DAM/PR/0303/6

DAMOCLES

DEBRISFALL ASSESSMENT IN MOUNTAIN CATCHMENTS FOR LOCAL END-USERS

Contract No EVG1 - CT-1999-00007

DETAILED REPORT OF
CONTRACTOR FOR
THIRD ANNUAL REPORT
(1 March 2002 – 28 February 2003)

University of Newcastle upon Tyne
UK

March 2003

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

3.1 OBJECTIVES OF THE REPORTING PERIOD (1/3/2002 – 28/2/2003)

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

(ii) Refining of SHETRAN data files.

(iii) Enhancement of SHETRAN landslide model with relationships from WP1.

(iv) Validation of SHETRAN for the focus catchments.

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

(vi) Scenario applications with SHETRAN for the Valsassina focus catchment (Italy) to provide a basis for a revised regional hazard assessment model, as input to WP2.

(vii) Scenario applications with SHETRAN to assess dependency of debris flow occurrence and sediment yield on land use, future climate and rainfall return period for the Valsassina and Ijuez (Spain) catchments.

(viii) Use of scenario simulation data to develop illustrative guidelines for land management to mitigate debris flow occurrence and impact, for the Valsassina and Ijuez catchments.

3.2 METHODOLOGY AND SCIENTIFIC ACHIEVEMENTS RELATED TO WORK PACKAGES

3.2.1 Project Staff

Following the departure of the project research associate, Dr Ahmed El-Hames, in November 2001, Dr Greta Moretti was appointed from 18 March 2002 to the end of the project. A revised work programme was instituted to enable the project deliverables to be completed on time.

Mr Michael Murray (Research Associate) was appointed to the project for three months to develop an electronic matrix for presenting simulation results.

Dr Ahmad Moaven-Hashemi (Research Associate) was appointed to the project for four months to generate the required climate scenarios.

Mr Aidan Burton (Research Associate) was funded for one month for computer systems and SHETRAN software support (replacing Mr Rob Hiley).

3.2.2 Workpackage 4: SHETRAN Landslide Model

3.2.2.1 Summary

During the reporting period the data needed for running SHETRAN were refined, SHETRAN was validated for the Valsassina (Italy) and Ijuez (Spain) focus areas, scenario applications were carried out to investigate the impacts of climate and land use changes, and the results were transferred to the project end-users as the basis for developing guidelines for future land management to mitigate debris flow occurrence and impact. In addition, work was carried out to enhance the landslide model, to develop scenarios of future conditions and to integrate the SHETRAN modelling approach with the WP2 hazard assessment procedure.

3.2.2.2 Valsassina validation

The validation period for Valsassina is 1/1/93 – 31/12/99, selected in part because it contains the major landsliding event of 27/28 June 1997 which affected the neighbouring Esino valley. The first year (1993) is used as a “settling down” period to minimise the effect of the initial conditions and does not contribute to the final simulation results. The full simulation area consists of the Pioverna valley (Valsassina) (160 km^2) and the Esino valley (20 km^2). The SHETRAN model grid resolution was 500 m and the subgrid resolution for landslide modelling was 20 m.

Hydrology validation

There was no discharge record for the Pioverna or Esino rivers which could 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 1 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.1. On this basis the hydrology model is considered to be validated for Valsassina.

Landslide validation

Two sets of data were available for validating the landslide simulations. The first was for 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 them during the above event. The aim of the validation was 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 was 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 was to reproduce the general spatial distribution of landslide occurrence.

The procedure for simulating the June 1997 event was the same as reported earlier in the project for the Llobregat application. Hydrological input was provided by the baseline flow simulation and bounds on the landslide simulation were 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 were : soil cohesion 4.32, 2.89 and 4.40 kPa; and angle of friction 32.0°, 30.7° and 36.8°. Soil depth (i.e. depth to the shear surface) was set at 0.8 m for shallow colluvial soils and 1 m elsewhere. Landslides were also precluded from occurring at slopes less than 25° and more than 50° 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.

Figure 2 compares the observed occurrence of landslides in the Esino valley for 1997 with the upper and lower simulated bounds for the event of 27/28 June 1997. The respective simulated numbers of 277 and 10 bracket the observation of 137. However, the spatial distributions of observation and simulation do not match. The model does in fact simulate landslides in the same areas as those observed but these were eliminated in the preceding simulation with the scaled rainfall. The results suggest that the simulation is representative at the catchment scale (including landslide sites both near to and distant from the channel) but that representation of spatial distribution needs improvement. Such improvement may depend on more detailed or more accurate rainfall and catchment property data as well as the procedure for eliminating landslides from the simulation. Alternatively wider bounds on the simulated occurrence may be required.

Figure 3 compares the 50-year map of observed landslides with the upper and lower simulated bounds for 1993-99. (In this case, the unconditionally unsafe squares were eliminated by excluding all landslides which occurred in the first 24 hours of the simulation.) Considering in particular the upper simulated bound, reproduction of the observed spatial distribution is very good, accounting both for areas observed to have landslides and areas observed not to have landslides: for example, contrast the north and south sides of the downstream half of the Pioverna valley.

On the basis of these results, the landslide model is considered validated. However, at least at the event scale, wider uncertainty bounds than those used here may be appropriate.

Sediment yield validation

There were no sediment yield records for Valsassina which could 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. Without the contribution from debris flows, the resulting sediment yield bounds simulated for 1994 - 99 were 3.05 – 4.95 t ha^{-1} yr^{-1} for the Pioverna outlet and 0.78 – 0.78 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. Adding the debris flow contribution raises the Pioverna sediment yield to 3.06 – 7.59 t ha^{-1} yr^{-1} and the Esino yield to 0.85 – 5.63 t ha^{-1} yr^{-1}. For the June 1997 event, the simulated sediment yield for the Esino catchment was 1.09 t ha^{-1} without the debris flow contribution and 1.15 – 31.07 t ha^{-1} with the lower and upper bounds for debris flow contribution.

Agreement with the validation data is reasonable. Possibly the simulated Pioverna yields are a little high and the upper bound on the Esino event yield may likewise be high.

3.2.2.3 Ijuez validation

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. The full simulation area is 47.25 km^2. The SHETRAN model grid resolution was 500 m and the subgrid resolution for landslide modelling was 20 m.

Hydrology validation

There was no discharge record for the Ijuez which could be used for validation. A discharge record was therefore obtained by scaling the Aragón river record at Jaca, using a regionally based scaling equation. This effectively determined 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.

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 for the baseline simulation. Dr Garcia-Ruiz (CSIC-IPE) has reviewed and approved the general pattern. The discrepancies in the first part of the 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, although the high simulated discharges for December 1995 and January 1996 are considered realistic. Otherwise the simulated flow magnitudes and month-to-month variations are realistic. The simulated runoff/rainfall coefficient is 0.48.

Figure 5 compares the simulated and measured (i.e. scaled) daily flow duration curves, including the simulated uncertainty bounds. As should be expected, this shows the Ijuez to have a more flashy regime than that represented by the Aragón. The scaled Aragón discharges may therefore not represent well the event-scale response of the Ijuez.

On the above basis the hydrology model is considered to be adequately validated.

Landslide validation

The basis for validating the landslide simulations was a map of the observed debris flow occurrence in the Ijuez catchment over the period 1956-2001. For this period 146 debris flows were identified: 21 of these occurred during 1990-2001. The principal aim of the validation was to reproduce the general spatial distribution of landslide occurrence. However, the observed incidence for 1990-2001 also provided a rough basis for testing the bounds on the simulated incidence.

Hydrological input was provided by the baseline flow simulation and bounds on the landslide simulation were obtained by setting bounds on the root cohesion (Table 2). It was found that smaller bound values were needed, compared with Valsassina, otherwise no landslides were simulated. The smaller values are justified by the poorer purchase afforded the roots by the thin soil and flysch structure. The other soil parameters were evaluated as, for soils 1 and 2: soil cohesion 4.42 and 4.13 kPa; angle of friction 29.8° and 29.7°. Depth to the shear surface was set at 0.85 m. Landslides were precluded from occurring at slopes less than 25° and more than 50°, while landslides which occurred in the first 24 hours of the simulation were eliminated as indicating squares defined as unconditionally unsafe.

Figure 6 compares the 50-year map of observed debris flows with the upper and lower simulated bounds for 1995-1998, superimposed on the vegetation map. Considering in particular the upper simulated bound, reproduction of the observed spatial distribution is good. The apparent discrepancy between the low observed incidence and high simulated incidence in the high meadow area at the north of the catchment is explained as follows. The simulations refer to landslides: according to SHETRAN's rule based approach these may evolve into debris flows on forested slopes but not on grassy slopes. The observations, however, refer to debris flows. CSIC-IPE scientists report that landslips do occur on the high meadows but these do not form debris flows.

Hence simulation and observation are in general agreement for the high meadows in terms of debris flow occurrence.

The bounds on the number of simulated landslides for 1995-1998 are 96 and 857. For the lower bound the number is made up mainly of landslides on the high meadows: very few landslides are simulated in the lower catchment. The corresponding bounds for the number of landslides which evolve into debris flows are 12 and 462. These bounds enclose the number of observed debris flows (21) for 1990-2001.

On the basis of these results, the landslide model is considered to be adequately validated.

Sediment yield validation

Regional long term yields of 1.5 – 4 t ha^{-1} yr^{-1} are reported for catchments of 190 to 2694 km^2 along the Central Pyrenees (Ebro valley) by Avendaño Salas et al. (1997). CSIC-IPE scientists have also measured yields of 2.04 and 1.87 t ha^{-1} yr^{-1} on two small catchments (2.84 and 0.95 km^2 respectively) in the flysch area near the Ijuez catchment, for a period of one year (1/10/99 – 30/9/00). The first of these refers to a largely deforested area and its yield is composed 73% of suspended (particulate) load. The second refers to a forested area and its yield is composed 73% of solute load.

For the simulations, uncertainty bounds were set on the soil erodibility coefficients for raindrop impact and overland flow (Table 2). The proportion of ground covered for all vegetations was set at 0.7. Without the contribution from debris flows, the sediment yield simulated for 1995-98 was 0.67 t ha^{-1} yr^{-1}, there being no sensitivity to the erodibility coefficients. As the simulation period was relatively dry it was expected that sediment supply from the hillslopes would be restricted (because of the low incidence of overland flow) and that the yield without a debris flow contribution would be low. Adding the lower and upper bounds for debris flow contribution, though, raises the yield to 0.77 and 2.08 t ha^{-1} yr^{-1} respectively. On this basis the sediment yield model is considered to be validated.

3.2.2.4 Scenario simulations

Possible future climate and land use scenarios were developed for the Valsassina and Ijuez focus basins. In both cases the climate scenarios were developed using data from the UK Hadley Centre global circulation model HadRM3 for the period 2070-99. One hundred years of rainfall data were generated and strictly the simulations should be run with this full time series to provide a statistically correct representation of conditions for 2070-99. However, the time constraints on completing the project did not allow the long simulation times required. The 100 years of rainfall data were therefore split into ten consecutive decades and the mean monthly values determined for each decade. Comparison was then made between the decades and with the corresponding data for the current period. This indicated that all the decades showed (for each catchment) a significant and similar change in rainfall pattern compared with the current conditions. That decade which was a rough average of the other decadal monthly distributions was then chosen for simulation. Relative to the current period, mean annual rainfall decreases (especially for Valsassina) but within this context winter rainfall increases slightly. Mean annual potential evapotranspiration increases. The relevant figures are shown in Tables 3 and 4.

Realistic land use changes are limited in each case. In Valsassina the likeliest change is for the hillslope meadows to be abandoned and to revert to (or be planted with) forest. In the Ijuez catchment the change of most interest is the effect of fire, i.e. removal of the tree cover. Valsassina was therefore modelled with the current hillslope meadows replaced by forest while the Ijuez catchment was modelled with a complete grass and pasture cover, representing the catchment a few years after a fire which has destroyed all the trees. These scenarios are extreme but enable the maximum impacts to be modelled and used in developing guidelines for catchment management.

The results of the scenario simulations are shown in Tables 3 and 4. Simulation uncertainty bounds are shown as appropriate. For the future climate, runoff is reduced, corresponding to the decrease in rainfall and increase in evaporation. Sediment yields derived from erosion by raindrop impact and sediment yield are likewise reduced. However, the numbers of landslides show only small decreases (Valsassina) or no decrease (Ijuez). This is because the future climate still has sufficient amounts and intensities of rainfall to cause landsliding near to the current rate of occurrence. Overall sediment yields (including the contribution from debris flows) fall more markedly for Valsassina than for the Ijuez catchment, probably because of the greater reduction in runoff for the former case.

The change to fully forested hillslopes in Valsassina produces a small reduction in landslide occurrence. Sediment yield is also reduced but this is due more to the reduction in non-landslide erosion (i.e. by raindrop impact and overland flow) and the reduction in runoff than to the reduction in landslides. Indeed, noting that conversion of pasture to forest could increase the number of landslides which evolve into debris flows, there is a possibility that the sediment yield derived from landslides may increase. This is suggested by the upper bounds on total sediment yield for the future climate (increase from 1.98 to 2.48 t ha^{-1} yr^{-1}).

The conversion of the Ijuez catchment to a full grass cover provokes an increase in landslide occurrence. However, none of the landslides develops into a debris flow, so there is a reduction in the amount of material delivered to the channel network and a corresponding decrease in sediment yield derived from landsliding. This is to some extent countered in the overall sediment yields by the increase in non-landslide erosion and in runoff.

The scenario results can all be explained in terms of model design and capability. In other words they are physically realistic, within the limitations of the model design and scenario characteristics. Comparison of the scenario results with the simulations for the current period provides an indication of the sorts of changes in catchment response which may be observed in the future and thus provides a context within which guidelines for land management can be developed to minimize debris flow impacts.

3.2.2.5 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 being tested for Valsassina in the following way:

(1) Run SHETRAN for the current conditions, providing a landslide map as the basis for generating a WP2 spatial probability map of landslide occurrence;

(2) Repeat step (1) by running SHETRAN for the land use scenario;

(3) Compare the landslide probability maps for the two cases to see the effect of land use change.

This comparison requires that the SHETRAN grid elevations and channel network be derived on the same basis and using the same topographic data as the WP2 hazard mapping procedure.

The comparison is still in progress.

3.2.3 Workpackage 5: Dissemination

The SHETRAN model is currently too complex to be transferred to the project end-users. Instead it has been used to simulate flow, sediment transport and landslide data for a range of land use and climate scenarios as described in Section 3.2.2.4: these data have then been transferred to the end-users for use in developing land management guidelines. A matrix system was 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. 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 was therefore developed, enabling users to access all relevant data by clicking on the relevant box. The ability to compare data from different boxes is also included. The complete DAMOCLES matrices for the two focus areas have been distributed on CD to the relevant end users: Servizio Azienda Speciale di Sistemazione Montana (Trento), Lombardy Region Geological Survey, Diputación General de Aragón, and the Geological and Mining Institute of Spain. The transfers were carried out through discussion meetings at the end-user offices.

A paper on the Llobregat validation is in preparation.

Conference presentation on the SHETRAN simulations are planned as shown in Section 3.6.

3.3 SOCIO-ECONOMIC RELEVANCE AND POLICY IMPLICATIONS

As noted in the Year 1 Newcastle report, the interests of the project end-users include:

- scenarios for altered hazard as a function of land use and climate change, for a 25-year planning horizon;
- catchment sediment yield (eg for public works);
- event-based responses (eg for different frequency rainfall events);
- rainfall thresholds for landslides;
- peak water discharge and total discharged volume for storm events;
- peak sediment discharge and total discharged volume for storm events.

Because of time constraints on completing the project it was not possible to investigate response in detail at the event scale. Scenario results have instead been presented at the monthly and annual scales. However, data relevant at the event scale are contained within the simulation results and could be analyzed in the future.

Rather than consider the 25-year planning horizon, simulations have been made for the longer term future (2070-99). The aim is to emphasize the general direction of future change with an indication of the possible long term magnitudes of change. Hazard assessments for the nearer future can then be developed within these limits.

Simulation data on debris flow occurrence and flow and sediment yield responses for both the current and scenario conditions have been distributed to the end-users as described in the earlier sections.

3.4 DISCUSSION AND CONCLUSION

(i) Validation of the SHETRAN landslide model was completed for the Valsassina and Ijuez focus catchments. The results demonstrate an ability to bracket the observed occurrence of debris flows with simulated distributions and to determine catchment sediment yield within the range of regional observations.

(ii) Future land use and climate scenarios were developed for the focus catchments, with advice from the local partners and end-users.

(iii) SHETRAN has been applied to the scenarios, giving debris flow occurrence and flow and sediment yield responses as a function of climate and land use.

(iv) The simulation results have been summarized in electronic matrices which have been transferred to the end-users on CD. The data are of use in developing guidelines for future land management to mitigate debris flow occurrence and impact.

(v) The use of SHETRAN to provide an altered pattern of landslides as a basis for the WP2 hazard mapping procedure is still being tested.

(vi) The Newcastle team has achieved its objectives and deliverables. It is clear, though, that rather more detailed and extensive simulations would have been completed if significant time had not been lost to the unforeseen departure of the original research associate in the middle of the project.

3.5 RECOMMENDATIONS ARISING FROM THE PROJECT

The Valsassina, Ijuez and the earlier Llobregat applications have provided considerable experience in validating the SHETRAN landslide model and using it in scenario investigations. At the same time a number of aspects which require further improvement have been highlighted.

(i) The model initially predicts a large number of unconditionally unsafe landslide squares. An objective means of eliminating these from the main simulation needs to be identified.

(ii) The simulated upper bound on the number of landslides is typically a large overestimate. Means of reducing the overestimate need to be investigated. One contributory cause may be that the model defines landslides at the scale of individual pixels. When neighbouring pixels fail they are counted as individual landslides when in fact they may be one single landslide. As the upper bound involves a large number of neighbouring pixel failures, a weighting scheme (perhaps based on observed landslide magnitudes) could be introduced to produce a more appropriate count of actual landslides.

(iii) The simulation of the Esino event should be revisited to see if the mismatch in landslide spatial distribution between observation and simulation can be eliminated or else explained.

(iv) The comparison and integration of the WP2 GIS-based hazard assessment methodology with the SHETRAN-based approach needs to be taken further.

(v) The scenario simulations should be refined and integrated with the findings from the focus areas on the weak impact of land use on debris flow occurrence, to develop more fully the guidelines for land use management.

(vi) Journal papers will be written, jointly with the appropriate partners, on the Valsassina and Ijuez simulations and on the integration of the SHETRAN and WP2 methodologies. These are likely to be supported by further simulations to refine the results.

3.6 PUBLICATIONS

Bathurst, J.C., Carrara, A., Crosta, G., Frattini, P. and Moretti, G. 2003. An integrated approach for assessing debris flow hazard at regional scale. European Geosciences Union XXVIII General Assembly, 6-11 April, Geophysical Research Abstracts, 5.

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

Parameter		Baseline Value	Bound values upper	Bound values 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	0.5
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):			
Natural pine	-	1500	700
Plantation pine	-	800	300
Shrubs/meadows		800	300

Table 3 Results for the SHETRAN Valsassina simulations

Scenario	Mean annual rainfall mm	Mean annual potential evapotranspiration mm	Simulated mean annual runoff mm	Simulated sediment yield		Simulated number of landslides
				without landslides t ha^{-1} yr^{-1}	with landslides t ha^{-1} yr^{-1}	
Current climate (1994 – 99):						
- current vegetation	1476	873	885	3.05 – 4.95	3.06 – 7.59	369 – 10661
- forested hills	1476	873	841	1.31 – 1.43	1.31 – 5.52	0 – 9923
Future climate (2070 – 99)						
- current vegetation	1001	982	470	1.10 – 1.30	1.11 – 1.98	296 – 9027
- forested hills	1001	982	420	0.43	0.43 – 2.48	0 - 8020

Table 4 Results for the SHETRAN Ijuez simulations

Scenario	Mean annual rainfall mm	Mean annual potential evapotranspiration mm	Simulated mean annual runoff mm	Simulated sediment yield		Simulated number of landslides
				without landslides t ha^{-1} yr^{-1}	with landslides t ha^{-1} yr^{-1}	
Current climate (1995 – 98):						
- current vegetation	1241	950	757	0.67	0.77 – 2.08	96 – 857
- pasture	1241	950	778	0.76	0.81 – 1.54	183 – 1089
Future climate (2070 – 99)						
- current vegetation	1084	1382	624	0.52	0.58 – 1.36	
- pasture	1084	1382	638	0.60	0.66 – 1.26	96 – 857
						183 - 1089

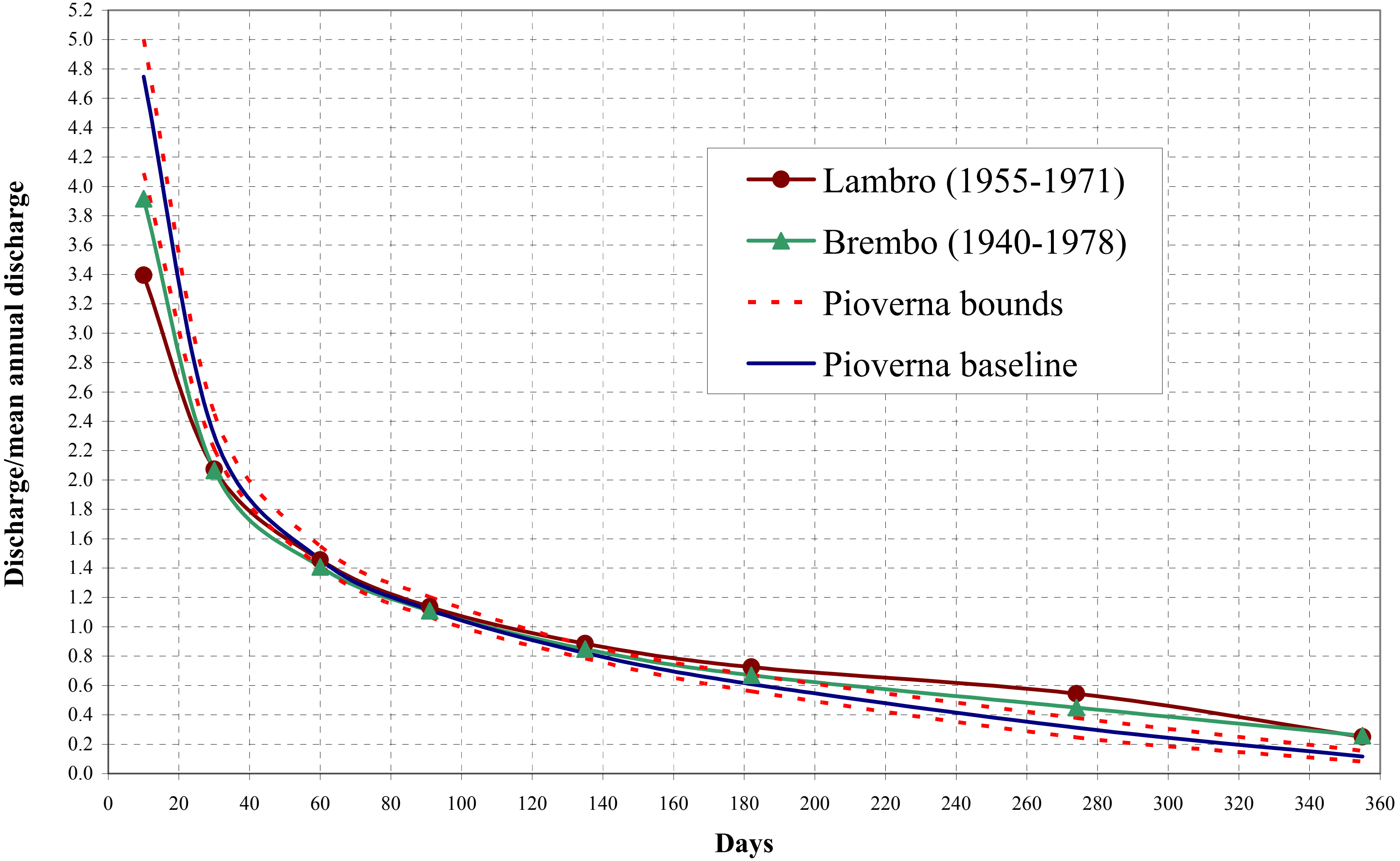

Fig. 1 Comparison of the normalized flow duration curves measured for the Lambro and Brembo rivers with the simulated baseline curve and uncertainty bounds for the Pioverna at Bellano

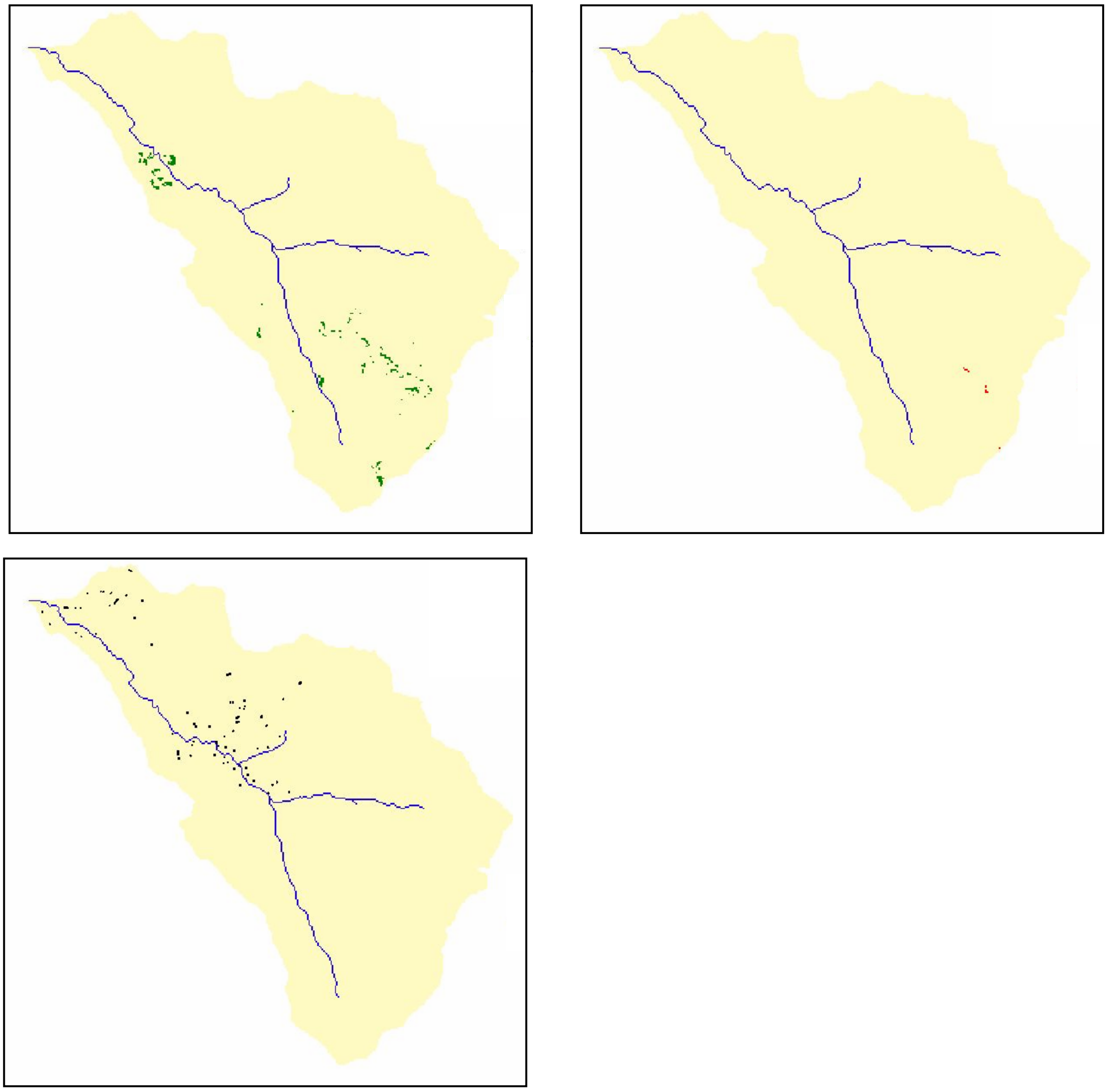

Figure 2. Comparison of uncertainty bounds for SHETRAN simulation (upper diagrams) with observed locations (lower diagram) of landslides in the Esino Catchment. Landslide locations are shown as dots

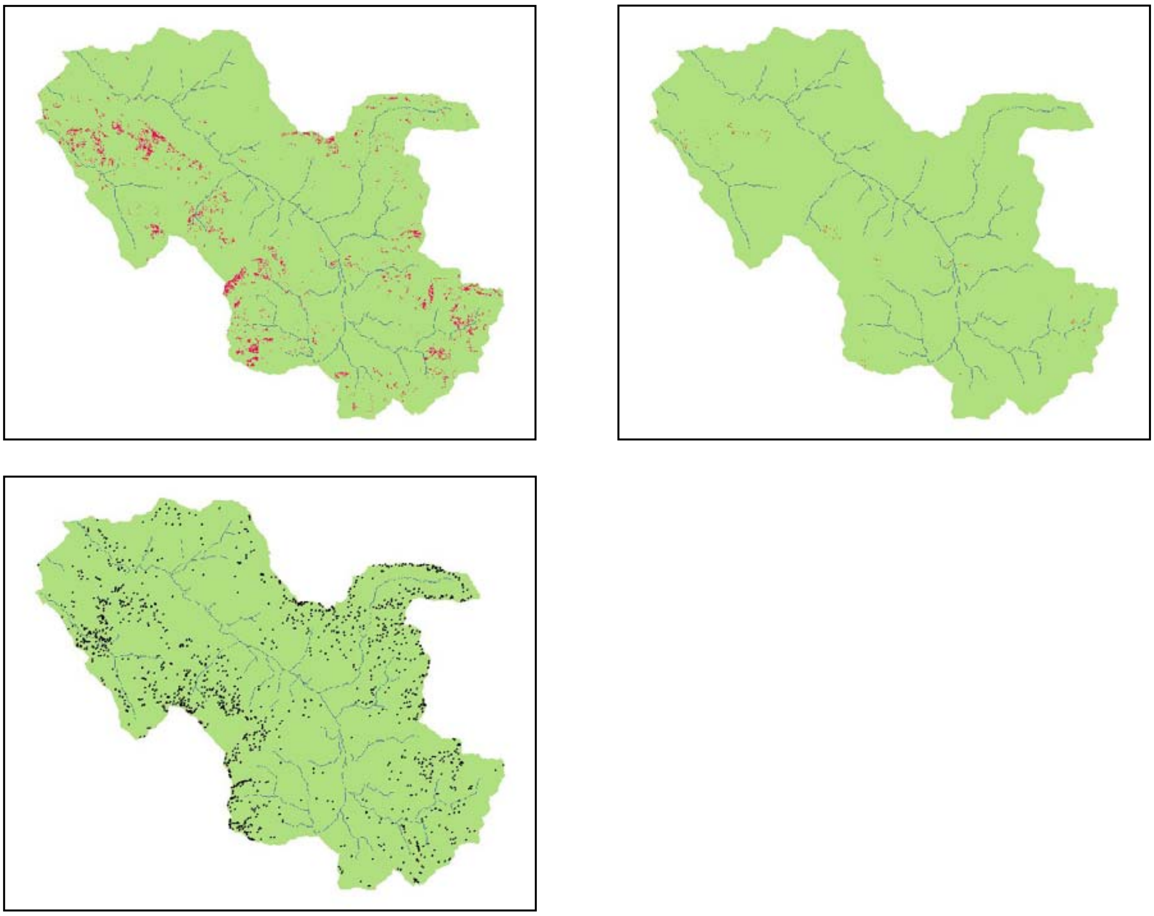

Figure 3. Comparison of uncertainty bounds for SHETRAN simulation (upper diagrams) with observed locations (lower diagram) of landslides in Valsassina. Landslide locations are shown as dots

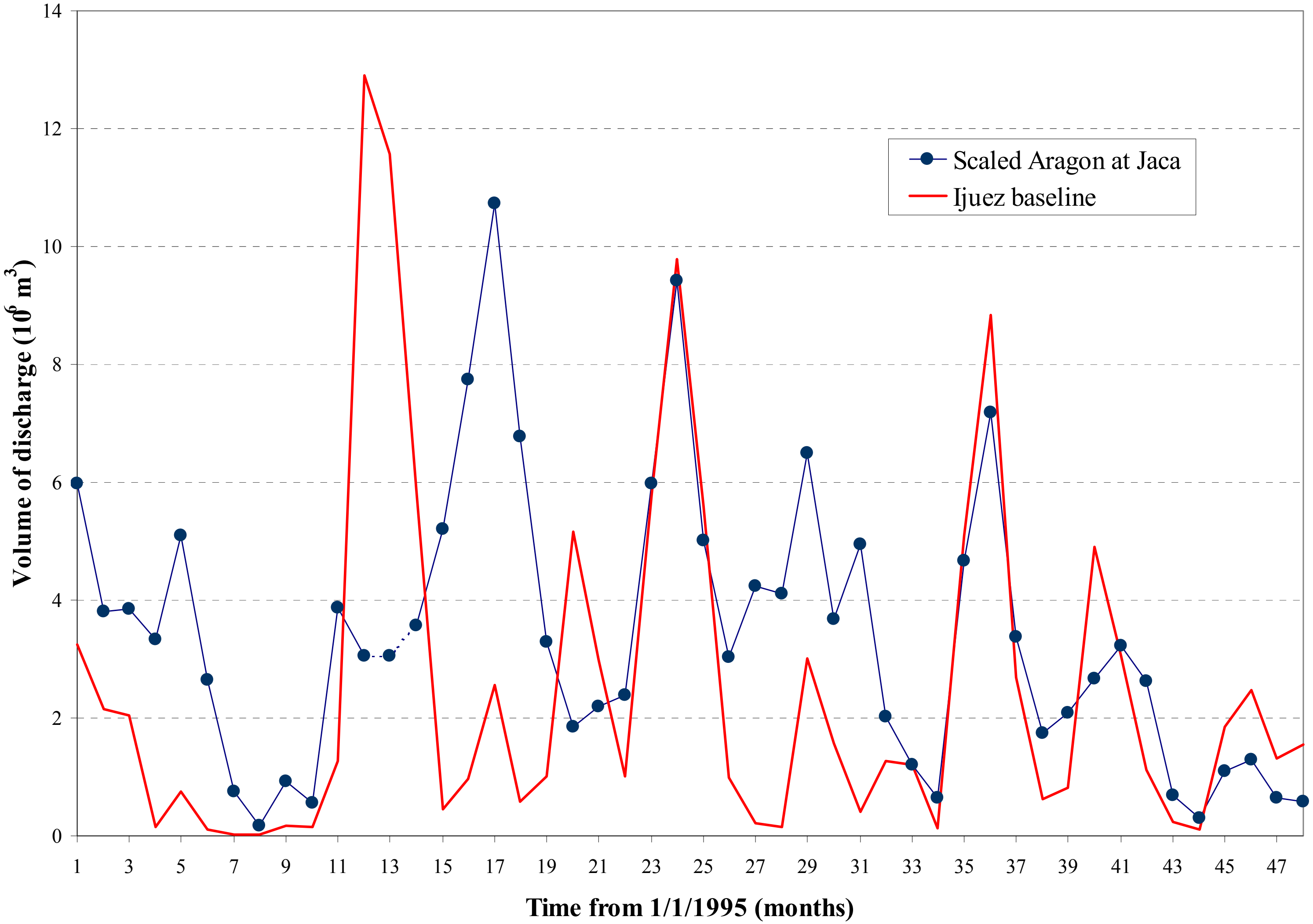

Fig 4 Comparison of the simulated baseline monthly discharge volume for the Ijuez outlet with the scaled values for the Aragón river at Jaca for the period 1/1/95 – 31/12/98

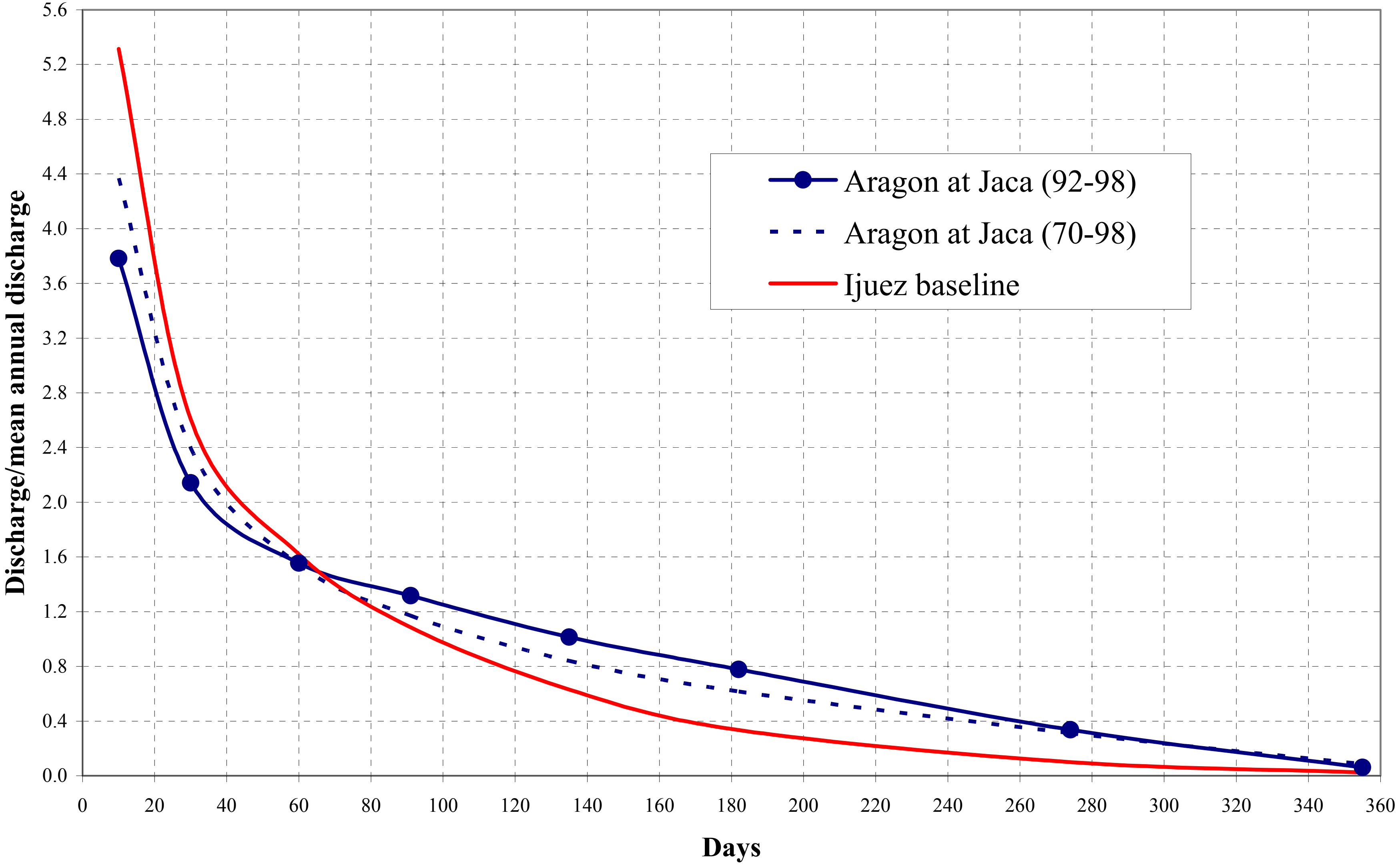

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Fig. 5 Comparison of the normalized flow duration curve for curve for the scaled Aragón discharge record at Jaca with the simulated baseline curve for the Ijuez outlet

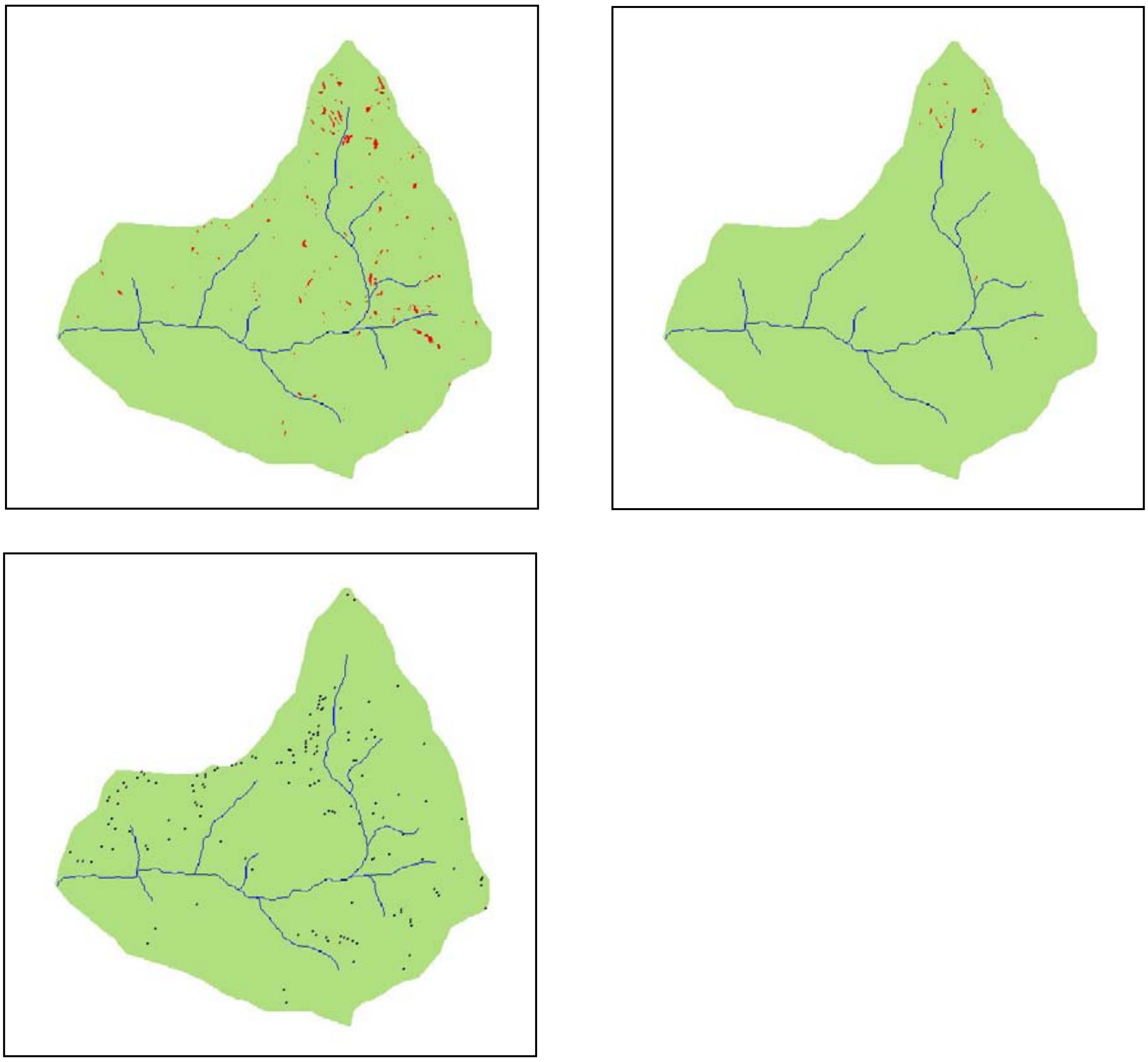

Figure 6. Comparison of uncertainty bounds for SHETRAN simulation (upper diagrams) of landslides with observed locations (lower diagram) of debris flows in the Ijuez Catchment. Landslide and debris flow locations are shown as dots