DAMOCLES

DEBRISFALL ASSESSMENT IN MOUNTAIN CATCHMENTS FOR LOCAL END-USERS

CONTRACT N° EVG1-CT-1999-00007

DETAILED REPORT OF CONTRACTOR FOR THIRD PROGRESS MEETING

PERIOD: 1 March – 31 October

University of Milano Bicocca

ITALY

DETAILED REPORT OF CONTRACTOR

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SUMMARY

The present report summarises the activity of Milano-Bicocca University team during the period 1 March – 31 October.

The main activity that were carried on during this period are:

- the collection of new data;
- the implemenation of rockfall model stone (with associate contractor CNR-IRPI Perugia);
- the preparation of a short review on granular flow.

The last activity is a 18 months-milestone for Milano-Bicocca team.

1 - OBJECTIVES OF THE REPORTING PERIOD (1/3/2001 – 31/10/2001)

1. 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)
2. development and testing of a software code for rock fall modeling in collaboration with associate contractor CNR-IRPI Perugia

3. preparation of a short review on granular flows showing some applications developed by the contractor (Deliverable)
4. 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
5. dissemination of previous results on Web.

2 - SCIENTIFIC/TECHNICAL PROGRESS

The activities of the project are going on as scheduled in the proposal including the preparation of the deliverables, data exchange with the partners, assistant- and sub-contractors, and the contacts with the end-users involved.

2.1 - RESOURCES USED

The manpower resources used for the project activities, during the period considered by this report (1 March – 31 October 2001), can be summarized as follows:

	Permanent Personnel	**Additional Personnel**
Workpackage 2	12	12
Workpackage 5	0.5	0.1
Workpackage 4	1	
TOTAL	**13.5**	**12.1**

The used manpower was mainly involved in activities for Workpackage 2, both in field and laboratory work, or in development of numerical models for shallow landslides and rockfalls. Personnel working on Workpackage 5 was mainly involved in data collection and transmission to the partners.

2.2 - WORKPACKAGE 2: STATISTICAL DISTRIBUTED MODELLING

2.2.1 - Summary

This section reports the activities that have been carried out in the reporting period within Workpackage 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 strategy consisted of an exploitation of all available data from published and unpublished literature and a collection of new data through field work, laboratory tests and aerial-photo interpretation. New data was collected in two different sub-areas, where a detailed analysis has been carried out.

The implementation of rockfall model STONE was performed through an accurate calibration of input parameters. Some application within Lecco Mountain area have been carried out, with different accuracy and resolution. Finally, an effort has been made to integrate the model into a hazard assessment procedure.

The review on granular flows, entitled "GRANULAR FLOWS AND NUMERICAL MODELLING OF LANDSLIDES", has been realized. The document is not a comprehensive review, but it focuses on some specific issues that can be interesting within Damocles Project framework.

In addition to these three main activities three simple distributed physically based models for shallow landslide triggering were developed in order to compare results with those obtained from a statistical multivariate distribute model in collaboration with subcontractor CNR-CSITE Bologna.

2.2.2 - Data collection for the Pioverna area (Focus area B)

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 Workpackage 2 (GIS model and Rockfall model) and Workpackage 5 (SHETRANS model).

During the first year of Damocles activity (see Annual Report) the following digital data were collected and finally transferred to Newcastle partner during the Damocles Meeting in Padova, May 9-11, 2001: topographic maps (Regione Lombardia, 1982+, scale 1:10000); land-use map (Regione Lombardia, 1987+, scale 1:10000); quaternary cover map (Regione Lombardia, 1987+, scale 1:10000); DTM (Regione Lombardia, 2001, pixel size 20x20 m); geological map (Regione Lombardia, 2001, scale 1:10000).

During the reporting period an effort was done for improving the quality of these data and for collecting new data.

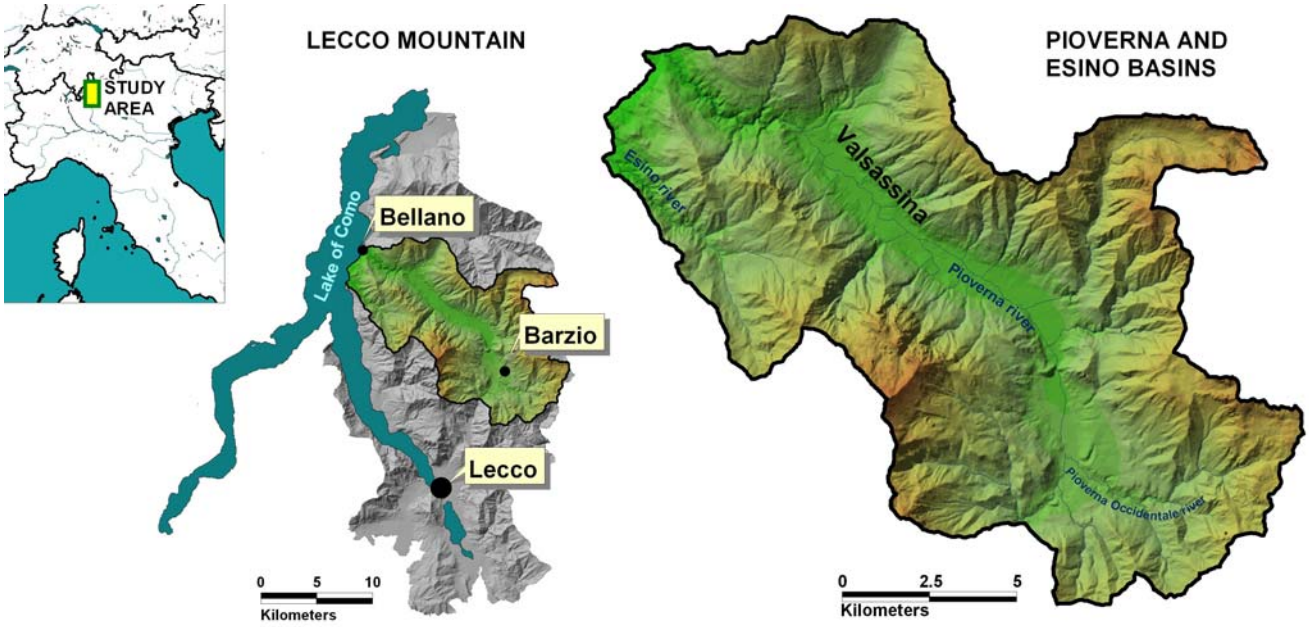


Figure 1. Location of Focus Area B (Pioverna and Esino Basins)

Digital Terrain Model

A new high resolution DTM (5x5 m pixel size) of the study area is in progress. The new DTM is automatically generated from scanned aerial photographs using Leica-Helava software.

Geology

An improvement of the geological map was performed in some parts of the basin through geological survey and collection of updated literature data.

Landslide map

A completely new inventory map for the study area was begun. Through the interpretation of a historical series of aerial photographs (1954, 1960, 1972, 1983, 1991 and 1995) a multi-temporal inventory will be created. This inventory will permit to relate the presence of landslides with particular rainfall events that are responsible for landslide occurrence. This possibility is very important as calibration tool for landslide models.

Precipitation, discharge and temperature records

Rainfall data, discharge data and temperature data have been collected from stations localized inside and around the study area (figure 2). 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 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. Finally, temperature records from Lierna station from 1988 to 1995 were obtained in digital format from Istituto Idrografico and Mareografico di Milano.

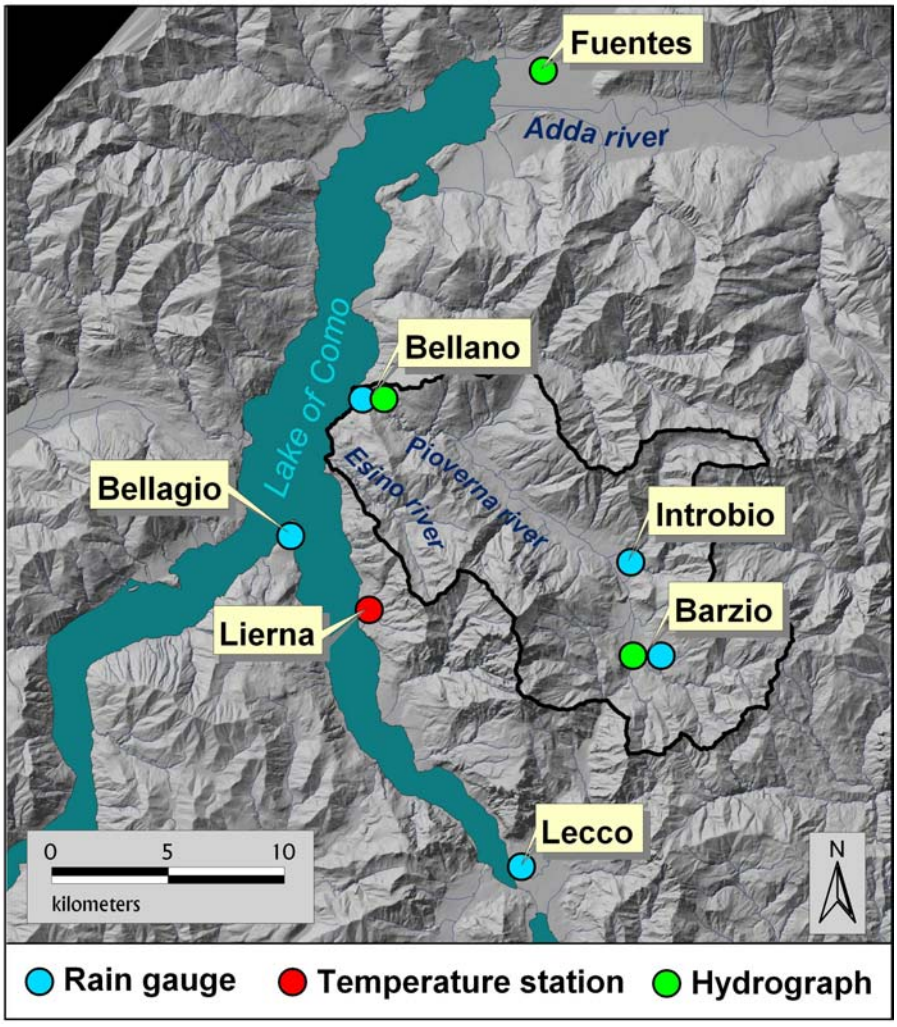


Figure 2. Location of rain gauges, hydrographs and temperture stations

Geotechnical data

Detailed Field survey have been performed within two sub_areas: Esino basin and Pioverna Orientale basin (figure 3). 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.

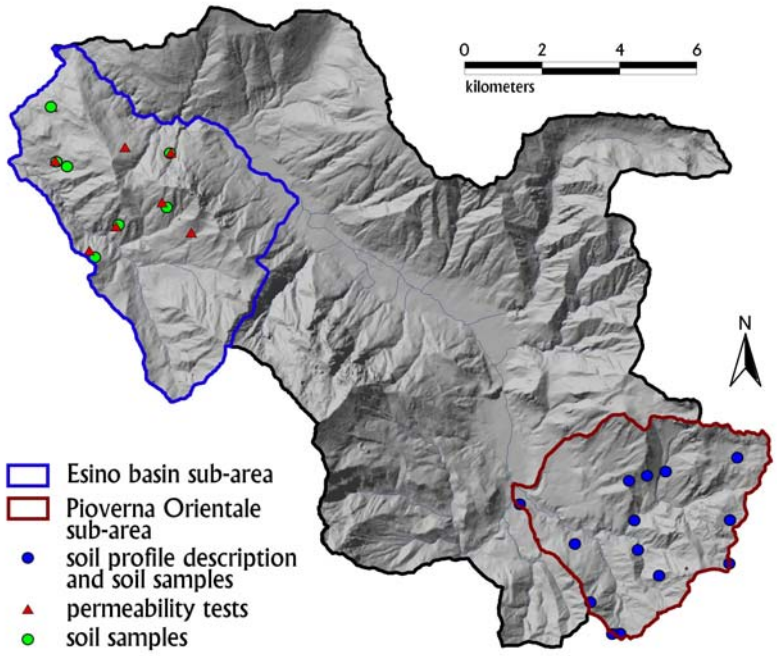


Figure 3. Location of field activity within the sub areas.

2.2.3 - Rock Fall Distributed Modelling

One of the objective of Workpackage 2 is the development, in collaboration with the 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 report by 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 4).

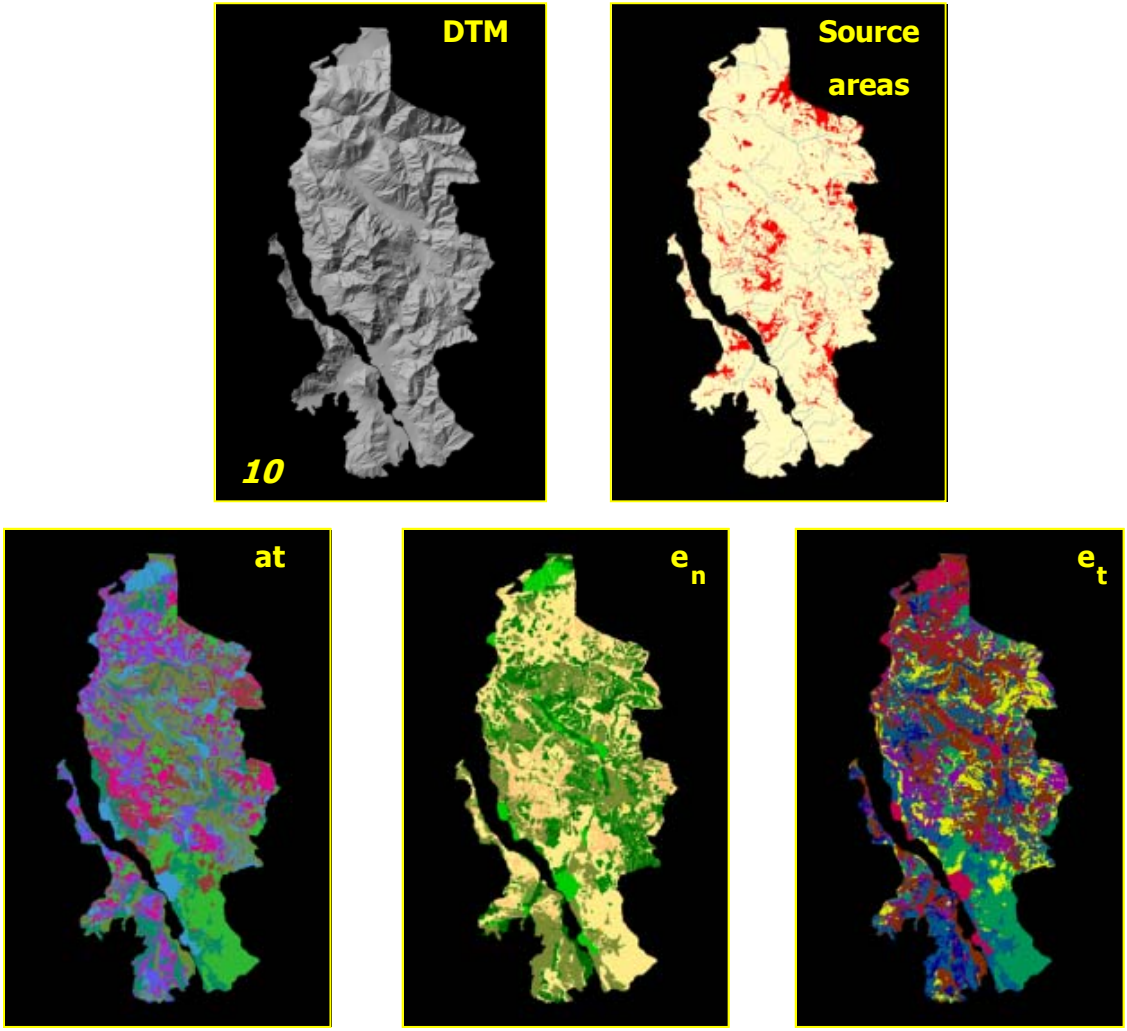


Figure 4. Input data for rock fall modeling of the Lecco Province. DTM (20*20 m cell size), map of source areas and derived maps of dynamic friction coefficient, normal and tangential coefficients of restitution.

A set of calibrated outputs has been obtained and some of the results are reported in figure 5, representing the number of rock fall trajectories passing through each pixel, the maximum velocity and height within each pixel. We don't report all the results because of the similarity with those already reported in the CNR-IRPI Report, but it is clear that small changes can occur in the final output because of the calibration of the model.

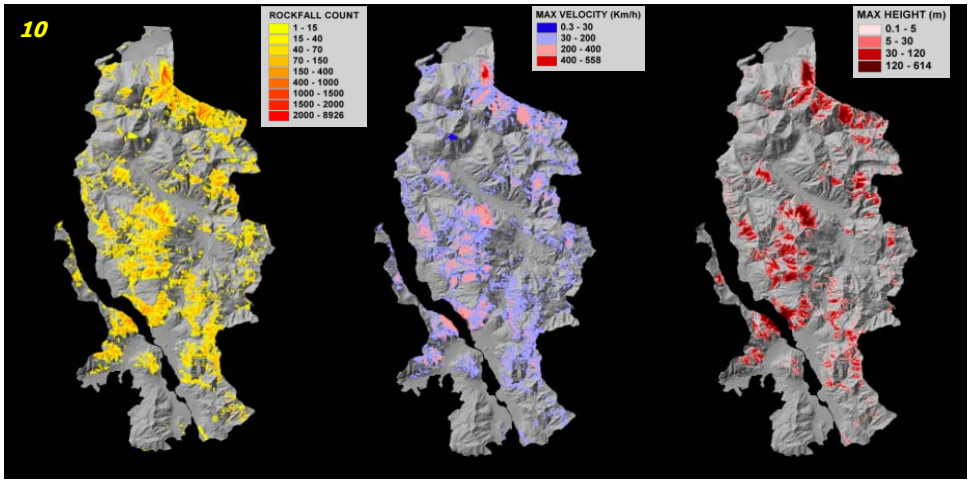


Figure 5. Raster output data for the Lecco Province reporting the number of rock fall passages through each cell, maximum velocity and height within each cell

The capability of the model to catch some of the actual rockfall paths is shown in figure 6 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.

Scope of this part of the report is to show the different performances of the model when working at different scales and when different types of data were available. For this reason 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.

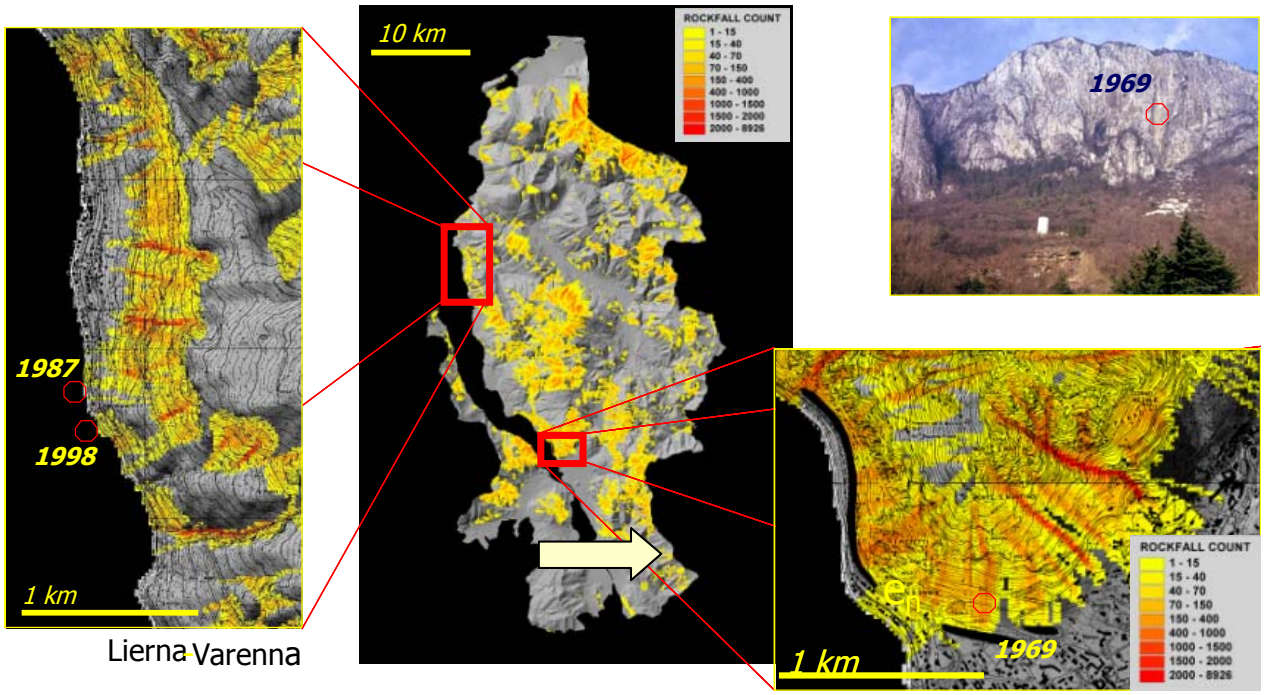


Figure 6. Enlargement of two areas adopted for the calibration of the rock fall model for the Lecco Province. Three events at Varenna and at the Mt. San Martino (Lecco) are reported. Distribution of arrest points of larger boulders has been used to calibrate the model.

Figure 7 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.

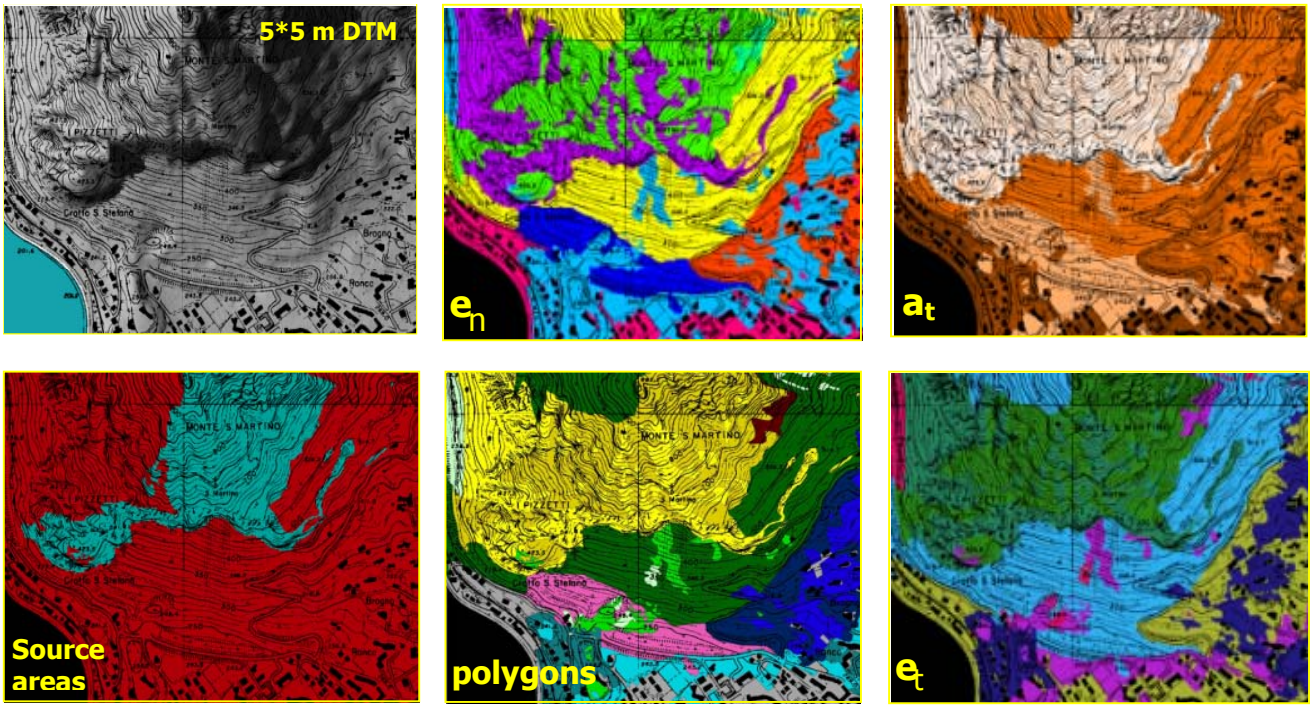


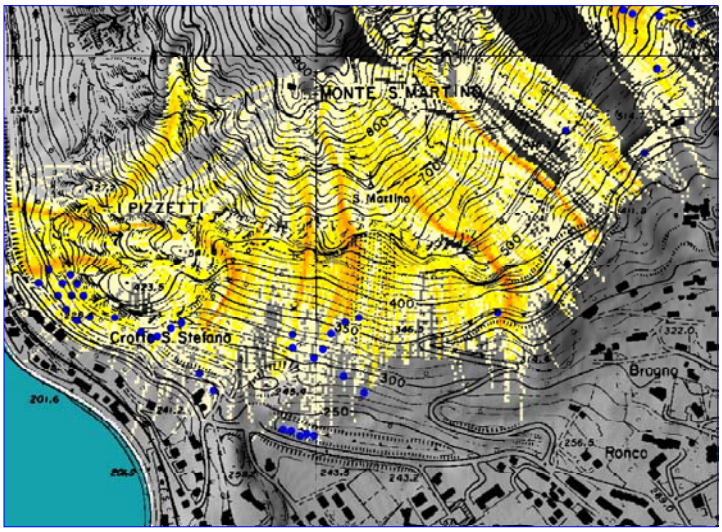
Figure 7. New dataset used as input for the simulation in the San Martino area.

Two maps for the count of passages and the maximum velocity as resulting from the analysis are reported in the following (figure 8). 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.

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 coul be ineffective in catching falling blocks because of the relative height of the parabolas followed by blocks.

a



b

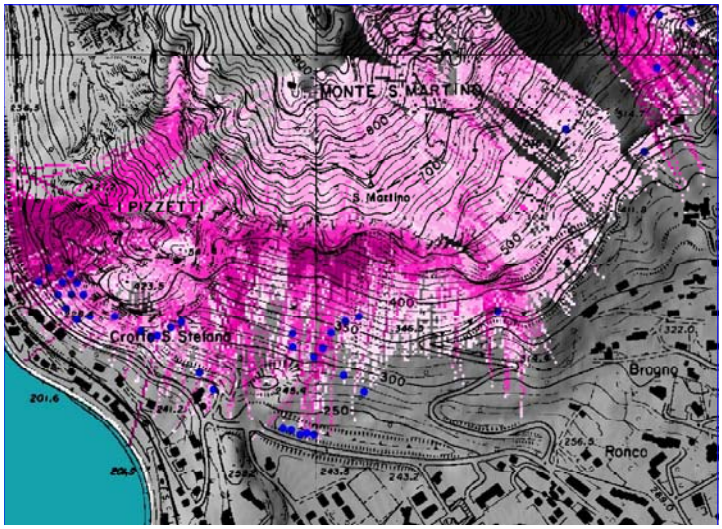


Figure 8. Outputs from the simulation in the San Martino area. a) count of passages; b) maximum velocities.

Future improvements

- development of a new method for rock fall hazard assessment
- development of methods and strategies for risk assessment both along corridors and large areas
- preparation of a new hybrid model combining a lumped mass and dynamic approach
- application to the simulation of geomorphological processes (scree slope and debris cone formation)
- development of relationships among angle of impact, soil material, block motion and distance. These relationships will analyses both impacts and rolling type of motion

2.2.4 - Preparation of a short review on granular flows

The review on granular flows, entitled "GRANULAR FLOWS AND NUMERICAL MODELLING OF LANDSLIDES", has been produced and has been recently completed. The document does not want to be a complete review of the existing studies on this subject but it simply wants to put in evidence some problems and applications (see 3. MILESTONES AND DELIVERABLES for details).

2.2.5 - 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 different 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 9).

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 10).

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

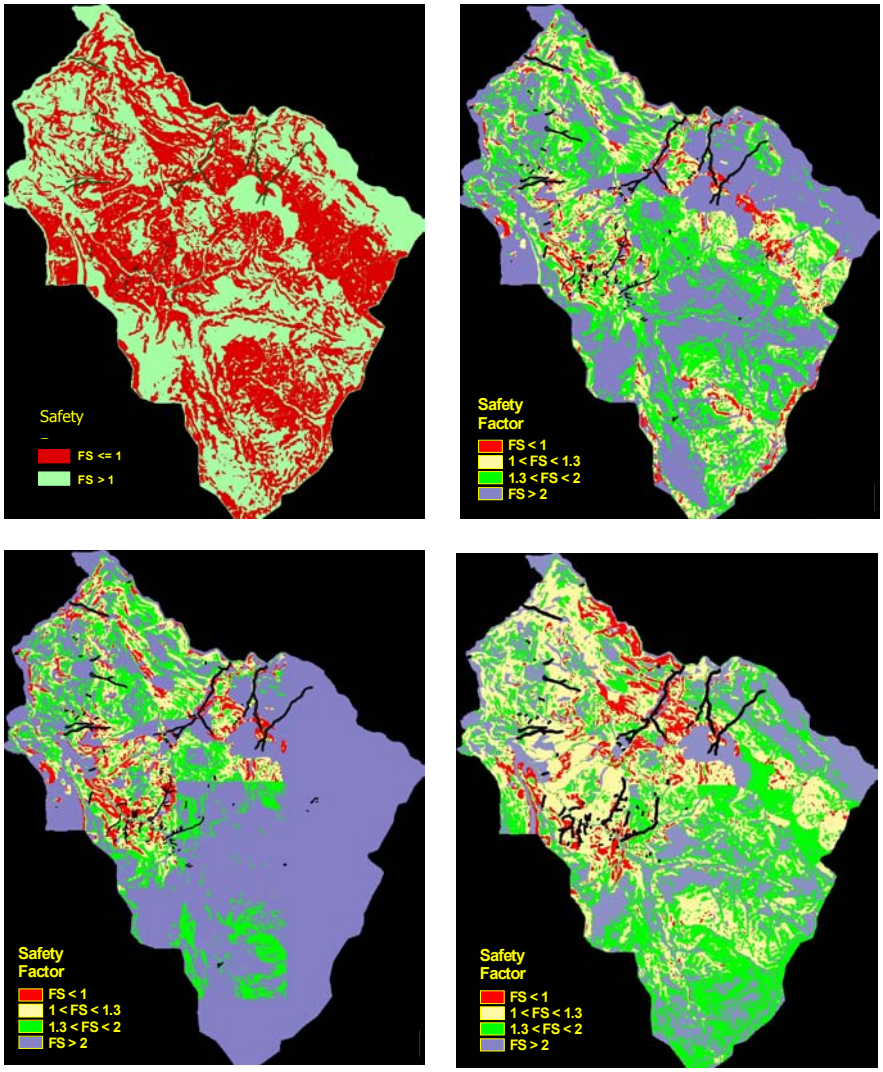


Figure 9: Slope stability maps with different hydrological models: a) steady state model; b) piston model with uniform precipitation; c) piston model with distributed precipitation; d) diffusive model with distributed precipitation.

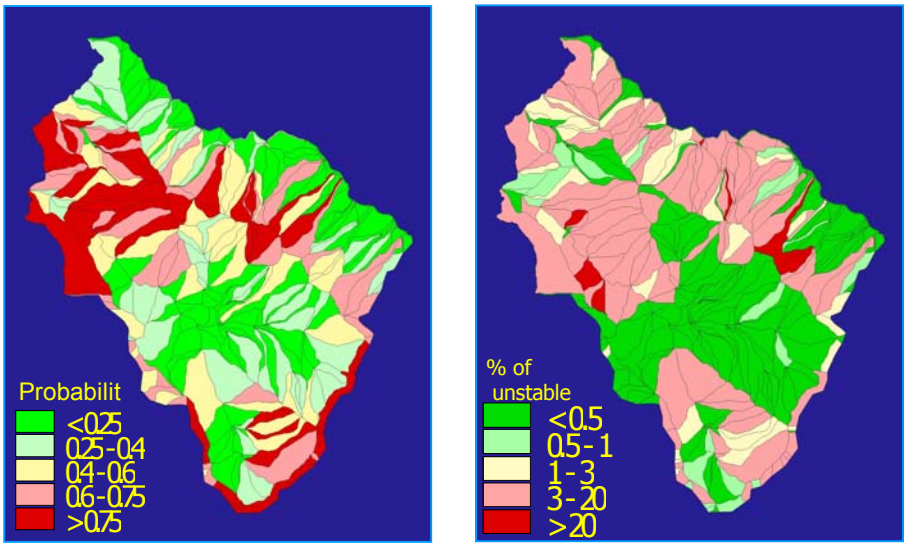


Figure 10. Direct confrontation between statistical model (left) and a simple fysically based model (transient piston flow model, right)

3 - MILESTONES AND DELIVERABLES

The Milano team was contracted to delivery a review on granular flows in Month 18 of the project (August 2001). The document 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
- empirical relationships.

The document contents are:

4 - DEVIATIONS FROM THE WORK PLAN AND/OR TIME SCHEDULE

There have been no deviations during the reporting period

5 - COORDINATION BETWEEN PARTNERS AND COMMUNICATION ACTIVITIES

A profitable collaboration with Newcastle team for data transer and field work in Valsassina has been carried out.

Dr Bathurst (Newcastle) and Dr Crosta (Milan-Bicocca) are joint convenors of a session on Rainfall Triggered Landslides and Debris Flows at the 27th European Geophysical Society General Assembly during 21 – 26 April 2002 in Nice.

6 - DIFFICULTIES IN MANAGEMENT AND COORDINATION

There have been no difficulties during the reporting period.

7 - PLAN AND OBJECTIVES FOR THE NEXT PERIOD

During the next period, the activity of the Milano Bicocca team will lead to:

- conclusion of data collection, with realisation of new DTM, multi-temporal landslide inventory and new geological map;
- utilisation of new data within statistical landslide model;
- further implementation of rockfall model.

8 – PUBLICATIONS

Published papers

Crosta, G.B. (2001) - Failure and flow development of a complex slide: the 1993 Sesa landslide. Engineering Geology, 59(1-2): 173-199.

Submitted papers

Guzzetti, F., Crosta, G.B., Detti, R. and Agliardi, F. (submitted) - Stone: a computer program for the three dimensional simulation of rockfalls. Computers & Geosciences, Part B.

Crosta, G.B. and Dal Negro, P. (submitted) - An insight 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. (submitted) - Shallow landslide triggered by rainfall: the 27-28th June 1997 event in Lecco Province (Lombardy, Italy). Natural Hazards and Earth System Sciences.

Crosta, G.B., Dal Negro, P. and Frattini, P. (submitted) - Shallow landslides triggered by rainfall: the 16-17-18th November 2000 event in Valtellina (Central alps, Italy). Natural Hazards and Earth System Sciences.

Oral presentations, abstracts and posters

Guzzetti, F., Detti, R., Crosta, G. and Agliardi, F. (2000) - STONE. A computer program to evaluate rock-fall hazard at the regional scale. Interreg IIC Falaises Meeting, Alagna, Italy, November 13-14, 2000.

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. European Geophysical Society XXVI General Assembly, 25-30March, 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). European Geophysical Society XXVI General Assembly, 25-30March. 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. European Geophysical Society XXVI General Assembly, 25-30 March - Geophysical Research Abstracts, 3. Oral Presentation and Abstract.

Crosta, G.B. & Frattini, P. (2000) - Rainfall thresholds for soil slips and debris flow triggering. European Geophysical Society Topical Conferences, 2^{nd} Plinius Conference on Mediterranean Storms, Siena, Italy, 16-18 October. Oral presentation and Proceedings.

Bathurst, J.C., El-Hames, A.S., Moretti, G., Crosta, G. and Frattini, P. 2001. Application of a basin scale, landslide sediment yield model, River Pioverna, Valsassina (Lake Como). Conference on La Prevenzione del Rischio Idrogeologico Attraverso la Conoscenza del Territorio. Regione Lombardia, Territorio e Urbanistica, Milan, 26-27 September. Oral presentation and Proceedings.

Crosta G.B. and Frattini P. (2001) - Physically based distributed modelling for shallow landslide hazard zonation. European Geophysical Society Topical Conferences, 3^{rd} Plinius

Conference on Mediterranean Storms, Baia Sardinia, Italy, 1-3 November. Oral presentation and Proceedings.

Crosta G.B. and Frattini P. (2001) - Coupling empirical and physically based rainfall thresholds for shallow landslides forecasting. European Geophysical Society Topical Conferences, 3rd Plinius Conference on Mediterranean Storms, Baia Sardinia, Italy, 1-3 November. Poster and Proceedings.

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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.