Modelling the Timing and Location of Shallow Landslides and Debris Flows using the SHETRAN Model

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Introduction

Rainfall is an important factor for triggering landslides but its effect is poorly understood. The aim of this work is to investigate the occurrence, and the associated sediment release, of shallow landslides and debris flows at the river basin scale as a function of rainfall return period. The timings and locations of landslides were simulated in response to rainfall patterns of different combinations of intensity and duration. The simulations were carried out using the SHETRAN landslide model.

The SHETRAN landslide model

• SHETRAN is a physically based, spatially distributed, integrated surface / subsurface modelling system for water flow and sediment transport in river catchments.
• The landslide component models shallow landslide occurrence and the resulting sediment yield at the catchment scale.
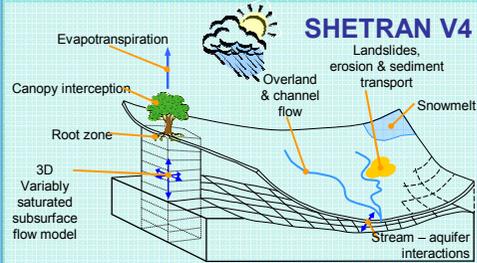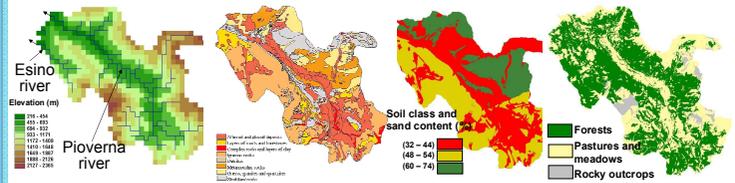

SHETRAN V4

The landslide component uses the topographic index to link the SHETRAN grid resolution (typically 100m – 2km), at which the basin hydrology and sediment yield are modelled, to the landslide component's sub-grid resolution (typically 10 – 20m), at which landslide occurrence and erosion are modelled.

• Landslide occurrence is determined as a function of the time- and space-varying soil saturation conditions simulated by SHETRAN using infinite-slope, factor-of-safety analysis.
• The SHETRAN landslide model is relevant to catchment scales of up to 500 km^2.
• SHETRAN can predictively examine the impacts of possible future changes in climate (including rainfall characteristics) and can therefore be used in hazard assessment and as a tool for developing mitigation strategies.

Focus Area & Input data

The Pioverna (Valsassina) catchment (160 km^2) & Esino catchment (20 km^2) are located in the pre-Alps of the Lecco province in Northern Italy. The rivers discharge into Lake Como (Lario). The area receives a mean annual rainfall of 1542 mm.

SHETRAN grid resolution = 500 m.
Landslide grid resolution = 20 m.

Method

1. Synthetic rainfall events were generated corresponding to selected observed extreme rainfall totals of given return period (RP), for a range of durations (1-day to 5-day)
   • A Generalised Extreme Value distribution was fitted to observed annual maxima data using L-moments.
   • 1- 5 day rainfall events, corresponding to selected return periods, were disaggregated to hourly resolution.
   • Four rainfall disaggregation patterns were evaluated with equal total precipitation but variable hourly intensity, called: Peak, Constant, Increasing and Decreasing.
2. Uncertainty was allowed for by setting upper and lower bounds on key model parameters.
3. The rainfall events were applied to the SHETRAN model which simulated landslides and the resulting sediment yield.
4. The results were analysed to investigate relationships between rainfall properties and the characteristics of the modelled landslides and their sediment yield.
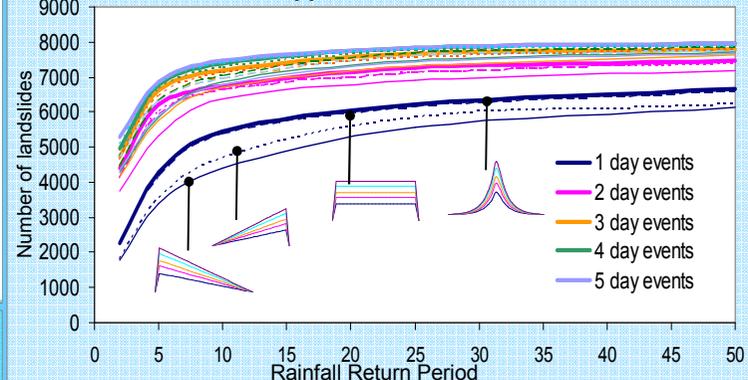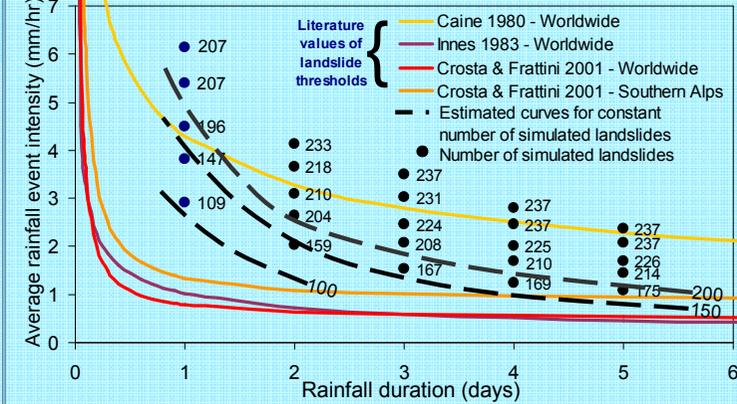

Rainfall disaggregation pattern. 1-day example shown below.
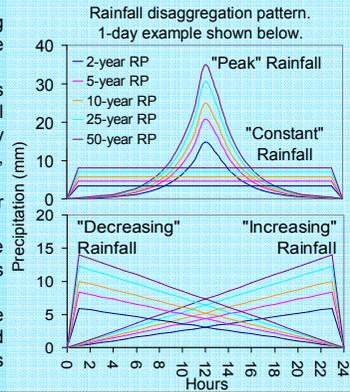
Results

Precipitation, river discharge and number of landslides for a 1-day rainfall event with a 2 year return period
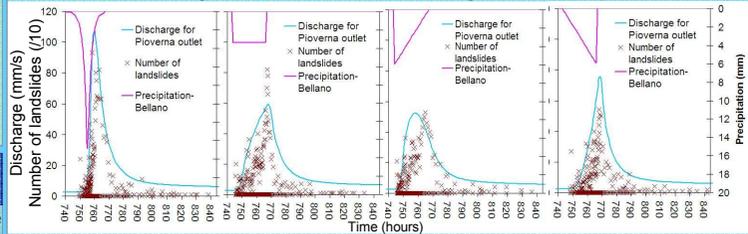
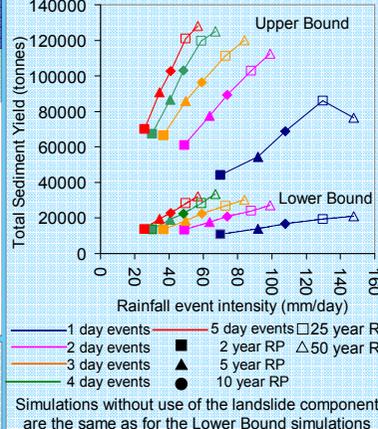### Number of landslides associated with different return periods for the upper bound simulations

- 1 day events
- 2 day events
- 3 day events
- 4 day events
- 5 day events

Simulated number of landslides compared to published zero-landslide thresholds for lower bound simulations

Literature values of landslide thresholds:
— Caine 1980 - Worldwide
— Innes 1983 - Worldwide
— Crosta & Frattini 2001 - Worldwide
— Crosta & Frattini 2001 - Southern Alps
- - - Estimated curves for constant number of simulated landslides
• Number of simulated landslides

Combined Sediment Yield for Pioverna & Esino River outlets

- 1 day events
- 2 day events
- 3 day events
- 4 day events
- 5 day events
- □ 25 year RP
- ■ 2 year RP
- △ 50 year RP
- ▲ 5 year RP
- ◆ 10 year RP

Simulations without use of the landslide component are the same as for the Lower Bound simulations

Location of landslides for rainfall events of 1 day duration & 2 year return period

• Landslide location (lower bound)
• Landslide location (upper bound)
— River
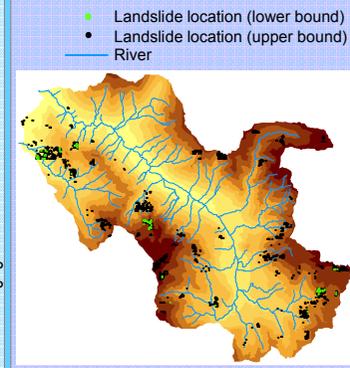
Conclusions

• The effects of different rainfall properties on simulated shallow landslide incidence and sediment yield were explored.
• The relationship between the simulated number of landslides and rainfall event intensity and duration was found to be similar to that in the literature. The upper bound simulations were found to be too high but the lower bound simulations were found to be consistent with Innes (1983) and Crosta & Frattini (2001).
• The timing and occurrence of landslides was shown to be influenced by rainfall distribution pattern as well as magnitude. The effects of antecedent conditions should now be explored.
• These results should help to develop forecasting, mitigation and hazard zonation strategies.