DAMOCLES

DEBRISFALL ASSESSMENT IN MOUNTAIN CATCHMENTS FOR LOCAL END-USERS

Contract No EVG1 - CT-1999-00007

DETAILED REPORT OF
CONTRACTOR FOR
THIRD PROGRESS MEETING

University of Padova
Italy

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Summary

- Development and preliminary validation of the 1-D submodel for gully-channelized debris flow routing in the Rio Lenzi catchment (test area C), including the “bridge” and “bend” sub-routines, therefore fulfilling the planned goals for Month 18.

- Field visit to the Benasques Valley in order to choose catchments and related fan areas for the applications of Padova’s sub-models. Corbedo, Runada, Senet and Sahún catchments were checked. Sahún channel (lowest reach) and its fan area have been selected as test area in the Pyrenee.

- The 2-D sub-model for debris flow propagation and sedimentation on the fan area has been developed. Preliminary simulations have been carried out for the Rio Lenzi fan area.

Section 1: Objectives of the Reporting Period (01/05/2001-31/10/2001)

According to the proposed work programme for DAMOCLES project the research team of the University of Padova (Mario A. Lenzi, Vincenzo D’Agostino, Carlo Gregoretti, Diego Sonda, Alberto Guarnieri, Francesco Comiti) had the following objectives included in the workpackge WP3 “Development of a small basin debris flow impact model”

- Development’s improvement and preliminary validation of the 1-D sub-model to the Rio Lenzi main channel.

- Development of the 2-D sub-model for debris flow propagation and sedimentation on the fan area.

Section 2: Scientific/Technical Progress Made in Different Work Packages According to the Planned Time Schedule

2.1 Resources used

The original planned and actual use of manpower resources from the start of the project (ie over 20 month) is as follows:

	Additional personnel (person-months)	Permanent personnel (person-months)
Workpackage 1	3	2
Workpackage 3	8	32
Total actual use	11	34
Original planned use	22	30

Mr. Alberto Guarnieri (Research Associated) was funded for six month for computer systems, models software support and GIS integrations.
The original planned and actual use of financial resources from the start of the project are respectively 100,500 and 59,600 euros.

2.2 Workpackage 3: MODDS (Muskingum-Cunge One Dimensional Debris-flow Simulation) improvements

2.2.1 Introduction

In the previous report the general setting out of the 1-D model for debris flow routing has been described. The work carried out successively has dealt whit the following topics:

A. Capability of the model to routing an arbitrary form of the debris flow wave;
B. Automatic control of the stability condition of Courant and time interval of computation;
C. Assessing the algorithm for simulating the overflow from the banks;
D. Capability to simulate the flow super-elevation due to bends;
E. Capability to insert a one span bridge in correspondence to each cross-sections.

A briefly descriptions trough points A-E is presented below.

2.2.2 Arbitrary debris flow hydrograph

The simulation of the debris flow routing by assuming a simplified triangular-shaped debris flow graph is a suitable hypothesis for testing the "hydraulic" behaviour of a channelized debris flow. Nevertheless such scenario may not be adequate in the case of debris flow waves with very steep rising stage, i.e. a debris flow triggered by a dam-break phenomenon. In addition, especially for muddy debris flow, hyperconcentrated flow and flows caused by landslides fluidification, the event may have a longer duration and present a series of surges (VanDine, 1996). The improvements carried out to MODDS allow to model these situations by using up to 50 data for describing the debris flow graph.

2.2.3 Courant condition

The first version of MODDS needed the selection of a fixed time step of computation (Δt). The Δt adopted was usually 5 s or even less (1 s) if the results showed a marked instability. In order to avoid that end-users must check the numerical behaviour of the model, an automatic adjustment for the computation time has been implemented. Further, when channel boundaries change very abruptly, i.e. when a bridge is present, the end-user can operate the channel description by using some cross-sections with a reduced interdistance (Δx). In such a case the Courant and Friedrich (1948) condition for explicit finite difference scheme requires the wave celerity (a) to be less or equal to the numerical celerity of computation ($\Delta x/\Delta t$) (Chaudry, 1993). Observed front velocities

(V) range from 0.5 to 20 m s^{-1} (Costa, 1984); nevertheless the limit of $6 \div 7$ m s^{-1} is rarely exceeded in the fan area. By taking V=7 m s^{-1}, a minimal required time step is : $\Delta t \cong \Delta x/10$. For preventing superfluous time of computation, the Δt set initially for the computation is automatically reduced only when required by Courant's condition. The computed results are recorded and stored by MODDS only for the Δt originally selected by the user.

2.2.4 Overflow algorithms

The model can run choosing between these two options:

I. routing simulation in a confined channel for which the overflow is not allowed (point 10 and 11 of fig. 1 are inserted);

II. routing simulation for the actual channel geometry and capability to estimate the overflow.

Some preliminary tests have been conducted for assessing an appropriate algorithm for the overflow computation from the right and/or left bank when the debris flow wave is higher than the Z coordinate of point 7 (fig.1) and/or the Z coordinate of point 8. The basic assumption was that the stage-discharge relationship for diverting a part of the debris flow follows the hydraulic law of a broad-crested weir. According to this hypothesis the right overbank discharge (fig.1) can be computed as follows:

$$Q_{OVER} = C_q \sqrt{2\ g}\ [(\overline{h - Z_7})^{1.5}\ L_R\ + (\overline{h - Z_8})^{1.5} L_S] \qquad (1)$$

where C_q is the pertinent coefficient of discharge; L_R and L_S are the bank lengths upstream of the current cross-section (n) where the overflow occurs; $(\overline{h - Z_7})$ and $(\overline{h - Z_8})$ are the related debris flow heads above the bank computed by averaging the head value along L_R and L_S respectively.

This unique hypothesis proved to be unable to divert a physically appropriate discharge. In fact, when the water head above a bank increases and eq.1 is applied, the residue discharge (Q_D) flowing downstream along the main channel become too small respect to the maximum capacity of the cross-section (excessive discharge is diverted). This gap has been solved adopting a combination of controls while computing the section n:

1. An appropriate coefficient of discharge can be chosen ($C_q \cong 0.3 \div .0.4$ for eq.1 in metric units);
2. For each channel cross-section we estimate the maximum allowable discharge (Q_{ALLOW}) before overflow occurs; this value corresponds to the minimum debris flow stage between Z_7 and Z_8;
3. The stage of the flow in the current cross-section is temporarily set equal to that of the run in the confined simulation; $(\overline{h - Z_7})$, $(\overline{h - Z_8})$ and a tentative Q_{OVER} are computed.
4. Downstream "confined" discharge (Q_D) is step by step reduced until eq.1 and the mass conservation along the reach (sections *n-1; n*) is respected.
5. Q_{ALLOW} for current cross-section (n) and for upstream ($n-1$) section are compared: the minimum value between two is termed Q_{MIN}.
6. If, during step 4, it occurs that $Q_D < Q_{MIN}$, Q_D is set equal to Q_{MIN}, then mass conservation is applied for Q_{OVER} evaluation and eq.1 for the debris flow profile upstream of the cross-section.

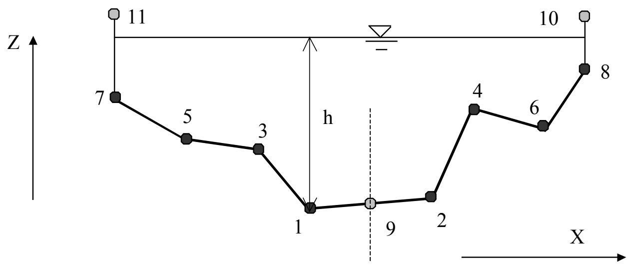

Fig. 1 – Sketch of the cross-section implemented in MODDS model

The adopted path of computation does not consider the possible clogging of the current cross-section imputable to coarse woody debris and big boulders stopping. The algorithm assumes that the channel uses its maximum conveyance before the overflow occurs. A scenario relative to obstructions in part of the channel can be modelled simply by modifying the original geometry of competent cross-sections.

2.2.5 Bendings

An estimate of super-elevation is required to determine the height of a debris flow on the outside bend of a curve. The model predicts overelevation (ΔH) using a forced vortex equation as outlined by Hungr et al. (1984), Chen (1987) and others. The used expression is:

$$\Delta H = k \ \frac{B \ V^2}{R \ g} \qquad (2)$$

b= surface width of flow; V= mean flow velocity; R=mean radius of curvature; g= acceleration due to gravity.

The constant k is equal to 1 for water (Ven Te Chow, 1959) and is related to viscosity and ver sorting that exists in debris flow; in the last case k varies between 1 and 5. (VanDine, 1996).

A slight cautionary hypothesis has been introduced in MODDS, by keeping the inside level in the curve equal to the straight channel value and assigning ΔH as difference in height between the central axis of the cross-section and the outside. A positive or negative input R value means that curve is in direction of the hydrographic right or left respectively; zero R value mear straight reach (radius of curvature tends in the true to infinity).

If super-elevation causes overflow, the computation starts from super-elevation for a confined flow and find, iteratively, a congruent solution according to the algorithm adopted for the overflowing.

2.2.6 Bridge

The presence of bridges is one of the most frequent cause of diversion in the lower part of debris flow torrents. Checking and designing the stream cross-section in correspondence of road crossing is a pressing demand coming from local Authorities (torrent control and public safety). In debris flow torrents of European Alps, adoption of bridges with intermediate piles is out of any reasonable use. The typical road crossing presents abutment near to the banks and an unique span (reinforced concrete slab or series of wood or steel beams).

The bridge schematisation inserted in the MOODS model is presented in figure 2. For any cross-section used for describing the channel geometry the superimposition of bridge is possible. Each bridge has to be described with three data: positions of the lower point of the beam in correspondence of the right and left bank (codes of points of fig.1 are necessary: i.e. 1 or 3 or 5 or 7 for the right), thickness s (fig.2) of the bridge.

The assumption in MODDS is to change the stage-discharge relationship - normally used in the Muskingum-Cunge computation (uniform flow) - if the flow surface is greater or equal to Z_c (Z coordinate of point c in fig.2). The adopted scheme is that of a flow under a gate with the head (h_B)

computed as distance between the flow surface and the centroid of the liquid area (A_B) below the bridge. In first approximation the discharge (Q) is given by:

$$Q = C_{B1}\ A_B\ \sqrt{2\ g\ h_B} \qquad (3)$$

where the discharge coefficient C_{B1} can be set by the user ($C_B = 0.4 \div 0.6$). In addition, when the stage is higher than Z coordinate of point d (fig.2), the flow over the bridge appears and it is computed by way a broad crested weir equation: C_{B2} is the related coefficient of discharge selectable by the user. If the debris flow stage during computation is over Z_7 and/or Z_8 , then overflow is also active using the algorithm previously described.

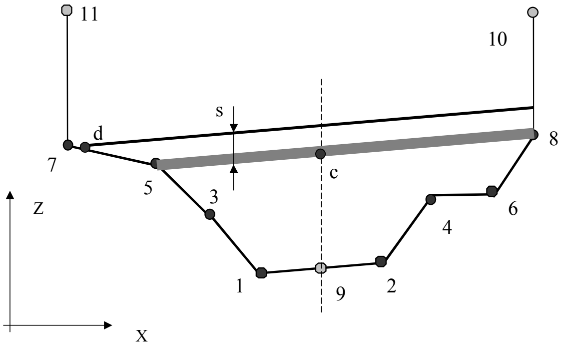

Fig. 2 – Sketch of a cross-section with a one span bridge

Example of application

A double peak entering debris-flow wave is taken into consideration: the first peak occurs after 150 s (discharge Q=70 m^3 s^{-1}) after the beginning of the flood. Tab. 1 illustrates the pattern of the flood. The channel under simulation is rectangular, 150 m long and 6 m width; its slope is 10% and its roughness, in terms of the dimensionless Chezy coefficient, equal to 2. Cross-sections used for describing the channel are 25 m equally spaced. From cross section n.1 (progressive x=0 m) to section n. 3 (x=50 m) the banks (vertical walls) have an height of 4 m above the bottom. From section 5 to section 7 the walls are 3 m high. In section n. 4 the right of bank have a difference of 1 m in height and a bridge (s=1) in points 5 and 6 is superimposed (fig. 3).

Tab. 1 – Debris flow wave routed by the MODDS model

t=0 s	Q=2 m^3 s^{-1}	t=750 s	Q=40 m^3 s^{-1}
t=150 s	Q=70 m^3 s^{-1}	t=900 s	Q=20 m^3 s^{-1}
t=650 s	Q=2 m^3 s^{-1}	t=1100 s	Q=2 m^3 s^{-1}

The results of the simulation are summarised in figure 4 (flow rate) and 5 (depths above the bottom) and can be comment on as follows:

- The highest simulated peak values of the discharge is at the limit of the conduction capacity for the section from 1 to 3: a first overflow occurs (x=25 m) for both right and left bank; the initial triangular shaped hydrograph assumes a flatter form;
- When the flow encounters the bridge a second larger overflow occurs mainly on the right bank (x=75 m); the depths in section 4 remain almost constant for the whole overflow duration and the discharge hydrograph in the last cross-section x=150 m is markedly reduced;
- When the second peak hydrograph passes trough the bridge the stage remain at the limit of overflowing: the stage hydrograph increases quickly for a gate controlled flow but maintains the “peak-like” form. (see x=75 m second wave of fig. 5).

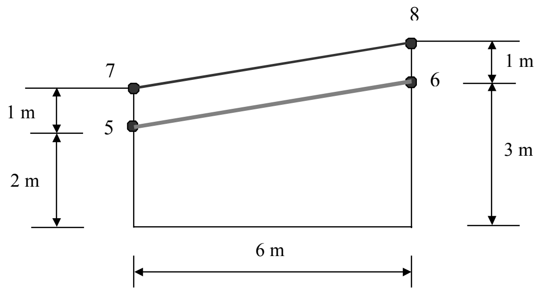

Fig. 3 – Cross-section n. 4 in correspondence of the bridge (*x*=75 m)

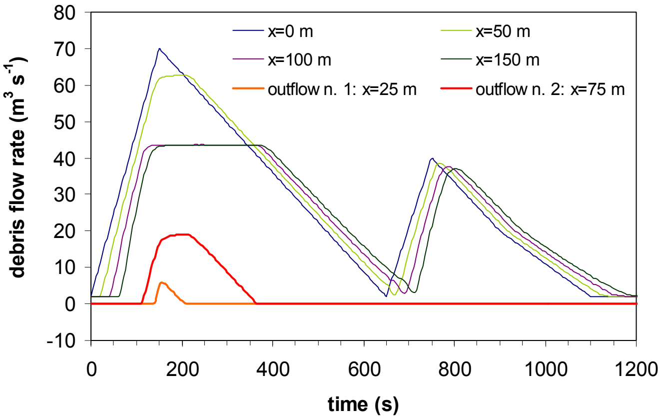

Fig. 4 – Discharge hydrograph routing results

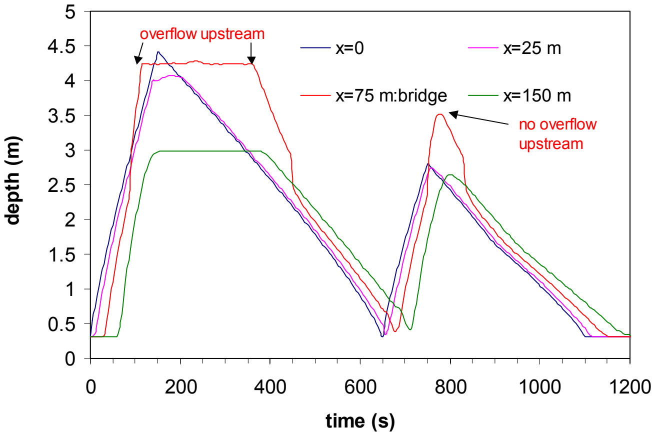

Fig. 5 – Stage hydrograph routing results

2.3 Workpackage 3: 2-D sub-model development

The debris flow distributed propagation model is a DEM-based model, where the fan is discretized by square cells and each cell is assigned an altitude on the sea level; the cells of the catchment are split into two categories: source cells and stripe cells.

The source cells receive the input hydograph: the cells close to the torrent which are flooded by the debris flow overflowing the torrent embankment are source cells. The stripes cells are the cells flooded by debris flow coming from the surrounding cells.

At the first time step only the source cells are flooded by debris flow coming from the torrent. At the second time step a certain number of cells are flooded by debris flow coming from the source cells. These cells constitute a stripe of cells and are assigned order two. At the third time step another group of cells are flooded by the debris flow coming from the cells whose order is two. These cells constitute another stripe and are assigned order three. The cell order of a stripe is the time step number corresponding to the transition from dry to flooded state.

The mass transfer or momentum exchange between cells is governed by two different mechanisms. The mass transfer is allowed only by a positive or equal to zero flow level difference between the drained cell and the receiving cell.

The mass transfer is limited by a not negative final flow level difference between the drained cell and the receiving cells. This limitation excludes the case of possible oscillations in the mass transfer. Another limitation is that the mass drained by a cell should be less than the available mass in that cell. This last condition provides the respect of mass conservation.

The first mechanism of mass transfer is the gravity. The mass in a cell is transferred to the neighbouring cells with lower altitude and flow level according to an uniform flow law:

$$q_j = w_j C h (g h i)^{0.5} \qquad (4)$$

being:

q_j	unit width flow discharge
C	conductance coefficient
g	gravity acceleration (9.81 m/s^2)
h	flow depth
i	$\sin \vartheta$
ϑ	angle between the horizontal and the line joining the centres of two neighbouring cells
w_j	weight function = $\sin \vartheta_j / \sum \sin \vartheta_j$

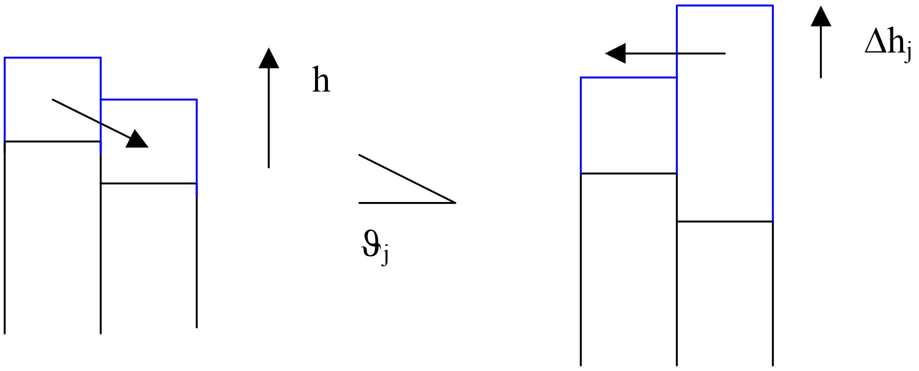

Fig. 6 - Sketch of mass transfer mechanics between cells

The second mechanism of mass transfer is the broad-crested weir. The mass in a cell is transferred to the neighbouring cell with higher altitude but with lower flow level according to the following discharge equation:

$$q_j = w_j\ 0.385\ (2g)^{0.5}\ \Delta h_j^{1.5} \qquad (5)$$

being:

q_j unit width flow discharge

Δh flow level difference

w_j weight function = $\Delta h_j / \sum \Delta h_j$

Each cell can transfer mass up to the eight neibouring cells:

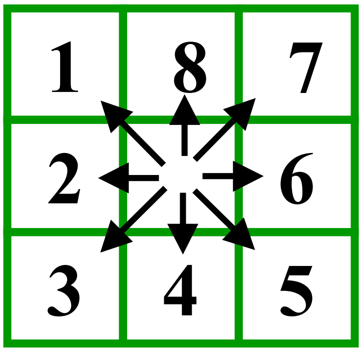

Fig. 7 - Possible flow directions.

The time step in not fixed but depends on the CFL condition:
$\Delta t = \Delta x / a < 1$ with Δt time step, Δx cell side, a wave celerity = $U + (g\ h)^{0.5}$.
The input data of the model are the time step number, the columns and rows number of the DEM file (bynary file), the number of source cells, the input hydrograph and Courant number value (suggested value 0.95) and the DEM file.
At the beginning the model has been tested by a little artificial basin with slopes up to 50%.

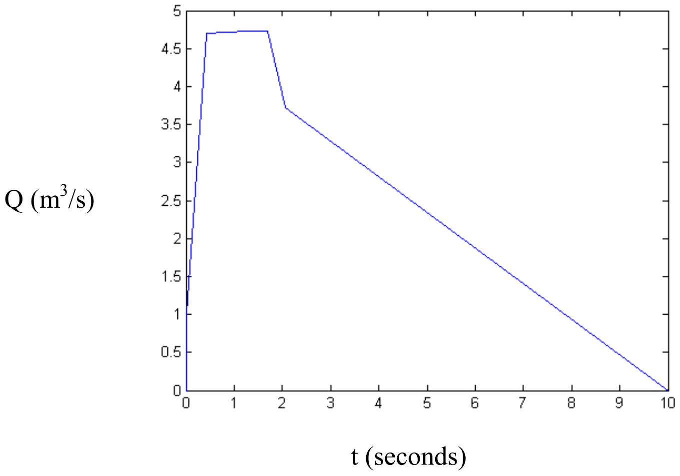

Fig. 8 – Input idrograph for the simulation.

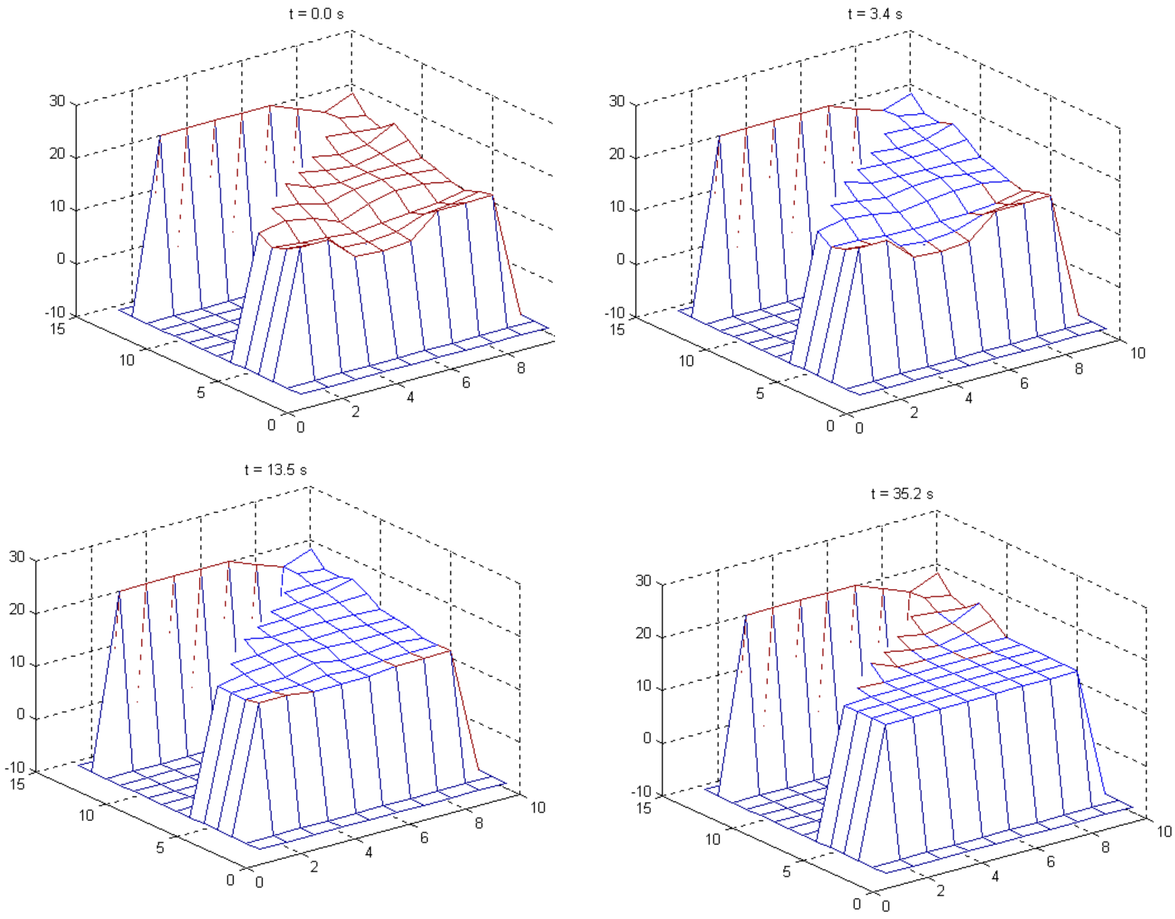

Fig. 9 – Model results for t = 0, 3.4, 13.5 and 35.2 seconds. Brown lines mean dry cell whereas blue lines stand for flooded cell.

The model can support the following input data and parameter value if at least a pc Pentium II, 450 Mhz, Ram 256 K is used:

Number of columns	1000
Number of rows	1000
Number of time steps	50000
Number of source cells	6
Courant Number value	0.95

2.4 Workpackage 3: Accompanied by the IGME team, the Benasque Valley was visited on September 2001 and a small basin was selected (Sahún catchment) to apply the 1-D and 2-D models for gully debris flow propagation on the stream and sedimentation on the fan area. A detailed analysis of the Sahún catchment, main collector and fan area has been carried out in relation with the required inputs. Suggestions for the topographic survey on Sahún fan in order to get cross-sections and longitudinal profile has also been provided.

Section 3: Milestones and Deliverables Obtained

Padova team was contracted to delivery a data base on debris flow characteristics and impacts in small basins in Month 15 of the project (May 2001). A debris flow form was created and debris flow characteristics from small basins in Northern Italy were reported by the end of May. A preliminary 1-D debris flow impact user-friendly model was also planned, as milestone in Month 18 of the project (August 2001). Results were produced by the end of September and reported in section 2.

Section 4: Deviations from the Work Plan and/or Time Schedule and Their Impact on the Project

Sub-contract with ARPA-Avalanche Center of Arabba was not successfully concluded for political and administrative problems relative to the Veneto Region. Recruitment of both one research associated and one research assistant has begun (June 20, 2001) following our University's public procedure of "competitive examination". This has lead to a 3-months delay and will unfortunately cause a delay in the Padova project.

Section 5: Coordination of Information Between Partners and Communication Activities

A field visit to the Benasques focus areas was carried out to choose the catchment and related fan area for the applicability of the Padova's sub-models with the IGME team. Both teams have benefited greatly from the collaboration , particularly in relation with the data collection and provision for the future application of our debris flow impact model to the Sahún catchment.
Data collected on debris flow characteristics related to small torrents of the Northern Italy (Dolomite area), have been sent to all partners. Methodologies developed by the Padova team for the assessment of both debris flow volumes and magnitude-frequency relations have also been delivered to the Pyreneen Institute of Ecology, Milan-Bicocca and IGME teams.
A two-days training course at Agripolis (Padova), in relation with "Part 1, Debris flow routing and sedimentation, 1-D and 2-D model application", has been proposed. It will be organised in collaboration with Milano-Bicocca (September 9-13, 2002).

Part of the team (V. D'Agostino and F. Comiti) partecipated at the European Summer University on Natural Hazards organised by the "Pole Grenoblois Risques Naturels" and by "Cemagref" in Briancon (France, 10-15 September, 2001). The topic of the session was "Torrent Risks" and particular emphasis was given to debris flow characteristics (volumes, discharges and velocities) and and control measures such as open check-dams and retention basins.

Section 6: Difficulties Encountered at Management and Coordination Level

There have been no difficulties during the reporting period.

Section 7: Plan and Objectives for the Next Period

The following WP3 activities are required to meet Padova team's contractual obligation to deliver a final impact model, to be used either by itself or as a part of WP2 in Month 24 (February 2002):

1) Calibration and simulation of the 2-D propagation and sedimentation model onto the fan area of the Rio Lenzi (test area C).
2) Integration of the 2-D model and fan DTM within a GIS system.
3) Initial model application in the Rudan catchment ant in the Sahún catchment (Spain).
4) Organization of Damocles training course (in collaboration with Milano-Bicocca).

The impossibility to conclude the sub-contract with ARPA-Avalanche Center of Arabba and the time needed for recruiting the researchers is likely to cause a delay in the team schedule.

Section 8: Publications

D'Agostino V., Marchi L., 2001. Debris flow magnitude in the Eastern Italian Alps: data collection and analysis. Physics and Chemestry of Earth, Part C, Vol 26/9, 657-663.

D'Agostino V., Sonda D., Piccoli E., 2001 . Delimitazione su conoide delle aree soggette a pericolo di debris flow medianti indagini di campo. Proceedings of "V Seminario Internacional Ingeniería y Ambiente", Universidad Nacional de La Plata, Argentina, La Plata, 9-10 November 2000, 34-50.

Lenzi M.A., 2001. Fluvial geomorphology and biological-ecological analysis to planning and designing torrent control and restoration works. In: Alves Soares A. and Mattana Saturnini H. (eds.), Competitive use and conservation strategies for water and natural resources, Brazil, pp. 56-66.

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