# DAMOCLES

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## DEBRISFALL ASSESSMENT IN MOUNTAIN CATCHMENTS FOR LOCAL END-USERS

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**Contract No EVG1 - CT-1999-00007**

**PERIODIC CONTRACTOR REPORT**
**FOR THE PERIOD**
**2000-2001**

**Contractor: Università degli Studi di Milano - Bicocca**

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

## CONTRACTOR PERIODIC REPORT


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### 3.1 OBJECTIVES OF REPORTING PERIOD

The Periodic Report covers the period 1 March 2000– 1 March 2001. The main project objectives for this first year of the Damocles project were:

(i) The start-up of the project (from 1st March 2000) with recruiting of technical personnel and involvement of the subcontractors in the project.

(ii) Initial contacts with all the other partners and subcontractors to clarify objectives and start collaboration and data sharing.

(iii) Data collection and data base implementation at different levels for three different areas to choose the more feasible for the continuation of the project. Acquisition of material and equipment.

(iv) Preparation of technical reports to use with assistant contractor (CNR-IRPI), sub-contractor and end users (Regione LOMBARDIA) for the development of a software code for rockfall simulation and hazard zonation.

(v) Involvement of the end users for the choice of local situations, within the selected study area, as specific test areas.

## 3.2 METHODOLOGY AND SCIENTIFIC ACHIEVEMENTS RELATED TO WORK PACKAGES

The adopted methodology involved a series of different steps including:

- Collection of bibliographic and historical data
- Evaluation of available data and selection of the best study area
- Collection of field data for the study area
- Laboratory testing
- Data digitization
- Initial development of a statistical multivariate model
- Initial development of a rockfall simulation code.

Historic and bibliographic data have been collected initially for different areas in the Central Alps. The three areas were Valcamonica, Valseriana and Valsassina.
The following data have been collected:

- historical landsliding events;
- rainfall data, including daily and hourly intensities;
- lithological and structural maps;
- land-use and vegetation maps;
- landslide inventories and geomorphological maps.
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According to data availability and the type of data required to run the SHETRAN model (WP4 - University of Newcastle) the Valsassina area (about 150 $km^2$) has been chosen as study area in the Lombardy Region. This choice has been done also for the availability of a well documented event (June 28th, 1997) with information about rainfall intensities and debris flows occurrence (figure 1 and 2).
Geological maps have been prepared and transformed in digital format for the Valsassina area by using all the available literature. The existing geological maps (at 1:10,000, 1:25,000, 1:50,000 and 1:100,000 scales) have been revised in order to obtain an updated and homogeneous geological map for the study area. Lithological and structural maps have been derived by the reclassification of the original geological units. The lithological map includes 18 classes whereas 5 different types of structural domains have been mapped according to the slope aspect and dip direction of strata or schistosity, to the massive or chaotic structure of the rock masses. Land use maps have been partially compiled by using existing maps (scale 1:10,000, Regione Lombardia, 1986) and by field checking.

Some more data have been collected beyond those listed above. In particular, we have collected or we are collecting:

- hydrographs for the main creek in Valsassina, at two different locations within the catchment for the periods: 1998-2000 (at Bellano), 1999-2000 (at Moggio);
- rainfall intensities for the same periods of the hydrographs; both radar images and rain gauges data for the 1997 event have been collected and compared; data of 4 rain gauges (Barzio, Bellano, Lecco and Pagnona) from the Valsassina area have been transformed in digital format and analysed in order to describe the rainfall regime within the area;

- geotechnical data by performing field (Guelph permeameter) and laboratory tests (grain size analyses, Atterberg limits, direct shear tests);
- topographic data to prepare a DTM for the Valsassina area (with CNR-IRPI and CNR-CSITE) with a 20*20 m cell size. The DTM was obtained by interpolating contour lines derived from regional cartography (scale 1:10,000; Regione Lombardia, 1980), with an average elevation interval of 25 meters. This DTM has been made available to the University of Newcastle to develop a Shetran model. A 10*10 m DTM has been prepared for a specific area exposed to the 1997 event (Esino - Bellano area).
- a more detailed topographic map has been used to prepare a detailed DTM (5*5 m cell size) for an area of specific interest (rockfall simulation in the Lecco-S. Martino-Mt. Coltignone area)
- historical data concerning landsliding and debris flow activity on alluvial fan; historical data about landslide and flood events for the last two centuries have been collected for Valsassina and have been introduced in a Microsoft Access database including 449 reports;
- positive of aerial photos to verify the possibility to realise a high definition DTM for the entire area
- basins and fans morphometric and geological data, to find the relationship among morphometric characteristics and the type of activity and possible magnitude of events on alluvial fans
- source areas for rockfalls have been mapped to allow the successive modelling of the phenomena through the developed software (see the Rockfall chapter).

Finally, a study of debris flows characteristics on scree slope and of very large debris flows from complex slides has been started. Data from the Valsassina area and from different areas in the Lombardy Region have been partially collected. This study will allow to find and/or to verify the use of empirical relationships to evaluate debris flow magnitude, velocity and runout.
Almost all these data are now in digital format and can be used to run some simulations. In fact, both deterministic and statistical models have been used at this first stage of the project.

## Multivariate statistical models

A multivariate statistical approach, as proposed by Carrara (1983, 1989, 1992) and Carrara et al. (1991, 1995), has been adopted to model the debris flow hazard in the entire Valsassina area. This part of the project has been realized with the contribution of CNR-CSITE (subcontractor) and CNR-IRPI (assistant contractor).
The evaluation of landslide hazard requires the preliminary selection of a suitable mapping unit. The term mapping unit refers to a portion of the land surface which contains a set of ground conditions which differ from any adjacent unit across definable boundaries. At the scale of the analysis, a mapping unit represents inhomogeneous domain that maximises internal homogeneity and between-units heterogeneity.
Among the different types of land units we used slope units, automatically derived from the DTM (figure 3). Slope units partition the territory into geomorphological regions comprised between drainage and divide lines (Carrara, 1988). Depending on the type of instability to be investigated the mapping unit correspond either to the sub-basin or to the

main-slope unit. Furthermore, the minimum and maximum size of each unit must be chosen according to the average size of the existing or investigated landslides.
A particular problem has been encountered during the subdivision of the Valsassina - Lecco territory in slope units. In fact, the presence of the Lario Lake generates a series of difficulties because it can cause the incomplete discretization of the territory in units along the shoreline. As a consequence some corrections have been introduced and only a limited set of hydrologic networks were generated.

The prevalent landslide types in the Valsassina area are debris flows and rockfall. In particular, debris flows s.l. are both of the soil slip/debris flow type along plan slopes and hollows and of the debris flow or debris torrent type.
As a consequence the best application of a statistical approach involves the analysis of the source areas of these phenomena and in particular of those occurring along slopes or within first order stems. Nevertheless, as a first trial, we applied the approach also for transport sectors of the debris flow phenomena and for the combination of source areas and transport sectors. The main slope units (right / left side of the sub-basins) have been chosen as the mapping unit. Two different drainage networks have been generated with a minimum contributing area of 26.4 ha and 10.4 ha (4265 generated main slope units), respectively.
To simply show the landslide distribution within the study area we have produced a landslide density (isopleth) map by computing the number of source areas within each main slope unit. Of the 919 main slope units (22.0% of the total number) which contain debris flow source areas, 663 of them contain less than 2 source areas, 242 more than 3 and less than 5 source areas, whereas only 74 more than 5.

To treat separately source areas and transport areas of the debris flows we have generated a synthetic hydrographic network and separated source areas from transport areas depending from their position along first order stems or along higher order stems, respectively.
According to a step-wise selection procedure, 41 variables were included in the model for source areas, 32 for the transport area model and 35 for the general model including both source and transport areas.
The more relevant variables are the terrain gradient, the presence of highly weathered bedrock outcrops and of natural vegetation. For the source areas model we found among the dominant variables: alluvial sediments, marls and limestones, medium to high average dip angle of strata, slope unit area, average slope unit elevation. For the transport areas model the most important variables are: alluvial sediments, order and inclination of the stem, roughness index of the slope unit, slope unit area.
According to the results of this initial analysis we observe that the best model is the one for source areas (figure 4), even if it is based on a relatively high number of predictors (41). The other models are characterized by a lower discriminating capacity (72.2%) but make use of less predictors (32 and 35). Finally, the percentages of the slope units classified as unstable by the models (22.5%, 25.5% and 27.3%) may suggest that some of the debris flow have not been mapped in a homogeneous and systematic way.

The results of the models are summarised in the following tables:

| SOURCE AREAS MODEL | | | |
|---|---|---|---|
| ACTUAL GROUP | N° of UNIQUE CONDITION UNITS | PREDICTED GROUP MEMBERSHIP | |
| | | Group (stable units) | Group 2 (unstable units) |
| Group 1 (stable units) | 3180 | 2464 | 716 |
| Group 2 (unstable units) | 1085 | 320 | 765 |
| Unique condition units correctly classified: 74.8 % | | | |
| **TRANSPORT AREAS MODEL** | | | |
| ACTUAL GROUP | N° of UNIQUE CONDITION UNITS | PREDICTED GROUP MEMBERSHIP | |
| | | Group 1 (stable units) | Group 2 (unstable units) |
| Group 1 (stable units) | 3408 | 2476 | 932 |
| Group 2 (unstable units) | 857 | 256 | 601 |
| Unique condition units correctly classified: 72.2 % | | | |
| **SOURCE & TRANSPORT AREAS MODEL** | | | |
| ACTUAL GROUP | N° of UNIQUE CONDITION UNITS | PREDICTED GROUP MEMBERSHIP | |
| | | Group 1 (stable units) | Group 2 (unstable units) |
| Group 1 (stable units) | 2889 | 2153 | 736 |
| Group 2 (unstable units) | 1376 | 448 | 927 |
| Unique condition units correctly classified**: 72.2** % | | | |

## Rockfall

Rockfalls are one of the most dangerous phenomena in Alpine areas together with debris flows. The University of Milano Bicocca and its Associate Contractor (CNR-IRPI), under the strong suggestion by the Geological Survey of the Lombardy Region, decided to develop a method for the zonation of areas subjected to rockfall hazard.
A preliminary version of a distributed rockfall simulation model has been developed by CNR-IRPI Perugia (associate partner **AC3**). The model worked on a raster DTM by using a AML Arc/Info Macro Language. The model simulated the rolling of a single block, calculating velocities on the basis of topographic and lithological characteristics. After this first trial a document with a comprehensive review of existing methods for rockfall modeling has been compiled. The document has been the theoretical basis for the rockfall distributed model that has been realized in cooperation with CNR-IRPI Perugia. A complete description of the code (STONE) has already been done by the CNR-IRPI in its Periodic Report and to that report we send for it.
At this stage some theoretical work is going on to develop a more complete model. In particular we are studing the transformation of the cinematic lumped mass model into a more complete 3D dynamic model.

A first assessment of the rockfall hazard in the Valsassina – Montagna Lecchese area has been performed by using STONE. The input data necessary for such a model have been:

- DTM with a 20*20 m cell size
- Landslide inventory map
- Lithological-geomorphological map
- Land use map.

A triplet of mechanical parameters (coefficient of restitutions and friction coefficient) have been automatically attributed to each of the delimited polygons representing slope sectors with different characteristics. The rockfall source areas, as identified in the landslide inventory map prepared by the Geological Survey of the Lombardy Region, amount to about 56 $km^2$ or about the 10% of the total area of the Valsassina – Montagna Lecchese area. This area corresponds to a total number of 140835 source pixel from which one block has been launched during the simulation. About 312.301 cells are interested by the rockfall paths for a total 125 $km^2$ (22% of the total area).
The maps generated by the code have be used to produce both intensity and hazard maps. This is the first rockfall hazard zonation performed in a deterministic way over a very large territory.
The figures representing the performed analysis can be found in the CNR-IRPI Periodic Report.

At the same time some tests have already been done on a specific area chosen in agreement with the Lombardy Region Geological Survey. The Lecco-S. Martino-Mt. Coltignone area has been studied by a multi temporal analysis of aerial photos and through field surveys to delineate:

- source areas (susceptible to detachment or more recent)
- scree slope deposits (vegetated and not)
- position of largest blocks
- type of outcropping materials (loose or dense debris, with different grain size, glacial and colluvial materials, bedrock or shallow soil cover, etc.)
- limits of urbanised areas, position of passive countermeasures.

A 5*5 m cell size DTM has been prepared by digitising contour levels for the whole Lecco-S. Martino-Mt. Coltignone area. Finally a series of different runs have been done by using these data, on DTMs with a different cell size (5, 10 and 20 metres) and by introducing the variability of controlling parameters (restitution coefficients, friction coefficient, number of launched blocks, initial velocity, angle of departure) (Figures 5 and 6).
The results can be considered very satisfying considered the comparison made with:

- geometry of active talus deposits,
- position of largest blocks
- runout of large historical rockfalls.

Eventually, the results, obtained in this fist stage of the project, show that the use of existing geomorphological data and field observations can be used both in the calibration and the verification phase of the rockfall simulation.

## Basin and fan data collection

At this moment, a database with data from 170 alluvial fans has been created, collecting different kind of information (figure 7). Morphometric parameters have been collected through aerial photo interpretation and the use of topographic maps and Digital Terrain Models (see table).
Historical data, geological characteristics and geomorphological features have been collected from bibliographic sources in collaboration with the Geological Survey of the Lombardy Region (**SC/EU8**). An estimation of the kind of depositional typology (stream flow, debris flow, mixed) and the magnitude of the maximum expected event (maximum deposition) on different alluvial fans has been performed using all available information (historical data, landslide maps, erosion features, experts knowledge, etc.). Furthermore, sedimentological description of alluvial fans are under way were possible to substantiate the attribution of a specific building mechanism to each fan. The dataset has been used to perform a series of statistical analysis in order to:

- investigate any significant statistical relationship among the parameters;
- discriminate the type of depositional processes;
- assess the maximum expected magnitude for an event able to reach the alluvial fan.

Results of these analysis are supposed to be useful for WP1 for the development of procedures for automatic identification of active basins likely to generate debris flows.
We will encourage the discussion of this dataset with all the other partners involved in similar data collection activities (University of Padova (UNIPD), Italy; Instituto Pirenaico de Ecologia (CSIC), Spain; Instituto Tecnològico y Geominero de Espagna, Spain).
Analysis of these data is also underway with SC7.

Table of morphometric parameters collected for basins and alluvial fans

| *Symbol* | *Units* | *Parameter* | *Description* |
|---|---|---|---|
| Ab | $km^2$ | Drainage basin area | Area of the horizontal projection of basin surface |
| DT | m | Total drainage length | Length of horizontal projection of main and minor channels in the basin |
| DD | $m^{-1}$ | Drainage density | DD = DT / Ab |
| Hmaxb | m | Max basin elevation | Elevation of the the basin higher point |
| Hb | | Medium basin elevation | Hb= (Hmaxb + Hapex)/2 |
| DHb | m | Relief energy | DHb = Hmaxb – Hapex |
| Mb | - | Melton's number | Mb = (Hmaxb – Hapex) / $Ab^{0,5}$ |
| Qb | - | Area/length ratio | Qd = Ab / $Lcl^2$ |
| Cb | $m^{-1}$ | Melton * drainage density | Cb = Mb * DD |
| Lcl | m | Main stem length | Length of the horizontal projection of the main stem. |
| Hmaxcl | m | Maximum stem elevation | Elevation of the the stem higher point |
| DHcl | m | Relief energy of the stem | DHcl = Hmaxcl – Hapex |
| Scl | % | Mean slope of the main stem | Scl = DHcl / Lcl |
| Af | $km^2$ | Fan area | Area of the horizontal projection of the fan |
| Vf | $m^3$ | Fan volume | Vf =1/3 Ac 1000000 DHf  cos (Sf p/ 180) |
| Vf/Af | m | Fan volume/fan area | |
| Af/Af | - | Basin area/fan area | |
| Hapex | m | Maximum fan elevation | Elevation of the fan apex |
| Hminf | m | Min fan elevation | Elevation of the fan toe |
| Hf | | Medium fan elevation | Hf= (Hapex + Hminf)/2 |
| DHf | m | Fan relief energy | DHf = Hapex – Hminf |
| Lf | m | Fan length | Length of the horizontal projection of the fan bisector |
| Lcl_f | m | Stem length along fan | Length of the horizontal projection of the main stem along the fan |
| Sf | % | Mean fan slope | Sf = DHf / Lf |
| Scl_f | % | Mean stem slope along fan | Scl_f = DHf / Lcl_f |
| Qf | - | Area/length ratio of the fan | Qf = Af / Lcl_ $f^2$ |
| Mf | - | Melton fan number | Mf = (Hapex– Hminf) / $Af^{0,5}$ |

## 3.3 SOCIO-ECONOMIC RELEVANCE AND POLICY IMPLICATION

End-users occupy a central position in DAMOCLES. As a consequence the direct application of the proposed methods and models and the use of the obtained results is a must that the partners agreed to satisfy. For this reason, we have continuously interacted with the Geological Survey and Geological Risk Office of the Lombardy Region. They have actively participated to the collection of data by providing us with their database of geological and geomorphological information. Furthermore, we have choosen our study and test areas according to the existing interests of  the Regional and Provincial Administrations. This has been done for the Valsassina - Montagna Lecchese area where debris flow and rockfall events are quite common and caused damages. The Lecco-S.Martino- Mt Coltignone area has been chosen as a test area for the rockfall model because of its extremely high hazard. In fact, small rockfalls are quite common in the area whereas large rockfalls already induced some casualties and damages (8 persons died on 1969).

The development of a rockfall model able to simulate the propagation of blocks by using 3D topographic information and geological-geomorphological data is then fundamental for any authority or technical office in charge of the delineation of hazard and risk areas for land-planning.

The same kind of interest exists in this area and in other alpine and prealpine areas for the debris flow hazard on alluvial fans.

## 3.4 - DISCUSSION AND CONCLUSION

The first year of the Damocles project has been spent to collect data, to develope initial models and to prepare the first series of maps concerning debris flow and rockfall hazard. These points, which are the main concern of WP2, have been faced with the help of subcontractors (CNR-CSITE-Bologna, Regione Lombardia) and of associate contractors (CNR-IRPI-Perugia). At this stage of the project the results can be only considered initial but very promising according to the available data.

Some work has also been done on WP3 by collecting morphometric and geomorphological data about debris flows on scree slopes and along slopes. This type of debris flows is frequently found in the Alps and Prealps and the development of functional relationship for the understanding of debris flow behaviour is fundamental. At the same time the development of empirical and semiempirical relationships , as well as the evaluation of the existing ones, could be eventually useful for the development of semi-empirically based transport models. These models could be implemented under a GIS environment.

## 3.5 PLAN AND OBJECTIVES FOR THE NEXT PERIOD

The work plan for the next period will include for the WP2:

- refinement of the STONE software code to transform it from a purely kinematic model to a dynamic model
- introduction of empirical laws to scale mechanical and geomorphological parameters
- testing of STONE on different areas within and outside the Valsassina-Montagna Lecchese study area
- preparation of a refined DTM for the study and test areas
- preparation of a multi-temporal landslide inventory
- collection of field data and cross checking of data collected from aerial photos
- development of the mutivariate statistical model for landslide hazard zonation at a regional scale

## 3.6 REFERENCES

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Carrara A., Cardinali M., Detti R., Guzzetti F., Pasqui V. e Reichenbach P., 1991. Geographical information systems and mutivariate models in landslide hazard evaluation. Proc. ALPS 90 - 6th Int. Conference and Field Workshop on Landslides.

Carrara A., Cardinali M., Guzzetti F. e Reichenbach P., 1995. GIS technology in mapping landslide hazard. In: A. Carrara e F. Guzzetti (Eds.), Geographical Information Systems in assessing Natural Hazards, Kluwer Pub., Dordrecht, The Netherlands, 135-175.

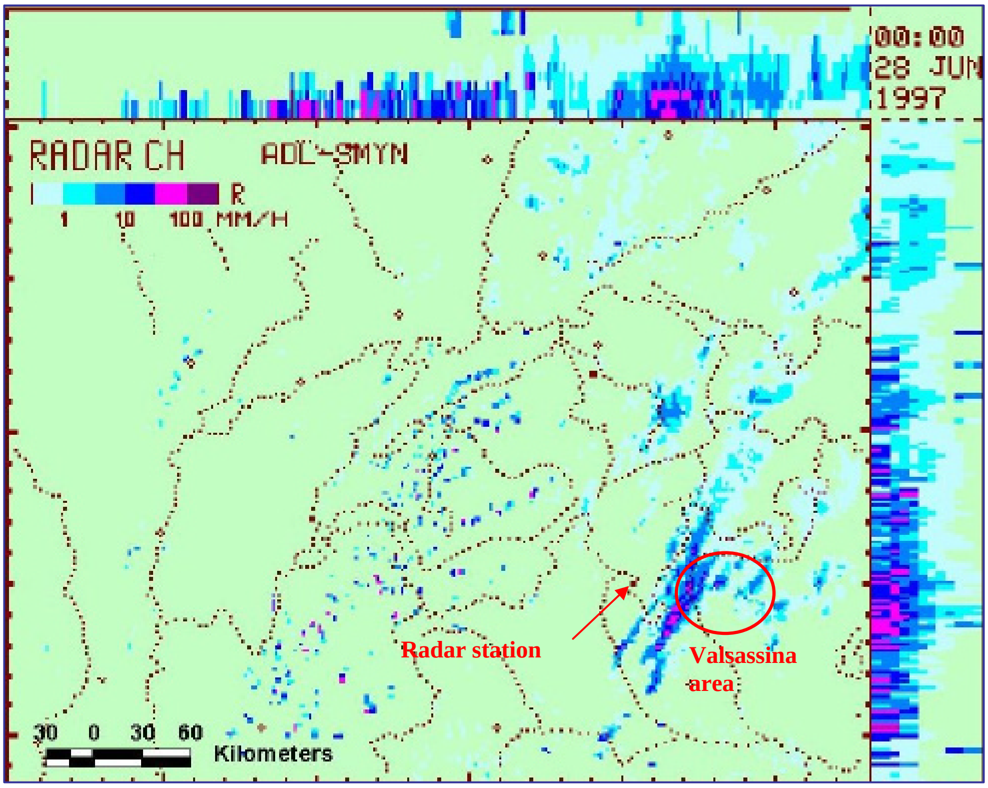


**Figure 1**: Image from the Swiss Meteorological Radar System for the 28th June, 1997 rainstorm (pixel size: 2 km; images are taken every 30 minutes).

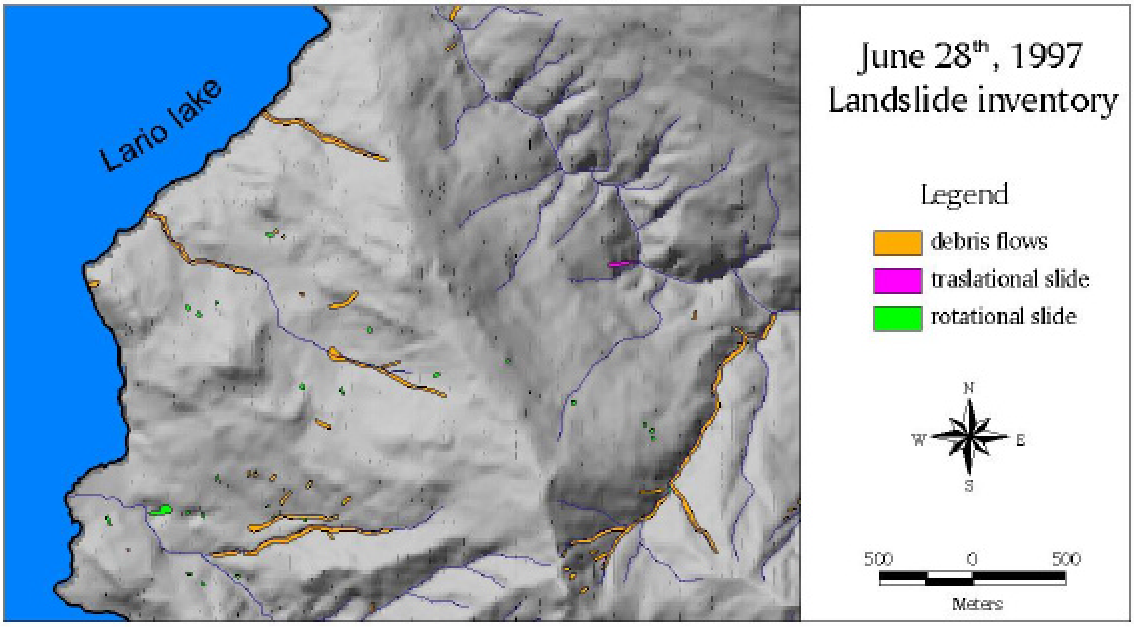


**Figure 2**: example taken from the landslide inventory map for the 28th June 1997 event.

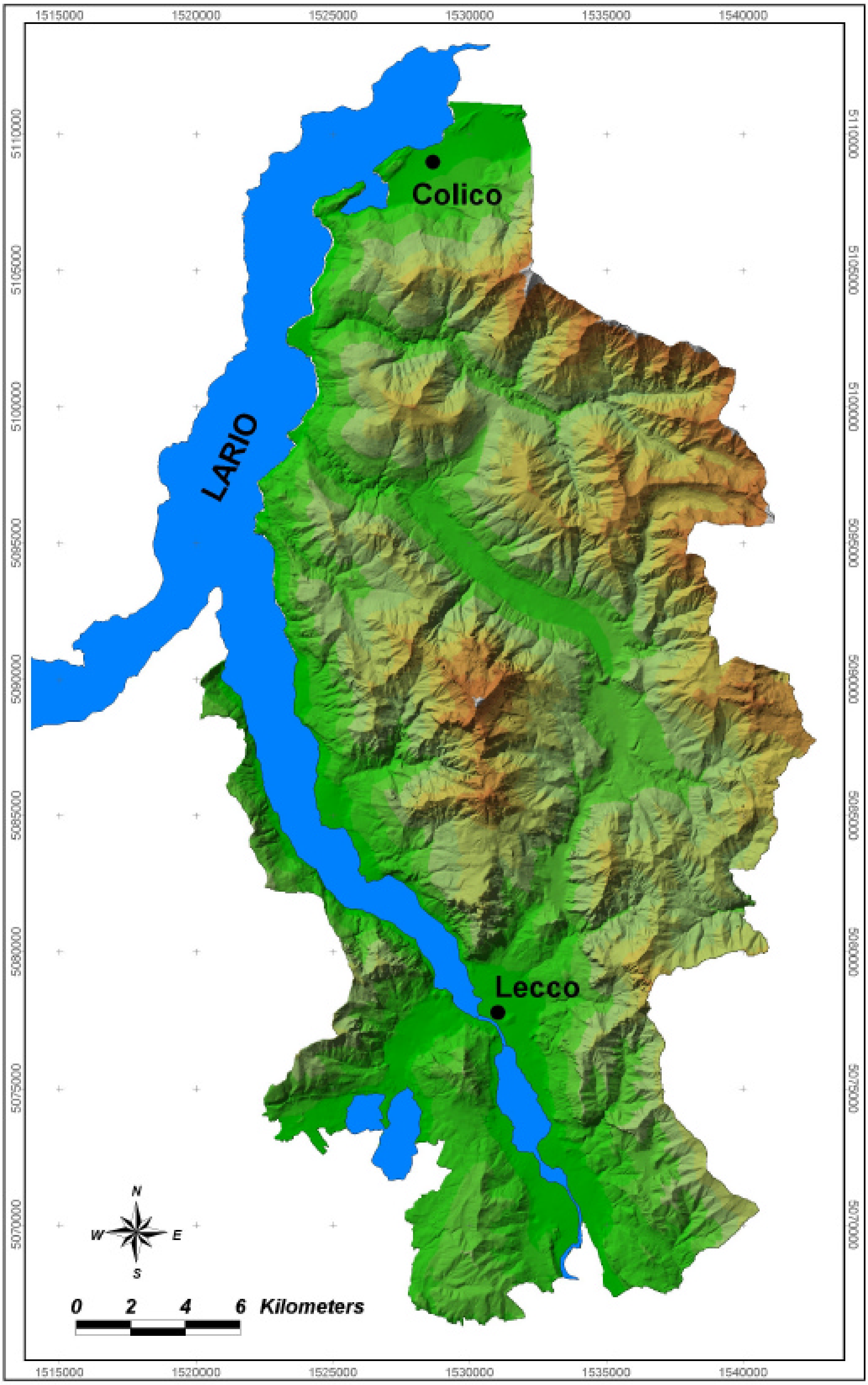


Figure 3: Digital Terrain Model for the Valsassina-Montagna Lecchese area. Pixel size 20 *20 m

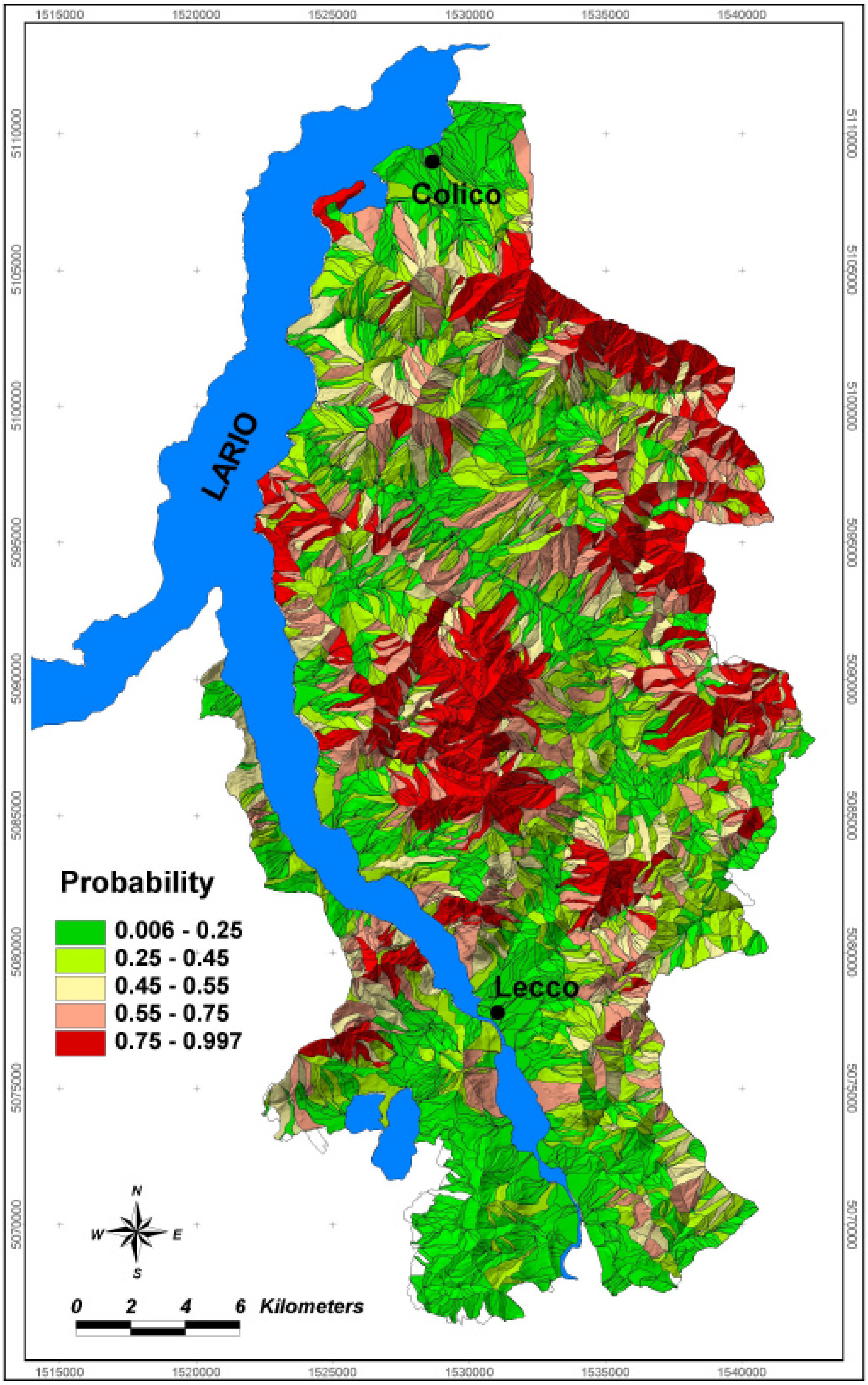


Figure 4: Results of the application of a Discriminant Model for debris flow source areas in the Valsassina-Montagna Lecchese area.

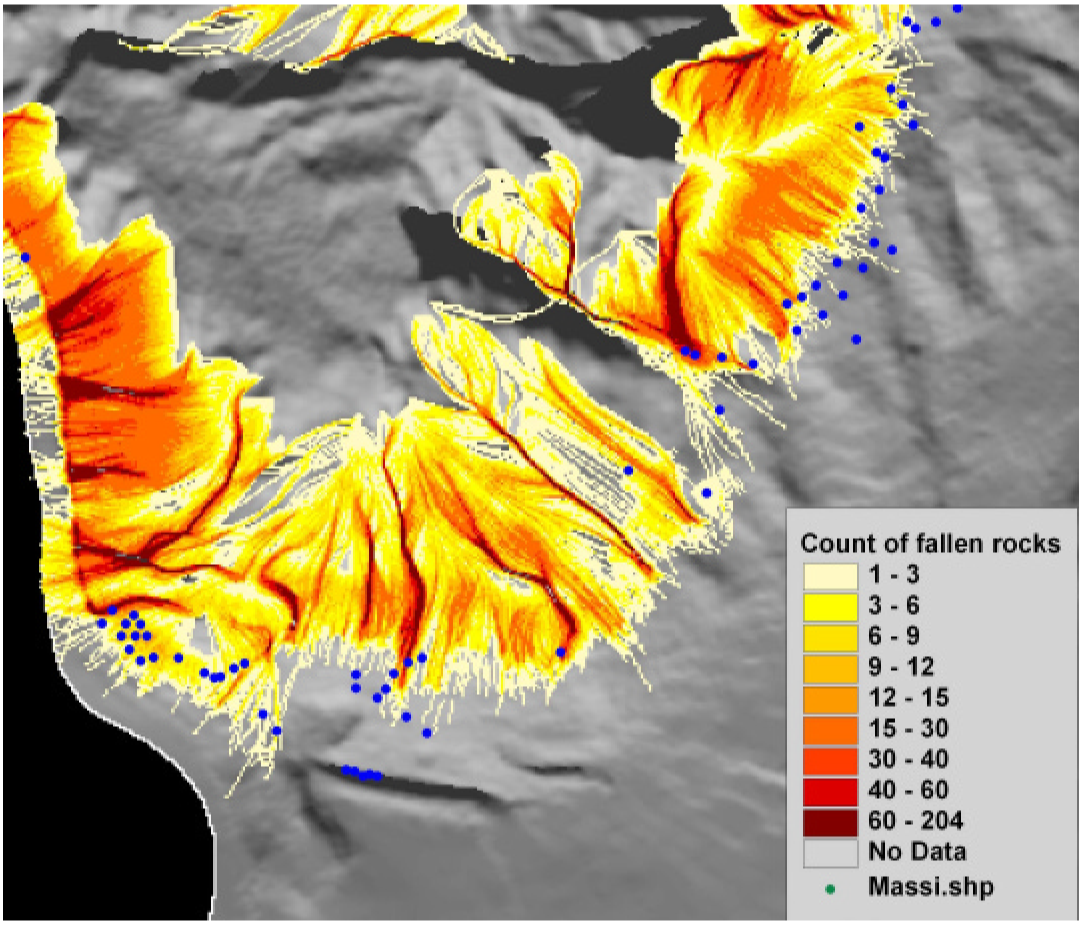


Figure 5 - Lecco-S. Martino-Mt. Coltignone area - Map of the number of block transits across each 5*5m pixel superimposed to the shaded relief image. Blue dots show the position of major blocks mapped by field surveys. Source areas of blocks are all the vertical subvertical rock outcrops.

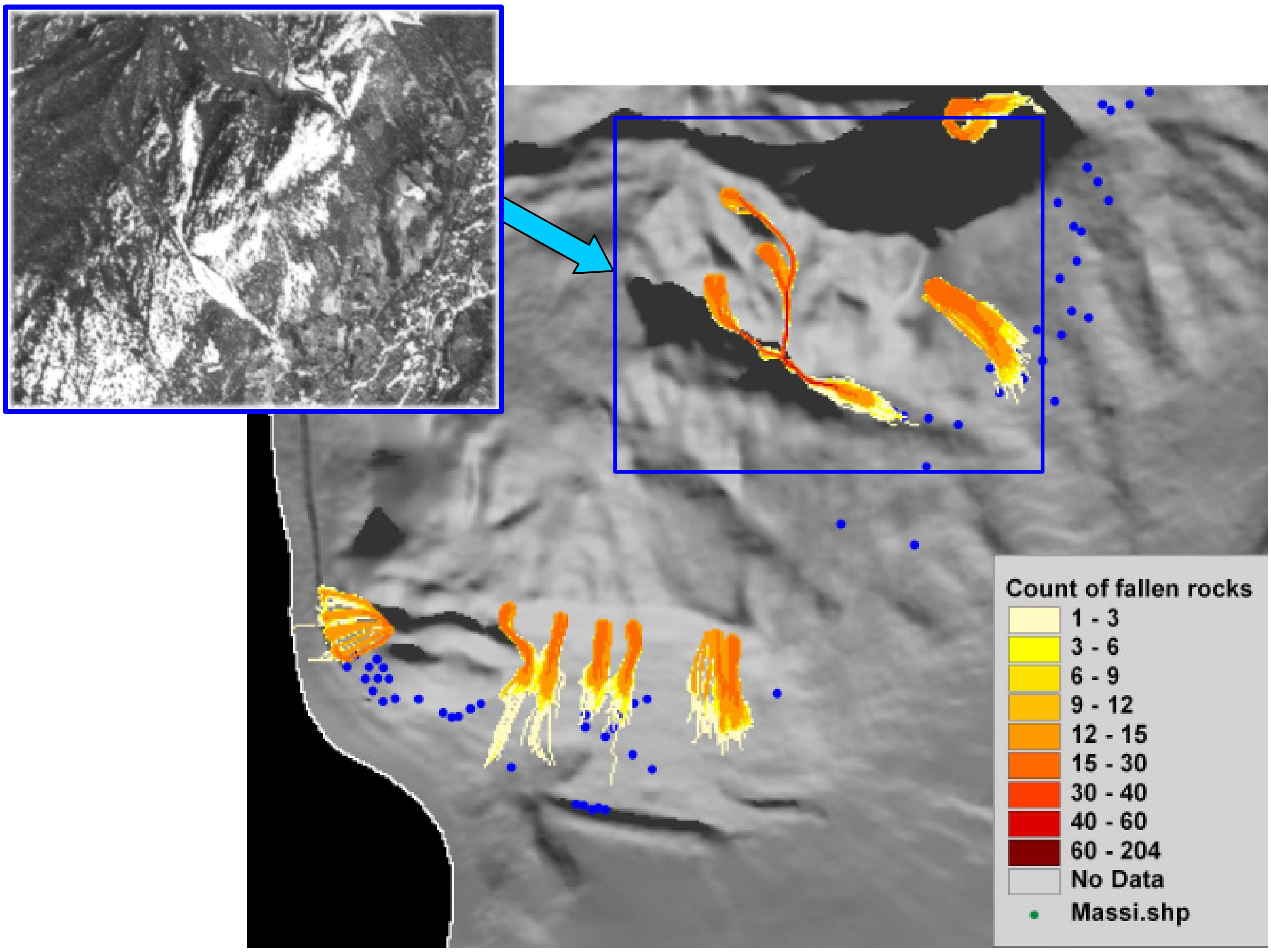


Figure 6 - Lecco-S. Martino-Mt. Coltignone area - Map of the number of block transits across each 5*5m pixel. Blue dots show the position of major blocks mapped by field surveys. Source areas of blocks are all the vertical subvertical rock outcrops recently (last 50 years) interested by rockfall events of different size.

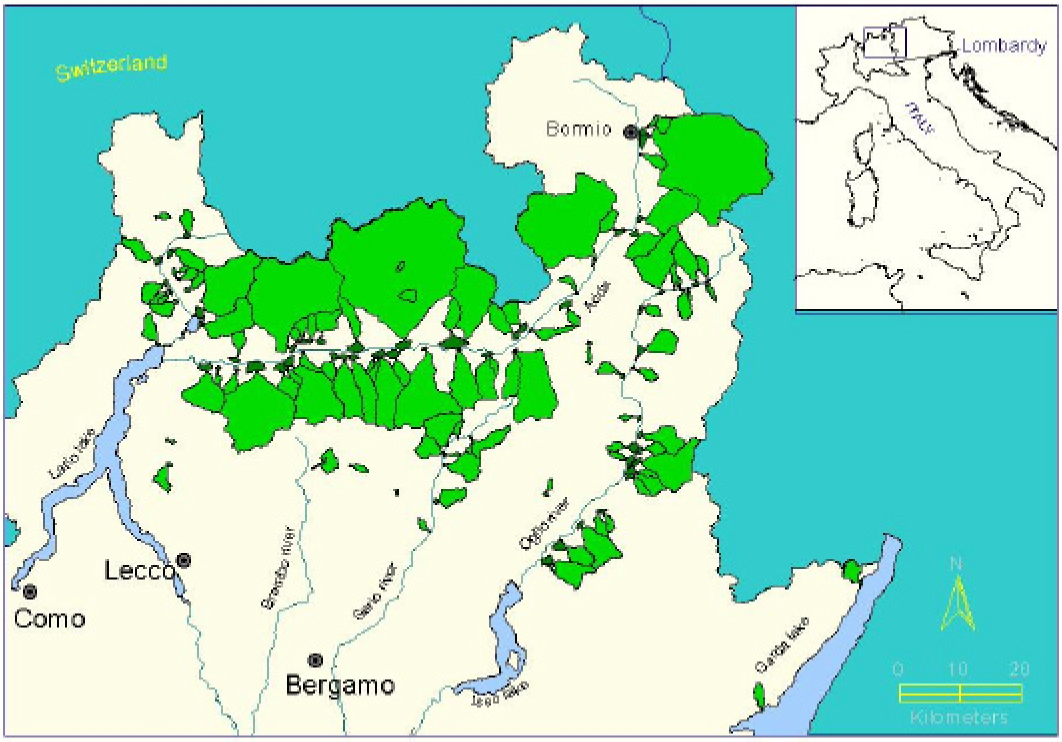


Figure 7: location of the alluvial fans studied within the Lombardy region area.