use coverages, that have been provided kindly by the IPE team, and some aspects linked to climatic data feed by the *Instituto Meteorológico Nacional.*

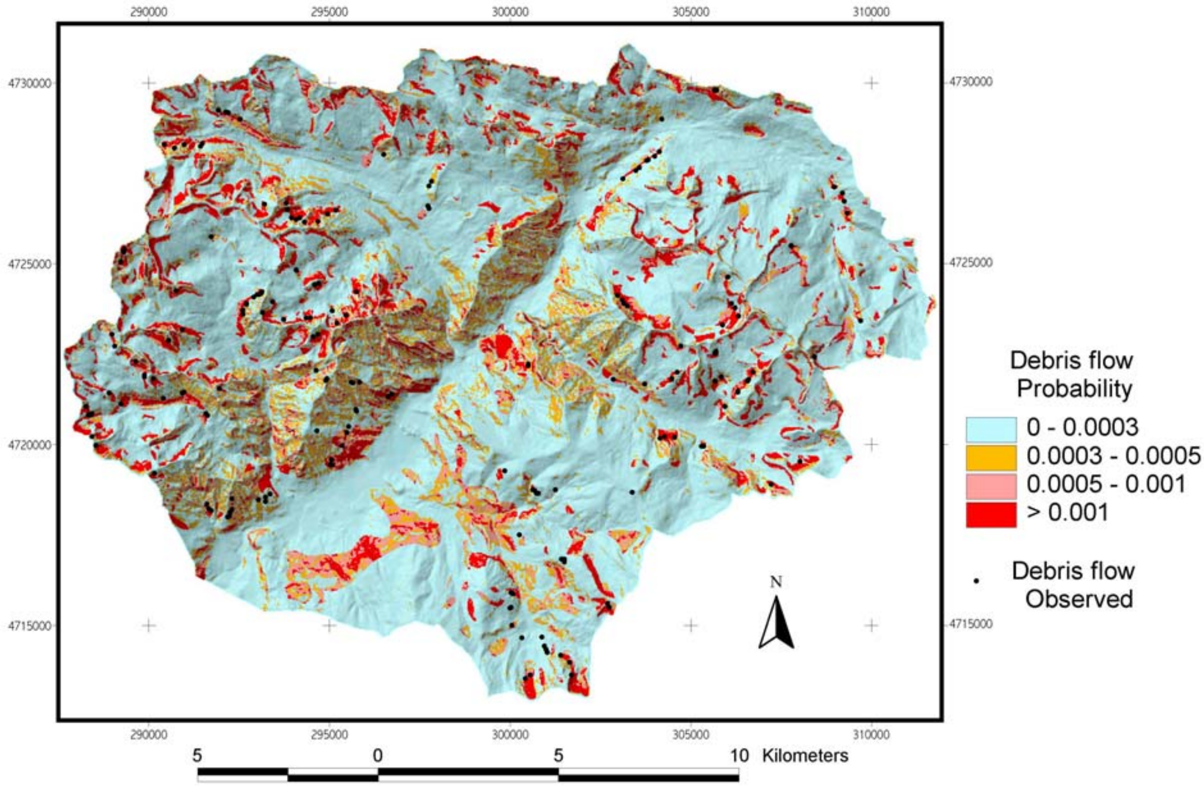
- **Regional analysis of debris flows**: A statistical method was applied in order to obtain a model of the probability of occurrence of hillslope debris flows in the Benasque valley at regional scale. This task was carried out along with the *Instituto Pirenaico de Ecología* (IPE) team.

The study area (300 km^2) was subdivided in a regular grid of 25 x 25 m cells (having a total of 465642 square slope units). This way, every cell or slope unit has information about the output variable (whether or not that cell corresponds with a debris flow starting point), and about a set of potential predicting variables or potential conditioning factors that we estimated or deduced from the DTM and from the thematic maps.

These potential factors or variables taken into account were: lithology, vegetation, land use, aspect, slope gradient, height, curvature, distance to divide and to the closest stream.

To reach to know which of these factors linked to the terrain control the spatial distribution of the starting points of hillslope debris flows, a multivariate statistical analysis was undertaken, in particular, a binary logistic regression (by means of SPSS) which builds a linear function with the more predicting variables and subsequently computes the probability of failure in every slope unit.

The variables in the equation were only three: Lithology (specially slope quaternary deposits), Slope gradient and Curvature of the slopes. The probability values computed by the logistic regression for every pixel were grouped in four intervals and four colours were assigned in order to draw the final map.



Hillslope debris flow probabilistic map of the Benasque valley

Overlapping the starting points of the 188 observed hillslope debris flows, we have seen that the 70% of them are predicted by the model. That is to say, they fall within the reddish (higher probability) areas.

- **Regional analysis of rockfalls**: A 3D rockfall simulation program (named STONE) developed by the *Dipartimento di Scienze Geologiche e Geotecnologie*, University of Milano-Bicocca, Italy, together with the *CNR-CSITE* from Perugia, Italy (Agliardi & Crosta 2002; Guzzetti et al., 2002), has been applied in the Benasque valley.

The software was conceived to perform a large number of simulations of 3D rockfall paths using a simple cinematic modelling approach rather than a dynamic one. The energy lost at each impact or during rolling depends on a variety of factors. These parameters are difficult to determine at any spatial scale. Thus, "contact functions" relating the kinematics of the block or its dynamics before and after each impact, are used by STONE to model the energy loss. These functions are expressed as restitution and friction coefficients. The 3D nature of actual slope geometry strongly affects the trajectories and the partition of kinetic energy into translational and rotational components. Pseudo-random stochastic modelling is allowed and a scaling relationship for evaluation of restitution coefficients has been implemented within the code.

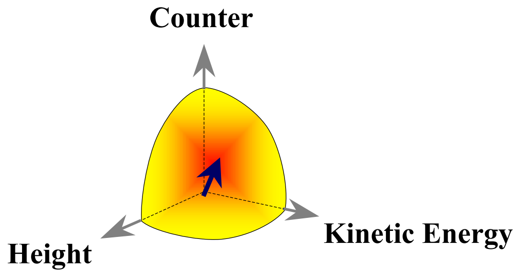
Input data are in a spatially distributed form: lithology, geomorphology, land use, vegetation, outcropping areas, rock fall source areas, rockfall blocks, talus deposits, water, snow and ice covered areas, and topography is provided as a raster Digital Elevation Model with a ground resolution of 25 m.

Both 2D (raster) and 3D (vector) outputs are provided. Raster maps portray at each cell: the cumulative count of rockfall transits, the maximum computed velocity and the largest flying height. Vector outputs provide instantaneous velocity and fly height at each point sampled along the computed fall paths.

The simulation of the rockfall blocks motion was calibrated through a geomorphologic approach checking that talus limits and largest mapped blocks felt directly within the invasion areas as computed by the code. Overlapping the mapped blocks, we see that 70% of them are along the trajectories predicted by the model. Overlapping the talus limits, we see that the 76% of the taluses extent are affected by trajectories.

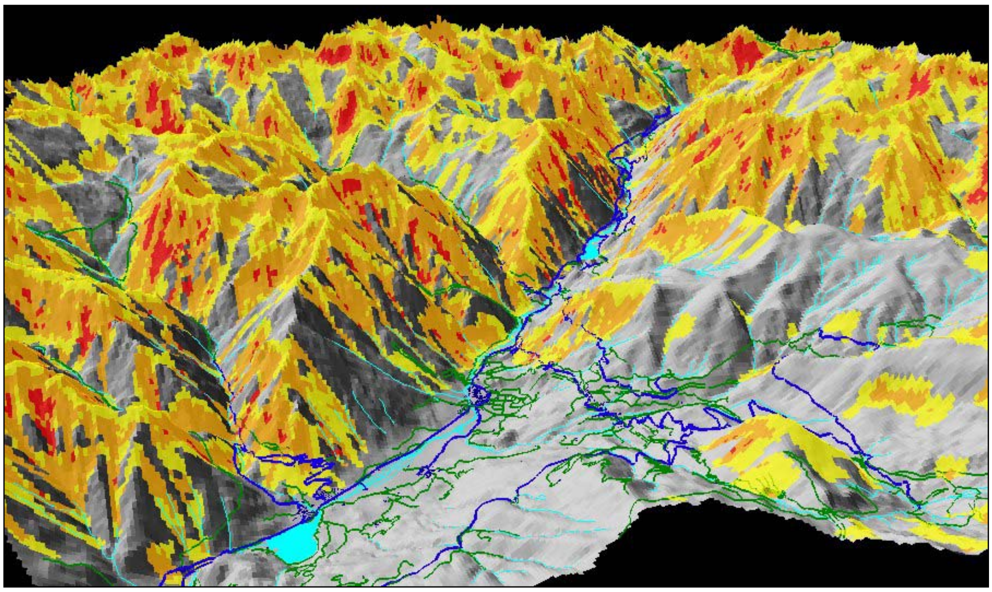
Once STONE was applied and its outputs provided, the next step was to assess the rockfall hazard by means of the three variables we have obtained for every cell: number of blocks that pass over each square slope unit (counter), velocity (now the mass of the falling blocks is introduced and their kinetic energy obtained), and height.

With these 3 variables, a Rock Hazard Vector (*RHV)* is built. The RHV modulus allows an easy classification and ranking of the hazard. The higher these three values, the higher the modulus, and thus, the higher the hazard level.



Obtaining the RHV in one cell

The value of this modulus representing the rockfall hazard level in each cell can be visualized by means of a GIS.



3D partial view of the rockfall hazard assessment in the Benasque valley

3.2.3 WP3 Development of a small basin debris flow impact model

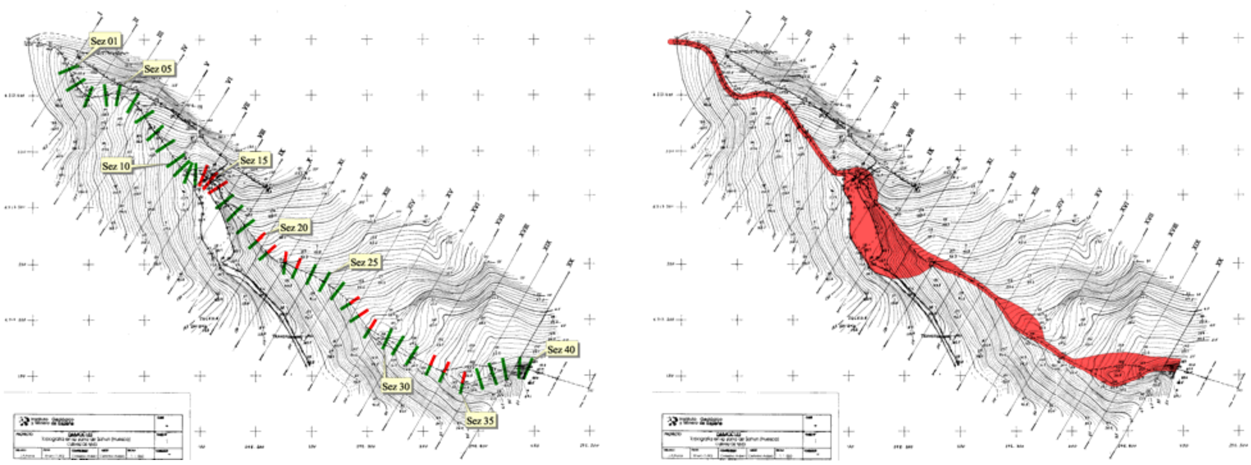
A local analysis of canalised debris flows was undertaken in the Sahún area applying the model MODDS developed by the *Department of Land and Agro-forest Environment, Water Resource Division, University of* Padua, Italy*.*

The *Muskingum One Dimensional Debrisflow Simulation* (MODDS) was applied to compute those points or sections along the fan channel where an hypothetical debris flow would overflow.

To estimate the magnitude of an hypothetical debris flow great event, it was necessary to assess the potential volume of sediment yield in the basin (3.3 km^2). For that, a variety of empirical equations were applied and different values obtained, from which, the mean value was taken. These equations take into account the morphology, land use, vegetation, lithology and geomorphology of the basin. All this information is represented in the formulas by means of parameters such as the basin area, mean gradient of the main channel in the basin, geological index and transport index. According with the climatic scenario, it was also necessary to know the water flow peak at the exit of the basin. For a return period of 50 years, a water discharge peak of 24.6 m^3/s was obtained. From this value, the peak of an hypothetical debris flow was calculated by multiplying this water peak by a variable factor (Hashimoto, 1978). For the Sahún torrent, considering the degree of entrenching and the general conditions of the basin, a value of 8 was chosen by the experts and therefore, the resulting debris flow peak for that return period was 197 m^3/s.

To simulate the impact of this 197 m^3/s debris flow in terms of sediment deposition on the alluvial fan, the morphology of the fan channel was surveyed in detail. Cross sections along the fan channel were built (left figure) as MODDS required. After running MOODS, those sections where a total overflow would occur were coloured in red (in the reach of the channel corresponding to sections 14, 15 and 16, there is a bend and a small bridge). Those sections represented as green and red lines (20-23, 27-29 and 33-35) show lateral overflow. A re-entry of the overflowed material upstream has been supposed.

The right figure would be the preliminary map of the areas affected by the 197 m^3/s debris flow event, obtained after applying the Ikeya (1984) stopping distance formula.



(Left) Cross sections along the Sahún fan channel. The red ones indicate total overflow, the red and green ones indicate lateral overflow. (Right) Debris flow affected areas

3.2.4 WP5 Dissemination of the project deliverables.

These have been the contributions in the objectives of WP5:

- Inclusion of the meetings, progress and annual reports in the Damocles web site.
- Participation in workshops held in Spain and Italy with other potential end-users.
- Attendance together with other potential end-users to the Damocles training course held in Italy on September 2002.
- Two papers about debris flows and rockfall presented in a congress held in Zaragoza (Spain) and in a conference held in Mallorca (Spain).

Section 3.3: Socio-economic Relevance and Policy Implication

As end-users of the models developed in the course of the Damocles Project, we have applied on our test area of Benasque, regional and local models for predicting debris flows and rock falls prone areas. These models have allowed us to make a first hazard assessment of these rapid slope movements, and a preliminary classification of the territory according to the hazard level. This is an important goal that a good land use planning ought to take into account in order to avoid possible losses that these processes could produce in the assets of the study area.

This policy would imply convenient prediction, prevention and protection measures to try to mitigate their effects. A first step in doing a good use of the land is to know predictability that means knowing the occurrence of these natural hazards in a given space-time scenario. For doing that, the application of the models is also a first step.

Section 3.4: Discussion and Conclusion

Working with the other Damocles teams and attending to the training courses that the Project organised last September in Italy, have enabled us to acquire a better knowledge about the debris flows and rockfall matter as well as to enhance our management of GIS techniques.

We are conscious that in the regional assessment of debris flows hazard we have applied an statistical analysis on some of the hillslope debris flows population. These represent a minimum part of debris flows that can occur. The future analysis we want to carry out has to do with the canalised debris flows that can feed many of the mapped alluvial fans. The presented analysis has been made on the basis of a regular subdivision of the territory: cells of 25 x 25 m. In our mind is to apply the statistical model based on a more geological and natural subdivision of the area studied and to compare both methods. In the validation procedure, we have deployed the same population used to develop the model. In the future, we will use two samples of debris flows, one for develop the model and the other one to validate it.

In the rockfall analysis we are conscious of the simplification that the model implies and we will try to improve our knowledge of the parameters that the model needs as data inputs.

We hope that in the future, we will enhance our understanding about the conditioning factors, triggering factors and behaviour of these slope phenomena and thus, progress in our prediction capabilities.

Section 3.5: Recommendations Arising from the Project

Little information of these processes was known in the Benasque area before our participation in the Damocles project. Integrated in the Damocles Project, we have obtained some preliminary information about the spatial prediction, at regional and local scale, of some debris flows and rock falls active processes in this study area.

In the future we will try to improve the natural hazard knowledge linked with this phenomena in this one and others mountain areas of the Spanish territory contributing in this manner to mitigate the damages caused by these rapid slope movements.

Section 3.6: References

- Acosta, E., Lorente, A. y Ríos, S. Application of a regional model for the prediction of debrisflows hazard areas in the Esera upper basin (Central Spanish Pyrenees). XI Congreso Internacional de Industria, Minería y Metalurgia. 4 a 7 de junio de 2002. Zaragoza.

- Acosta, E, Agliardi, F., Crosta, G. B. & Ríos, S. 2002. Regional rockfall hazard assessment in the Benasque valley (Central Pyrenees) using a 3D numerical approach. In, *Proceedings 4th European Geophysical Society Plinius Conference, Mallorca, Spain, October 2002.*

- Acosta, E., Ríos, S. Geomorphological mapping and hazard assessment in the Benasque area, Pyrenees *Workshop: "Tecnologie GIS nella previsione, monitoraggio e mitigazione dei rischi idrogeologici"* organizado por el grupo GISIG (Geographical Information System International Group), celebrada en Milan el 21 de noviembre de 2002.