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Section 1 - Objectives of the reporting period

DAMOCLES is aimed at developing technologies for assessing the distribution of rapid slope failures (including debris flows and rock-falls) and their hazard, for determining the physical impact of debris flows and rock-falls, for assessing the mitigating effects of control and defensive works and land management. Emphasis is given to the transfer of the project deliverables to relevant end-users. Among the project objectives, those pursued by CNR-IRPI can be summarised as follows:

- To develop and apply advanced models for hazard assessment, impact prediction and mitigation studies, relevant at a range of scales, using Geographical Information System (GIS) technology for assessing the regional scale debris flow and rock-fall hazard. This includes assembling databases of thematic (geographical) information in support of model development and refinement. These objectives are addressed by WP2, led by the University of Milano-Bicocca of which CNR-IRPI is an Assistant Contractor (AC). WP2 is intended to develop a GIS-based hazard and risk assessment methodology using field data, available data and model developments. This involves statistical and physically based modelling and benefits from the data and model developments of other work packages. The result will be a quantitative hazard and risk modelling technology for rock-falls and debris flows applicable to mountain environments in Europe. The principal field areas is currently located in the Lombardy pre-Alps.
- To transfer the technologies and deliverables to key end-users and to make the outcomes accessible through the public domain. These objectives are addressed by WP5 led by the

University of Newcastle. Within this work package CNR-IRPI has designed, implemented and is maintaining the DAMOCLES Internet Web site, and has tested the possibility of using GIS-based Web technology to publish on the Internet thematic and landslide hazard maps. The test area selected for the experiment is the Montagna Lecchese, in the Lombardy Region of Northern Italy.

Section 2 - Methodology and Scientific Achievements

The CNR-IRPI is a sub-contractor of the University of Milano Bicocca. The sub-contract activities focus on two issues, namely: the production of debris-flows and rock falls hazard and risk assessment procedures using GIS technology; and data dissemination, including thematic maps, using web technology.

Working Package 2

CNR-IRPI, in cooperation with the University of Milano Bicocca, has completed an experiment aimed at testing the possibility of using GIS technology as an aid to the evaluation of rock-fall hazard in an alpine environment.

To evaluate the feasibility of the project, firstly an experiment was set up to test a preliminary procedure using Arc/Info®, a well known GIS software commonly used to store and analyse geographic information at various scales. The area selected for the test extends for about 100 km^2 in the Upper Valcamonica, an alpine valley in the Lombardy Region. To describe the topographic surface a DTM with a ground resolution of 20 x 20 meters was used. The DTM was originally prepared by interpolating the elevation values obtained form 30, 50, 80 and 100 m contour lines available on the 10,000 scale regional topographic maps. The source areas of rock falls were obtained from a landslide inventory and surface geology map prepared by CNR-IRPI for the Lombardy Region within the framework of a previous research contract (Antonini et al., 2000). Beside the source cells, stopping cells were identified as areas where a falling rock would stop, for whatever reason. For the test, stopping cells were obtained from the higher order streams present on the topographic maps.

Simulation of the rock fall process was kept very simple. Boulders were simply “rolled” from a source cell to a stop cell along the steepest path computed on the DTM. Friction was considered constant throughout the area. The loss of energy due to friction and impacts was computed as a fixed percentage (30 to 50%) of the available energy at each cell. Neither the sliding nor the flying motion of the boulder were modelled. Since most of the rock fall process occurs flying along parabolic trajectories, the latter was a major simplification. The simulation, albeit physically very simple, proved that it was possible to model rock-fall trajectories using GIS technology and thematic data available for a basin or an entire Province, i.e., for areas extending from some hundreds to few thousands square kilometres. The test also showed the limits of the GIS software used for the experiment. These were:

– The extremely slow processing of the information. To complete the test over an area of 100 km^2 a few days of computer time were needed, making the calibration of the input parameters virtually impossible. This limitation is largely due to limits in the matrix algebra of the Arc/Info® software when used within an AML (Arc/Info Marco Language) program.

– The practical impossibility of refining the physical model, and in particular the impossibility to perform a continuous 3-D simulation over a (discontinuous) DTM.
– The impossibility of modelling the flying motion of a boulder along a parabolic trajectory.
– The difficulty in modelling the friction and energy dissipation parameters is a realistic fashion.

Given the promising results provided by the test and the limitations shown by the GIS software, we decided to develop a specific computer program capable to prepare maps useful to the assessment of rock fall hazard at the regional and local scales. We then designed, implemented and tested STONE, a computer program that simulates in three-dimensions the fall of a boulder along a slope. The program, written in ANSI C language, was designed to use thematic data already available for large areas, or that could be obtained from geologic, geomorphologic and land use maps or through reconnaissance investigations, and to generate spatially distributed information useful to assess rock-fall hazard at the regional and local scales.

STONE requires the following input data:

- a DTM, representing topography in raster format;
- a raster map (a grid) showing the location of the “starting cells”, i.e., the cells from which rock-falls occur. Values in the grid may range from 1 to 1000, indicating the number of boulders “launched” from each starting point (i.e., the number of trajectories computed from each grid cell). The grid may also contain –1 values, indicating cells where a rock-fall must stop (“stopping cells”, e.g., the location of effective defensive measures, a river in an open flat valley, etc.);
- two grids for the normal and tangential restitution coefficients, used to compute the loss of velocity where the boulder impacts on the ground;
- a grid for the dynamic friction coefficient, used to compute the loss of velocity where the boulder is rolling along the slope; and
- a text file containing initial and controlling parameters.

For convenience, the 5 input grids are provided to the program as ascii (text) files in the Gridascii format supported by the ArcInfo® and ArcView® GIS softwares.

STONE uses a “lumped mass” approach to simulate rock-falls, i.e., the boulder is considered dimensionless with all the mass concentrated in a point (the centre of mass). The size, shape and mass of the boulder are not considered and a cinematic simulation of the rock-fall process is performed. The advantage of the lumped mass approach lays in its simplicity and in the computational speed. Taking into account the mass of the boulder, its shape and size would allow for a complete dynamic modelling, but would introduce uncertainties (particularly due to the irregular shape of the boulder), would increase the computation time, and would generate a large variability in the results making it more difficult to ascertain rock-fall hazard at the regional scale.

The trajectory of a boulder is computed automatically from the DTM, without any user involvement. The trajectory depends on the starting point, the topography, and the coefficients used to simulate the loss of velocity at the impact point or where the boulder is rolling (Ritchie, 1963; Broili, 1973; Piteau and Clayton, 1976; Hoek, 1987). To describe topography, the representation of the terrain based on equally spaced elevation points (DTM) is subdivided into regular triangles making up a Terrain Regular Network (TRN) (Figure 1). Triangles are planar and of two types: type 1 (upper-right triangle) is constructed with the upper left, upper right and lower right elevation points of each DTM cell; type 2 (lower-left triangle) is constructed by taking the upper left, lower left and lower right elevation points. The advantages of using a TRN, i.e., a vector representation of topography based on regular planar triangles, can be summarised as follows:

- A TRN maximises the information on elevation given by the DTM. Triangles allow for the detailed tracking of a rock-fall trajectory within a DTM cell, providing a higher spatial resolution than the original DTM. This is particularly important if the DTM is coarse.
- Triangles allow to use cinematic equations working along slope profiles on a discrete representation of topography (the DTM).
- Planar triangles are easy to compute and are generated only where needed (i.e., where a rock-fall trajectory intersects or "flies" over a triangle), making the computation faster. As a drawback, triangles may be computed more than once if the trajectories coming from different source areas cross the same DTM cell.

To compute the rock-fall trajectory a local Cartesian coordinate system is used. The x and y axes of the local system lay on the local triangle, with the x axis to the right for triangles of type 1 and to the left for those of type 2, and the y axis pointing upslope for triangles of type 1 and down slope for those of type 2 (Figure 1). The z axis is perpendicular to the local triangle and points upwards. Appropriate functions were developed to transform from absolute (latitude, longitude and elevation) to local (x, y, z) coordinates and back. The use of a local coordinates system simplifies the calculations and makes the computation faster.

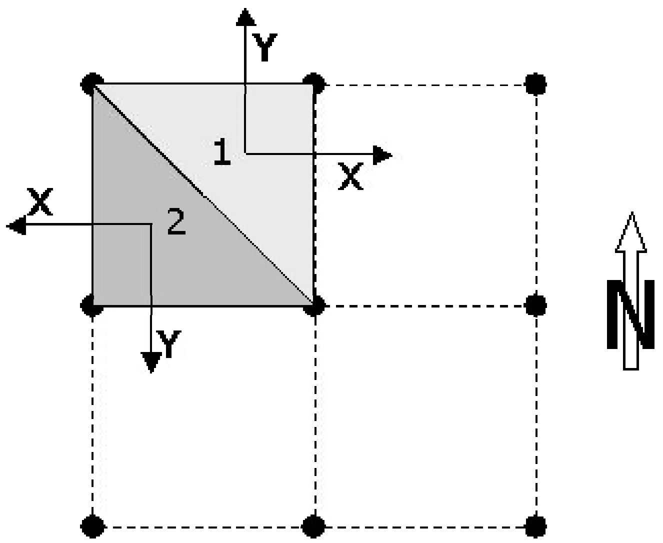


Figure 1. Triangular Regular Network (TRN) derived from a Digital Terrain Model (DTM) and used to represent topography for modelling purposes. Black dots represent the location of regularly spaced elevation points on the DTM. Grey areas are examples of type 1 (upper-right) and type 2 (lower-left) triangles.

STONE is capable of modelling three of the four "states" that a rock-fall can take, namely: free falling, bouncing and rolling. Sliding is not considered because it represents a (usually) negligible part of a rock-fall. If necessary, sliding could be modelled by the same equations used to describe rolling, but with higher friction coefficients.

Starting from a source cell, STONE “shoots” a boulder horizontally out of the cell along the steepest slope and at an initial velocity set by the user. High starting velocities can simulate the triggering of rock-falls by seismic shaking. After the horizontal start, the boulder, driven by gravity, follows a parabolic (ballistic) trajectory (free falling) until it hits the ground. Air drag is neglected, for simplicity. The impact (intersection) point is determined by checking the elevation (z) of the boulder against the elevation of the local triangle at the same x and y local coordinates. If a boulder flies over the edge of the local triangle, a nearby triangle is computed and the trajectory tracked over the new triangle. A specific algorithm determines which side of the local triangle is crossed and selects the proper DTM cell to calculate the new triangle.

When the location of the impact point has been determined, the new direction of the trajectory and the local velocity components (v_x, v_y and v_z) of the boulder are computed. The boulder “escape” direction is obtained by mirroring the incoming direction, i.e., the rebound (or escape) angle is considered to be equal but opposite to the impact angle. To simulate the loss of energy at the impact point, the escape velocity components are computed by multiplying the incoming velocity components by the user-defined tangential (for x and y components) and normal (for the z component) restitution coefficients. Normal and tangential components are treated separately for a better and more flexible simulation of the rock-fall process (Piteau and Clayton, 1976; Hoek, 1987). Indeed, results of field experiments show that the normal component is about half of the tangential component (Barret et al., 1989; Pfeiffer and Bowen, 1989a 1989b; Azzoni et al., 1991). When the escape direction and velocity have been computed, the boulder starts a new parabola and a new intersection point is searched further down slope, inside or outside the local triangle.

STONE simulates rolling of a bolder on a surface (the local triangle) using a rather simple approach. The loss of velocity due to the dynamic friction is modelled by a dragging force acting on the local plain against the direction of movement. The local coordinates of the boulder and its velocity components along the surface are computed by iteration, introducing at each time step a dragging (resistance) force equal to $f = \sin(\mathrm{atan}(F_d)) \times g$, where F_d is the user-defined dynamic friction angle for the corresponding DTM cell.

STONE determines the position of a boulder flying or rolling along a slope at successive time intervals. To track the boulder trajectory accurately the local coordinates (x, y, z), the velocity and the flying height are computed using an adaptive time step (?t). The time step (in seconds) is computed as the ratio of the local velocity (in $m \cdot sec^{-1}$) and the user defined tabulation steps (in meters). Tabulation steps are different for free fall and rolling. Thus, regardless of the velocity, the coordinates and cinematic information along a rock-fall trajectory are recorded always at the same distance, along the direction of motion. A peculiar condition arises at the impact point that may occur during a time step, and not at the end of it. For this reason the last time step is adjusted to match exactly the impact point.

Since the trajectory of a rock-fall is a (complex) mixture of free falling, bouncing and rolling, a set of "conditions" were adopted to switch from one "state" to the other. Some of the transitions are simple and intuitive, others require an a priori decision from the user. Transition between free falling and impact is obvious: it occurs where a boulder impacts (intersects) the topographic surface. After the impact a boulder is forced to fly (rebound), unless: the velocity of the boulder is lower than the user defined minimum velocity, in which case the boulder is stopped; or the velocity of the bolder is below a user defined threshold and the span of the last free-fall segment is less than a user defined value. In the latter case the boulder is considered to be rolling and the appropriate algorithm is used.

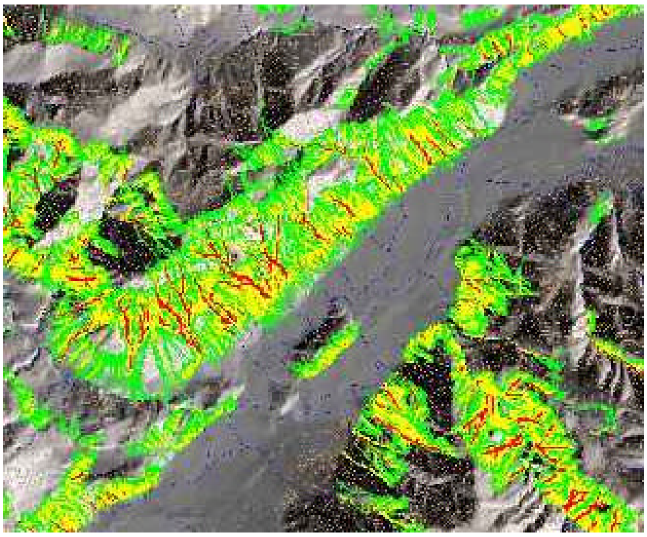
Transition between rolling and free falling is controlled by topography. A boulder that starts rolling within a local (planar) triangle will keep rolling until it stops because its velocity falls below the lower velocity threshold, or it reaches one of the edges of the local triangle. In the latter case the elevation (z) of the boulder is checked on the next local triangle to see if the boulder will keep rolling on the new triangle, or if it will fly above it along a new ballistic trajectory ("jumping" condition).

STONE outputs the results of its calculations in both raster and vector formats. Raster outputs are represented by three grids (of the same format and size of the input grids) showing for each cell: the cumulative count of rock-fall trajectories that passed through each cell, the highest computed velocity, and the largest flying height (distance to the ground) computed along the rock-fall trajectories. Figure 2 shows examples of the three output grids for the Brenno sample area, in the Lombardy Region (Northern Italy). The grid showing the total number of rock-fall trajectories (Figure 2A) provides information on the expected frequency of occurrence of rock-falls. For each grid cell the count of trajectories is a proxy for the probability of being intercepted (crossed) by a rock-fall. The larger the number of computed trajectories, the higher the frequency of occurrence of rock-falls. The grids of the highest computed velocity (Figure 2B) and of the largest height to the ground (Figure 2C) provide information on the (maximum) expected intensity of a rock-fall, a proxy for the maximum kinetic energy expected at each grid cell. Raster outputs are provided in the same format used for input grids, and are easily read by ArcInfo® or ArcView® GIS systems for display, mapping and analysis.

Vector outputs can take different forms. For users interested in two-dimensional (planar) representations of the rock-fall trajectories (i.e., in the production of maps showing where rock-fall trajectories are located, and in the 2-D distribution of rock-falls velocities and flying heights) STONE outputs two files, in ASCII format, containing respectively:

- the ID (unique identifier) and the geographic (x and y) coordinates of the points along the rock-fall trajectories; and
- the ID, elevation, velocity, and flying height at each point along the trajectories.

These files can be imported into ArcInfo® or ArcView®, as well as other GIS and CAD systems. They can be "joined" using the unique identifier (ID) and used to prepare maps showing the spatial (planar) distribution of the rock-fall trajectories. Points along the trajectories can be displayed with different symbols or colours depending on velocity, flying height and travel mode (Figure 3).



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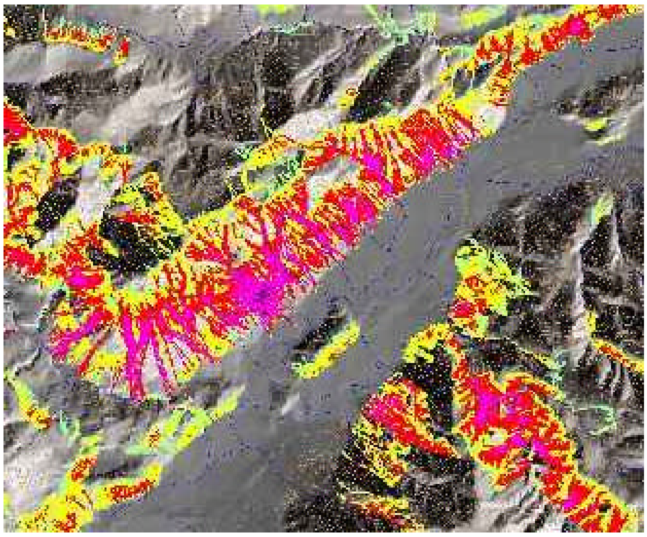

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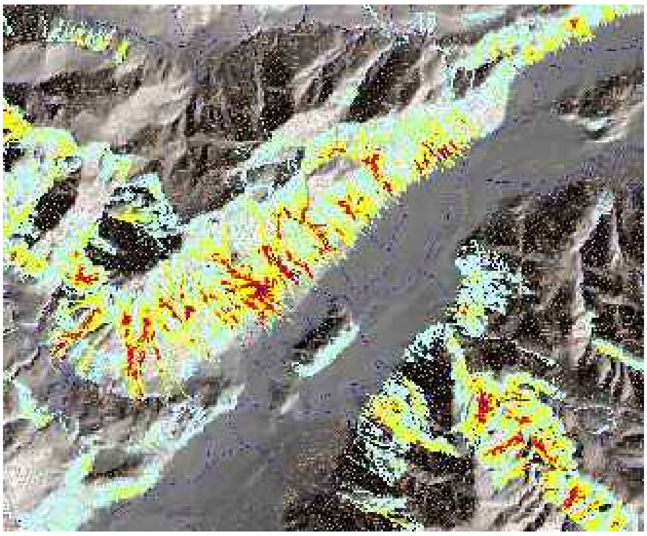

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Figure 2. Examples of raster outputs of the program STONE for the Erbanno sample area, in the Lombardy Region. The area shown in the figure extends for about 20 km^2.

A) Count of rock-fall trajectories passed through each cell. Green, yellow and red show a few, a medium and a large number of trajectories.
B) Maximum rock-fall velocity. Colours indicate increasing velocity, from less than 50 $km{\cdot}h^{-1}$ (green) to more than 300 $km{\cdot}h^{-1}$ (violet).
C) Maximum height of the trajectory above the ground. Colours indicate increasing height, from less than 5 m (light blue) to more than 100 m (violet).

For users interested in the three-dimensional display of rock-fall trajectories, STONE outputs an ASCII file containing the x, y and z coordinates of all the points along the trajectories, and the velocity and distance from the ground at each point. The file can be read by three-dimensional CAD and GIS systems, provided that a specific conversion program is available. A second ASCII file containing the 3 triplets of x, y, and z coordinates defining the local triangles used to compute the rock-fall trajectories is also produced and can be used to help visualising the rock-fall trajectories with respect to topography (Figure 4).

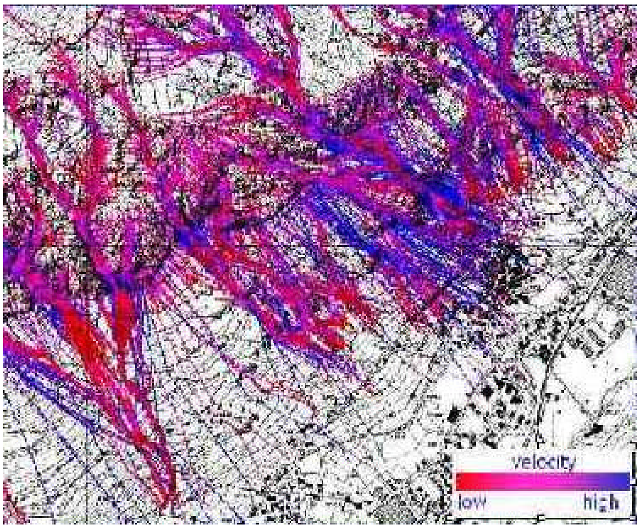

Figure 3. Map of point velocity. Violet tones indicate low velocity values, blue tones represent high velocity values. The map is an example of the planar (2-D) outputs of the program STONE.

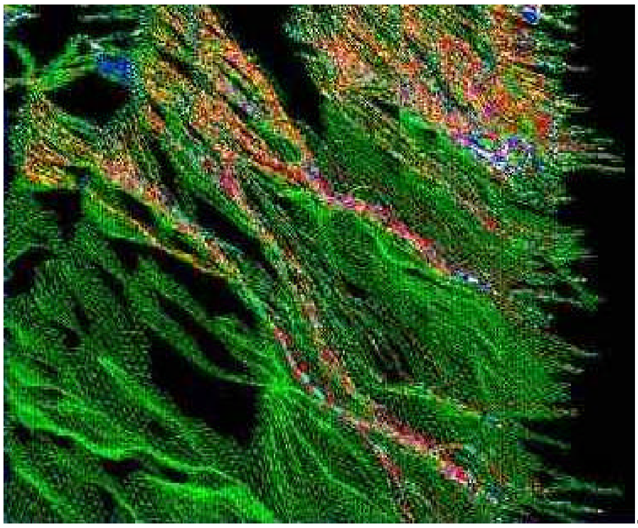

Figure 4. Example of a three-dimensional representation of rock-fall trajectories computed by the program STONE

The size of the 2-D and 3-D vector files can become very large (easily exceeding 200 Mb for large areas), depending on the user-controlled output resolution, the extent and complexity of the study area, the number of source cells, the friction and energy restitution coefficients, and the initial and minimum velocities set by the user. Even if the dimension of the output files is limited only by computer memory and disk space, in practice we prepared raster outputs for areas exceeding 600 km^2 (i.e., 1.5 million cells with a ground resolution of 20x20 meters) (Figure 5), we prepared two-dimensional representation of rock-fall trajectories for areas extending from few hectares to several tens of square kilometres (Figure 3), and we displayed 3-D rock-fall trajectories for areas up to few square kilometres (Figure 4).

Parameters such as the rock-fall starting velocity and direction, the dynamic friction coefficient and the normal and tangential energy restitution coefficients vary largely in nature and are difficult to define precisely, particularly over large areas. STONE provides a way to cope with the natural variability and local uncertainty associated with such information by adding to these values a random component. The user can select a range of variation around the given (default) values. During the computation, where needed (i.e., at the beginning of a new trajectory for the starting angle, at each impact point for the normal and tangential energy restitution coefficients, and where the boulders rolls for the dynamic friction coefficient), STONE draws randomly a value from the selected range around the given (default) values. As an example, if a user selects the ranges ± 3% and ± 2% for the normal and tangential energy restitution coefficients respectively, and the values in the input grids for any given cell are 50 and 65, respectively, STONE will select randomly a value for the normal coefficient in the range 47-53 and a value for the tangential coefficient in the range 63-67. Values for the range of variation are kept separated for the various input parameters. Thus, the normal and/or tangential energy restitution coefficients can be varied separately keeping the dynamic friction coefficient and the staring angle constant. Similarly the starting angle can be selected randomly keeping the parameters controlling the loss of energy constant. This allows for flexible and complex simulations, and for sensitivity analyses. If one or more of the selected ranges is set to zero, STONE will use for that parameter the given (default) value.

The algorithm generating pseudo-random numbers used by STONE needs an initiation seed. If the seed is left unchanged, two successive runs of the program will provide exactly the same results. This should be considered a positive feature because it allows to replicate random simulations. To obtain completely different simulations the value of the seed must be changed before each run. Thus, if the random component is used to model rock-falls, separate runs of the program based on the same input data and control parameters will provide the same results only if the seed is the same, otherwise results will be different. Adding the random components to the simulation proves very useful to test the program outputs for errors or inconsistencies due to local conditions. When combined with the possibility of triggering a large number of boulders from each starting cell, the use of the random components provides a way of coping with the natural variability and the intrinsic uncertainty associated with rock-falls. As a drawback the time required to complete a simulation increases.

We used STONE to ascertain rock-fall hazard in the Montagna Lecchese study area, an alpine territory that extends for about 600 km^2 in the southern Alps (Figure 5). The area has a long history of rock-falls that have repeatedly caused damage at several sites. For the area, a DTM with a ground resolution of 20 x 20 meters, and a landslide inventory and surface deposits map at 1:10,000 scale were available. The DTM was prepared through the interpolation of contour lines obtained from 1:10,000 scale topographic maps. In the area a landslide mapping completed by the Geological Survey of the Lombardy Region shows that about 56 km^2 (10 percent of the total area) were mapped as possible source areas of rock-falls. By transforming these areas into cells with a 20 x 20 meters resolution (i.e., with the same resolution of the DTM) 140,835 "starting cells" were identified. From each cell a boulder was launched and a rock-fall trajectory was computed. Dynamic friction coefficients and energy restitution coefficients were obtained from thematic maps including a landslide inventory map, a lithological map and, for about half of the area, a land-use map.

The output of STONE for Montagna Lecchese shows that 312,301 cells, corresponding to 125 km^2 (22 percent of the total area, including the "starting cells") can be interested by rock-fall trajectories. The map of the count of rock-falls (Figure 5) shows that in certain areas quite a few cells are intersected by more than 100 rock-fall trajectories. These are mostly (but not only) channels and concave areas that concentrate the rock-fall trajectories. The maps of the maximum height above the ground and of the maximum velocity (not portrayed, see Figure 2 for examples in a sample area) illustrate that velocity locally exceeds 300 $km \cdot h^{-1}$ and flying height locally exceeds 300 metres above the ground. These particularly high values are recoded near high cliffs.

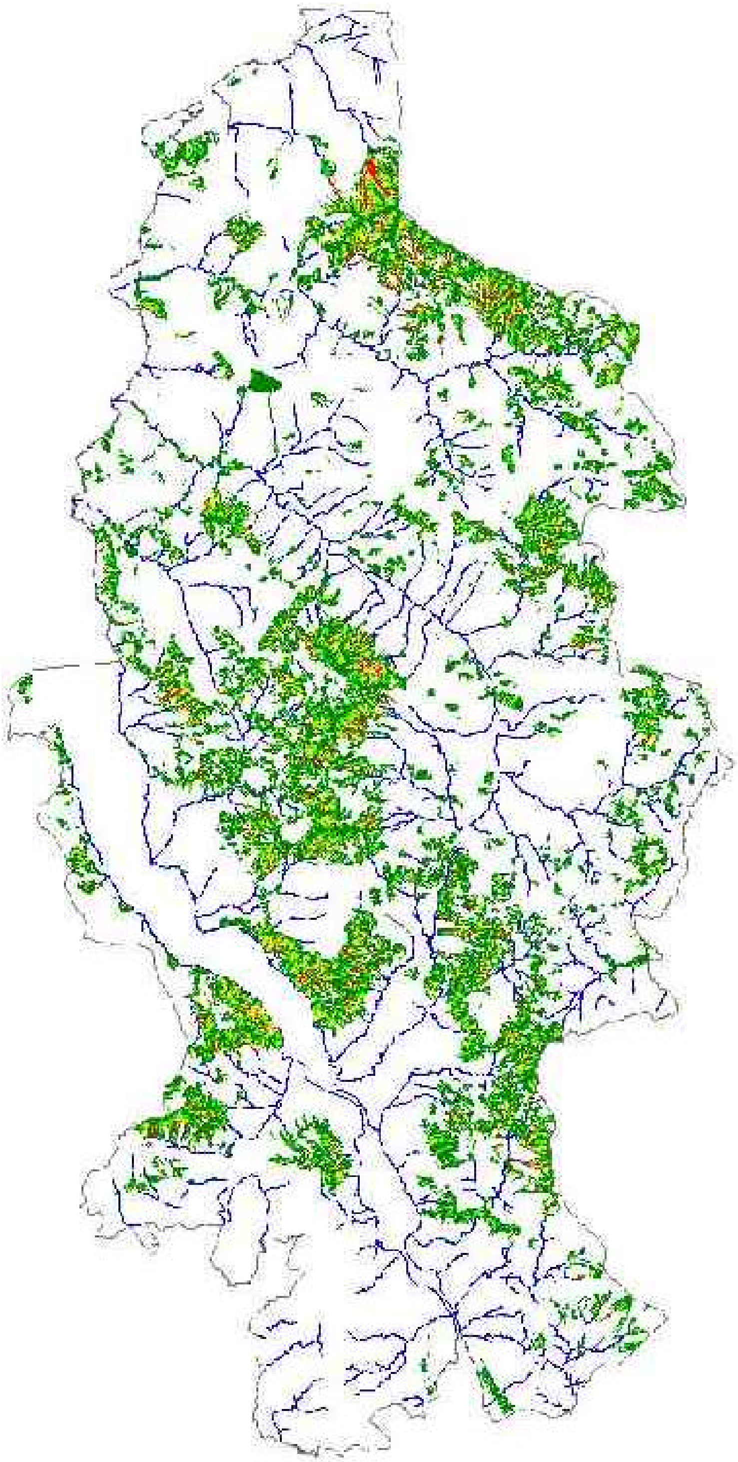

Figure 5. Map showing the count of rock-fall trajectories for the Montagna Lecchese study area, in Lombardy Region (Italy). The area extends for about 600 km^2. In the entire area there are 56 km^2 of possible source of rock-falls. The map shows the 312,301 cells (including source areas), corresponding to 125 km^2 (22% of the total area), that can be affected by rock falls. Dark green=1-5 rock-falls, green=6-10 rock-falls, yellow=11-25 rock-falls, pink= 25-50 rock-falls, red > 50 rock-falls.

The three raster maps produced by STONE (i.e., count of rock-fall trajectories passed through each cell, maximum rock-fall velocity, and maximum height of the trajectory above the ground) provide useful information to access rock-fall hazard. The count of rock-fall trajectories shows the number of rock-fall trajectories that have intersected (in the model) a grid cell. If we assume that each staring cell has the same probability of generating a rock-fall, the map the count of rock-fall is an estimate of the probability that a cell in hit by a rock-fall. For each cell the larger is the counter, the higher is the number of rock-fall trajectories, and, as a result, the larger is the hazard. The maps of the maximum rock-fall velocity, and maximum height of the trajectory above the ground provide information on the kinematics of the rock-fall trajectories. The larger is the recorded velocity, the larger are the energy and the falling height of the boulder and, as a result, the larger is the hazard. Rock-fall trajectories flying very high from the ground are difficult to stop with passive defensive measure, and therefore a particularly dangerous.

To evaluate rock-fall hazard (and risk) the raster outputs provided by STONE must be combined and interpreted. Several strategies can be followed to combine the three raster maps produced by STONE. For this experiment we decided to use a very simple approach, combining first the maximum velocity and the maximum height to the ground (kinematics parameters) to obtain a rock-fall intensity map. The intensity map is then re-coded and combined with the map of the count of rock-fall trajectories (frequency parameter) to obtain a rock-fall hazard map. To simplify the calculation values of the three output grids were ranked into 3 classes. Figure 6 shows the rock-fall hazard map prepared for the entire Montagna Lecchese study area.

The hazard map of Figure 6 shows that 22.5% of all the cells interested by rock-fall trajectories exhibit low hazard values (i.e., they are characterised by low values of rock-fall intensity and by a limited number of rock-fall trajectories), and that about 4.8% of the cells interested by rock-falls exhibit high hazard values (i.e., they are characterised by high values of rock-fall intensity and by numerous rock-falls). Where hazard is predicted to be low, “active” (“structural”) defensive measures, such as retaining walls and elastic fences, can be implemented. To the opposite, where the hazard is predicted to be high (or very high) rock-falls are too numerous and travel at speeds allowing only for “passive” (“planning”) defensive measures. More complex, and uncertain, is understanding (and using) the hazard map where the hazard is predicted to be intermediate. One should separate areas where the rock-fall intensity is moderate but the frequency of occurrence is large (about 6.8%), from the areas where rock-fall are infrequent but their intensity is high (about 3%). In the first areas “active” defensive measures (retaining walls and fences) can probably be effective since the predicted energy of the rock-falls is in the working range of such structures. In the latter cases, only “passive measures can be implemented.

For WP2 two team members were involved for about 20 days each to prepare the procedures with the Arc/Info® GIS and the thematic data sets, to run the various versions of the program STONE and to analyse the results. A computer programmer (financed with funds not coming from the DAMOCLES project) has worked for about 45 days preparing the computer program STONE. The work was done according to the time-table.

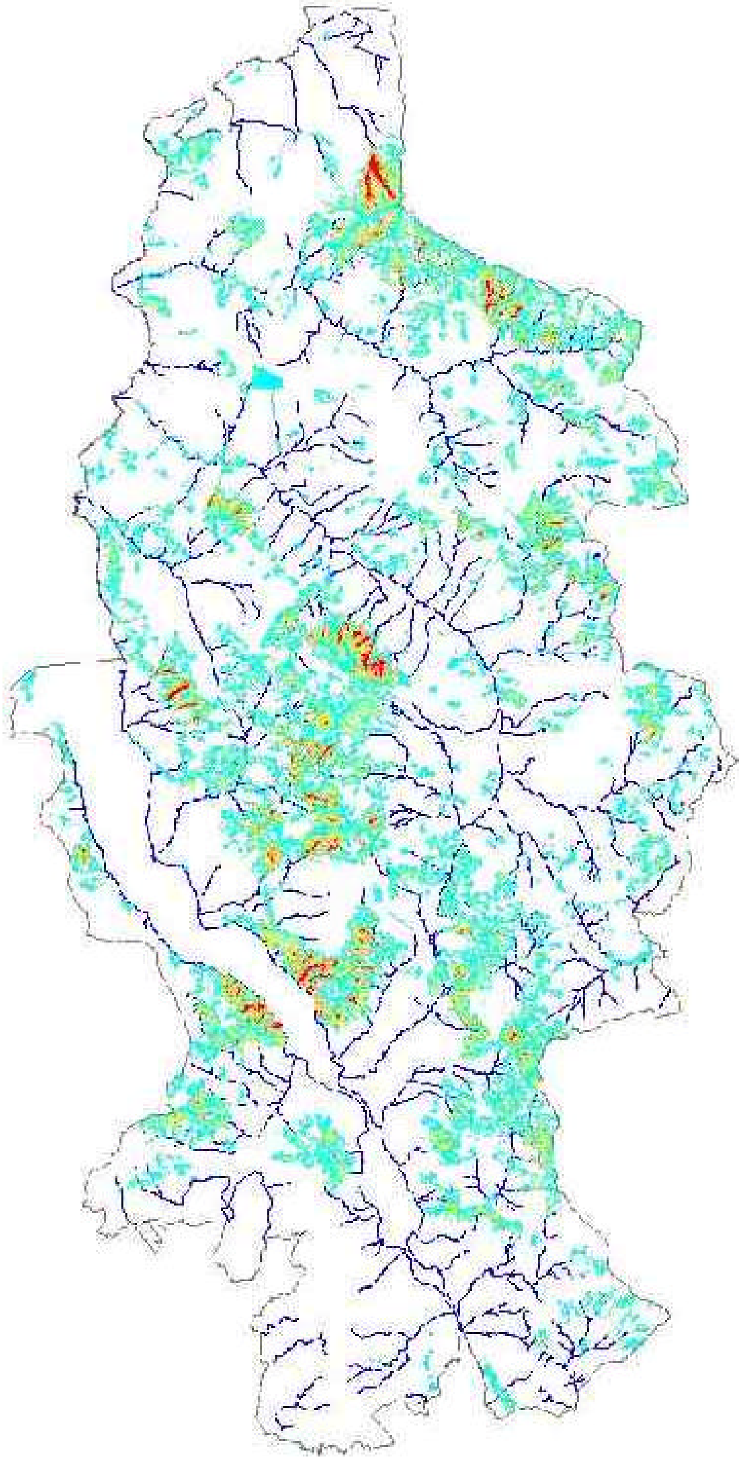

Figure 6. Map showing the rock-fall hazard for the Montagna Lecchese study area, in Lombardy Region (Italy). Light blue and green represent low hazard values, yellow represents intermediate hazard, and red represents high hazard levels.

Working Package 5

WP5 deals with the dissemination of the most relevant project achievements (i.e., the project deliverables). The work package is led by the University of Newcastle. CNR-IRPI focused its activities on two issues: the development and maintenance of the DAMOCLES project Web site; and the development of a GIS-based Web site capable of publishing thematic maps on the Internet.

The DAMOCLES project Web site can be accessed at the URL http://damocles.irpi.pg.cnr.it. The home page (Figure 7) provides access to specific sessions on:

- the project goals and the expected results;
- the project consortium, with information and addresses of each partner;
- the study areas, and in particular the Benasque study area in Spain, and the Rio Lenzi and Montagna Lecchese study areas in Italy;
- the minutes of the Milano and Saragoza meetings, held in April and September 2000, respectively;
- the progress reports.

The Web site, to be maintained for 3 years after the project completion, provides interested users, including fellow scientists, local end-users and the general public, with the opportunity to get access to the project deliverables. The site, updated frequently and whenever new information becomes available, runs on a Sun Ultra workstation running Solaris 7 and Netscape Enterprise Server, release 3.5. Both hardware and software are provided to the project by CNR-IRPI.

A second Web site was set up to publish thematic maps on the Internet using state of the art GIS technology. The site can be accessed at the URL http://maps.irpi.pg.cnr.it/damocles/lecco/viewer.htm and runs on an personal computer running Microsoft Windows NT, release 4.0, and the public domain Apache web server software. For publishing geographic information we used the ESRI® ArcIMS™ software.

ArcIMS™ is an Internet Map Server (IMS) software suite for authoring, designing, publishing and administering Internet mapping applications (ESRI, 2000). ArcIMS™ provides the mechanisms to allow Web clients such as Netscape or Internet Explorer, map servers, data servers and a Web server to communicate with one another. The choice of the ArcIMS™ suite was due mostly to its availability, its recently improved capabilities and its price, lower (at least for educational users) than that of competing products. Installation of the entire software suite was not straightforward and required several attempts and adjustments. This was also due to the fact that we made the choice to use of open source or public domain programs (such as the Apache Web server and the Jserv servlet engine). Despite the difficulties, when the software suite was installed and properly configured publication on the Internet of thematic maps was fairly easy.

Figure 7. The home page of the DAMOCLES project, at the URL http://damocles.irpi.pg.cnr.it. To the left the main topics covered in the home page.

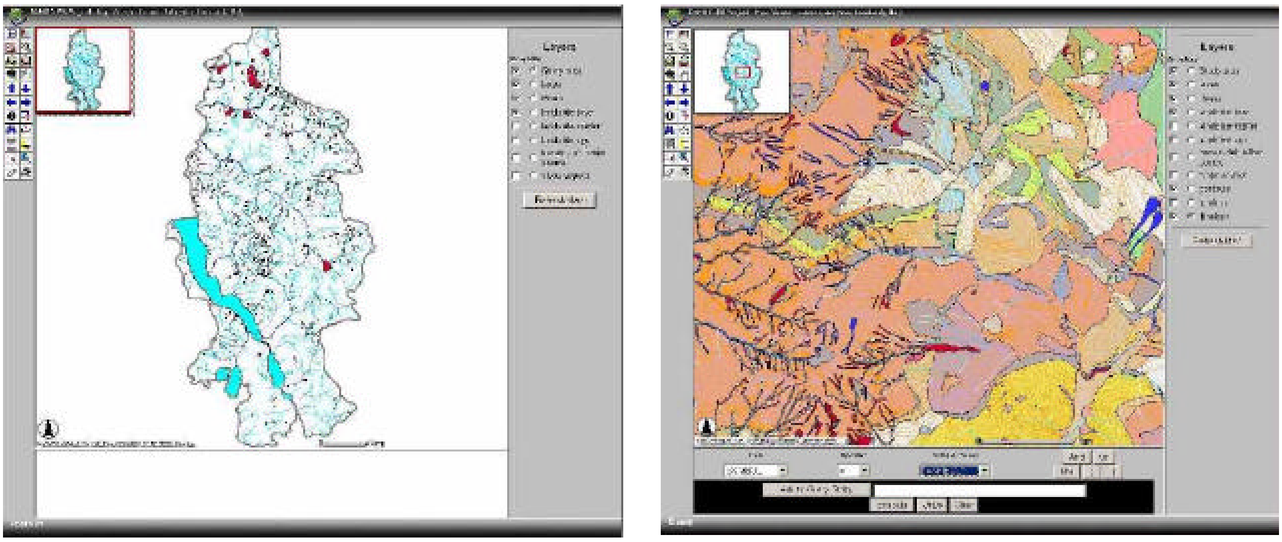

Figure 8. Montagna Lecchese study area. Examples of thematic maps published on the Web using the ARC-IMS™ software. Left: at small scale only landslides and the river network are shown. Right: at a larger scale several layers can be displayed, including landslides, land use, lithology, contour lines, and the hazard associated with debris flow source areas. The maps can be accessed at the URL http://maps.irpi.pg.cnr.it/damocles/lecco/viewer.htm.

To test the capabilities and performances of ArcIMS™ we used a data-set available for the Montagna Lecchese study area. The data-set was the result of a previous research project carried out by CNR IRPI (Perugia), CNR CSITE (Bologna), and Università Bicocca (Milano) for the Geological Survey of the Lombardy Region (Antonini et al., 2000). The data-set includes several thematic layers, some of which were selected for publication on the Internet. These include:

- the outline of the study area,
- the river network, derived from large scale topographic maps,
- the contour lines, derived from large scale topographic maps and used to prepare a DTM with a ground resolution of 20 x 20 meters;
- a lithological map, obtained compiling geological, structural and lithological maps of various age and at different scales;
- a land-use map, prepared in the eighties by the Regione Lombardia;
- a landslide inventory map, originally prepared by the Lecco Pronince, and then updated by CNR-IRPI and the University Bicocca;
- a map showing morphometric parameters derived from the DTM, and
- a debris flow hazard map, prepared through the statistical analysis (discriminant analysis) of morphometric, lithological and land-use data.

Figure 8 shows examples of maps available published on the Internet. The number and type of thematic layer that a user can access using a Web browser changes with scale. At small scale (< 100,000) only the area outline, the river network (including the Lecco lake) and the landslide inventory are shown. If a user zooms in at a larger scale (> 100,000) morphometric, lithological, land-use and hazard maps become accessible (and visible). At even greater scale (> 10,000) the contour lines are also shown. To maintain the property on the information and on the original data-sets thematic information is provided to the user as a raster image (i.e., a JPEG file).

For WP5 two team members were involved for about 8 days each to prepare the data-set for publication and help designing the Web site structure. A sub-contractor, paid with funds coming from the DAMOCLES project, has worked for about 50 days to install, set-up and customize the ArcIMS™ software suite, the Web server software, and the data set. The work was completed more or less according to the timetable.

Section 3 - Socio-economic Relevance and Policy Implication

As stated in the project proposal end-users have an important role to play in DAMOCLES. In particular, in the case of the Geological Survey of the Regione Lombardia, on one hand they have posed problems, provided data and information, and contributed advice to the project. On the other hand they are already testing some of the project deliverables, namely the preliminary rock-fall hazard maps prepared using the STONE computer program. We regard the development of STONE as a good example of a positive co-operation between scientists and decision makers. The need for a rock-fall hazard assessment for an entire, large alpine valley was posed by the geologists of the Regione Lombardia. We were then faced with the problem of producing an hazard assessment based on the thematic data available at the

Lombardy Region and within a limited time. These operational and time constrains were taken into consideration in designing and developing the software. Preliminary hazard assessments, together with their advantages and drawbacks, were discussed with geologists of the Lombardy Region. The available hazard map is currently undergoing reliability tests by the Geological Survey. If the tests will be satisfactory the Lombardy Region will include the rock-fall hazard assessment prepared by STONE as one of the thematic layers for estimating landslide hazard and risk in the Region.

In addition to the direct involvement of the Geological Survey of the Lombardy Region as advisor and data suppliers, with the development of the prototype Internet Map Server (IMS) for publishing on the Internet maps and related geographical information on landslide hazard and risk, information on debris flow hazard for the Motagna Lecchese, an area that extends for about 600 km^2 is now available not only to end-users, but also to anyone that has access to the Internet.

It should be noted that software and other copyright or trade names cited in the text are for illustrative purposes only and do not imply any endorsement of the products by CNR-IRPI or any other partner of the DAMOCLES project.

Section 4 - Discussion and Conclusion

During the first year of the DAMOCLES project CNR-IRPI has worked on two separate, albeit complementary aspects. Within WP2 we have developed a computer program to help assessing rock-fall hazard at the regional scale. Within WP5 we have set up and maintained the project Web site.

Working Package 2

Rock-falls pose a continuous hazard in mountain areas world wide. Assessing rock-fall hazard is a difficult, intrinsically uncertain operation particularly over large areas where the variability of the lithological, morphological and topographical factors controlling the rock-fall process is large. We developed a computer program for the three-dimensional simulation of rock-falls that, despite the limitations, proved to be reliable in modelling rock-falls in three-dimensional morphological settings, and to be capable to provide useful information for the assessment of rock-fall hazard over a large alpine valley.

It is worth pointing out that having developed a computer program capable to provide detailed rock-fall simulations at the regional and local scales doesn't necessarily mean that a simulation can be performed everywhere. The input themes (including topography) required by the program STONE are easily obtained from topographical, geological and land-use maps, but the quality of the simulation largely depend on the quality, resolution and accuracy of the input data. In particular, the spatial resolution and the vertical accuracy of the DTM are important factors controlling the resolution and the accuracy of the simulation. For a reliable simulation the DTM must portray all the morphological features (e.g., escarpments, channels, spurs, hummocks, counter slopes) controlling or influencing (at the scale of the analysis) the rock-fall trajectories.

A reliable and accurate definition of the location and the extent of the rock-fall detachment areas is another factor controlling the quality of the simulation. This is not easy task, particularly over large areas, but it can be accomplished by expert geomorphologists coupling photo-geological techniques and field surveys. Where rock-fall source areas are not identified rock-fall trajectories will not be computed and rock-fall hazard will be underestimated. On the other hand if rock-fall source areas are mapped in areas that are not prone to failures, rock-fall trajectories will be erroneously computed and the hazard will be overestimated.

Lastly, the coefficients controlling the loss of velocity at rebound or during rolling, obtained from the literature or inferred from field surveys, clearly influence the rock-fall simulation. Despite their large variability, the possibility given by STONE to add to these values a random component and to compute from each starting cell more than one trajectory, mitigate the effects of error and uncertainties associated with the coefficients controlling the loss of energy.

We regard STONE as a good step towards the development of a methodology for the quantitative assessment of rock-fall hazard at the regional scale in mountain environments.

Working Package 5

The design and implementation of the DAMOCLES Web site was completed as expected. In the future, the site will be updated to include the most relevant project achievements, whenever these become available. Particularly important was the preliminary analysis of the possibility of using Web-based GIS technology to publish on the Internet landslide hazard assessments and related thematic maps. The experiment showed that the technology is mature and that maps and other geographical information can be made available to other scientists, decision makers and interested users through the Internet, at relatively low costs and with limited resources.

Section 5 - Plan and Objectives for Next Period

In the second year CNR-IRPI intends to continue its activities on both WP2 and WP5. Within WP2, activities will focus on the further development and testing of the computer code STONE. In particular we plan to test the program on different mountain areas and at various scales. If the thematic information needed to run the program will be available for the other project study areas, we could test the performance of the program in different regional environments. Within WP5, CNR-IRPI plans to keep the project web site updated, publishing the project reports and additional information on the study areas when this will become available. We also plan to design a better defined interface to publish on the Internet the available thematic and hazard maps.

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