INSTITUTO PIRENAICO DE ECOLOGIA, CSIC

REPORT FOR THIRD DAMOCLES PROGRESS MEETING
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Summary of the work carried out

The work carried out can be divided into the following sections:

i) Field and laboratory work to prepare a data base on different parameters of debris flows for statistical analysis and modelling.

- Measurement of debris flow parameters in the field.
- Preparation of a table with the information taken in the field.
- Statistical analysis to establish relationships between different parameters

ii) A detailed study on the spatial distribution of extreme rainfall events has been made.

iii) Information on the characteristics of the Ijuez catchment and surrounding areas has been sent to the Newcastle's team.

- First of all, a short field campaign was made with the Newcastle's team in the Ijuez catchment.
- Secondly, climatic and hydrological data were sent in order to run the SHETRAN model.

iv) An approach to the temporal recurrence of debris flows has been made, as well as a study of the land-use factors explaining the triggering of the most recent debris flows.

- Identification of the most recent debris flows (since the 50's) by means of three series of aerial photographs and field work.
- Temporal occurrence of debris flows.
- Relationships between the occurrence of debris flows and recent land-use changes.

Section 1. Objectives of the reporting period

During the last six months the main objectives of the IPE's team have been the following:

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

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

Secondarily we have tried to get information on the periodicity of debris flows in the study area.

Section 2. Scientific progress made in different work packages

Workpackage 1

A) <u>Field measurement and analysis of debris flow characteristics</u>

In previous progress reports we informed that a statistical analysis was made with the information obtained from the location of almost 1,000 debris flows distributed by the whole study are. With this information we were 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 we obtained a debris flow susceptibility map, which needs to be improved by adding information on the spatial distribution of extreme rainfall events. Now we have made an intensive field work in order to obtain detailed information on different debris flow parameters which has allowed us to establish statistical relationships between such parameters (see Bathurst et al., 1997).

The study has been made in the Flysch Sector, since most of debris flows of the study area are located in this lithology. It is important to take into account that the flysch is a geomorphologically active area, with steep gradients and the alternance of thin sandstone and marl beds, encouraging the triggering of shallow (as well as deep) landslides. Intense human activities have favoured forest wasting, accompanied by wildfires and cropping of sunny steep slopes (even by shifting agriculture). The occurrence of debris flows is especially dense in these areas intensively managed for centuries, mainly in the most tectonized areas and where very old slumps have been identified. A total of 98 debris flows have been measured in the field.

The following variables have been considered:

- ALTSCAR: The altitude of the debris flow scar in metres above the sea level.
- ALTBASE: The altitude where the runout deposit begins (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.
- SCARº: Gradient of the debris flow scar.
- CANALº: Gradient of the debris flow canal.
- BASEº: Gradient of the debris flow deposit.
- DEPOSIT: Length (in m) of the debris flow deposit.
- SCAR: 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. 1 shows a longitudinal profile of a typical debris flow, with some of the measured variables.

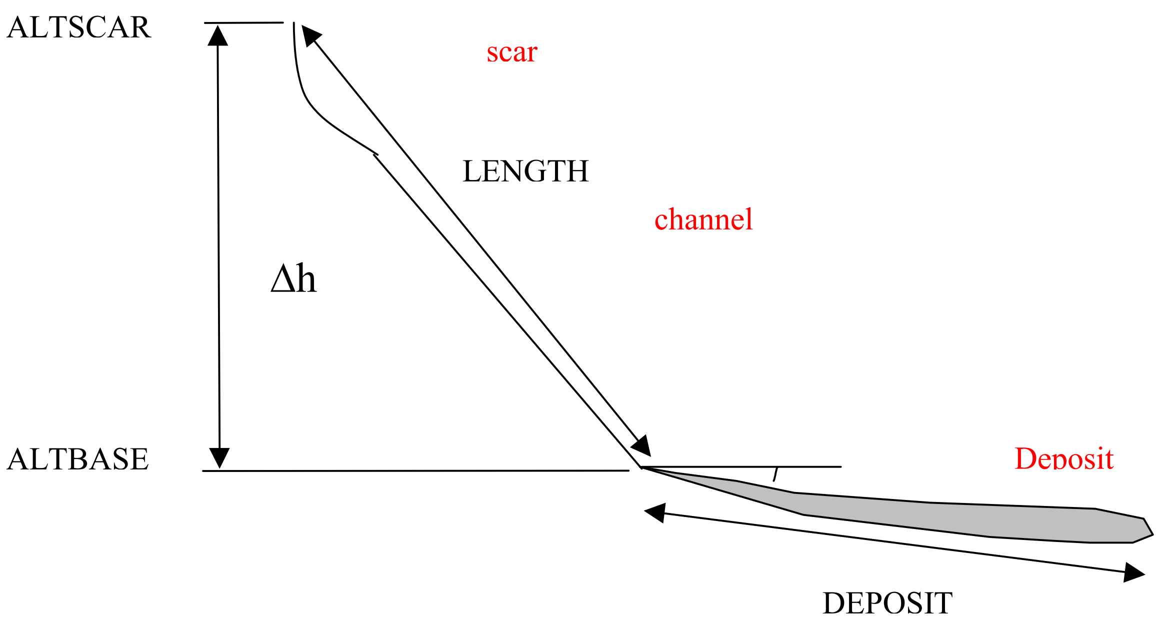

Fig. 1. Some of the parameters measured in the debris flows.

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 (already sent to Newcastle), 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. The Pearson correlation coefficients between the different variables were also obtained.

Nevertheless, the construction of histograms 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.

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 unsatisfactory (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 in comparison with the previous analysis.

All this information has been put in Tables. Histograms have also been made and have to be delivered to the Project Coordinatior with a separate report. Next, only the most interesting results are explained.

1. For the relation α the mean value is 0.606 for all the cases, 0.575 without outlayers, and 0.605 without outlayers and doubtful cases. This figures can be used to calculate the debris flow runout distance. The three values are reliable, but we recommend the use of the third one because it has been obtained using the "best field information".

2. As for the gradient from which deposition starts, the values are 17.5º, 17.2º and 17.8º respectively, 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 values obtained are appropriate for unconfined debris flows, that is, shallow landslides that become debris flows.

For the rest of the parameters only the selected data (without outlayers and doubtful cases) are included. The results from correlations and multiple lineal regressions are also based on these data.

3. The characteristic landslide scar dimension is in average 15.94 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.

4. 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.

5. The mean length of the deposit 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.

6. The mean altitude at which the landslides are triggered is 1157 m, coinciding 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: 17.8), and the median is 35 m. The maximum difference is 85 m, and the minimum 7 m.

7. Most of landslide scars develop around 30º. Mean: 33.9º; Median: 33º; Maximum value: 45º; Minimum value: 18.5º.

8. 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 gradient 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 (SCARº) is well related with CANALº, CANAL2 and with the runout distance.
- The runout distance mainly depended on the difference in height (Δh) (r = 0.80), the LENGTH (r = 0.67), the gradient of the debris flow scar, and the volume of the deposit.
- The width of the debris flow scar is well related with the gradient in the channel and deposit, and very well with the volume of the deposit (r = 0.94).
- Finally, the volume of the deposit is correlated with the difference in height, the length of the debris flow, the length of the deposit, the soil depth and the width of the debris flow scar, that is, most of the factors that characterise the size of the debris flow.

9. 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, SCARº AND BASEº. The adjusted r^2 is 0.664 and the most significant variables are Δh and SCARº. The equation that related the runout distance to the 4 variables is as following:

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

- 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 between 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:

$$DEPOSIT = 1.393 + 0.533\Delta h$$

- Fig. 2 faces the observed and the predicted values of the runout distance. Predicted values have been obtained from the multiple linear regression with 6 variables. In general, observed and predicted values are scattered around a straight line, but the model subestimates the largest values and overestimates the lowest values. This is confirmed in Fig. 3, which relates the observed values of the runout distance and the residuals from the previous regression.

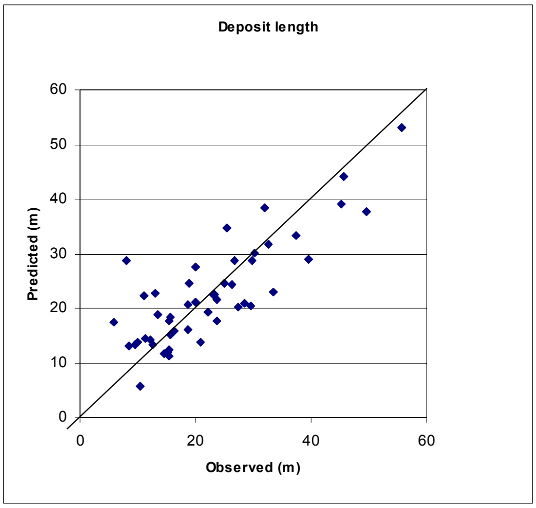

Fig. 2. Relationships between the observed and predicted values of the runout deposit, according to the regression model with 4 variables.

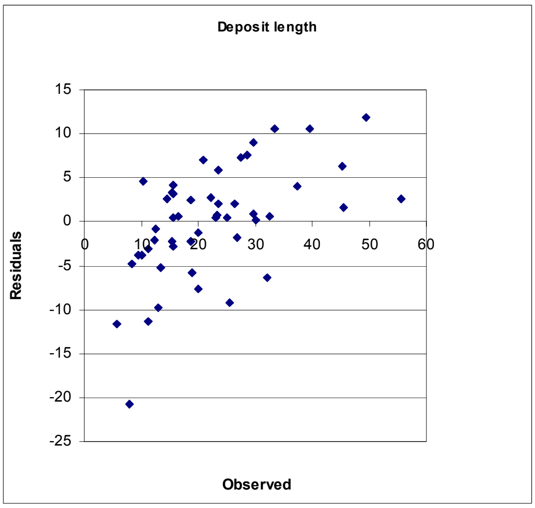

Fig. 3. Relationship between the observed values of the runout deposit and the residuals from the regression of the Fig. 2.

B. <u>Debris flow recurrence and its relationships with extreme rainfall events and land use changes</u>

Information on this problem is under elaboration. Efforts have been made on both the recurrence of extreme rainfall events and the periodicity of debris flows in the Central Spanish Pyrenees.

B.1. Recurrence of extreme rainfall events

Debris flows are clearly related to relatively intense rainstorm events. For this reason a study of the spatial distribution of the maximum annual precipitation in 1, 3, 5 and 7 consecutive days has been calculated. The study uses information from 37 weather stations with between 25 and 50 years of record. Two different periods have been considered: i) winter, between October and May, and summer, between June and September. Different topographic variables have been estimated from a Digital Terrain Model: Aspect, altitude, roughness, gradient, including that corresponding to a radius of 0.5, 1, 2, 5 and 8 km around each cell.

Different maps have been obtained on the distribution of maximum rainfalls in both winter and summer. The use of the Principal Component Analysis and regressions allows us to conclude that in summer the main factor explaining the most intense rainfalls is the macro-relief, whereas in winter the weight of other factors also arise: the influence of the relief around each point, the gradient and the roughness.

B.2. 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 procedure 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 analysed 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 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. It is located between the rivers Estarrun and Aragon, close to Jaca, within the general study area of the DAMOCLES Project. This selection allows 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 human 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. 4 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 significant trend.

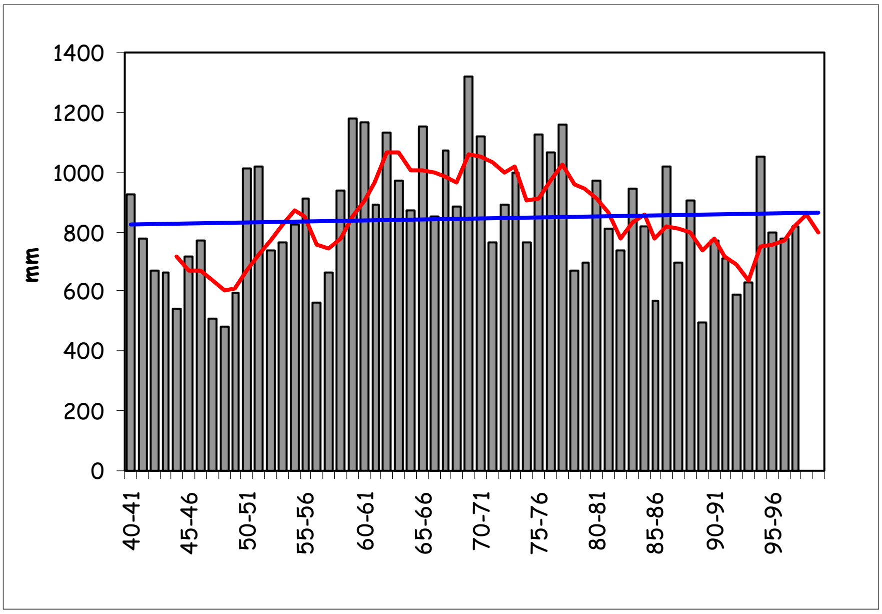

Fig. 4. Evolution of annual precipitation at Jaca (1940-1996)

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. 5 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.

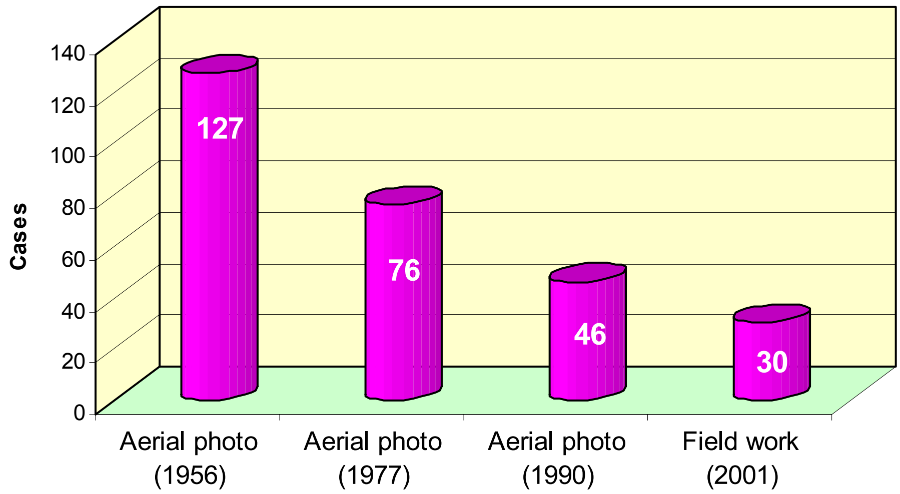

Fig. 5. New debris flows observed by aerial photographs and field work

Fig. 6 shows the accumulated evolution of debris flows since 1956. A clear straight 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, he 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 hillslopes for decades. Another relevant conclusion is that the triggering of debris flows do not need extreme rainfall events. As Figs. 5 and 6 state, shallow landslides that become debris flows are a common phenomenon in the flysch area of the Central Pyrenees. Most probably, rainstorms corresponding to less than a 10 year return period are enough to develop shallow landslides.

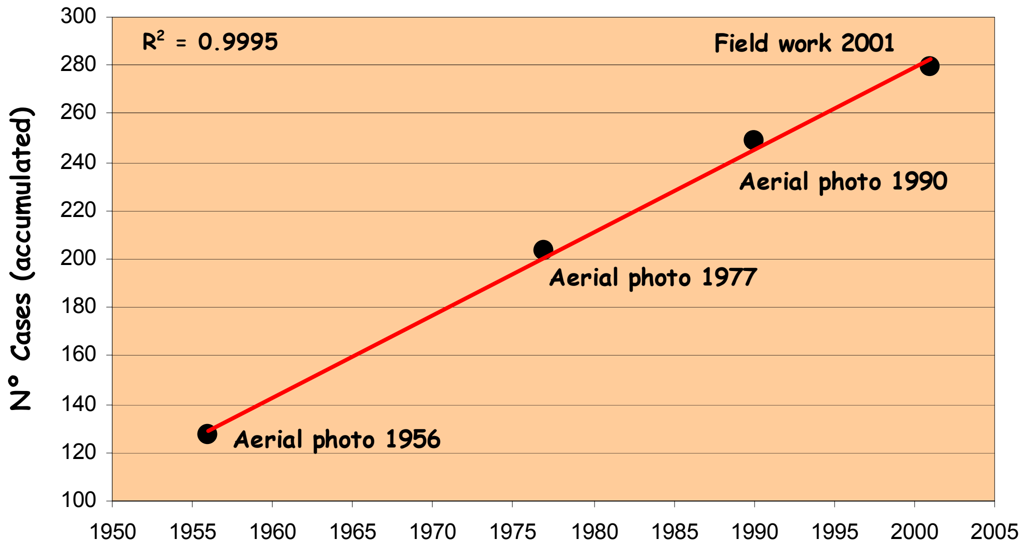

Fig. 6. Accumulated evolution of debris flows since 1956

B.3. Influence of land use changes on recent debris flows

In spite of the conclusion stated immediately above, a new effort has been made in order to relate the occurrence of recent debris flows to any plant cover or land use. In 1956 most of debris flows affected abandoned fields and shrub areas, with few cases within the forest. In 1977 the majority of debris flows occurred in reafforested old fields and shrub areas. In 1990 reafforested fields and shrub areas again concentrate many debris flows, but the proportion of old fields and the forest has increase. In the last decade most of debris flows have triggered in forest cover areas, much more than in shrub areas and in old fields. Then, not a clear trend can be observed, because the occurrence of debris flows in the forest has chanched during the study period.

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.

First 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 45.37 km^2 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 campaign was made in the Ijuez catchment with the Newcastle's group at the middle of June 2001, in order to select soil sampling points, to make some shear strength 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, coordinates 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.

COST STATEMENTS (Euro currency)

Year 1 (March 2000-March 2001)

Personnel and Overheads

a) DAMOCLES proposal

Staff Cat.	Hours	Personnel Costs	Overhead costs
1	1300	46800	45396
2	350	5950	5771
4		10133	0
Total		62883	51167

b) Real costs

Staff Cat.	Name	Hours	Personnel amount	Overhead amount
1	García Ruiz, J.M.	600	21600.38	20951.28
1	Martí Bono, C.	600	21600.38	20951.28
1	Valero Garcés, B.	100	3600.06	3491.88
2	Errea Abad, M.P.	350	5950.92	5772.12
4	Seeger, M.	600	4237.14	0
4	López Moreno, J.I.	1000	6376.74	0
4	Lorente Grima, A.	250	2288.35	0
4	González Sampériz, P.	250	1798.53	0
Total			67452.50	51166.56

The overhead amount was coincident with the foreseen, the total personnel amount exceeded the budget in Staff Category 4.

Consumables costs

a) DAMOCLES proposal……………….4500
b) Real costs……………………………..2138.96

Travel and subsistence

a) DAMOCLES proposal
Project meetings………………4500
Field work…………………… 3200
b) Real costs
Project meetings………………1580,20
Field work……………………..2308.73

Year 2 (March 2001-September 2001)

Personnel and Overheads

a) DAMOCLES proposal

Staff Cat.	Hours	Personnel Costs	Overhead costs
1	735 (1469: 2)	26990	26181
2	200 (400: 2)	3468	3364
4		5066	0
Total		35524	29545

b) Real costs

Staff Cat.	Name	Hours	Personnel amount	Overhead amount
1	García Ruiz, J.M.	300	11016	10686
1	Martí Bono, C.	300	11016	10686
1	Valero Garcés, B.	135	4808.7	4808.7
2	Errea Abad, M.P.	200	3468	3364
4	Lorente Grima, A.		4576	0
4	González Sampériz, P.		3596	0
Total			38480.7	29544.7

Consumables costs

a) DAMOCLES proposal……………….3250 (all year)
b) Real costs (April-September)………..2404

Travel and subsistence

a) DAMOCLES proposal
   Project meetings (all year)…………………………. 3500
   Field work (all year)………………………………… 3200
b) Real costs
   Project meetings and Field work (April-September)…6611

MANPOWER USED DURING YEAR 2
(In man month)

	WP1	WP2	WP3	WP4	WP5	TOTAL
García Ruiz	2		0.5			2.5
Martí Bono	2				0.5	2.5
Valero Garcés	1					1
Errea Abad	1.75					1.75
Lorente Grima	5		1			6
González Sampériz	4					4
TOTAL	15.75		1.5		0.5	17.75

Section 3. Milestones and deliverables obtained

During the last six months the following milestones and deliverables have been obtained:

-Maps on the distribution of extreme rainfall events in the Upper Aragon and Gallego Rivers.

- The Table with different debris flow parameters measured in the field.

- The statistical analysis and final relationships between the debris flow parameters.

- A first approach about the periodicity and the intensity of rainstorms that trigger debris flows.

Section 4. Deviations from the Work Plan and/or Time Schedule and their impact on the Project

The only deviation has been a delay in the finalisation of the field work. This was planned to be finished during May, but it was not possible until August, due to the difficulties to work in an area with steep slopes covered by a dense shrub cover. The delay obligated to do the statistical approach and relationships during September. Now it has been finished and a report is going to be presented.

No important problems can be detected as a consequence of this delay.

Section 5. Coordination of information between partners and communication activities

Coordination between partners and with the General Coordinator of the Project has been very good. During the last six months the following coordination aspects stand out:

- Close relationships with the Newcastle's group in order to prepare and send information from the Ijuez catchment.

- The Debris Flow Susceptibility Map obtained from the Upper Aragon and Gallego Basins has been sent to Alberto Carrara, in order to discuss the possibilities of improving the methods and the results.

- A report about debris flow relationships in the Italian Alps has been received from Mario Lenzi. The purpose is to include in a general report (produced in Zaragoza) about unconfined and confined debris flow relationships.

- A report is almost finished about debris flow relationships in the Central Spanish Pyrenees.

- Information on some of the IPE's group results has been sent to Fausto Guzzetti to be included into the DAMOCLES Web Page.

6. Difficulties encountered at management and coordination level

No difficulties has been found at management and coordination levels. The relationships with the General Coordinator of the Project (Prof. James Bathurst) has been very fluid and (in our view) unproblematic.

Section 7. Plan and objectives for the next period

During the next months the work to be done by the IPE's group is the following:

- New work around the cartographic products and database for WP5. We will improve the methodology applied for obtaining a debris flow susceptibility map, including new spatial variables (distribution of extreme rainfall events), and discussion with the italian groups of the Project.

- Organisation of a workshop and training course in the Pyrenees, showing the most important results obtained in the Project (April 2002).

- A new approach to the knowledge of debris flow periodicity will be made in another focus area.

- Progress in the development of the Adrian Lorente's Ph. D. Thesis on debris flows in the Pyrenees. The Ph. D. will be presented at the University of Zaragoza along the year 2002.

Section 8. Publications

Garcia-Ruiz, J.M., Valero, B., Gonzalez, P., Lorente, A., Marti-Bono, C., Begueria, S. & Edwards, L. (2001): Stratified scree in the Central Spanish Pyrenees: Paleoenvironmental implications. *Permafrost and Periglacial Processes,* 12: 233-242.

Garcia-Ruiz, J.M., Marti-Bono, C., Lorente, A. & Begueria, S. (in press): Geomorphological consequences of frequent and infrequent rainfall and hydrological

events in a Mediterranean mountain area. *Mitigation and Adaptation Strategies for Global Change.*

Section 9. References

Bathurst, J.C., Burton, A. and Ward, T.J. (1997): Debris flow run-out and landslide sediment delivery model tests. *Journal of Hydraulic Engineering,* 123 (5): 410-419.

Garcia-Ruiz, J.M., Begueria, S., Lopez-Moreno, J.I., Lorente, A. and Seeger, M. (2001): *Los recursos hídricos superficiales del Pirineo aragonés y su evolución reciente.* Geoforma Ediciones, 192 pp., Logrono.