The DAMOCLES European Project

Debris fall assessment in mountain catchments for local end-users

DAMOCLES PROJECT WORK

INSTITUTO PIRENAICO DE ECOLOGIA, CSIC
ZARAGOZA, SPAIN

Section 3: Field and Laboratory activities during 2001

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SECTION 3

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3.1. Objectives of the Reporting Period

During the second year of the DAMOCLES Project (year 2001) the main objectives of the IPE's team have been the following:

i) To write and send to the Project Coordinator a report on the factors explaining the spatial distribution of hillslope debris flows in the Flysch Sector of the Central Spanish Pyrenees.

ii) To finalize the field work in order to prepare a data base on differents debris flow parameters and to analyse this information in order to establish statistical relationships between them.

iii) To prepare and send the information needed to run the SHETRAN model in the Ijuez catchment.

iv) To get information on the periodicity of debris flows in the study area.

3.2. Methodology and Scientific Achievements Related to Work Packages

Workpackage 1

A) Field measurement and analysis of debris flow characteristics / debris flow relationships

In the first year report (year 2001) the main results about the location of almost 1,000 debris flows distributed by the whole study area were included. With this information we are able to explain the distribution of debris flows according to the lithology, gradient, aspect, altitude, distance to the divide, plant cover, evolution of the land use and other environmental factors. Furthermore, using complex statistical procedures this information allows us to perform a debris flow susceptibility map. Since the spring of 2001 an intensive field work has been made, in order to obtain more detailed information on different debris flow parameters. The main purpose has been to establish statistical relationships between such parameters (see Bathurst et al., 1997).

98 debris flows have been selected in the most geomorphologically active areas of the Flysch Sector, that is, close to the contact between the Flysch Sector and the marls of the Inner Depression, especially in the Ijuez and Acumuer valleys and in the southern aspects of the Flysch Sector between Jaca and Sabinanigo (Fig. 1).

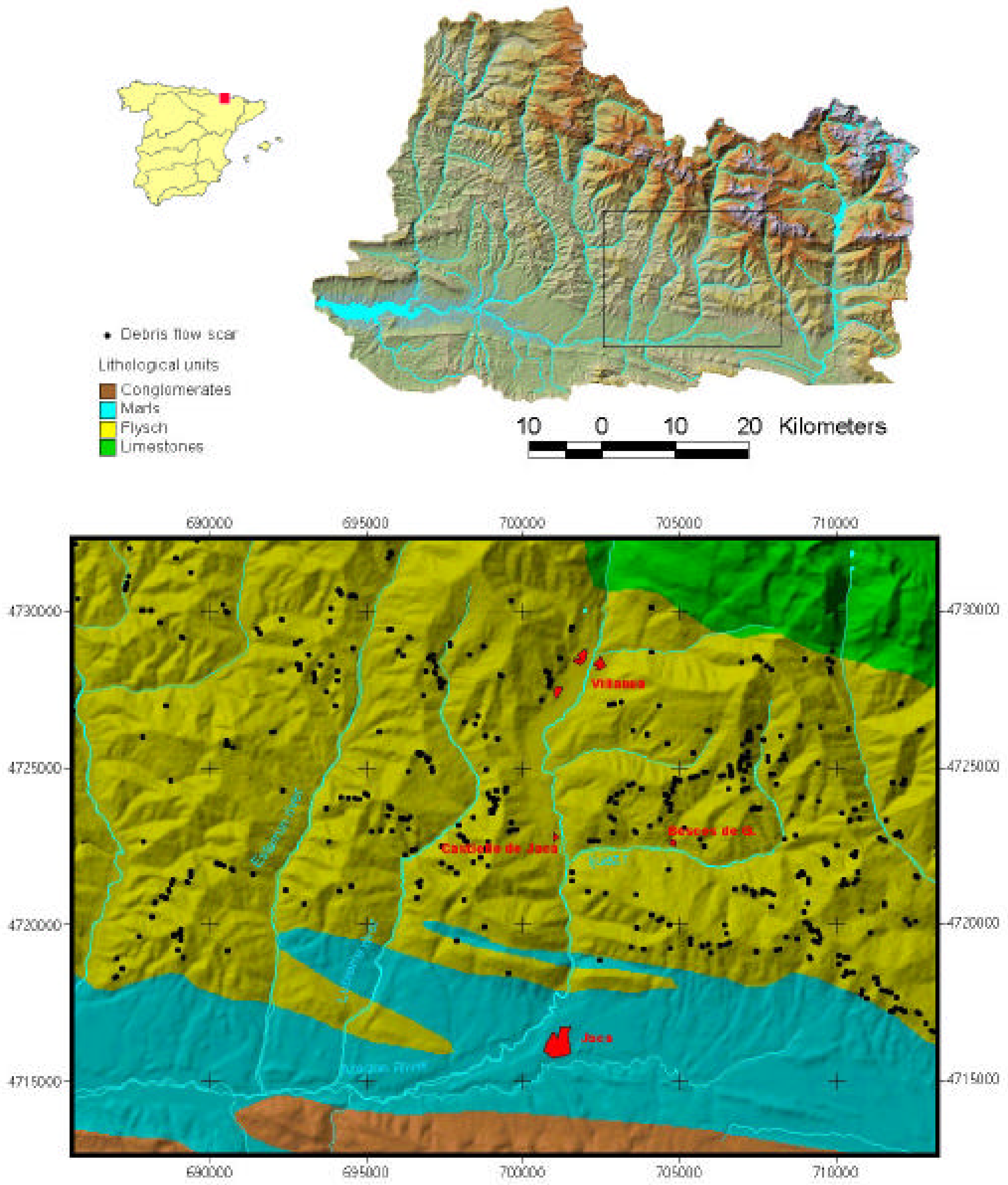


Fig. 1. Location of Focus Area

The following variables have been measured in each one of the 98 selected debris flows:

- ALTSCAR: The altitude of the debris flow scar in metres above the sea level.
- ALTBASE: The altitude where the runout deposit beguins (in m).
- Δh: Difference in height (m) between ALTSCAR and ALTBASE.
- LENGTH: Total length of the debris flow between the upper part of the scar and the beginning of the deposit.
- SCAR°: Gradient of the debris flow scar.
- CANAL°: Gradient of the debris flow canal.
- BASE°: Gradient of the debris flow deposit.
- RUNOUT: Length (in m) of the debris flow deposit.
- SCAR2: Width (in m) of the debris flow scar.
- CANAL2: Width (in m) of the debris flow canal.
- BASE2: Width (in m) of the debris flow deposit.
- VOLUME: Estimated volume (m^3) of the material mobilized by the debris flow.
- SOILM: Average soil depth (m).

In the office, the relationship between DEPOSIT and Δh has been obtained, that is, the relationship between the length of the debris flow deposit and the difference in height. This parameter has been called α.

In total, 13 variables have been measured in the field. Fig. 2 shows a longitudinal profile of a typical debris flow, with some of the measured variables. Furthermore, in the most recent debris flows soil samples were taken in order to obtain their grain size distribution. The results from soil analysis are not included in this report.

A general table was obtained, to which descriptive statistical procedures were applied. First of all, the statistical analysis was carried out with all the measured debris flows (98 in total), thus obtaining the Mean, Median, Standard deviation, Variance, Rank, Maximum and Minimum value, as well as the percentiles. Posteriorly the Pearson correlation coefficients between the different variables were obtained.

Nevertheless, the construction of histogrames of the variables allowed us to observe the normality of the variables and the presence of the so-called outlayers. These anomalous data have been eliminated, in such a manner that a new statistical approach has been made with 85 cases. It is interesting to note that, after this selection, the correlation coefficients have been considerably improved.

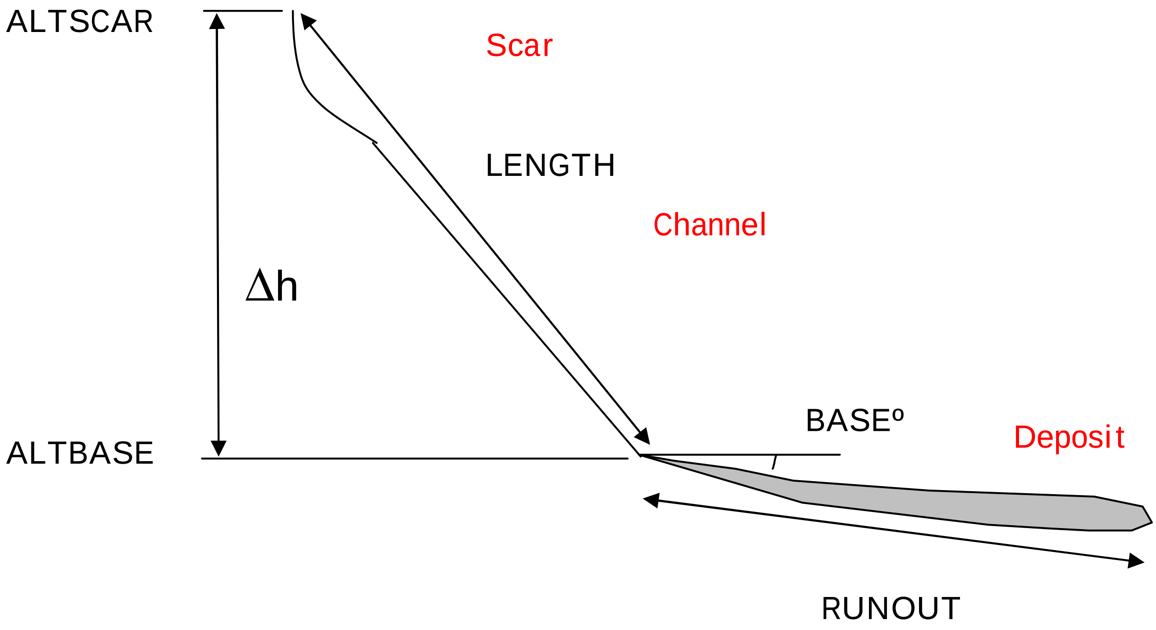


Fig.2. Some of the parameters measured in the debris flows.

Finally, taking into account our experience in measuring the debris flows in the field, a new selection was made, avoiding those cases that were doubtful or insatisfactory (i.e, existence of uncertainties in the determination of the runout distance). This new statistical analysis considered 64 cases. The results obtained do not represent almost any variation comparing the average values with the previous analysis. However, this reduced Table leads to better correlation coefficients between the parameters, and to lower figures of standard deviation and variance, and this is the reason why the 64 cases analysis has been used in this report.

These are the main features of debris flows as measured in the field:

1. The characteristic landslide scar dimension is in average 15.4 m width, (standard deviation: 5.3). The median is 14.5 m. The larger scar measured is 30 m width, and the minimum, 7.4 m.

2. The mean altitude at which the landslides are triggered is 1157 m, coinciding very well with the results obtained from the general distribution of debris flows in the Flysch Sector. The difference in height between the upper part of the scar and the beginning of deposition (Δh) is 36.6 m (standard deviation: 17.9), and the median is 35 m. The maximum difference is 85 m, and the minimum 7 m.

3. Most of landslide scars develop around 30º. Mean: 33.9º; Median: 33º; standard deviation: 5.0º; Maximum value: 45º; Minimum value: 18.5º. This is consistent with the results supplied by other authors, who find most debris flows occurring between 25 and 38º (Takahashi et al., 1981) or between 32 and 42º (Innes, 1983). In a more general sense, the gradient of the initiation point is establishes between 15 and 60º (Bathurst et al., 1997; Reneau & Dietrich, 1987; Moser & Hohensinn, 1983).

4. The mean length of the deposit (runout distance) is 22.1 m (standard deviation: 11.1), and the median is 20 m. The maximum length is 55.6 m, and the minimum 5.8 m.

5. As for the gradient from which deposition starts, the value is 17.8º, showing a large rank from 8 to 27º. This variance can be explained due to the conditions in which the debris flows occur in the Flysch Sector, since the angle of deposition can be very much influenced by the presence of bench terraced fields or forest patches. The value obtained is appropriate for unconfined debris flows, that is, shallow landslides that evolve into debris flows.

6. One of the most interesting problems in determining debris flow hazard is to devise a simple formula for run-out distance starting from other parameters. One of these formulas is that from Vandre (1985), who found that run-out dustance is about 35-45% of the difference in height between the head of the landslide and the point at qhich deposition starts. The formula devised is:

$$L = \alpha \Delta h$$

where L= run-out distance from the point at which deposition starts,

Δh = elevation difference between the head of the landslide and the point at which sedimentation starts,

α= an empirically derived fraction.

According to Vandre's (1985) calculations, α value is set at 0.4, that is, run-out distance is 40% of the parameter Δh.

In the case of debris flows measured in the Flysch Sector of the Spanish Pyrenees, the mean value is 0.605.

7. The volume of material mobilized by the landslides is, in average, 179.9 m^3 (standard deviation: 131.9). The median is 135.7 m^3.

8. The depth at which the plane of the landslide occurs is 0.67 m (standard deviation, 0.12, median, 0.6, extreme values, 1.1 and 0.45), confirming that they affect the soil and superficial colluvium.

Pearson correlations show good relationships between some of the parameters. Thus:

- Δh is very well correlated with LENGTH (r = 0.80) and with the distance travelled by the deposit (runout distance) (r = 0.80). Good relations are also obtained with the width of the scar (r = 0.46) and the volume (r = 0.46). These results confirm that a larger difference in height can explain very well the runout distance, due to the energy of the landslide. Besides, the volume of the deposit is also larger due probably to the erosion along the channel. Similar relationships are obtained for the LENGTH.
- The gradient of the debris flow scar (SCAR°) is well related with the gradient of the channel (r = 0.57) and the width of the channel (r = 0.41).
- The runout distance mainly depends on the difference in height (Dh) (r = 0.80), the LENGTH (r = 0.67), the gradient at which deposition starts (r = 0.29), the width od the scar (r = 0.48), and the volume of the deposit (r = 0.48).
- The width of the debris flow scar is well related with the gradient in the channel and deposit, and the difference in height (Δh) and very well related with the volume of the deposit (r = 0.94).
- Finally, the volume of the deposit is correlated with the difference in height (r = 0.45), the length of the debris flow (r = 0.55), run-out distance (r = 0.48), the soil depth (r = 0.40) and the width of the debris flow scar (r = 0.94), that is, most of the factors that characterise the size of the debris flow.

Two multiple lineal regressions have been done in order to predict the length of the runout distance, according to several variables.

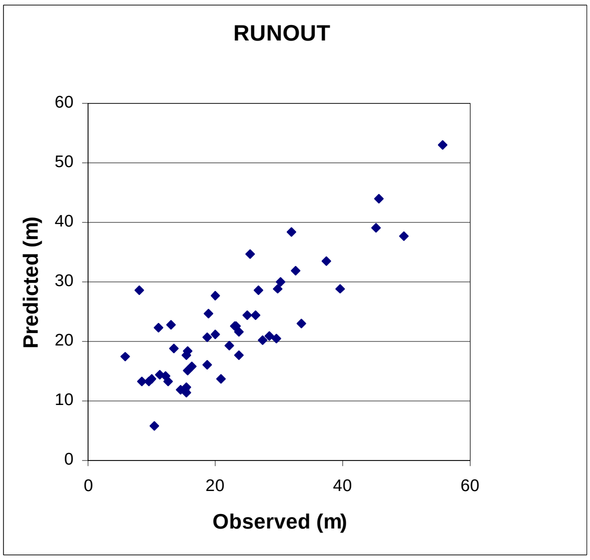
- A first analysis has been done using 4 variables: Δh, LENGTH, SCAR° and BASE°. The adjusted r^2 is 0.664 and the most significant variables are Δh and SCAR°. The equation that relates the runout distance to the 4 variables is as following:

$$\text{DEPOSIT}=-14.447+0.477\Delta h+0.709\text{LENGTH}+0.365\text{SCAR}^{o}+0.18\text{BASE}^{o}$$

- Finally, a simple regression has been done in order to explain the runout distance according to the difference in height (Δh). Both variables are very well correlated, with an adjusted r^2 of 0.63. This demonstrates that most of the variability of the runout distance is mainly explained by the difference in height betweeen the upper part of the debris flow scar and the beginning of the deposition. The rest of variables participate in a very marginal way. The equation of the simple regression is as following:

$$\text{DEPOSIT}= 1.393+0.553\Delta h$$

- Fig. 3 faces the observed and the predicted values of the runout distance. Predicted values have been obtained from the multiple linear regression with 4 variables. In general, observed and predicted values are scattered around a stright line, but the model subestimates the largest values and overestimates the lowest values. This is confirmed in Fig. 4, which relates the observed values of the runout distance and the residuals from the previous regression.



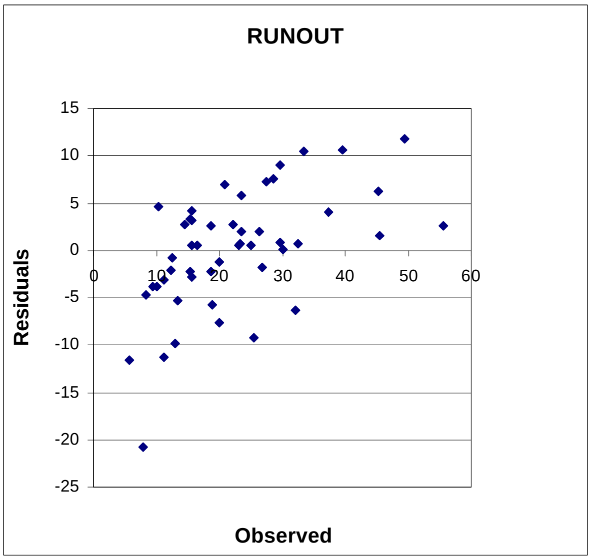


Fig. 3. Relationships between the observed and predicted values of the runout deposit, according to the regression model with 4 variables.

Fig. 4. Relationship between the observed values of the runout deposit and the residuals from the regression of the Fig. 3.

B) Periodicity of debris flows

It is very difficult to have information on the recurrence of debris flows and the moment in which they have triggered. Some papers have used dendrochronological techniques to date debris flows and other mass movements, but this proceduce is very slow, needs good samples and is not always satisfactory. Besides, it is difficult to have a long series of debris flows to achieve final figures of return periods. In the Central Spanish Pyrenees a rapid approach to this topic could be made by using aerial photographs of different dates.

Aerial photographs from 1956, 1977 and 1990 have been carefully analyzed in order to detect the presence of debris flows. A map for every one of these dates has been produced, locating the debris flows corresponding exclusively to each period. Furthermore, debris flows triggered between 1991 and 2001 have also been mapped after field work, a new debris flow map has been produced with the most recent cases.

The most geomorphologically active sector of the flysch area of the Central Spanish Pyrenees has been selected. Is is located between the rivers Estarrun and Aragon, close to Jaca, within the general study area of the DAMOCLES Project. This selection allowes us to have more reliable information about debris flows triggered during the last decade.

It is well known that the main factors that explain debris flows are topography, lithology, climate and land use changes. Obviously, topography and lithology do not change (at least not at a humen scale), and then the only factors that could explain any temporal variability in the triggering of debris flows are climate and land use changes.

Fig. 5 shows the evolution of the average annual precipitation in Jaca. Not any trend has been detected at long term (Garcia-Ruiz et al., 2001), like in the rest of Pyrenean weather stations. The mobile mean since 1940 shows a large fluctuation with minimum values at around 1947-1948, and a progressive increase until the period 1960-1977. Since then precipitation has decreased again. From 1993 onwards it seems that a new recovering of precipitation occurs. A fluctuation like this is very normal in the Pyrenees. A study from the beginning of the past century has demonstrated the existence of several, almost regular oscillations of the precipitations. without any singnificant trend.

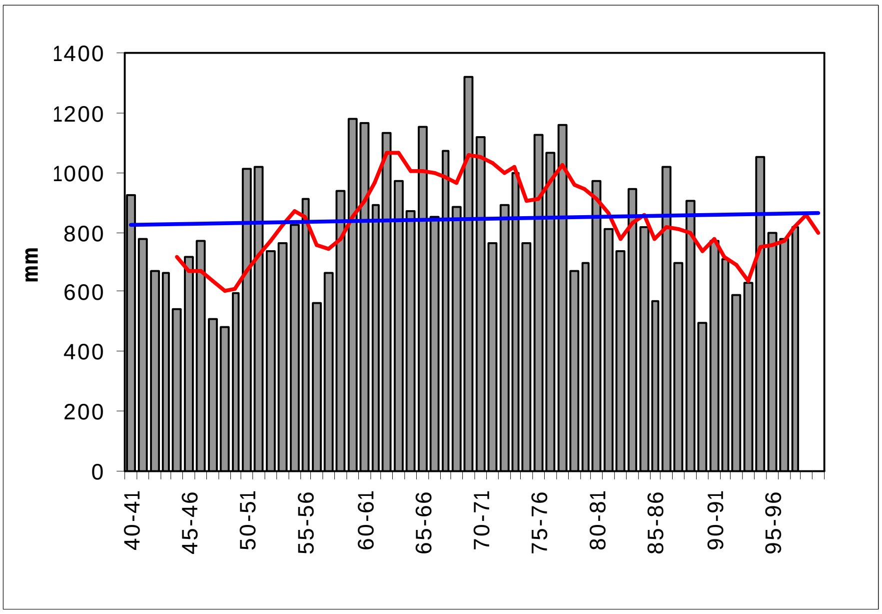


Fig. 5. Evolution of annual precipitation at Jaca (1940-1996)

As for land use changes, a large proportion of the selected study area was cultivated up to the middle of the 20th century, especially between 800 and 1500 m a.s.l., and on sunny hillslopes. At the end of the century most of the territory has been abandoned, and the old farmed area has been colonized by dense scrubs and reafforestations. Thus, a clear plan recovering has occurred, and the soil is much more protected than a few decades before.

A total of 279 debris flows have been mapped. Fig. 6 shows their temporal distribution according to aerial photographs and field work: 127 in the 1956 aerial photograph, 76 in the 1977 aerial photograph, 46 in the 1990 aerial photograph, and 30 according to field work in 2001. A clear decrease is seemengly detected, but if the average number of annual debris flows is calculated, then not a clear trend is apparent. Between 1956 and 1977, 3.62 debris flows per year occurred, and a similar value has been obtained for the period 1977-1990 (3.54 debris flows per year). Between 1990 and 2001 a slight decrease is assessed, though the mapping system must include some sampling errors.

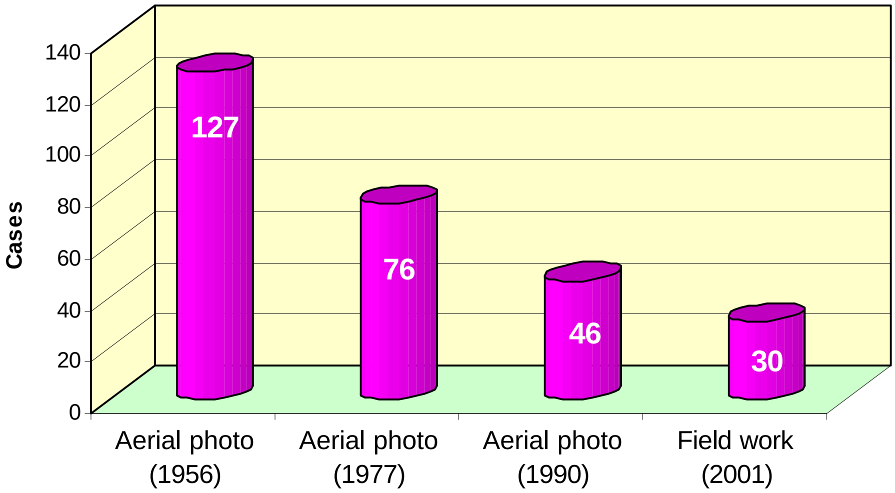


Fig. 6.. New debris flows observed by aerial photographs and field work

Fig. 7 shows the accumulated evolution of debris flows since 1956. A clear stright line demonstrates that no relevant changes in the triggering of debris flows can be detected in the last 50 years. Since precipitation has not substantially changed at long term, whereas land uses have very much changed in the same period, it can be concluded that debris flows are mainly controlled by precipitation and not by possible land use changes. Nevertheless, the effects of land use inertia are not excluded, that is, the effects of forest wasting, fires, overgrazing and shifting agriculture during centuries, which could have conditioned the geomorphological dynamics of the hillsopes for decades. Another relevant conclusion is that the triggering of debris flows do not need extreme rainfall events. As Figs. 6 and 7 state, shallow landslides that become debris flows are a common phenomenon in the flysch area of the Central Pyrenees. Most probably, rainstorms correspondieng to less than a 10 year return period are enough to develop shallow landslides.

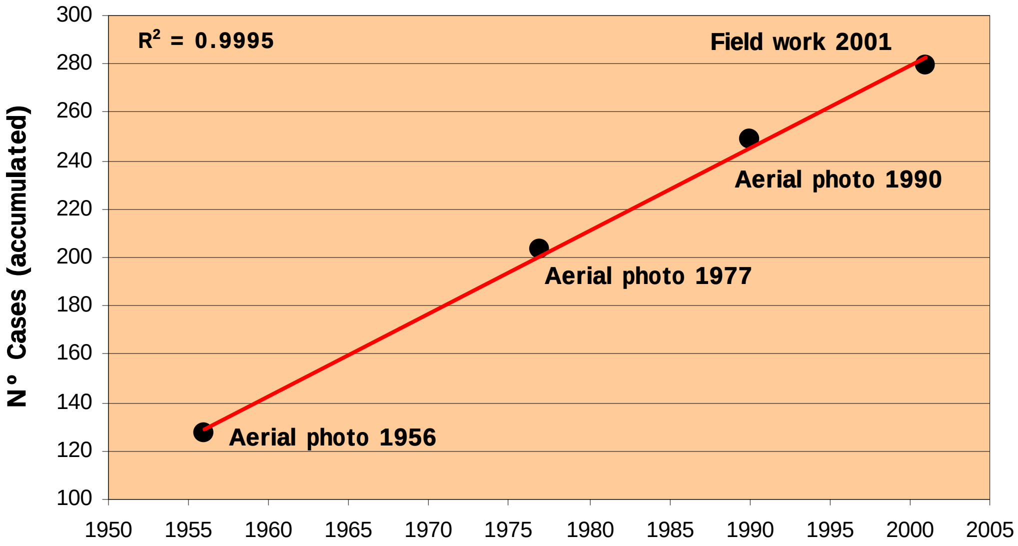


Fig. 6. Accumulated evolution of debris flows since 1956

Workpackage 4

The contribution of the IPE's group to Workpackage 4 consisted on the preparation and elaboration of a variety of information for sending to the Newcastles's group.

Forst of all the Ijuez catchment was selected. It was necessary to have a representative catchment of the flysch sector, where the most active debris flows are located. The Ijuez catchment has an area of 45 km2 and was cultivated in a large proportion until de 50's of the 20th century. Posteriorly it was abandoned and reforested with pines. Now it is completely forest covered, except for a small area in the subalpine sector (above 1700 m a.s.l.). The growth of the reforestations shows a large heterogeneity, depending on the aspect, the quality of soils and the history of land uses. Usually, the sunny hillslopes are subject to low growing rates.

A short field camplaign was made in the Izas catchment with the Newcastle's group at the middle of June 2001, in order to select soil sampling points, to make some shear stress tests, and to have a general overview of the catchment. Besides, the following information has been prepared and sent to Newcastle with the main purpose of preparing a data base for the SHETRAN model:

- MDT of the Ijuez catchment.
- Vegetation map
- Precipitation from the Bescos weather station
- Data from Jaca (Aragon River) and Aragues (Osia River) gauging stations
- Mean annual and monthly discharges from different gauging stations located in the Upper Aragon River Basin

- Average precipitation from 37 weather stations of the Pyrenees, as well as their distance to the Bescos weather station, coordenates and altitude

-Hourly precipitation from Jaca

Furthermore, the Table obtained for Workpackage 1 (fieldwork measurement of debris flow parameters) has also been sent to Newcastle.

3.3. Socio-economic Relevance and Policy Implication

The results obtained represent an important step to understand the distribution and triggering factors of debris flows in the Central Spanish Pyrenees. It is important to take into account that detailed information of geomorphic hazards is scarce or rare in the Central Pyrenees, where the Public Administration has been especially engaged in the study of snow avalanches and floods as the most visible and seemingly destructuve geomorphic hazards. Nevertheless, our study has stated i) the widespread occurrence of debris flows in the Pyrenees, and ii) their frequent occurrence, linked to relatively low frequency rainstorm events.

The work done is in the way of the socio-economic goals outlined in the original project proposal. It gives information on the spatial occurrence of debris flows, and the runout distance, allowing the use of models to predict the areas most affected by debris flow hazard. This is a basic information for different departments of the regional government, in order to plan the location of different infrastructures and touristic settlements.

3.4. Discussion and Conclusion

In general, the width and depth values for debris flow scar, as well as the sediment volumes reported in this paper are of the same order of magnitude than those reported by other authors. This is the case for debris flows in the Central California (Reneau & Dietrich, 1987), Central Nepal (Caine & Mool, 1982; Ramsey, 1987) or Central Austria (Moser & Hohensinn, 1983). However, the relationships between some major parameters are somewhat different:

- Deposition of the sediment carried out by the debris flows starts at 17.8º, a value much higher than those reported by other authors. Thus, Bathust *et al.* (1997) point out that deposition begins once the slope falls below 6-10º, and Ikeya (1981) suggests that deposition should begin at the 10º slope. The reason for the beginning of sedimentation at steeper slopes in the Flysch Sector of the Central Pyrenees remains unclear. Further analysis is needed in order to assess the role of the volume of sediment involved, as well as microtopography and vegetation.

- The α value in the Vandre's (1985) formula is 0.6 in de case of debris flows in the Flysch Sector of the Spanish Pyrenees, that is, the runout distance represents

60% od the difference in height between the debris flow scar and the point at which sedimentation stars. This value represents a longer distance than that derived from the Vandre's (1985) study, in which a is 0.4. The difference can be explained by two reasons:

i) The material involved in the landslide contains a high proportion of clay and sand (around 70%) and less stones than in other studies on debirs flows. Most probably, the mixture of stones, water and fine material is fluid enough to encourage a longer debris flow runout.

ii) The gradient at which sedimentation starts (17.8º) is higher than in other areas, and this probably enables the maintenance of high energy levels.

It is interesting to note that good correlations have been obtained between different parameters. Special attention must be payed by the relations between the volume of sediment and the runout distance.

Finally, the occurrence of debris flows is a very common geomorphic process in Central Spanish Pyrenees, especially in the Flysch Sector. A temporal analysis has demonstrated that they are mainly controlled by the intensity of precipitation and not by land uses, though these have a clear influence.

No extreme rainfall events are needed for the triggering of debris flows. Rainstorms corresponding to less than a 10 year return period are enough to develop shallow landslides that evolve into debris flows.

3.5. Plan and Objectives for the Next Period

During the year 2002 the work plan of the IPE's group is the following:

i) To enlarge the study on the temporal variability of debris flows. Until now this study has been focused on the area most affected by the occurrence of debris flows in the Central Spanish Pyrenees. Other areas have been selected in order to repeat the same study and to get information on the frequency of debris flows there where the conditions are less favourable **(May, 2002)**.

ii) To map the areas directly affected by debris flow occurrence, by crossing the information from the landslide susceptibility map and from the debris flow relationships. The final map would include not only the points where debris flow scar will trigger, bau also the areas affected by the debris flow tongues (runout distance) (**June, 2002**). Previous results will be presented during the XVII General Assembly of the European Geophysical Society at Nice (**April, 2002**).

iii) Adrian Lorente must finish his PhD on "Debris flows in the Central Spanish Pyrenees: Space-time distribution and probability of occurrence in the Upper Valleys of the Aragon and Gallego Rivers" (**August, 2002**). Public presentation at the University (tentatively), in **October-November, 2002**.

iv) To prepare papers to be sent for publication in international journals. A paper on "Debris flow relationships" is almost ready to be sent to James Bathurst (**March, 2002**) and, after correction, to Natural Hazards and Earth System Sciences (**April, 2002?**). Another paper on the debris flow susceptibility map will be sent to the journal Geomorphology (**June-July 2002?**).

v) To organise a workshop in Zaragoza, including a fieldtrip in the Pyrenees, in order to disseminate the results from DAMOCLES Project (**May, 2002**).

vi) To organise the next Progress Meeting at Zaragoza (**May, 2002**).

vii) To write the final Project Report (**January-February, 2002**).

3.6. References

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