Modelling the hydrological state for debris-flow triggering and magnitude in the Illgraben catchment, Switzerland

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Motivation

- Predicting debris-flow magnitude for hazard analysis, scenario design and mitigation
- Identifying key hydrological controls for debris-flow magnitude formation

Study site

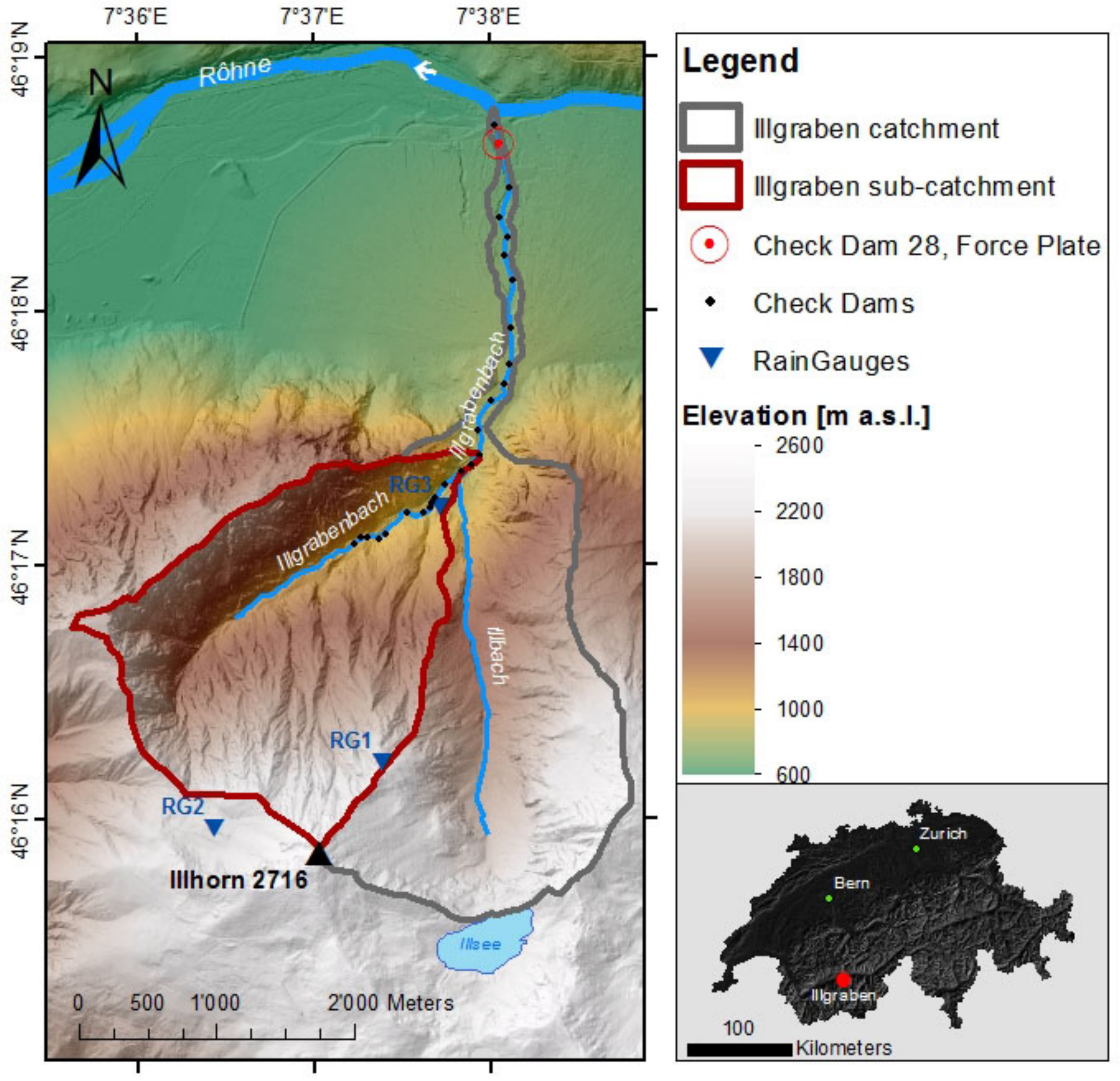

Fig. 1: The Illgraben catchment

The Illgraben catchment

- Area: 4.8 km^2
- 44% exposed bedrock, 42% forest and 14% grassland
- 3-4 debris flows per year on average
- Force plate installed in 2003 (McArdell et al. 2007)
- 75 debris flows (and floods) recorded, whereof 52/62 are analysed here

Meteorological Data

- Local rain gauge
- RhiresD: gridded (1 km), daily precipitation product from MeteoSwiss
- MeteoSwiss station: Sion (20 km west)
- Hydrologischer Atlas Schweiz: yearly actual evapotranspiration

Runoff coefficients

- Measures the fraction of rainfall contained in the debris flow and leaving the catchment
- A rainfall event is defined by a minimum inter-event time of 3 hours.
- The debris-flow water content is assumed to be 50 vol%
- runoff coefficients (Ψ) are then defined as follows:

$$\Psi = \frac{f \cdot V_{DF}}{\int_{t_0}^{t_e} P(t)dt}$$

f: fraction of water on debris flow (50 vol%)

V_{DF}: debris flow magnitude [m^3]

P: precipitation

t_0, t_e: event starting and ending time

Results

- median(Ψ) = 0.03
- Ψ > 1: snow melt or entrainment of interstitial pore water
- Antecedent wetness is **not a pre-condition**, but it **enhances entrainment** of sediments by increased pore-water pressure

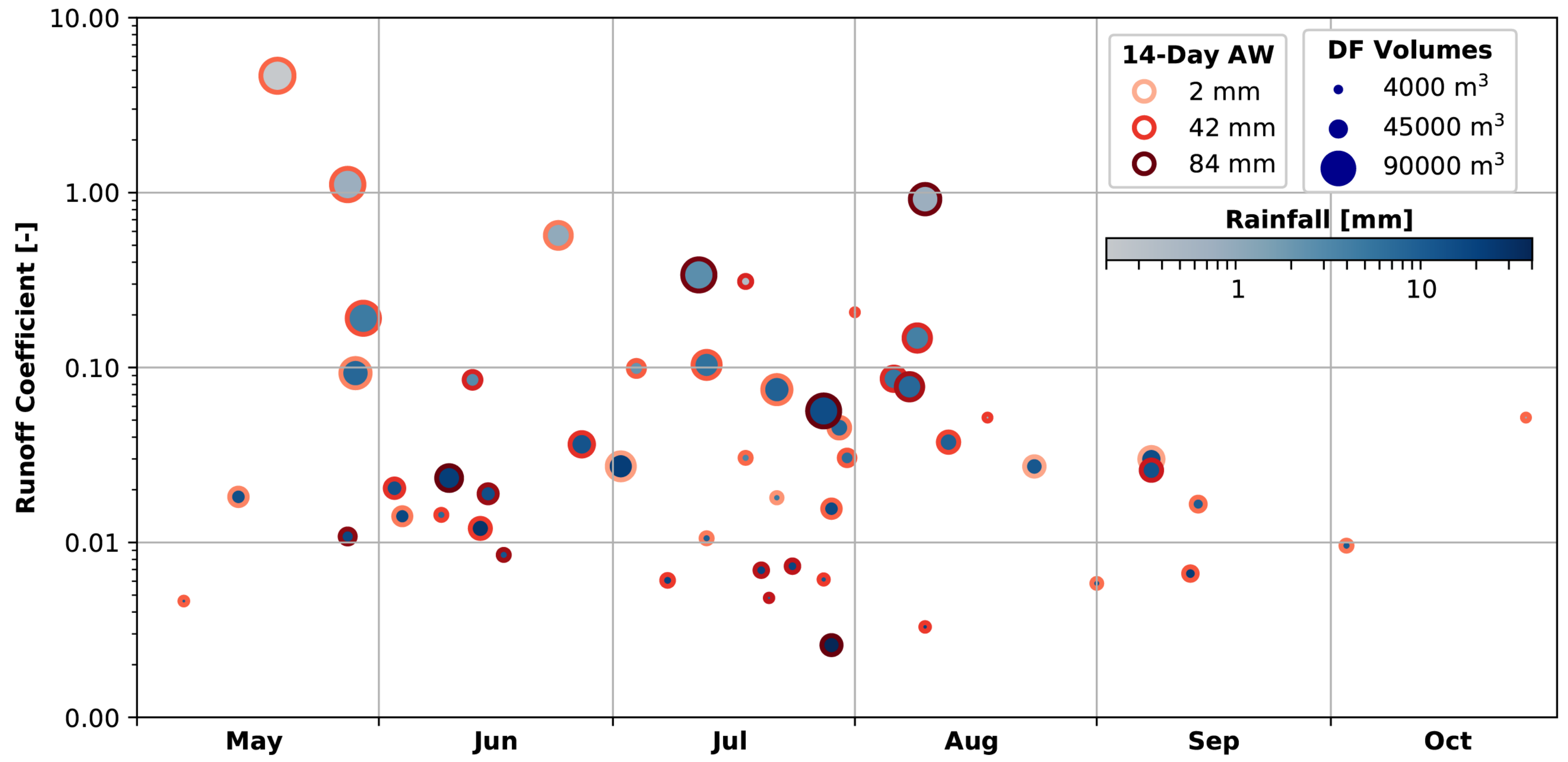

Fig. 2: Runoff coefficients estimated from debris flow volume records

Soil water storage

- A spatially lumped **linear reservoir** to simulate runoff as a function of soil water storage in the catchment
- Accounts for **all relevant processes**: precipitation, snow, evapotranspiration, and soil water storage
- Hourly resolution

m: melt rate factor

T*: Temperature threshold for snow accumulation

k: mean residence time

α: parameter for ET efficiency

Mass continuity for soil water storage:

$$Q(t) = Q_1(t) + Q_2(t)$$

$$\frac{dS_w}{dt} = P(t) + Q_m(t) - ET(t) - Q(t)$$

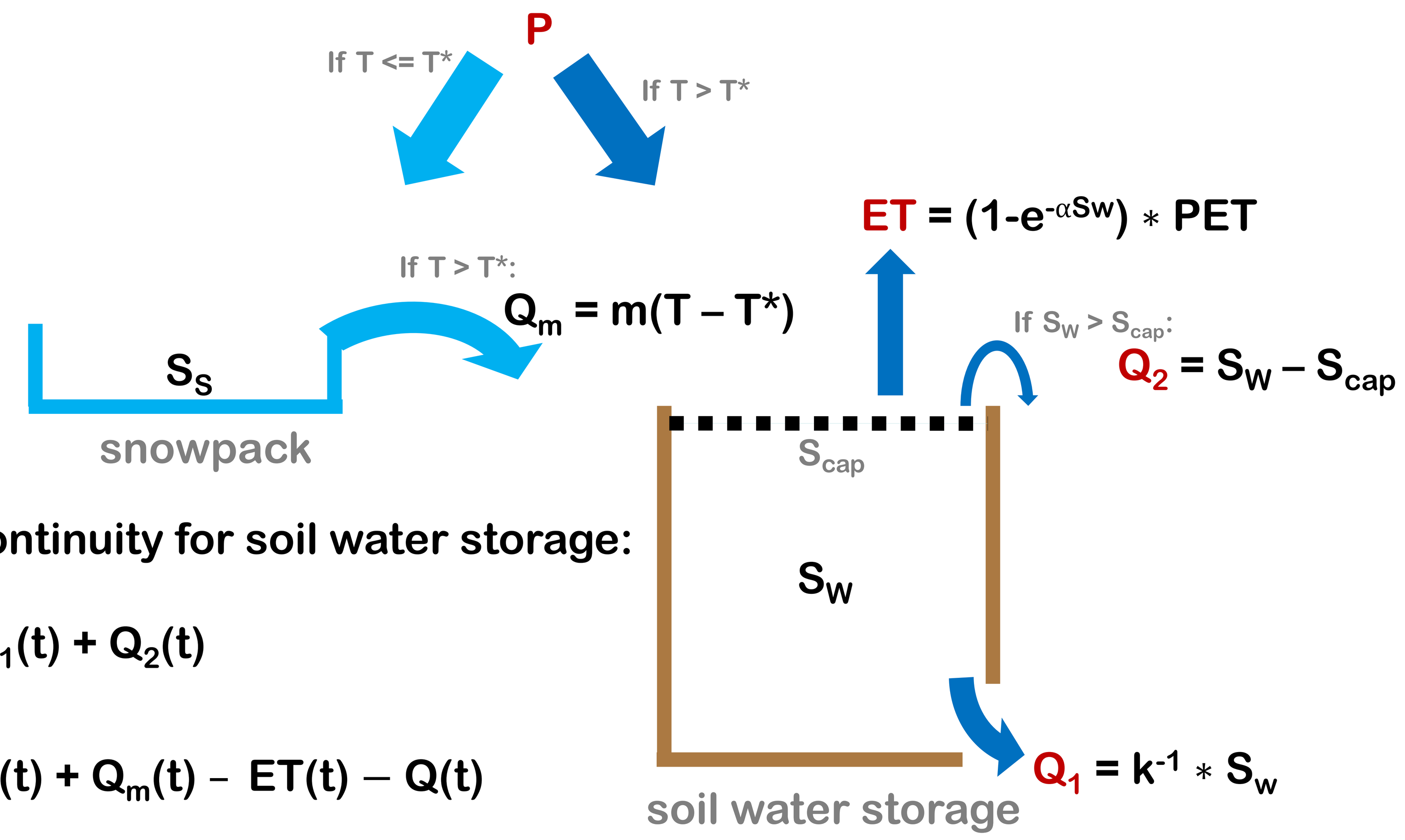

Fig. 3: The hydrological model concept (modified from Bennett et al., 2014)

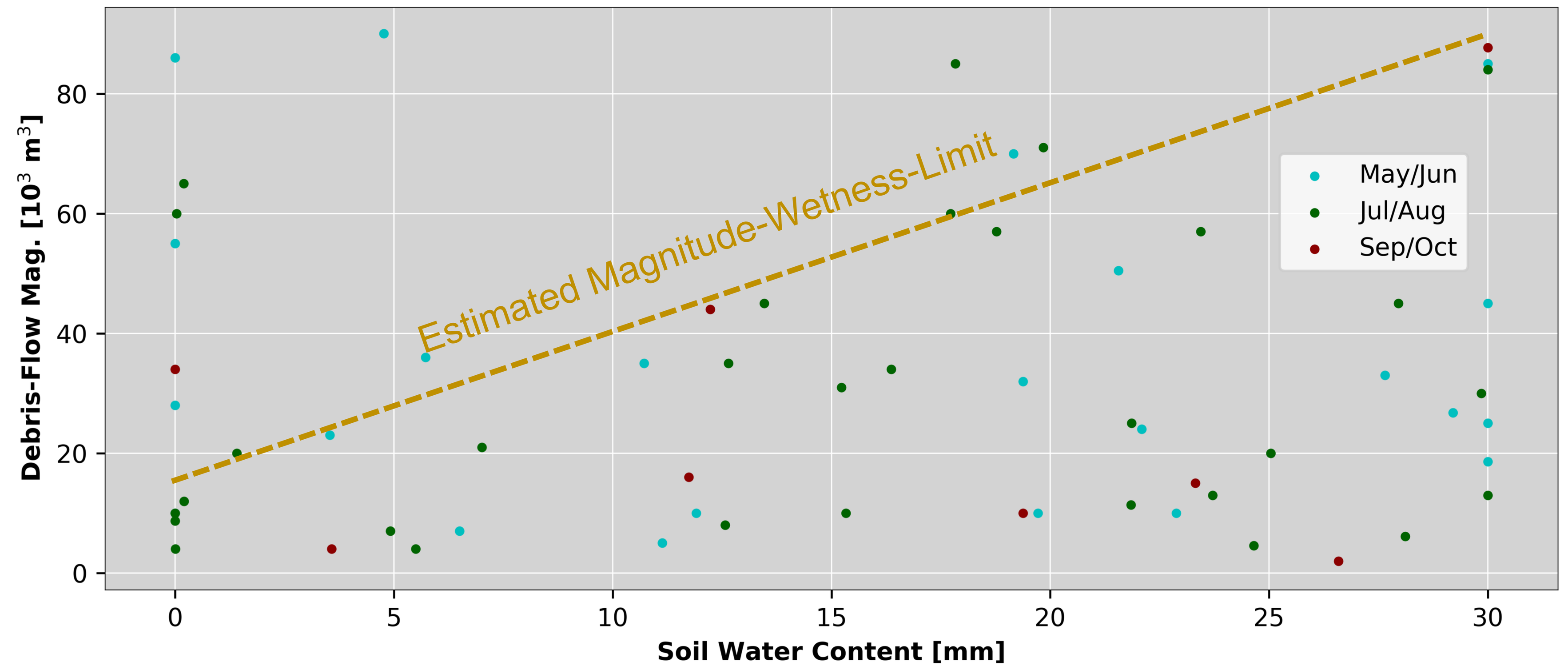

Fig. 4: Soil water content at the time of observed debris flows

Results

- A theoretical magnitude-wetness limit is apparent
- The simple hydrological model cannot fully account for snow-melt processes
- The significance is limited because of **the lumped spatial representation** and the **disregard of sediment availability**

Fig. 5: The Illhorn summit.

Outlook

- Investigate **geomorphological conditions** (i.e. sediment availability) using the SedCas model (Bennett et al. 2014)
- Using SedCas for prediction of magnitude-frequency distributions with **climate change scenarios**
- Developing SedCas2D:
  - Semi-distributed hydrological model
  - Kinematic wave modelling
  - Further parameterisation of hillslope erosion processes
- Apply the model to selected sites in the Swiss Alps

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Photography encouraged