DAMOCLES

DEBRISFALL ASSESSMENT IN MOUNTAIN
CATCHMENTS FOR LOCAL END-USERS

Contract No EVG1 - CT-1999-00007

PERIODIC CONTRACTOR REPORT
FOR THE PERIOD
2000-2001

Contractor: Università degli Studi di Milano - Bicocca

Coordinator : Dr James C Bathurst

University of Newcastle upon Tyne, UK

Project web site : http://damocles.irpi.pg.cnr.it/

SECTION 2: Executive publishable summary for contractor Milano Bicocca

Contract n°	EVG1–CT-1999-00007	Reporting period:	March 2001 – February 2002
Title	DAMOCLES Debrisfall Assessment in Mountain Catchments for Local End-userS		

Objectives:

a) Development of different techniques of data collection for rockfall and debris flows; data collection at basin scale in areas of the Lombardy Region (Italy) with preparation of a detailed DTM for the Pioverna study area

b) Development of GIS models for debris flow and rockfall hazard assessment applicable both at regional and at local scale; integration of modelling software codes with GIS

c) revision of different techniques for granular flow modelling applied to landsliding (deliverable, 18 months)

d) suggestion of standards and planning criteria to local and technical administrators

Scientific achievements:

a) evaluation of the 3D effects of morphology, land use, slope materials on rockfall movement; calibration and verification of models characterized by different modelling approaches; b) testing of multivariate statistical models for zonation of soil slip debris flow occurrence areas; c) verify possible interactions between physically based models and multivariate statistical models , e.g. to model influence of climatic changes; d) analysis of geological, structural and morphological characteristics influencing basin and alluvial fans activity

Socio-economic relevance and policy implications:

a) development of a database for debris flows and rockfall processes at a regional scale;
b) preparation of hazard zonation maps both at a regional and local scale for rockfall and debris flows;
c) development of codes able to simulate debris flow and rockfall occurrence and spreading;
d) direct interaction with end users to evaluate scientific and technical results and possible introduction in standards for land use planning and mitigation procedures

Keywords:

debris flow, rockfall, physically based models, statistical models, hazard assessment, Lombardy

Publications (cumulative list)

Peer Reviewed Articles:

Authors	**Date**	**Title**	**Journal**	**Reference**
Crosta, G.B.	2001	Failure and flow development of a complex slide: the 1993 Sesa landslide.	Engineering Geology	59(1-2): 173-199
Frattini, P. , Crosta G.B.	2002	Modelling the impact of forest management changes on landslide occurrence	Int. Conference on Instability – Planning and Management, Ventnor, Isle of Wight	In print
Guzzetti, F., Crosta, G.B., Detti, R. and Agliardi, F.	2002	Stone: a computer program for the three dimensional simulation of rockfalls	Computers & Geosciences	In print

Non refereed literature:

Authors / Editors	**Date**	**Title**	**Event**	**Reference**	**Type**
Guzzetti, F., Detti, R., Crosta, G. and Agliardi, F.	2001	A computer program to evaluate rockfall hazard and risk at the regional scale. Examples from the Lombardy region	EGS XXVI General Assembly, 25-30 March	Geophysical Research Abstracts, 3	Oral Presentation and Abstract
Crosta, G.B., Frattini, P. and Siena, L.	2001	Shallow landslide triggered by rainfall: the 27^{th} –28^{th} June 1997 event in Lecco Province (Lombardy, Italy)	EGS XXVI General Assembly, 25-30 March	Geophysical Research Abstracts, 3	Oral Presentation and Abstract
Crosta, G.B. and Dal Negro, P.	2001	Triggering of soil slips and rapid mudflows in pyroclastic soils. The event of Sarno, 1998	EGS XXVI General Assembly, 25-30 March	Geophysical Research Abstracts, 3	Oral Presentation and Abstract
Bathurst, J.C., El-Hames, A.S., Moretti, G., Crosta, G.	2001	Application of a basin scale, landslide sediment yield model, River Pioverna, Valsassina (Lake Como)	Conference "Prevenzione del Rischio Idrogeologico Attraverso la Conoscenza del Territorio". Regione		Oral presentation and Proceedings

and Frattini, P.			Lombardia, Milan, 26-27 September		
Crosta G.B. and Frattini P.	2001	Coupling empirical and physically based rainfall thresholds for shallow landslides forecasting.	EGS Topical Conferences, 3rd Plinius Conference on Mediterranean Storms, Baia Sardinia, Italy, 1-3 November		Poster and Proceedings.
Crosta G.B. and Frattini P.	2001	Physically based distributed modelling for shallow landslide hazard zonation	EGS Topical Conferences, 3rd Plinius Conference on Mediterranean Storms, Baia Sardinia, Italy, 1-3 November		Oral presentation and Proceedings

Others: (Patents, CD ROM's, videos,…)

Planning of future publications: (type, date, contents, …)

Crosta, G.B. and Dal Negro, P. (in print) - Observations and modelling of soil slip-debris flow initiation processes in pyroclastic deposits: the Sarno 1998 event. Natural Hazards and Earth System Sciences.

Frattini, P. and Crosta, G.B. (in print) – Distributed modelling of shallow landslide triggered by intense rainfall. Natural Hazards and Earth System Sciences.

Crosta, G.B., Dal Negro, P. and Frattini, P. (in print) – Soil slip and debris flows on terraced slopes. Natural Hazards and Earth System Sciences

Abstracts presented:

Crosta G.B., Dal Negro P., Frattini P. (2002) Distributed modelling of shallow landsliding in volcaniclastic soils. EGS XXVII General Assembly, Nice, France, April 2002, NH7.02 Landslides and related phenomena: Rainfall triggered landslides and debris flow

Crosta G.B., Imposimato S., Roddeman D. (2002) Numerical modelling of large landslide stability and runout. EGS XXVII General Assembly, Nice, France, April 2002, NH7.01 Landslides and related phenomena:Open session on monitoring, modelling and mapping of mass movements

Agliardi F., Crosta G.B., Guzzetti F., Marian M. (2002) Methodologies for a physically based rockfall hazard assessment. EGS XXVII General Assembly, Nice, France, April 2002, Risk assessment and mapping: Landslide risk assessment and mapping

Agliardi F., Crosta G.B. (2002) High resolution 3D numerical modelling of rockfalls EGS XXVII General Assembly, Nice, France, April 2002, Landslides and related phenomena: Open session on monitoring, modelling and mapping of mass movements

Presentations:

At the Newcastle Meeting (1-2 November 2001) of the Damocles Project with the EC referees:

- Data collection: issues, strategies and results
- Multivariate models for predicting debris flows
- Rockfall hazard assessment by a 3D GIS-integrated software

Crosta G.B. Identification, classification and modelling of large rock slope instabilities. Atelier de Travail PNRN-ACI 24-25 January 2002, Geosciences Azur, Site de Sophie Antipolis, CNRS-UNSA, Nice.

Agliardi F. Modelli di pericolosità per frane di crollo nelle aree campione del progetto. Il programma Stone. Conference on "La prevenzione del rischio idrogeologico attraverso la conoscenza del territorio", Milano 27-27 settembre 2001, Regione Lombardia.

Crosta G.B. Modellazione di frane a elevato espandimento. Conference on "La prevenzione del rischio idrogeologico attraverso la conoscenza del territorio", Milano 27-27 settembre 2001, Regione Lombardia.

Moretti G., Bathurst J.C., El-Hames A.S., Crosta G.B., Frattini P. Modellazione a scala di bacino del contributo da frane superficiali al trasporto solido, torrente Pioverna, Valsassina (Lago di Como). Conference on "La prevenzione del rischio idrogeologico attraverso la conoscenza del territorio", Milano 27-27 settembre 2001, Regione Lombardia.

Frattini P. Analisi morfometrica delle conoidi alpine lombarde e valutazione della suscettibilità all'attivazione da colate detritiche. Conference on "La prevenzione del rischio idrogeologico attraverso la conoscenza del territorio", Milano 27-27 settembre 2001, Regione Lombardia.

Agliardi F., Crosta G.B. Principi di analisi di stabilita' e modellazione dei meccanismi di espandimento. Convegno sulla zonazione delle aree a rischio, 8 Giugno 2001 - Bolzano

SECTION 3: DETAILED REPORT OF CONTRACTOR MILANO-BICOCCA

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3.1 OBJECTIVES OF REPORTING PERIOD

- data collection for the Pioverna area (Focus area B), with field work and laboratory tests; transfer of collected data into digital format so to allow the use of the datasets for the analysis; transmission of data to interested partners within the project (University of Newcastle);
- development and testing of a software code for rock fall modelling in collaboration with assistant contractor CNR-IRPI Perugia;
- preparation of a short review on granular flows showing some applications developed by the contractor (deliverable);

development of simple distributed physically based models to compare results with those obtained from a statistical multivariate distribute model in collaboration with subcontractor CNR-CSITE Bologna; calibration and validation of the different models
dissemination of previous results on Web.

3.2 METHODOLOGY AND SCIENTIFIC ACHIEVEMENTS RELATED TO WORK PACKAGES

3.2.1 – Work package 2

The activity was mainly oriented in three directions: data collection, implementation of rockfall model and preparation of a review on granular flows.

Data collection

A strong effort has been made to exploit all available existing data for the Focus Area B (figure 1). Data collection is aimed to the modelling activity of Work package 2 (GIS model and Rockfall model) and Work package 5 (SHETRANS model). A new high resolution DTM (5x5 m pixel size) of the study area was completed. The new DTM was automatically generated from scanned aerial photographs using Leica-Helava software. An improvement of the geological map was performed in some parts of the basin through geological survey and collection of updated literature data. A new inventory map for the study area was also completed. Through the interpretation of a historical series of aerial photographs (1954, 1960, 1972, 1983, 1991 and 1995) a multi-temporal inventory was created. The main advantage of a multi-temporal inventory lie in the possibility to relate the presence of landslides with particular rainfall events that are responsible for the occurrence of landslides. This possibility is very important as calibration tool for landslide models. Rainfall data, discharge data and temperature data have been collected from stations localized inside and around the study area (figure 1). Precipitation records from rain-gauges of Lecco (1949-2000), Bellagio (1954-1998), Bellano (1954-1997) and Introbio (1954-1977) where obtained from Autorità di Bacino del Po. Daily (from 1967 to 2000) and hourly (from 1985 to 2000) rainfall from Barzio rain gauge have been collected from COE (Centro Orientamento Educativo, Barzio). All these data have been informatized and transferred to Newcastle team as digital data. Collection of useful discharge records was a major problem for the study area. Stage data were collected for the Pioverna river at the Bellano outlet station from Bellano Municipality, but

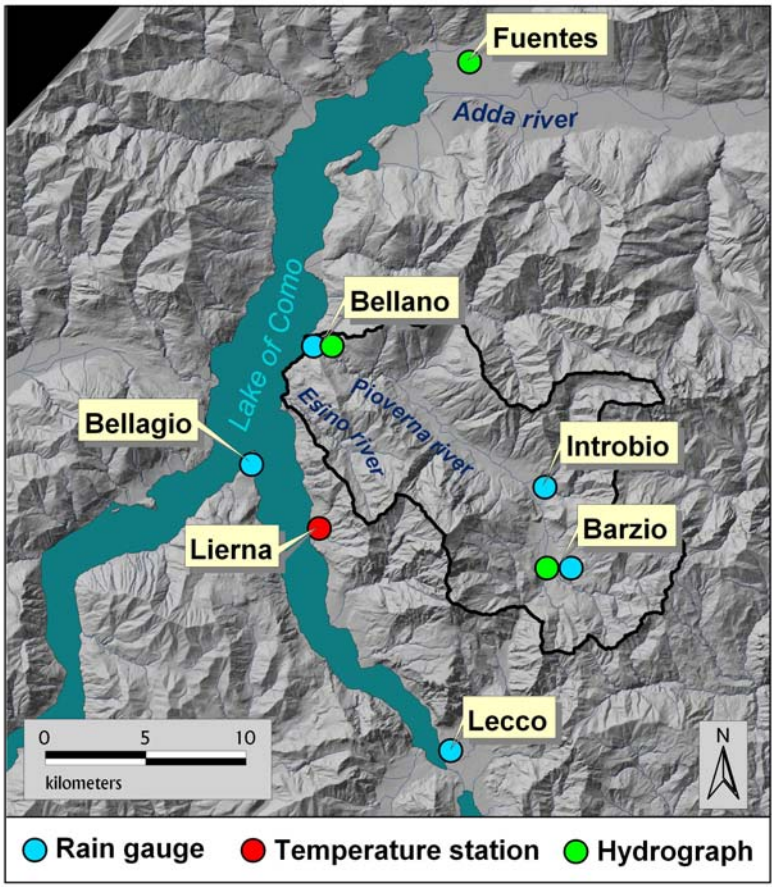

Figure 1. Location of rain gauges, hydrographs and temperature stations

these data showed to be unreliable. Thus, discharge data for Adda river at Fuentes station were collected from Consorzio dell'Adda and transferred to Newcastle team in order to perform a regionalisation analysis. Temperature records from Lierna station from 1988 to 1995 were obtained in digital format from Istituto Idrografico and Mareografico di Milano. Finally, a set of 36 cross sections (scale 1:200) for the Pioverna river channel has been collected and prepared in a digital format. These cross sections will be transferred to the Newcastle team for further use in the SHETRAN model.

Detailed Field survey have been performed within two sub_areas of Focus area B: Esino basin and Pioverna Orientale basin (figure 2). Esino basin was selected for detailed field work because it was hit by an intense rainstorm that triggered more than 150 shallow landslides in less than 35 km^2. This event was studied in detail because it will be used to calibrate landslide models. In-situ permeability were performed with Guelph permeameter and laboratory tests on soil samples were carried out, in order to assess the grain size distribution, Atterberg limits and, through a direct shear test, friction angle and soil cohesion. Pioverna Orientale sub-basin were selected for detailed soil characterisation because at the outlet of the basin (Barzio) a stage station is located, with discharge records that will be available within few months. A good soil description of the area together with discharge data and rainfall records will probably permit to substantially improve model calibration. Within the Pioverna Orientale basin, soil profile description were performed. Collected samples were analysed in laboratory for assessing the grain size distribution, Atterberg limits, friction angle and soil cohesion. Finally, eighteen soil samples were collected in different locations in the catchment through field work conducted by the Newcastle and Milan-Bicocca teams. These samples were analysed in the laboratory by the Newcastle team.

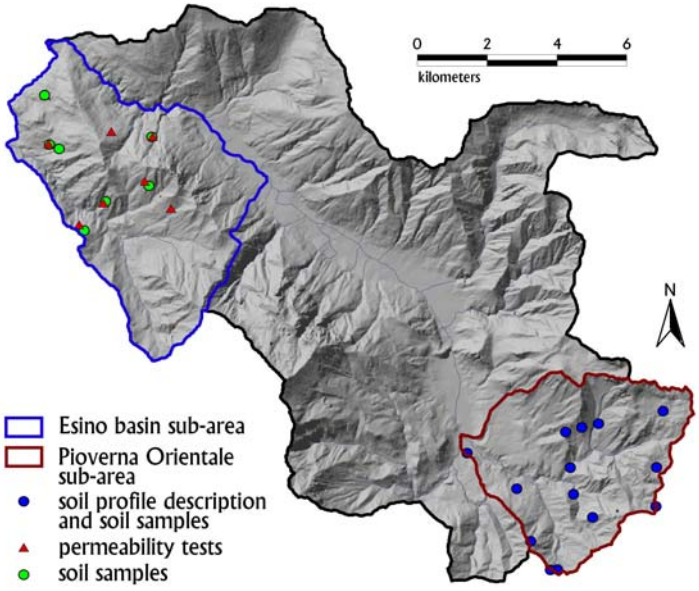

Figure 2. Location of field activity within the sub areas.

Rock Fall Distributed Modelling

One of the objective of Work package 2 is the development, in collaboration with the assistant contractor CNR-IRPI Perugia, of a physically distributed model for rockfall modeling and hazard zonation. A software code has been developed during this part of the project (see also detailed report of CNR-IRPI) and has been called "STONE". The code makes use of a DTM and some thematic maps derived by geo-lithologic, land use, geomorphologic and landslide inventory maps. We present in the following the part of the workpackage concerning the testing, calibration and validation of the developed model.

Testing of the code has been performed at different scales, on different areas and both within and out of the Focus area B. The choice of the areas for a detailed testing of the model derived both by technical requirements and by specific interest of the end-users (Lombardy Region Geological Survey). A first step has been the calibration of the regional model by using available thematic maps and database of occurred rock falls (see figure 3).

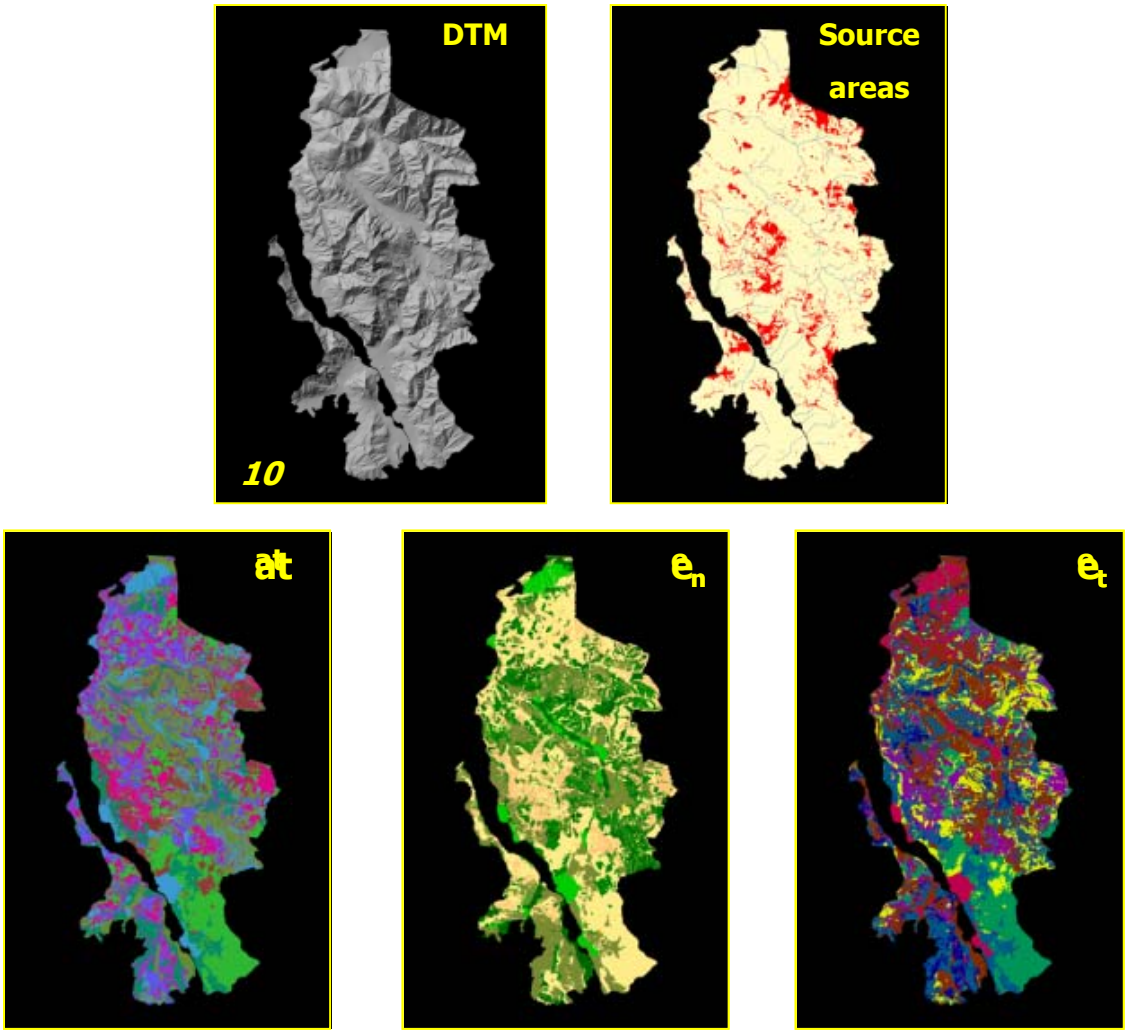

Figure 3. Input data for rock fall modeling of the Lecco Province. DTM (20*20 m cell size), map of source areas and derived maps of dynamic friction coefficient, normal and tangential coefficients of restitution.

A set of calibrated outputs has been obtained, representing the number of rock fall trajectories passing through each pixel, the maximum velocity and height within each pixel. The capability of the model to catch some of the actual rockfall paths is shown in figure 4 where the results for the Varenna and San Martino (Lecco) areas are represented. In these two areas historical rock falls occurred causing damages and casualties (Varenna: 1987, 2 casualties; Mt San Martino: 1931, 1969, 2 and 7 casualties, respectively) and the sites have been subject of extensive studies for hazard and risk reduction and for planning purposes.

In order to show the different performances of the model when working at different scales and when different types of data were available, we concentrated our efforts on the S. Martino area. A much more detailed DTM has been prepared for the area starting from an available 1:5000 topographic map, with a 5 m countour interval, for the area. A digital countour map have been created starting from a printed copy of the original map. A 5x5 m cell size DTM has been produced. A new set of geological, geomorphological, land use and source areas maps has been produced by field surveys, aerial photo interpretation and use of ortho rectified images.

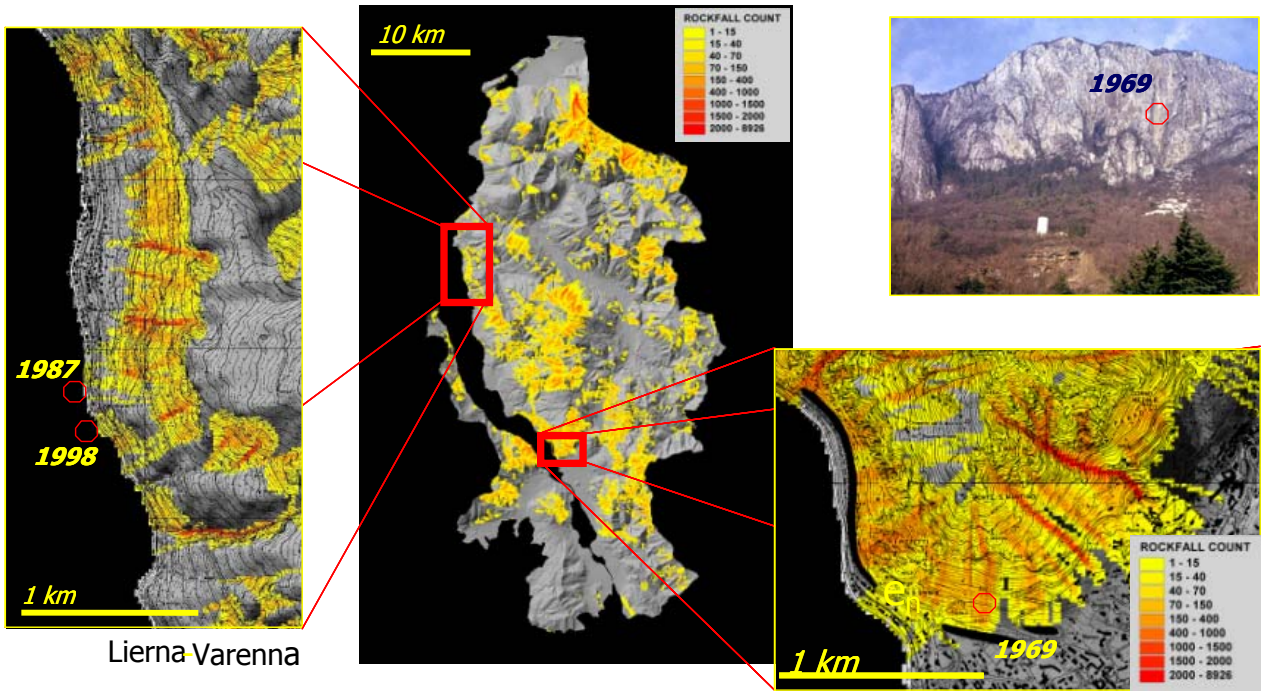

Figure 4. Enlargement of two areas adopted for the calibration of the rock fall model for the Lecco Province. Three events at Varenna and at the Mt. San Martino (Lecco) are reported. Distribution of arrest points of larger boulders has been used to calibrate the model.

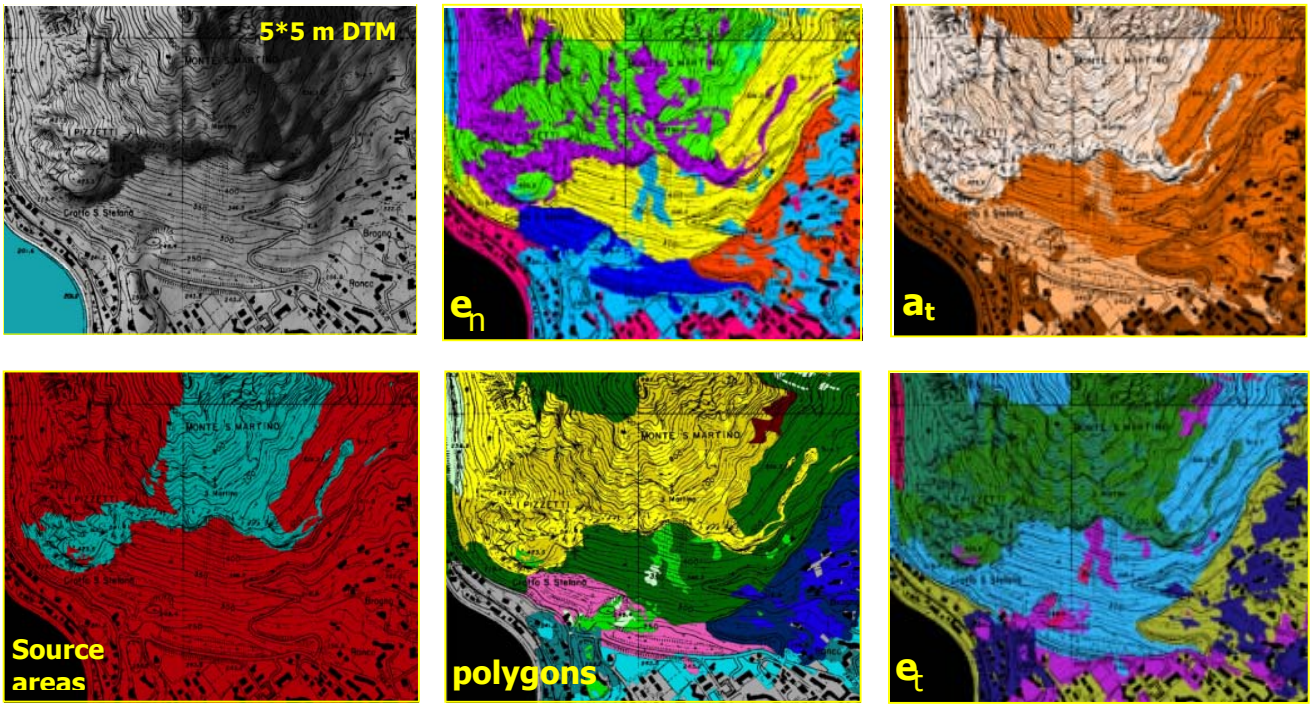

Figure 5. New dataset used as input for the simulation in the San Martino area.

Figure 5 shows the new dataset and the derived maps used for the simulation in the San Martino area. The following features characterizes the model:

- 5x5 m DTM containing 118.813 cells;
- the source areas, individuated by aerial photo interpretation and geomechanical field surveys, occupy 22.262 cells, or 56 hectars (19% of the model area);
- coefficients for the analyses have been obtained through an intersecting and recoding approach. 608 terrain units have been identified through field survey and aerial photo interpretation.

Calibration of the model has been performed through field surveys and collection of historical data. We have used, in particular, the following elements:

- location of single blocks mapped in the field and blocks of maximum size
- location, extension and geometry of large rock fall deposits
- scree slope limits
- historical data and interviews.

Two maps for the count of passages and the maximum velocity as resulting from the analysis are reported in the following (figure 6). The two maps show also the location of large boulders as mapped in the field and used for model calibration together with scree slope limits.

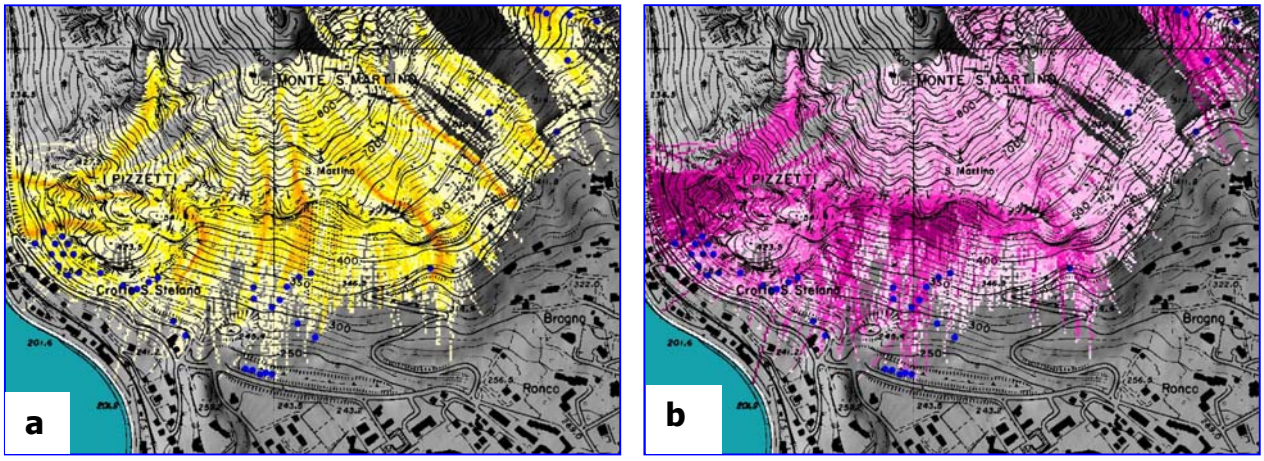

Figure 6. Outputs from the simulation in the San Martino area. a) count of passages; b) maximum velocities.

The simulations demonstrate that:

- 43.959 cells (110 ha, 47% of the study area) are exposed to rockfall transit or arrest; topographical effects strongly control the pattern of rockfalls and their downslope evolution;
- potential phenomena can be characterized by an exceptional magnitude, describe by very high velocity and flying height;
- existing passive countermeasures seems to be effective. This is especially true for the earth embankment at the foot of the San Martino rock cliff;
- passive countermeasures represented by elasto-plastic catching nets could be ineffective in catching falling blocks because of the relative height of the parabolas followed by blocks.

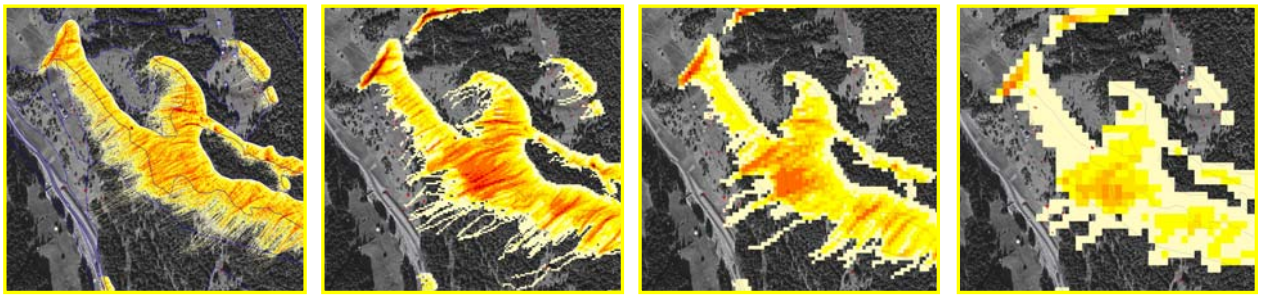

Figure 7 – Example of DTM influence on a rockfall simulation. Four DTMs with 1*1 m, 5*5m, 10*10 m and 20* 20 m cell size have been tested

The code is actually under testing and calibration. In particular, during the last year the effects of DTMs realized with different cell size have been checked (see figure 7) as well

as the capabilities of the probabilistic module of the software. Finally, a new document containing the algorithm for the implementation of a 3D hybrid model has been prepared.
The code has been presented at a national conference organized by the Geological Survey of the Lombardy Region on hazard assessment techniques and at he meeting in Newcastle in presence of two referees for the EC project.
Different approaches for the hazard assessment have been developed and are presently under development. The idea is to develop an approach as much objective as possible allowing for repeatability of the classification and zoning. The initial and very preliminary results have been presented at the meeting in Newcastle with the EC referees.

Preparation of a short review on granular flows

The review on granular flows, entitled "GRANULAR FLOWS AND NUMERICAL MODELLING OF LANDSLIDES", has been produced (Month 18 deliverable). The document (71 pp) includes therefore a short revision of existing theories on granular flows and it especially includes some applications produced by the Milano team:

- distinct element modeling for rapid dry granular flows
- depth averaged model for gravitational mass flows
- finite element modelling of landslides with large runout
- empirical relationships for the assessment of debris flow runout distances.

Development of simple distributed physically based models to compare results with those obtained from a statistical multivariate model

An important issue for Damocles Project is the comparison between statistical multivariate models and physically based models. In order to test the possibility to make this comparison, three simple grid-based distributed hydrological models have been implemented in ArcInfo Macro Language (AML): a steady state model (Montgomery and Dietrich, 1994), a transient "piston-flow" wetting front model (Green and Ampt, 1911), and a transient diffusive model (Iverson, 2000). These models have been coupled with an infinite slope stability analysis and applied to simulate the triggering of shallow landslides due to the rainfall event of June 27th-28th (figure 7).

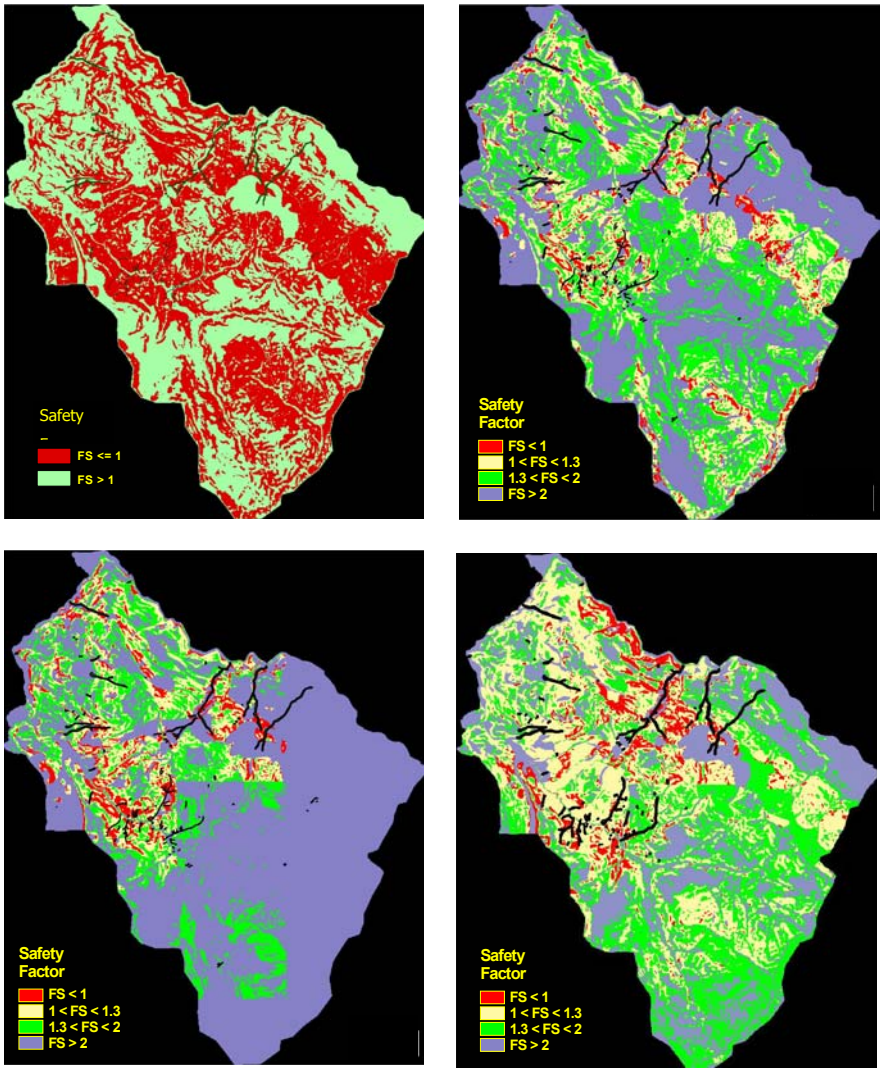

Figure 7: Slope stability maps with different hydrological models: a) steady state model; b) piston model with uniform precipitation; c) piston model with distributed precipitation; d) diffusive model with distributed precipitation.

The calibration was essentially performed on the basis of prior information about soil and vegetation, with adjustments made to improve the distribution of computed Safety Factor with respect to the actual distribution of triggered landslides. A more hydrologically sound calibration was not possible due to the unavailability of data like discharge and other internal state model variables (water table levels, soil moisture level, etc.).

In order to develop a common environment that allows a comparison between models, automatically generated main slope units were used. These units were reclassified according both to the percentage of unstable areas modelled by physically based models and to the probability of landslide presence modelled by statistical models (figure 8).

A direct confrontation of these reclassified units permits to outline similarities and differences of the models.

The results of these activities have been already presented at two international conferences (EGS XXVI General Assembly, Nice and 3rd EGS Plinius Conference on Mediterranean Storms) and are under publication.

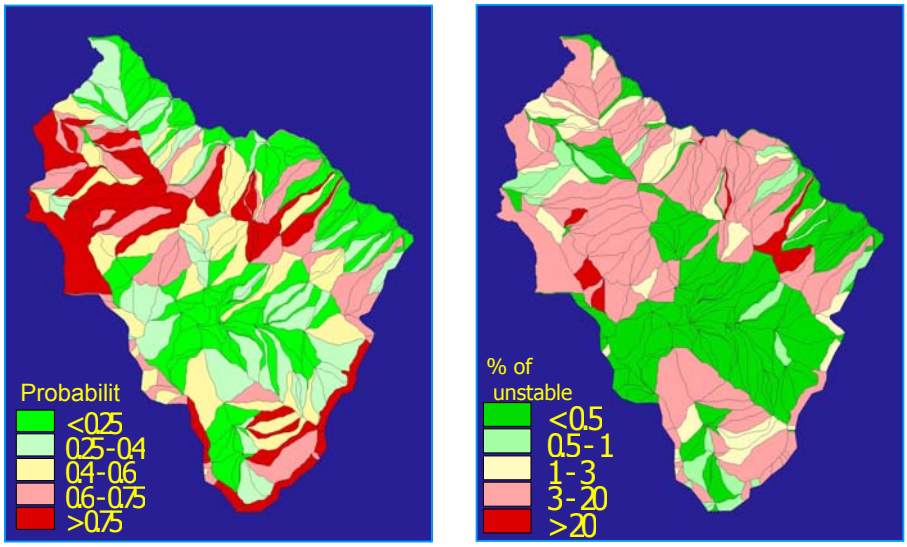

Figure 8. Direct confrontation between statistical model (left) and a simple fysically based model (transient piston flow model, right)

3.2.2 – Work package 5

Work package 5 deal with the dissemination of the projects results and some deliverables. Updated thematic maps for the Focus area B were provided to CNR-IRPI of Perugia to be published on the web site (http://damocles.irpi.pg.cnr.it). Detailed metadata were created for the thematic maps that are available on the Internet.

In addition, the 18 month deliverable, i.e. the granular flows review document, was also provided to the CNR-IRPI of Perugia for publication on Web.

3.3 SOCIO-ECONOMIC RELEVANCE AND POLICY IMPLICATION

The socio-economic relevance of the second year activity is very high, both in terms of developed methodologies, both in terms of achieved results. During the collection and improvement of data, an effort was made to assess the role and importance of data quality and quantity in modeling process. The presentation held at the Newcastle Meeting (1-2 November 2001) of the Damocles Project with the EC referees ("Data collection: issues, strategies and results") was aimed to point out this effort. End-users and policy makers, in general, must have clear which is the kind, the quality and the amount of data needed by the models, in order to assess the expected costs. Moreover, they need to

evaluate the uncertainties and the reliability inherent in the modelling process for the correct use of the results.

Regarding in particular the local End-user of the Damocles Project, i.e. the Geological Survey and Geological Risk Office of the Lombardy Region, a big effort was made, during the reporting year, to interact with them. Both the collection of the data and the choice of the study and test areas was made together with the End-user, and according to its interest. This continuous interaction reached the apex with the organization of a two-day scientific conference on 26-27 September 2001 in Milano (Italy) ("La prevenzione del rischio idrogeologico attraverso la conoscenza del territorio") where preliminary results of the Damocles projects have been presented.

3.4 - DISCUSSION AND CONCLUSION

During the second year of activity, the following objectives have been accomplished:

- the collection of data for the Pioverna area (Focus area B) has been completed, with new geotechnical and geomorphological information. A multitemporal landslide inventory was prepared (month 24 deliverable: debris flow and rockfall database). The GIS database with all data is currently under preparation
- the rock fall model was tested and calibrated with experimental data and comparison with different existing codes: a new methodology for rock fall hazard assessment, with three different approaches, is under development; preliminary contacts with the ITGE Zaragoza team are underway for the application of the modelling approach to the Pyrenees
- the review on granular flows was delivered and published on the Damocles Web site: the review presents a series of new numerical models and empirical relationships;
- three different spatially distributed physically based models have been implemented in the ArcInfo macro-language (AML) to compare results with those obtained from a statistical multivariate distribute model in collaboration with subcontractor CNR-CSITE Bologna; calibration and validation of the different models has been performed for a small area (Esino basin, 38 km^2) within the Focus area B.

3.5 PLAN AND OBJECTIVES FOR THE NEXT PERIOD

The activity of the next year will focus on the following objectives (see table 1 for the project plan):

1. preparation and transfer of the GIS database on landslide distribution (rockfall, debris flow, etc.)
2. analysis, quality evaluation and application of the 5*5 m cell DTM: for statistical and physically based models, in collaboration with CNR CSITE sub-contractor
3. analysis of the database to obtain: empirical relationships for debris flow runout distances; the classification of alluvial fans and relative basins according to their susceptibility to reactivation by debris flow processes through a statistical approach
4. application of the rockfall model and of the hazard assessment methodologies to the Spanish Pyrenees in collaboration with the ITGE Zaragoza Team
5. development of a new method for rock fall hazard assessment and for risk assessment both along corridors and large areas;
6. improvement of the rockfall model
7. creation of the GIS-based model for debris flow hazard assessment, using the newly collected data
8. application of the rockfall models to the simulation of geomorphological processes (scree slope and debris cone formation) in different environments in the Central Alps, Italy
9. organization of the Damocles Training Course in collaboration with the Padova Team and the CNR CSITE sub-contractor
10. comparison and integration of the statistical approach with the physically based approach of the Newcastle team (SHETRAN), in collaboration with CNR CSITE sub-contractor
11. preparation of technical and scientific reports and publications

3.6 REFERENCES

Montgomery, D.R., and Dietrich, W.E, A Physically based model for the topographic control on shallow landsliding. Water Resource Research, 30, 83-92, 1994.

Iverson, R.M., Landslide triggering by rain infiltration, Water Resource Research, 36, 1897-1910, 2000.

Green, W.H., and Ampt, G., Studies of soil physics. Part 1. The flow of air and water through soils, Journal of the Agricultural Society, 4, 1-24, 1911.

Table 1. Third year project plan

	M	A	M	J	J	A	S	O	N	B	J	F	Activity
Task													
1													GIS database
2													DTM
3													Empirical and statistical relationships
4													Rockfall Pyrenees
5													Rockfall Hazard Methodology
6													Rockfall algorithm
7													GIS based model
8													Rockfall modelling
9													Damocles training course
10													Statistical vs. SHETRAN
11													Final report and papers