DAM/PR/0211/5

DAMOCLES

DEBRISFALL ASSESSMENT IN MOUNTAIN CATCHMENTS FOR LOCAL END-USERS

Contract No EVG1 - CT-1999-00007

DETAILED REPORT OF CONTRACTOR FOR FIFTH PROGRESS MEETING (1 March – 31 October 2002)

University of Newcastle upon Tyne
UK

November 2002

DETAILED REPORT OF THE CONTRACTOR

Contractor:	University of Newcastle upon Tyne
Responsible Scientist:	Dr J C Bathurst
Address:	Water Resource Systems Research Laboratory School of Civil Engineering and Geosciences University of Newcastle upon Tyne Newcastle upon Tyne NE1 7RU UK
Telephone:	+44 191 222 6333/6319
Fax:	+44 191 222 6669
Email:	j.c.bathurst@newcastle.ac.uk

SUMMARY

(i) The new project research associate, Dr Moretti, has familiarised herself with the SHETRAN modelling system.

(ii) The rainfall input data for the Valsassina focus basin have been checked and revised. The model grid systems and channel networks for both Valsassina and the Ijuez catchment have been revised using a 20-m and 10-m Digital Elevation Model respectively.

(iii) The model validation period for Valsassina is 1/1/93 – 31/12/99. A good validation of the hydrological model has been achieved through comparison of simulation results with the mean annual peak discharge obtained by a regionlisation analysis and with the flow duration curves and runoff/rainfall coefficients for the neighbouring Lambro and Brembo rivers. Simulated sediment yields for sediment eroded by raindrop impact and overland flow are comparable with yields from all erosion processes in the northeastern Italian Alps. Validation of the landslide model is still in progress. However, a good capability has been demonstrated for bracketing the observed landslide incidence for the event of 27/28 June 1997 and for reproducing the general spatial distribution of landslides which have occurred over the last 50 years.

(iv) The model validation period for the Ijuez catchment is 1/1/95 – 31/12/98. Validation of the hydrological model has been achieved through comparison of simulation results with the monthly runoff record and the flow duration curve for the scaled discharge record of the Aragón river at Jaca.

(v) The rules within SHETRAN for modelling debris flow behaviour have been requantified for the Ijuez catchment using the results of the CSIC-IPE field survey.

(vi) A procedure has been established for using SHETRAN to provide an altered pattern of landslides as the basis for the WP2 hazard mapping procedure, e.g. for future conditions.

(vii) An electronic matrix system is being developed for presenting and comparing simulation data for land use and climate scenarios in a user friendly manner. Matrices will be compiled for each focus areas as the basis for developing guidelines for basin management.

1 OBJECTIVES OF THE REPORTING PERIOD (1/3/02-31/10/02)

(i) Familiarisation of the new project research associate, Dr Moretti, with the SHETRAN model.

(ii) Refining of the SHETRAN data files for the Valsassina and Ijuez focus basins.

(iii) Enhancement of the SHETRAN landslide model with debris flow relationships derived in WP1.

(iv) Validation of the model for the focus basins.

(v) Development of scenarios for future land use and climate.

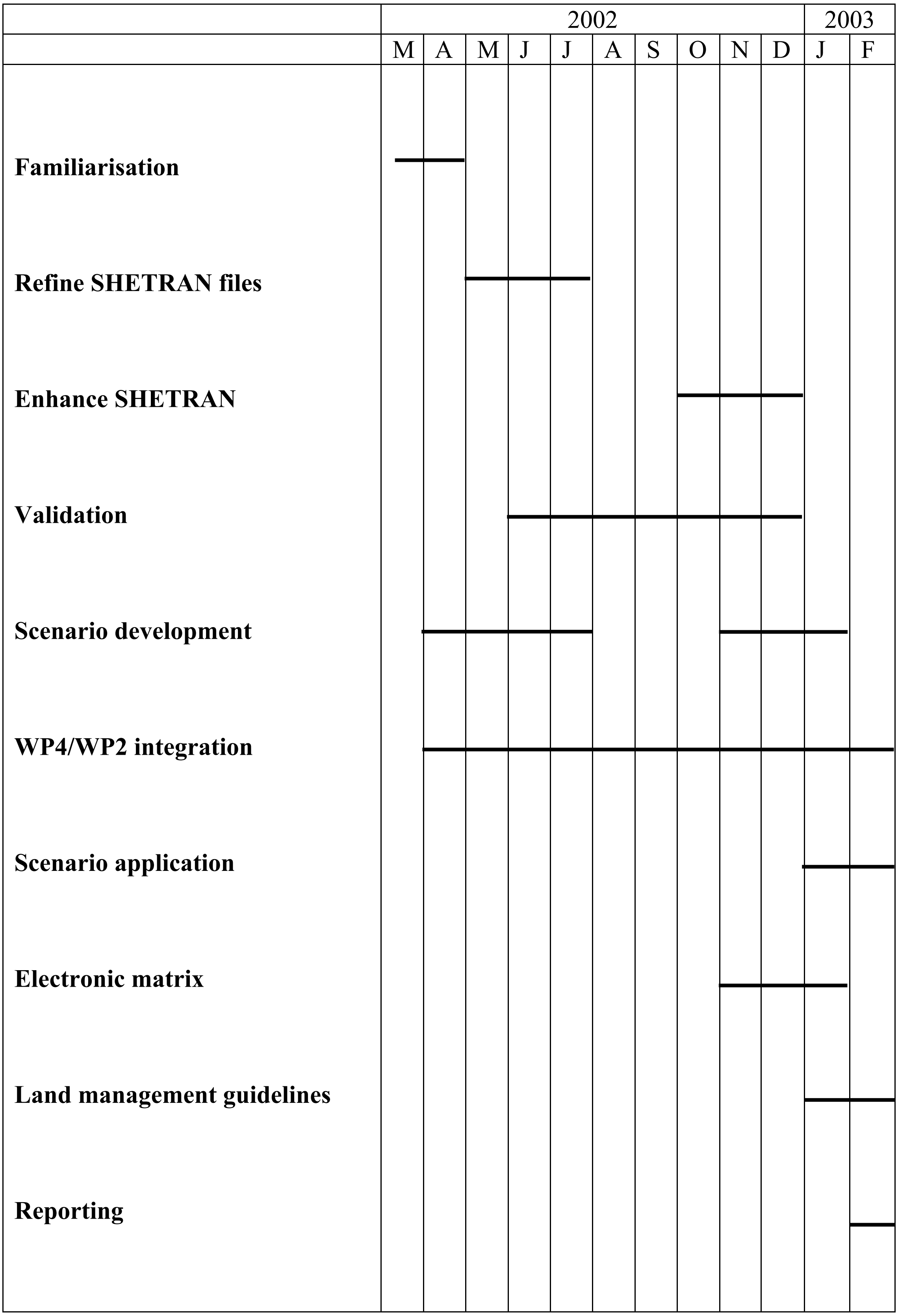
(vi) Integration with WP2 so that SHETRAN can be used to provide a basis for a revised hazard assessment map for Valsassina, for future conditions.

2 SCIENTIFIC/TECHNICAL PROGRESS

2.1 Timetable

The timetable for activities to the end of the project is attached.

Timetable for Newcastle WP4 activities, March 2002 – February 2003



2.2 Resources Used

The originally planned and actual use of manpower resources from the start of the project (ie over 32 months) is as follows:

	Additional personnel (person-months)	Permanent personnel (person-months)
Workpackage 4	27.0	2.8
Workpackage 5	0.1	0.7
Total actual use	27.1	3.5
Original planned use	32.0	4.0

Two additional research associates have been appointed from 1 November 2002 to ensure completion of the required work by the end of the project. Mr Michael Murray will develop an electronic matrix for presenting simulation results. Dr Ahmad Moaven-Hashemi will generate the required climate scenarios.

2.3 Workpackage 4: SHETRAN Landslide Model

2.3.1 Summary

At the time when the original project research associate, Dr Ahmed El-Hames, left in November 2001, work had reached the point where a complete simulation could be made with the SHETRAN landslide model for the selected validation periods for the Valsassina and Ijuez focus catchments. In other words, the necessary data were available, the hydrological, sediment transport and landslide components of SHETRAN were functioning and a map of landslide distribution could be produced from the output. However, the results were no more than a demonstration of capability and considerable refining of input data and simulation strategy were required before the model could be said to be validated.

Dr Greta Moretti was appointed as Dr El-Hames's successor in March 2002 and, following familiarisation with SHETRAN, has now carried the work forward to the point where validation is almost complete for both Valsassina and the Ijuez catchment. The principal steps in completing this work have been refining the data and validating in turn the hydrological, sediment transport and landslide components of SHETRAN. In addition work has been carried out on enhancing the landslide model, in developing scenarios of future conditions and integrating the SHETRAN modelling approach with the WP2 hazard assessment procedure.

2.3.2 Valsassina rainfall data

The validation period for Valsassina is 1/1/93 to 31/12/99, selected in part because it contains the major landsliding event of 27/28 June 1997. However, not all the five rainfall stations relevant to the catchment have unbroken records for this period. Also, only one of the stations recorded at the hourly interval needed for SHETRAN. The rest were daily gauges. A procedure for producing continuous hourly records for all the stations was derived and applied by Dr El-Hames but some direct measurements of rainfall were left unused, especially for the more extreme events. The procedure has therefore been repeated, incorporating the direct measurements. Correlations between gauges were used to fill the gaps in the daily records and the statistically based model RAINDIST was used to disaggregate the daily records to the hourly level for periods and locations without direct hourly measurements. The result was continuous hourly records for the full validation period for the five rainfall stations.

2.3.3 Valsassina model grid

A 20-m resolution Digital Elevation Model provided by the University of Milan-Bicocca (based on the 1:10,000 scale Carta Tecnica Regionale of 1980-83 compiled by Regione Lombardia) has been used to revise the SHETRAN model grid and elevation distribution, increasing the resolution from 1 km to 500 m. (The resolution of the landslide model is defined by the 20-m DEM.) The river network was also revised (by Professor Carrara, CNR-IEIIT, Bologna) by digitizing from a 1:10,000 scale electronic map supplied by Regione Lombardia. So as to provide a common basis for comparison with the hazard mapping procedure of WP2, this network was then reduced using the threshold applied by Professor Carrara, i.e. DEM cells (20 m x 20 m) with upslope areas of 2500 cells or more are classified as rivers. The result was to reduce the number of SHETRAN river links from 383 to 226. (This incidentally significantly reduced the simulated river discharges.) River channel elevations were derived from the 20-m DEM using ArcView. The revised model grid and channel network is shown in Fig. 1.

The full simulation area consists of the Pioverna valley (Valsassina) (160 km^2) and the neighbouring Esino valley (20 km^2). The SHETRAN model area is slightly smaller at 178.5 km^2. Also, in the model, the length of the Pioverna channel is 2 km longer than the actual channel because the model channel is constrained to follow the sides of grid squares and must therefore zig-zag instead of taking a direct line across a square.

2.3.4 Valsassina hydrology validation

There is no discharge record for the Pioverna or Esino rivers which can be used for validation. More indirect data were therefore used. First, a regionalisation analysis indicated that the mean annual instantaneous peak discharge should be in the range 88 - 116 m^3 s^{-1} (Brath and Franchini, 1998). (The range arises because the technique uses rainfall intensity and Valsassina lies in a band defined by a range of intensities.) Second, flow duration curves were obtained for two neighbouring rivers, the Lambro at Lambrugo (170 km^2) for the period 1955 - 71 and the Brembo at Ponte Briolo (765 km^2) for the period 1940 – 73 and 1975-77. Normalized to the mean annual discharge the two curves are very similar, suggesting a regional uniformity which could form a basis for validating the Valsassina simulations. (Differences for Valsassina might arise because the validation period in the 1990s was drier than the period for which the Lambro and Brembo flow duration curves were derived and because the validation period of 7 years is shorter than the period on which the measured curves are based.) The measured runoff/rainfall coefficients for the Lambro and Brembo respectively are 0.59 and 0.77.

In validating the hydrology model, adjustments were made to several of the parameters to which the results are most sensitive. In particular it was found necessary to increase the soil saturated zone hydraulic conductivity to the relatively large value of 10 m day^{-1} in order to simulate discharges with the appropriate magnitude and flow duration characteristics. This is large compared with the values of 0.67-1.2 m day^{-1} derived from the measured soil particle size distribution using the formulation of Saxton et. al. (1986). The value of 10 m day^{-1} may therefore be an effective value, representative at the model grid scale and for the steep gradients in Valsassina (e.g. Bathurst and O'Connell, 1992). The baseline values of the key parameters are shown in Table 1. Also shown are the bound values introduced to account for uncertainty (Ewen and Parkin, 1996). Soil depths were set in consultation with the University of Milan-Bicocca in the range 1.5 – 3 m, except for 0.2 m in rocky areas.

Simulations carried out for the eight combinations of bound values produced an uncertainty envelope for the model output. Figure 2 shows part of the envelope of maximum and minimum discharges for the Pioverna outlet at Bellano. Figure 3 compares the envelope of daily flow duration curves with the Lambro and Brembo curves. The simulation data are presented for 1994 – 99 only (i.e. 6 years) as 1993 is left as a "settling down" period for the model, to minimise the effect of the initial conditions. The bounds on the output are:

- mean annual discharge 3.81 – 5.07 $m^3 s^{-1}$
- mean annual peak hourly discharge 58 – 151 $m^3 s^{-1}$
- overall range of peak hourly discharges 21 – 346 $m^3 s^{-1}$
- mean runoff/rainfall coefficient 0.52 – 0.64.

The bounds agree well with the validation data derived above. In addition there is excellent similarity for the flow duration curves in Fig. 3. On this basis the hydrology model is considered to be validated for Valsassina.

2.3.5 Valsassina sediment transport validation

There are no sediment yield records for Valsassina which can be used for validation. More indirect data were therefore used. First the simulated baseline flow duration curve was combined with estimated bed load and suspended load transport equations to produce an estimated yield for the Pioverna outlet of 0.5 t ha^{-1} yr^{-1}. However, this is very much an approximation, indicating only the likely order of magnitude. Second, information provided by Professor Mario Lenzi, University of Padova, showed sediment yields in the northeastern Italian Alps to be in the range 1 - 10 t ha^{-1} yr^{-1}. Despite the geomorphological differences between Valsassina and the northeastern Italian Alps, these figures may again provide clues as to the expected order of magnitude of the Valsassina yield.

For the simulations, uncertainty bounds were set on the soil erodibility coefficients for raindrop impact and overland flow (Table 1). The proportion of ground covered for forest, pasture and rock was set at 0.9, 0.9 and 0.7 respectively. In addition a rock cover fraction of 0.25 was set for rock. The resulting sediment yield bounds simulated for 1994 - 99 were 2.6 - 5.2 t ha^{-1} yr^{-1} for the Pioverna outlet and 0.16 – 0.16 t ha^{-1} yr^{-1} (i.e. no sensitivity) for the Esino outlet. Further investigation showed that the lack of sensitivity for the Esino simulations is due to the simulated sediment yield being dominated by channel rather than hillslope sediment supply. Agreement with the validation data is reasonable. Possibly the simulated Pioverna yields are a little high, bearing in mind that they refer only to raindrop impact and overland flow erosion and do not a this stage include landslide derived sediments.

2.3.6 Valsassina landslide validation

Two sets of data are available for validating the landslide simulations. The first is a ten-day period of rain culminating in intense rain and landsliding during the night of 27/28 June 1997. The area most affected was the Esino valley. A landslide inventory compiled by the University of Milan-Bicocca shows that 137 landslides occurred in the Esino valley during 1997, most of these occurring during the above event. The aim of the validation is to bracket the observed incidence with lower and higher values. At the same time, the simulated occurrence elsewhere in Valsassina should be low, reflecting the lower rainfall intensities there. The second data set is a map of landslide occurrence in Valsassina over a 50-year period from the 1950s to the present day compiled by Professor Carrara, CNR-IEIIT, Bologna. This contains some landslides triggered by winter erosion processes as well as by rainfall. (SHETRAN simulates only the latter.) The aim of the validation is to reproduce the general spatial distribution of landslide occurrence.

The procedure for simulating the June 1997 event is the same as reported earlier in the project for the Llobregat application. Bounds on the landslide simulation are obtained by setting upper and lower bounds on the root cohesion. The values shown in Table 1 were obtained initially from the literature (Sidle et al., 1985; Preston and Crozier, 1999; Abernethy and Rutherfurd, 2001) and then adjusted to improve the simulation. Soil cohesion and angle of friction were reduced a little from the laboratory measured values to values nearer to those expected from the literature. This is justified on the grounds that the samples used in the laboratory analysis were small and contained roots. The values for soils 1, 2 and 3 are : soil cohesion 4.32, 2.89 and 4.40 kPa; and angle of friction 32.0º, 30.7º and 36.8º. Soil depth (i.e. depth to the shear surface) was set at 2 m. Landslides were also precluded from occurring at slopes less than 25º and more than 50º and where the land surface is rock. Also as part of the procedure a preceding simulation was carried out with a scaled version of the June 1997 rainfall in order to identify those landslides which might be expected to have occurred in previous years or which occurred in squares defined as unconditionally unsafe (i.e. for the given parameter values, the squares fail at the start of the simulation). The scaling factor is 70-75% based on the rainfall record at Bellano prior to 1997.

The landslide simulations were not complete at the time of writing but simulated incidences of more and less than the observed 137 landslides for the June 1997 event have been achieved. Likewise for the 50-year Valsassina inventory the simulations show excellent agreement with the observed spatial distribution, accounting for areas both with and without landslides.

2.3.7 Ijuez rainfall data

The validation period for the Ijuez catchment is 1/1/95 – 31/12/98. To provide a "settling down" period for the model (so that the effect of the initial conditions is minimised), this period is preceded by the last six months of 1998. Gaps in the Ijuez daily rainfall record (at Bescos) for 1995 - 97 have been filled by correlation with the

Jaca record. The daily record has then been disaggregated to an hourly record using the RAINDIST model (with statistics for the Jaca hourly data).

2.3.8 Ijuez model grid

A 10-m resolution DEM provided by CSIC-IPE has been used to revise the SHETRAN model grid (500-m resolution) and elevation distribution. As a result, the channel network has slightly altered and the number of channel links has slightly increased. A 20-m DEM has also been set up as the basis of the landslide model.

The full simulation area is 45 km^2.

2.3.9 Ijuez hydrology validation

There is no discharge record for the Ijuez which can be used for validation. A discharge record has therefore been obtained by scaling the Aragón river record at Jaca, using a regionally based scaling equation. This effectively determines the Ijuez discharge as 0.2 times the Aragón discharge.

In validating the hydrology model, the soil saturated conductivity was set at the relatively high value of 10 m day^{-1}, i.e. an effective grid-scale value. (The conductivities derived from the particle size distributions and the formulation of Saxton et al. (1986) were 0.09 – 0.2 m day^{-1}.

Table 2 shows the baseline and bound values of the key model parameters.

Currently simulation results are available only for the baseline run. As the Ijuez/ Aragón discharge scaling was based on monthly runoff data, comparison of the simulated and observed (i.e. scaled) Ijuez discharge time series is most appropriate at the monthly scale. Figure 4 shows this comparison. Dr Garcia-Ruiz (CSIC-IPE) has reviewed and approved the general pattern. The discrepancies in the first part of each year can be explained by a snowmelt contribution to the Aragón flows which would not in reality have appeared in the Ijuez flows. There are unexplained differences in December 1995, August 1996 and July 1997. Otherwise the simulated flow magnitudes and month-to-month variations are realistic. The simulated runoff/rainfall coefficient is 0.48.

Figure 5 compares the continuous daily simulated and measured (i.e. scaled) Ijuez discharges for 1996. The poorer agreement is expected because the Ijuez is a small, flashy catchment and the scaled Aragón discharges do not represent well the event-scale response.

Figure 6 compares the simulated and measured (i.e. scaled) daily flow duration curves. Again this shows the Ijuez to have a more flashy regime than that represented by the Aragón.

2.3.10 Landslide model enhancement

SHETRAN uses a rule-based approach to describe the transport of eroded material by debris flows. The survey and analysis of debris flow characteristics in the central

Pyrenees carried out by CSIC-IPE has enabled some of the rules to be requantified and the following changes will be made for the Ijuez simulations:

1) Debris flow runout distance = 0.6 x elevation difference between landslide scar and point at which deposition begins. A factor of 0.4 was originally applied.

2) The gradient below which debris flow deposition begins = 18º. Previously it was 10º.

2.3.11 Scenario development

Data from the EC WRINCLE project are used to generate a scenario of future climate for the two focus areas. The procedure is as follows:

1) Using existing station data, relationships are derived between monthly rainfall statistics and atmospheric circulation variables.

2) These relationships are applied to the atmospheric circulation variables in a Global Circulation Model prediction to give the corresponding monthly rainfall statistics. In the WRINCLE project the HadCM3 GCM was used to give predictions for most of Europe through to 2099. The rainfall statistics are obtained both for the current period (typically 1961-90) and for a future period (2070-99). Comparison of the statistics for the current period with the measured rainfall statistics enables the predictions to be adjusted.

3) A statistical rainfall distribution model (the Neyman Scott Rectangular Pulses model) is fitted to specified rainfall statistics for the current and future scenario periods.

4) The RAINSIM model generates synthetic hourly precipitation data using the NSRP model. Typically 100 years of hourly data are generated.

Before the future scenario data can be used with confidence as input to SHETRAN, the reliability of the method is checked by comparing the generated and measured rainfall statistics for the current period. At the time of writing a good comparison had been achieved for the Ijuez catchment (Bescos and Aragues rainfall stations) but further corrections were needed for Valsassina.

Once available the scenario data will be applied to see how landslide incidence and sediment yield may change with global warming.

2.3.12 Integrating WP4 and WP2

The use of SHETRAN to provide an altered pattern of landslides as the basis for the WP2 hazard mapping procedure (e.g. for altered future conditions) is to be tested for Valsassina. In order to ensure a common basis for representing landslide spatial distribution, the SHETRAN grid system has been revised as described in Section 2.3.3.

The procedure for integrating WP4 and WP2 is as follows:

1) Validate SHETRAN for present-day conditions in Valsassina;

2) Run the validated model with scenario data for the current climate, providing a landslide map as the basis for generating a WP2 spatial probability map of landslide occurrence;

3) Repeat step 2 with scenario data for a future climate;

4) Compare the landslide probability maps for the two cases to see the effect of climate change.

2.4 Workpackage 5 : Dissemination

The SHETRAN model is currently too complex to be transferred to the project end-users. Instead it will be used to simulate flow, sediment transport and landslide data for a range of land use and climate scenarios: these data can then be used by the end -users in developing land management guidelines. A matrix system is therefore being developed for presenting the simulation data in a user friendly manner. This tabulates the data for different land use scenarios for both current and future climates (Fig. 7). Each land use/climate scenario is represented by a box in the matrix. At the simplest level, the matrix can be prepared on paper and the data typed into each box. It is then a simple matter to compare, for example, sediment yields or landslide incidence for different land uses and to select the optimum land use for the future. However, a paper matrix is either limited in the data which can be contained in each box or else likely to become unwieldy with a set of attached datasheets. An electronic (screen) version is therefore being developed, enabling users to access all relevant data by clicking on the relevant box. The ability to compare data from different boxes will be included. The complete DAMOCLES matrices for the two focus areas will be distributed to the end-users on CDs.

A paper on the Llobregat validation is in preparation.

3 MILESTONES AND DELIVERABLES

The Newcastle team was contracted to deliver debris flow simulation data as input to WP2 by Month 24 of the project (February 2002) and illustrative guidelines for basin management as input to WP5 by Month 30 (August 2002). Because of the time lost following Dr El-Hames's departure, both deliverables are delayed to the end of the project. However, a scheme has already been developed for integrating the SHETRAN simulation data with WP2. Similarly, arrangements are also being made for the transfer of the basin management guidelines (in the form of the land use/climate scenario matrix) to the end users.

4 DEVIATIONS FROM THE WORK PLAN AND/OR TIME SCHEDULE

There are no deviations other than the delay consequent upon Dr El-Hames's departure.

5 COORDINATION BETWEEN PARTNERS AND COMMUNICATION ACTIVITIES

Collaboration has continued between the Newcastle team and the teams from the University of Milan-Biccoca and the Pyreneen Institute of Ecology over the Valsassina and Ijuez applications. Supporting data have also been provided by the University of Padova. Discussions have been held with Professor Carrara (CNR-IEIIT, Bologna) over the integration of the WP2 debris flow hazard assessment and WP4 debris flow simulation techniques.

A paper, co-authored with all the project partners, has been submitted for presentation at the Third International Conference on Debris-Flow Hazards Mitigation, to be held at Davos, Switzerland, during 10-12 September 2003.

6 DIFFICULTIES IN MANAGEMENT AND COORDINATION

There have been no difficulties during the reporting period.

7 PLAN AND OBJECTIVES FOR THE NEXT PERIOD

In the period to the end of the project on 28 February, the following activities will be carried out to meet the Newcastle team's contractual obligations:

(i) Completion of SHETRAN validation for the focus catchments;
(ii) Production of climate scenarios;
(iii) Scenario applications for the focus catchments;
(iv) Development of the matrix for comparison of scenario applications;
(v) Presentation of the scenario applications to the project end-users as guidelines for land management.

The timetable is shown in Section 2.1.

8 PUBLICATIONS

Bathurst, J.C., Crosta, G., Garcia-Ruiz, J.M., Guzzetti, F., Lenzi, M. and Rios, S. DAMOCLES: Debrisfall Assessment in Mountain Catchments for Local End-users. Submitted to Third International Conference on Debris-Flow Hazards Mitigation: Mechanics, Prediction and Assessment, Davos, Switzerland, 10-12 September 2003.

9 REFERENCES

Abernethy, B. and Rutherfurd, I. D. 2001. The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrol. Proc., 15, 63-79.

Bathurst, J. C. and O'Connell, P. E. 1992. Future of distributed modelling : the Système Hydrologique Européen. Hydrol. Proc., 6, 265-277.

Brath, A. and Franchini, M. 1998. La valuatzione regionale del rischio di piena con il metodo della portata indice. In: La Difesa Idraulica dei Territori Fortemente Antropizzati, U. Maione and A. Brath (eds.), BIOS, Cosenza, Italy, pp 31-60.

Preston, N. J. and Crozier, M. J. 1999. Resistance to shallow landslide failure through root-derived cohesion in east coast hill country soils, North Island, New Zealand. Earth Surf. Process. Landforms, 24, 665-675.

Saxton, K. E., Rawls, W. J., Romberger, J. S., Papendick, R. I. 1986. Estimating generalized soil-water characteristics from texture. Soil Sci. Soc. Am. J., 50, 1031-1036.

Sidle, R. C., Pearce, A. J. and O'Loughlin, C. L. 1985. Hillslope Stability and Land Use. Water Resources Monograph, American Geophysical Union, Washington DC. 140pp.

Table 1 Baseline and bound values for the principal SHETRAN parameters for the Valsassina simulations

Parameter		Baseline value	Bound values upper	lower
Strickler overland flow resistance coefficient:	forest	0.5	1	0.1
	pasture	1	5	0.5
	rock	5	10	1
Actual/potential evapotranspiration ratio at soil field capacity:	forest	0.5	0.8	0.3
	pasture	0.3	0.5	0.2
	rock	0.1	0.2	0.1
Van Genuchten coefficient for soil moisture content/ tension curve:	soil 1	1.59	1.9	1.52
	soil 2	1.66	1.9	1.52
	soil 3	1.74	1.9	1.52
Saturated zone conductivity (m day^{-1})		10	10	10
Soil erodibility coefficients:	raindrop impact (J^{-1})	-	0.2	0.05
	overland flow (mg m^{-2} s^{-1})	-	2	0.5
Root cohesion (Pa):	forest	-	7500	3000
	pasture	-	3500	700

Table 2 Baseline and bound values for the principal SHETRAN parameters for the Ijuez simulations

Parameter		Baseline value	Bound values upper	lower
Strickler overland flow resistance coefficient:	pine (natural)	0.5	1	0.1
	pine (planted)	0.5	1	0.1
	shrubs/meadows	1	0.5	0.5
Actual/potential evapotranspiration ratio at soil field capacity	pine (natural)	0.5	0.8	0.3
	pine (planted)	0.5	0.8	0.3
	shrubs/meadows	0.3	0.5	0.2
Van Genuchten coefficient for soil moisture content/tension curve:	soil 1	1.37	1.5	1.3
	soil 2	1.47	1.6	1.4
Soil depth (m)		1.5	1.5	1.5
Saturated zone conductivity (m day^{-1})		10	10	10
Soil erodibility coefficients:	raindrop impact (J^{-1})	-	0.2	0.05
	overland flow (mg m^{-2} s^{-1})	-	2	0.5
Root cohesion (Pa):	Pine	-	7500	3000
	Shrubs/meadows	-	3500	700

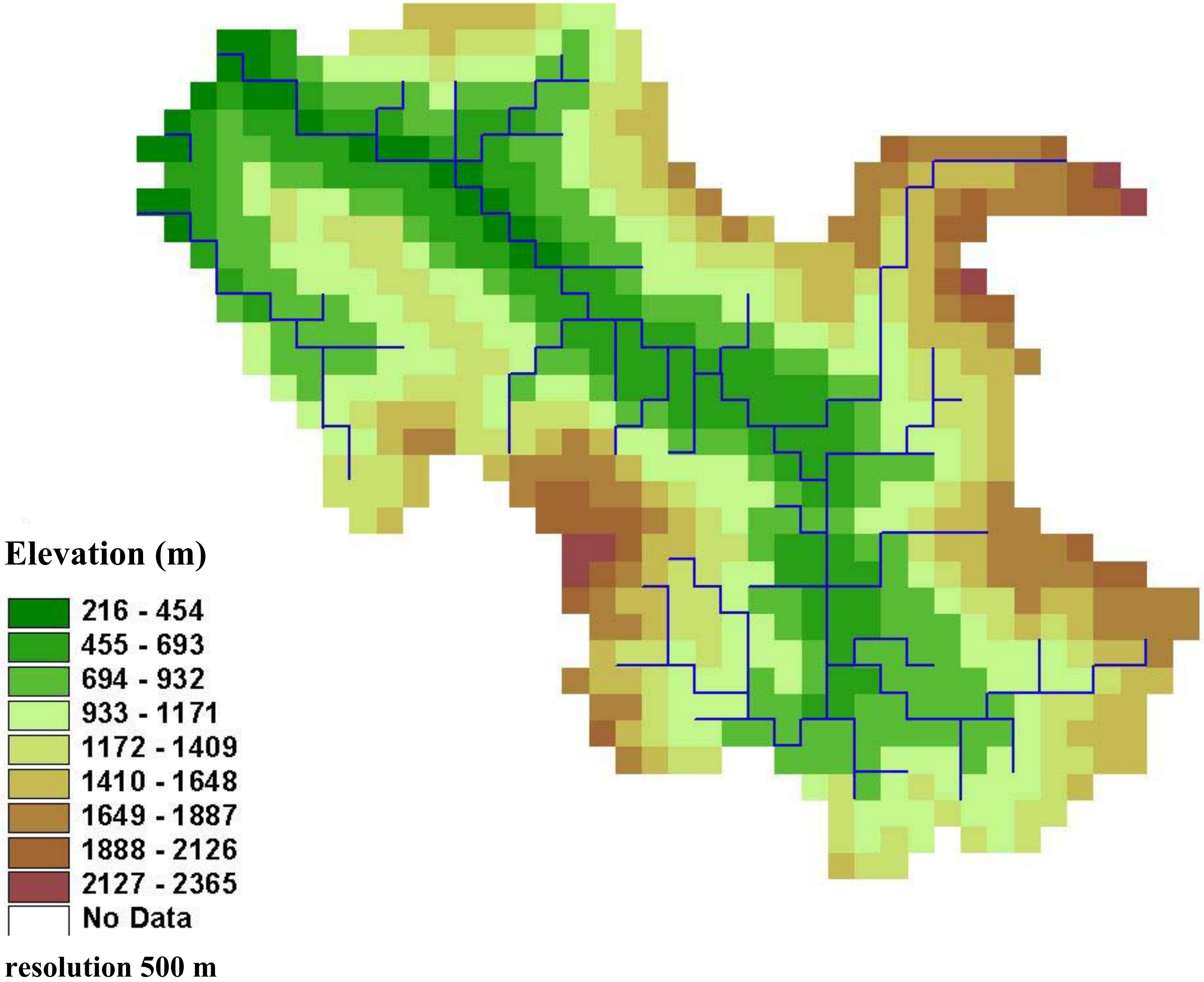


Fig. 1 SHETRAN grid system, channel network and elevation distribution for the Pioverna and Esino focus area

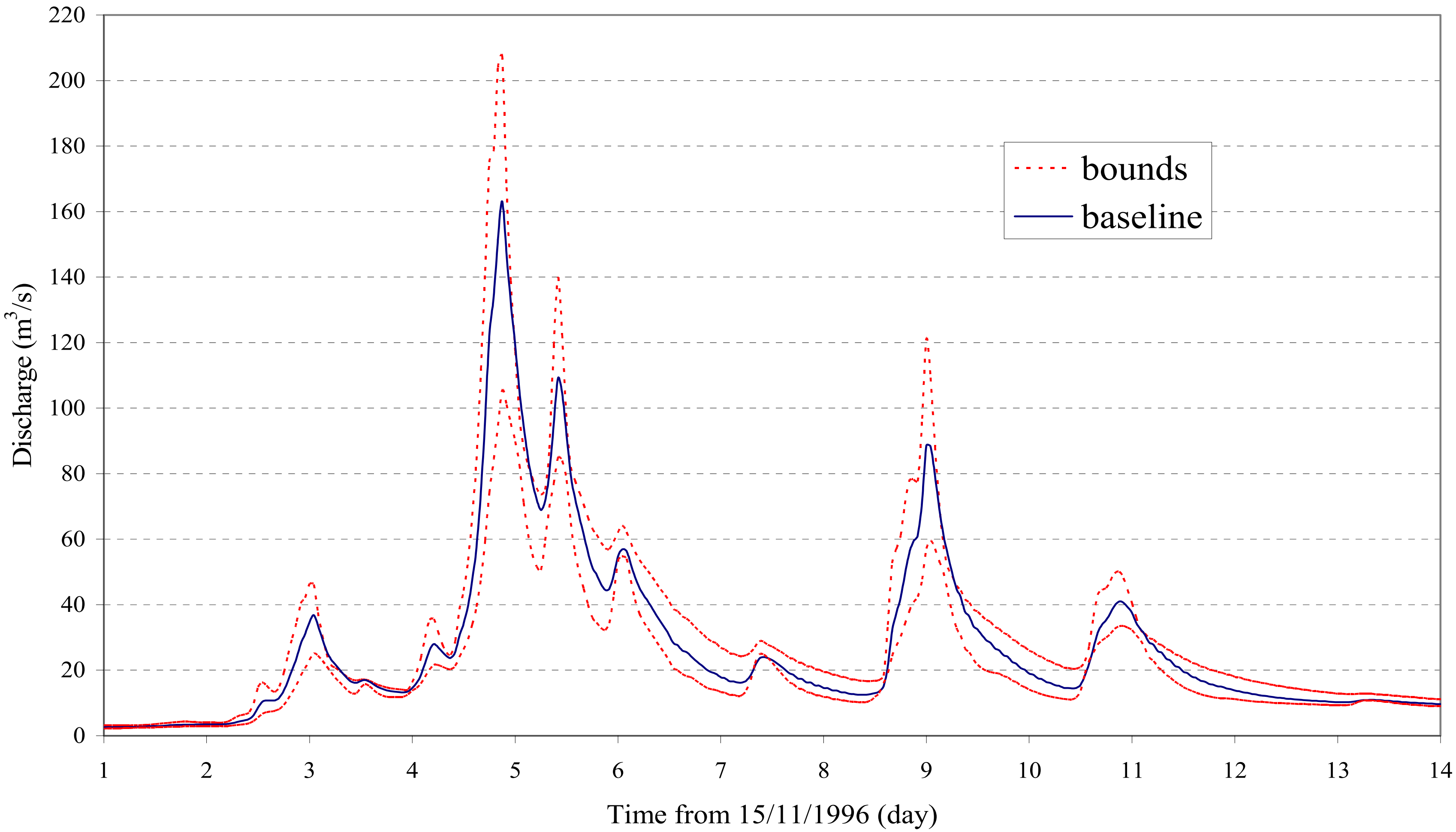


Fig. 2 Example of the simulation hydrograph uncertainty envelope for the Pioverna at Bellano, showing the baseline simulation and the uncertainty bounds

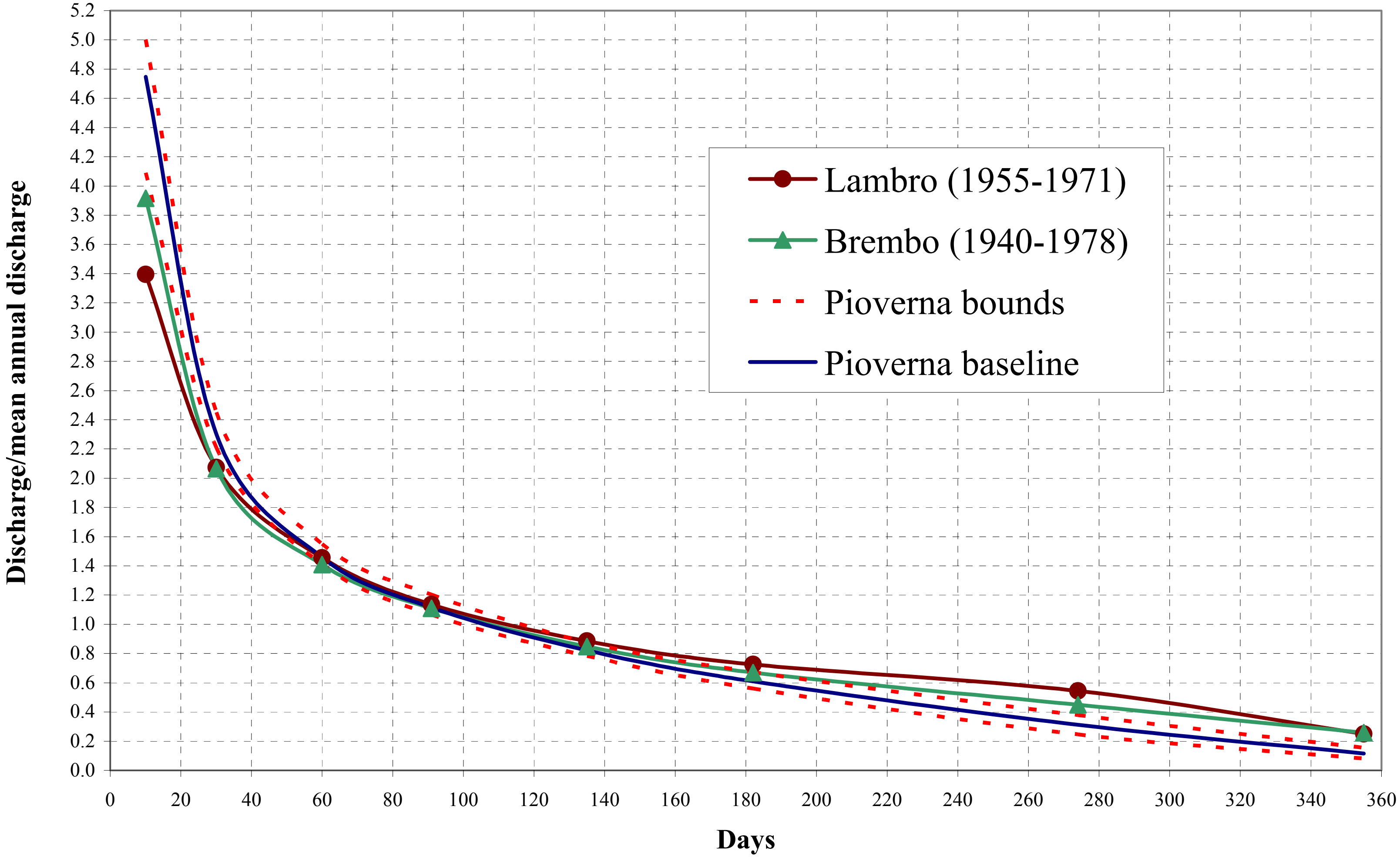


Fig. 3 Comparison of the normalized flow duration curves measured for the Lambro and Brembo rivers with the simulated baseline curve and uncertainty bounds for the Pioverna at Bellano

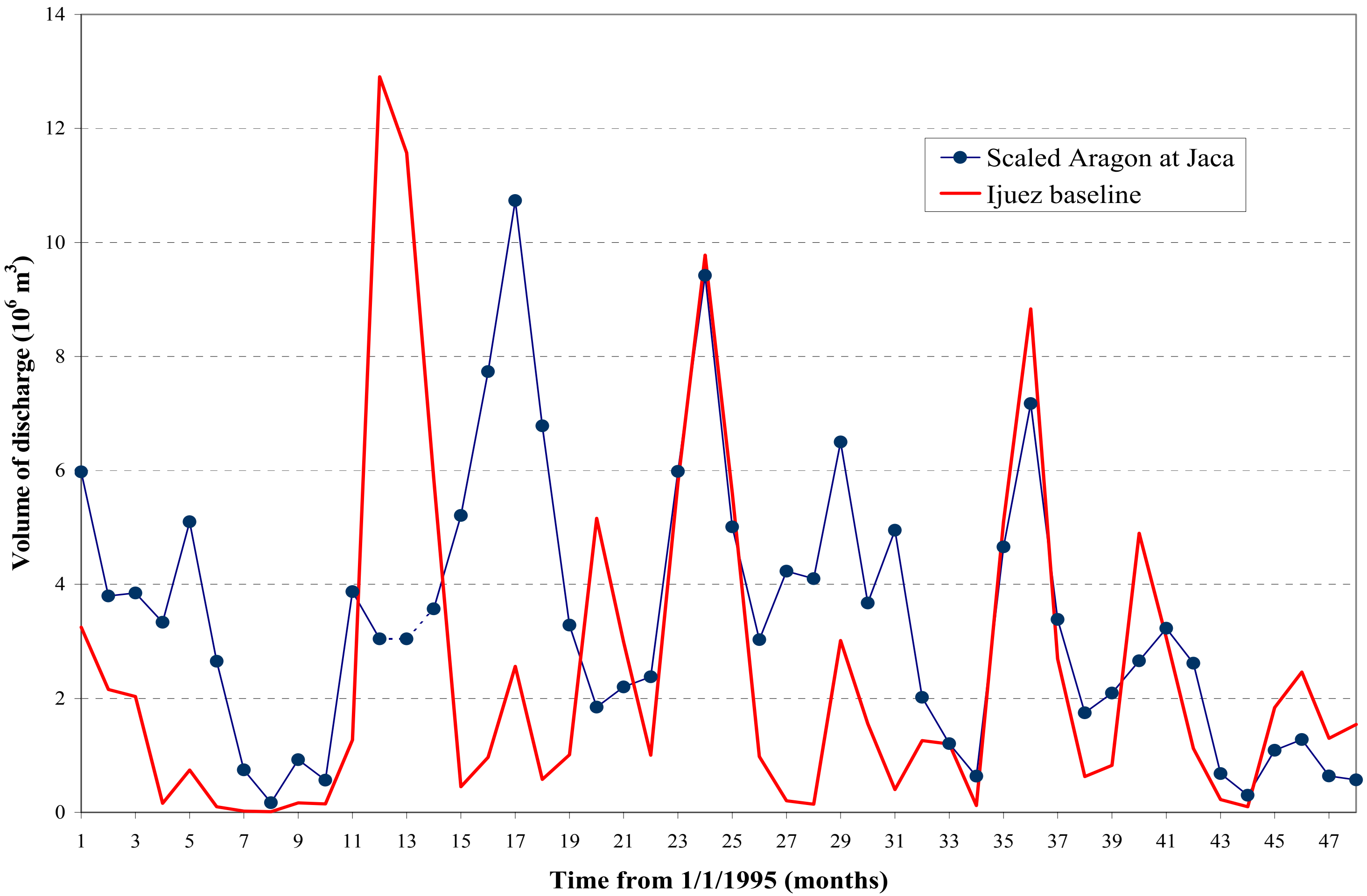


Fig.4 Comparison of the simulated baseline monthly discharge volume for the Ijuez outlet with the scaled values for the Aragón river at Jaca for the period 1/1/95 – 31/12/98

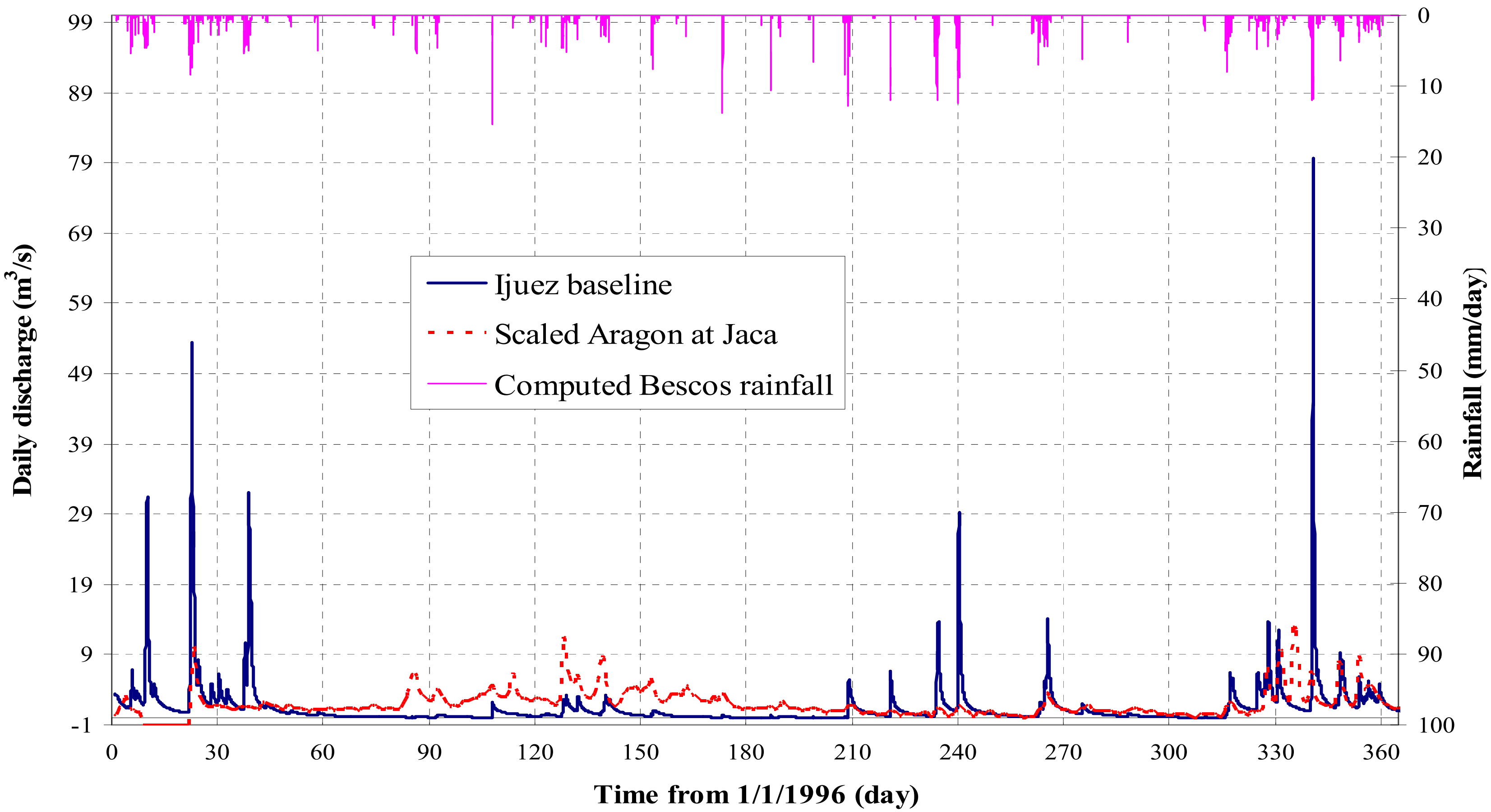


Fig. 5 Comparison of the simulated baseline daily discharge for the Ijuez outlet with the scaled discharge for the Aragón river at Jaca for 1996. Also shown is the rainfall record derived for Bescos in the Ijuez catchment

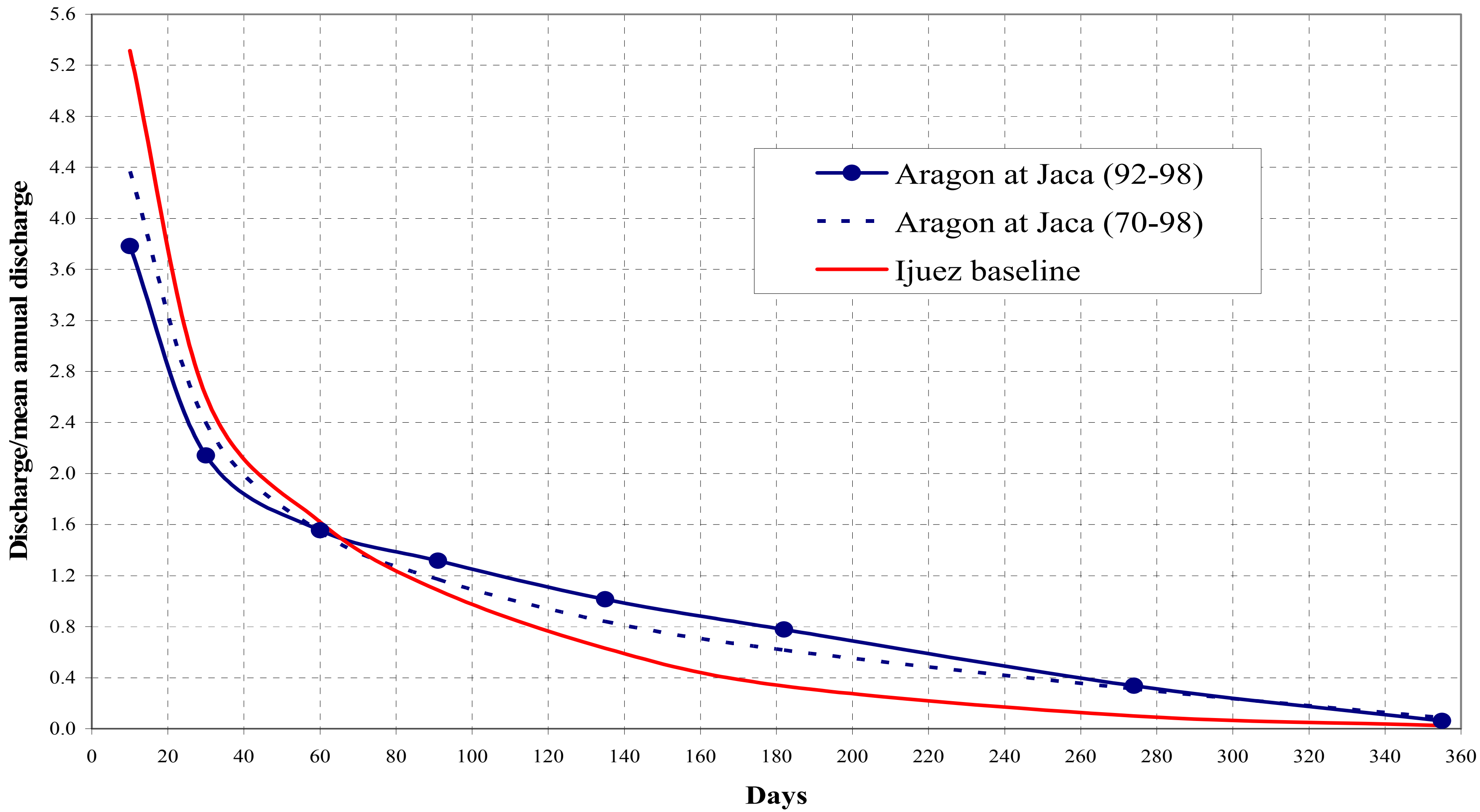


Fig. 6 Comparison of the normalized flow duration curve for the scaled Aragón discharge record at Jaca with the simulated baseline curve for the Ijuez outlet

OUTPUT MATRIX
For a specified region

LAND USE	CLIMATE	
	1990 - 99	2070 - 79
Pasture		
Plantation forest		Landslide map, sediment yield, 1 in 25 year flood
Abandoned land		

Fig. 7 The matrix system for presentation and comparison of SHETRAN scenario simulation results