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## EVALUATION OF A TWO-PHASE DEBRIS FLOW MODEL USING FIELD DATA FROM THE SWISS ALPS

Melissa Swartz, Brian Mc Ardell<sup>1</sup>  
Perry Bartelt, Marc Christen<sup>2</sup>

### ABSTRACT

We compared a new two-phase model (DBF-1D) of debris flow behavior with front velocity and flow depth data from two automated debris flow observation stations in Switzerland. The depth averaged mass, volume and momentum equations are written for the solid and fluid phases, which are coupled by a momentum transfer function. The Voellmy-fluid flow relation is used to calculate the flowing friction of the debris flow, treating the solid phase as a variably saturated Coulomb-type material. The frictional behavior of the fluid phase is described by a Chezy-type relation. To further constrain parameters used in the model, we estimated the momentum exchange coefficient using video analysis of large ( $D > 0.5\text{m}$ ) boulders traveling within coarse and muddy debris flows at the Illgraben observation station. Overall, this two phase approach provides a good approximation of the 1-dimensional behavior of debris flows, while taking into account the complex interactions between solids and fluids.

**Key words:** debris flows, two-phase model, Voellmy-fluid, comparison with field data

### INTRODUCTION

Debris flows are a significant natural hazard in mountainous regions, yet engineers have few tools that can be used to assess hazard or aid in the design of mitigation measures. In this paper we compare simulation results of a new two-phase debris flow model (DBF-1D) being developed at our institute with data from two well-documented debris flow events from the Schipfenbach and Illgraben automated debris flow observation stations operated by WSL. Data from the observation stations and related field work provide a unique data for model calibration and sensitivity analyses. Herein, simulated front velocities and flow areas are compared with the field data, allowing us to constrain appropriate model parameters; video analysis of large boulder motion near the granular front allows us to estimate the momentum exchange transfer between large particles and the bulk flow to be used in the model.

### THE OBSERVATION STATIONS

WSL operates four automated debris flow observation stations in the Swiss Alps (Fig. 1). The stations are equipped with:

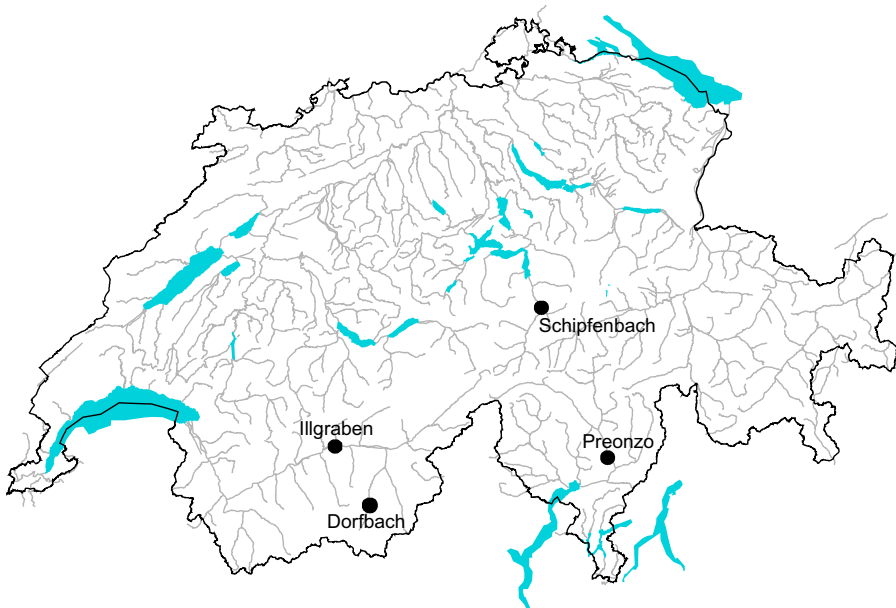
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<sup>1</sup> WSL Swiss Federal Research Institute, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland, [melissa.swartz@wsl.ch](mailto:melissa.swartz@wsl.ch)

<sup>2</sup> SLF Swiss Federal Research Institute, Flüelastrasse 11, CH-7260 Davos, Switzerland

- geophones, to record the vibrations caused by passing debris flows and also provide automatic triggering of the other sensors and data loggers in the catchments,
- ultrasonic or radar devices, to estimate flow depth and longitudinal profiles of the debris flow surge,
- video cameras, to allow analysis of flow geometry, flow behavior, sediment size, woody debris content and surface velocity, and
- rain gauges, to assess rainfall conditions at event initiation.

The geophones and ultrasonic or radar devices are synchronized, allowing estimation of the front velocity between instruments. The distribution of monitoring devices at the Schipfenbach and Illgraben catchments are illustrated in Figure 2. To assess the model, we use data from two events at the observation stations. A more detailed description of both stations is provided by Hürlimann et al. (2003) and Rickenmann et al. (2001).



**Figure 1** The location of the WSL debris flow observation stations.

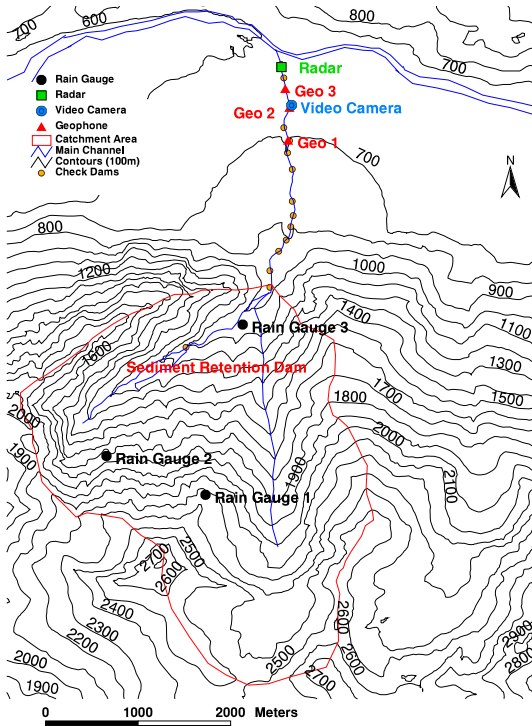
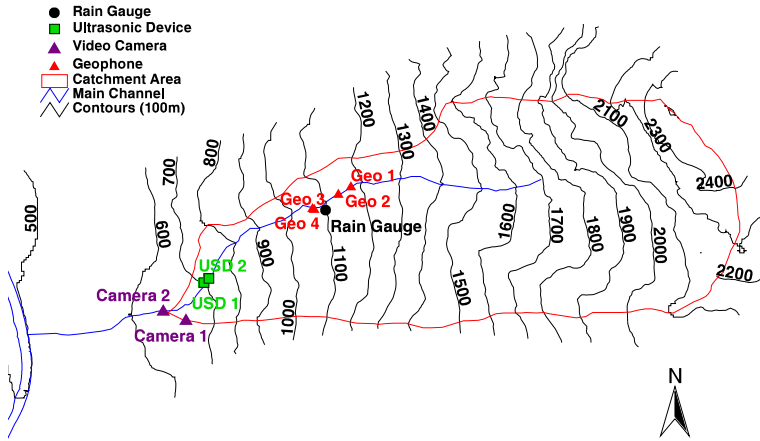


Figure 2 The instrumentation layout at the Schipfenbach (upper) and Illgraben (lower) catchments.

## Schipfenbach

The Schipfenbach observation station is located in central Switzerland in the northern Alps near Silenen in Canton Uri. The 1.8 km<sup>2</sup> catchment is steep, with an average torrent slope of 45% and an elevation difference of approximately 1930 m (Table 1). A sediment retention basin is located on the upper part of the fan, at about 650 m a.s.l.

On 6 August 2000 a debris flow with a total volume of 5000-5500 m<sup>3</sup> occurred at the Schipfenbach. Analyses of the data suggest the event occurred in two surges separated by about 1-2 minutes. Despite recording problems with geophones 1 and 2 at the onset of the event, normalized geophone data (Fig. 3a) illustrates the progression of the surges past the sensors. Subsequent field surveys and data analysis yields volume estimates for the two surges of 1600 and 3900 m<sup>3</sup>, respectively. Front trajectories calculated from the geophones and ultrasonic devices (Fig. 3b) indicate that, although the first surge was smaller, it was faster (Table 2). Further information on the event is available in Hürlimann et al. (2003).

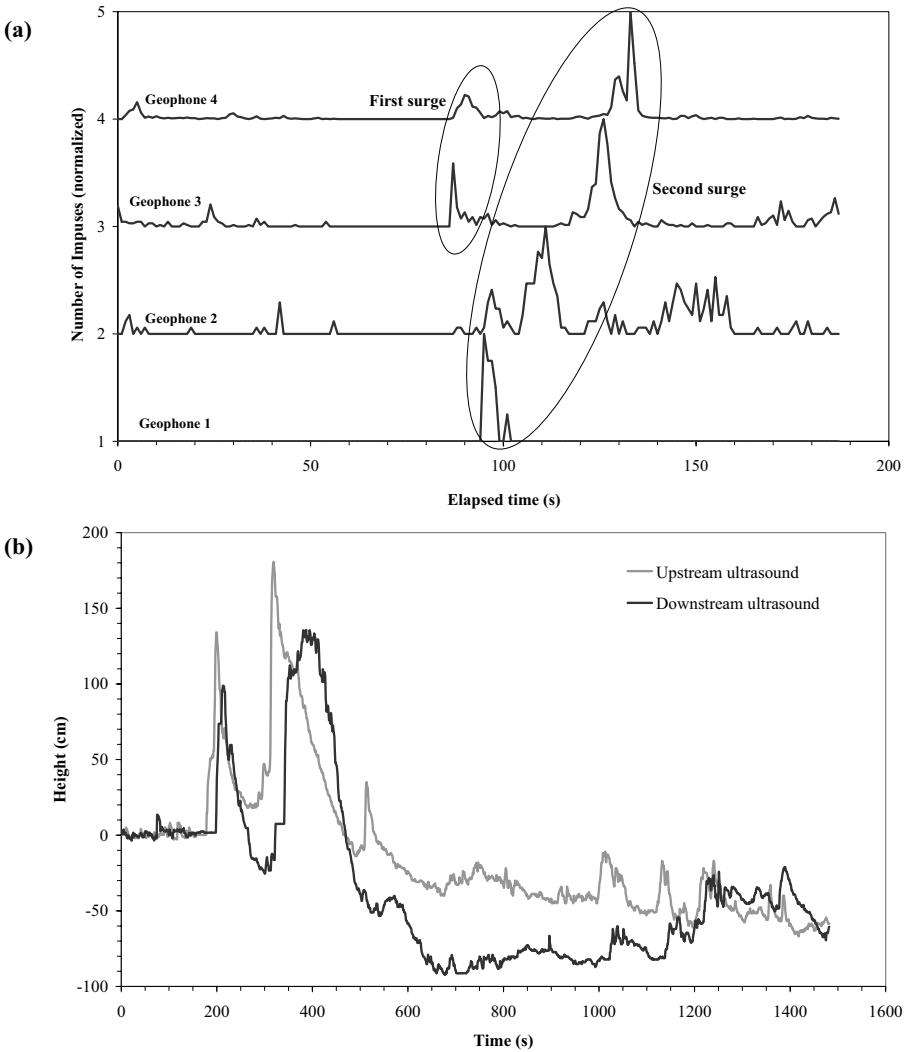
**Table 1** Characteristics of the Schipfenbach and Illgraben torrents.

<b>Parameter:</b>	<b>Schipfenbach</b>	<b>Illgraben</b>
Area (km <sup>2</sup> )	1.8	10.5
Ground coverage:		
Rock, loose material (%)	36	25
Forest (%)	45	30
Open vegetation (%)	19	43
Lakes (%)		2
Highest elevation (m a.s.l.)	2584	2790
Lowest elevation (m a.s.l.)	650	610
Aspect	W	N
Mean slope of torrent (%)	45	16
Mean slope of fan (%)	21	10
Length of main channel (km)	5.5	5.5

## Illgraben

The Illgraben observation station is located in the southern alps near Sierre in Canton Wallis. The catchment has an area of 10.5 km<sup>2</sup> ranging from the peak of the Illhorn (2790 m a.s.l.) to the Rhone River (610 m a.s.l.); the debris fan starts at about 850 m a.s.l. (Table 1, Fig. 2). Debris flows in the Illgraben generally have coarse granular fronts, although muddy debris flows also occur.

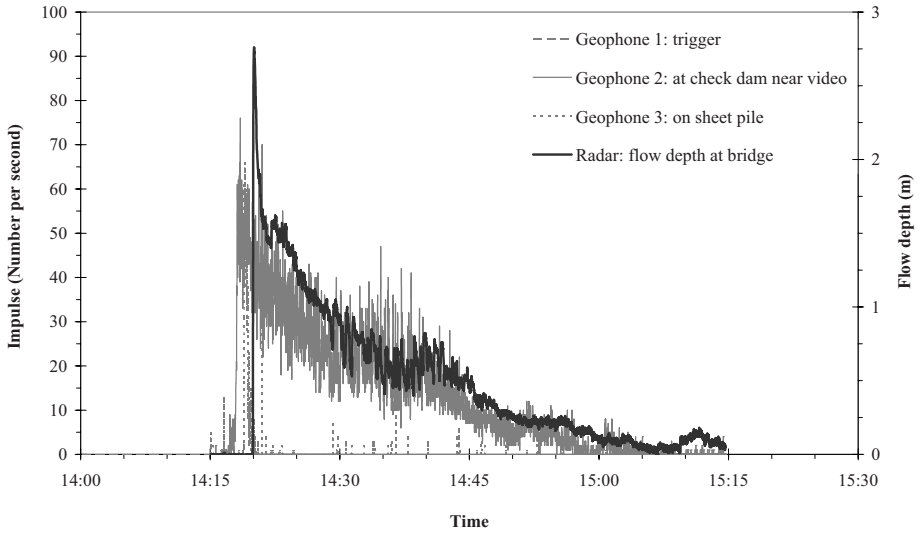
The 28 June 2000 debris flow event is estimated to have a volume of 70,000 m<sup>3</sup> (see Table 2). Geophone and radar data (Fig. 4) indicate the passing of one surge; video recordings of the event show a debris flow with a coarse granular front, followed by a muddy, turbulent flow. Video analysis of the movement of large boulders comprising the front indicates that while most boulders tend to move as fast as the flow, some travel slightly faster than the flow to become part of the granular front. Results of such video analysis can be used to estimate the momentum exchange between the large particles and the bulk flow in the model.



**Figure 3** Geophone (a, upper) and ultrasonic device data (b, lower) from the Schipfenbach event.

**Table 2** Event characteristics.

Event location and date	Volume (m <sup>3</sup> )	Peak discharge (m <sup>3</sup> /s)	Maximum flow height (m)	Maximum front velocity (m/s)
Schipfenbach 6 August 2000				
1 <sup>st</sup> surge	1600	30	1.4	6.7
2 <sup>nd</sup> surge	3900	52	1.8	6.1
Illgraben 28 June 2000	70,000	93	2.2	4.7



**Figure 4** Geophone (impulses) and radar (flow depth) data from the 28 June 2000 event at the Illgraben.

### THE DBF-1D MODEL

DBF-1D simulates the flow velocity, depth and runout distance of debris flows. It was created for practitioners for debris flow hazard mapping and to aid in evaluation of mitigation measure design in steep mountain torrents. Depth-averaged mass, volume and momentum equations are solved for the solid and fluid phases of a debris flow, and are coupled by a momentum transfer function. The fluid phase is composed of water, can include suspended sediment and may have a variable density. The solid phase consists of granular material and pore space, the proportions of which are held constant. In the flowing solid phase, the pore space is either fully or partially saturated with fluid.

DBF-1D employs the Voellmy-fluid relation to calculate the flowing friction of the debris flow, treating the solid phase as a variably saturated Coulomb-type material. The frictional behavior of the fluid phase is described by a Chézy-type relation. The flowing friction,  $F$ , of the two phases is described by

$$F_{solid} = \frac{v^2}{\xi_s h} + \mu \cos \alpha \quad \text{with } \mu = \tan \delta \quad (\text{solid phase}) \quad \text{and} \quad F_{fluid} = \frac{v^2}{\xi_f h} \quad (\text{fluid phase})$$

where  $v$  is the velocity (m/s),  $h$  is the flow height (m),  $\alpha$  is the local bed slope (-),  $\xi_s$  and  $\xi_f$  ( $\text{m/s}^2$ ) are Chézy-like friction terms for the solid and fluid phases, respectively and  $\mu$  represents the angle of internal friction of the solid phase ( $^\circ$ ).  $\xi_s$  and  $\xi_f$  are equal to the square of the Chézy friction coefficient,  $C$ , and are dependent on the channel roughness and flow properties;  $\mu$  is equal to  $\tan \delta$ , where  $\delta$  is equal to the internal angle of friction of the solid phase material.

Debris flow material is input via a hydrograph, which is divided into solid and fluid fractions based on the nature of the debris flow (i.e., granular or muddy), and which is based on an estimated event volume. We use an empirical relationship (Rickenmann, 1999) to calculate the peak discharge based on the event volume; the duration of the event is based on the peak discharge and volume data. The total input volume is then divided between the solid and fluid phases depending on the type of flow. Costa (1988) and Iverson (1997) indicate that solids typically comprise between 50 – 80% of the total debris flow volume; this percentage is likely to drop to 40 – 50% for lahars and muddy debris flows (Iverson and Denlinger 2001, Iverson and Vallance 2001). Here we assume that the solids comprise 70% of the flow by volume.

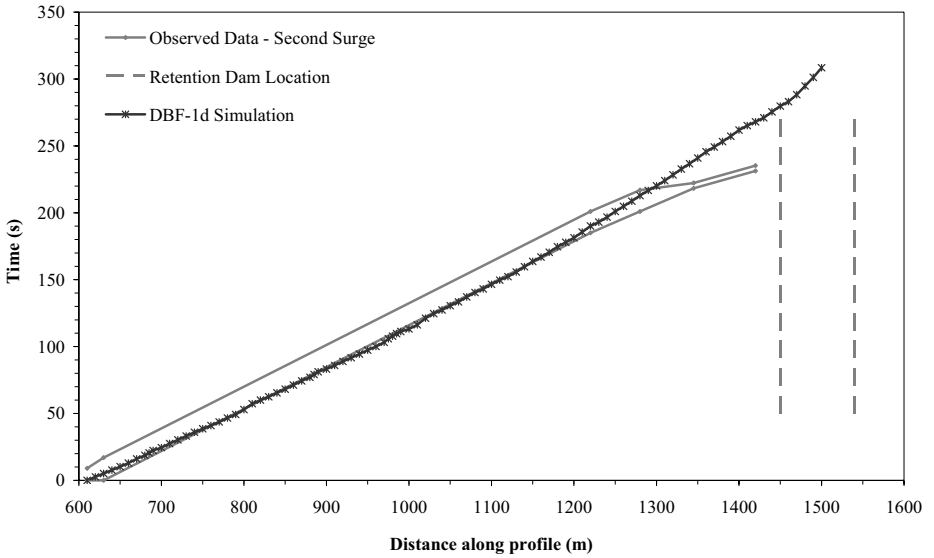
DBF-1D calculates flow velocities and heights using simplified rectangular or trapezoidal channel cross sections. Topographic data needed for model simulations include a longitudinal profile (x, y and z data), channel bottom width and the sidewall angle for the two channel banks.

## NUMERICAL ANALYSIS, RESULTS AND DISCUSSION

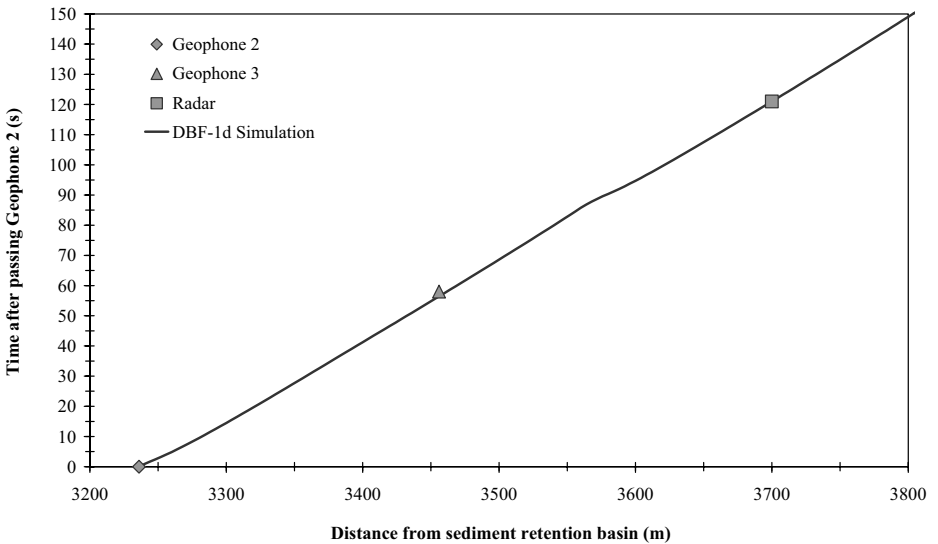
The Schipfenbach and Illgraben observation station data provide a unique opportunity to evaluate DBF-1D. For the Schipfenbach case, we present only the model results of the second surge, primarily because it was the larger of the two surges and flow area estimates from post-event field measurements are available. We used a rectangular topographic profile with 10 m grid spacing, variable slope and a constant width. The sediment retention basin is represented in the model by a width increase, followed by a width decrease to simulate the retention basin outlet. The input volume was 3900 m<sup>3</sup> with a peak discharge of 52 m<sup>3</sup>/s and a total duration of about 100 s.

To simulate the Illgraben event we used a rectangular channel profile with a 4 m grid spacing and a variable slope and width. Debris flows at the Illgraben do not stop on the fan, but discharge directly into the Rhone River. Therefore, deposition and runout are constrained only by the observation that the flows reach the Rhone River. The input volume was set at 33,000 m<sup>3</sup> (disregarding the muddy tail of the flow) with a peak discharge of 280 m<sup>3</sup>/s and a total duration of 235 s. The input peak discharge is greater than the observed value to account for attenuation of the wave height. The peak discharge approximately matches the observed value at the location of the radar sensor at the downstream end of the study reach. The momentum exchange coefficient was set large enough so that the phases have approximately the same velocity, as was observed in the video recordings.

Figure 5 shows our simulated front velocity results compared to the observation station data at Schipfenbach, those from the Illgraben are presented in Figure 6. We were able to match the observed front trajectory data using a number of parameter combinations. Overall, increasing the value of  $\xi_r$  and  $\xi_s$  increases the flow velocity and changes in  $\xi_r$  tend to have a significant influence on the debris flow velocity, while changes in  $\xi_s$  have less of an influence.

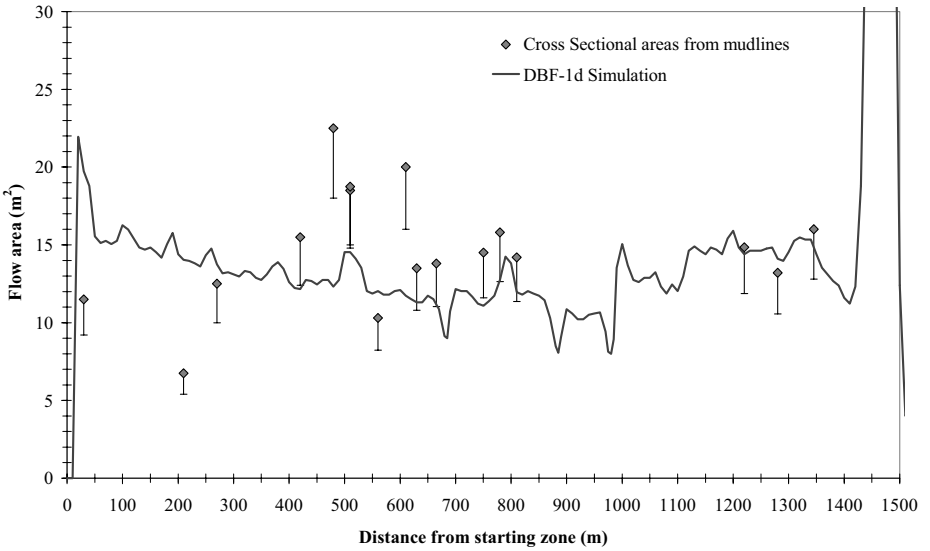


**Figure 5** Comparison of observed and simulated front trajectory for the second surge of the 6 August 2000 Schipfenbach event. The observed data are presented as an error envelope.

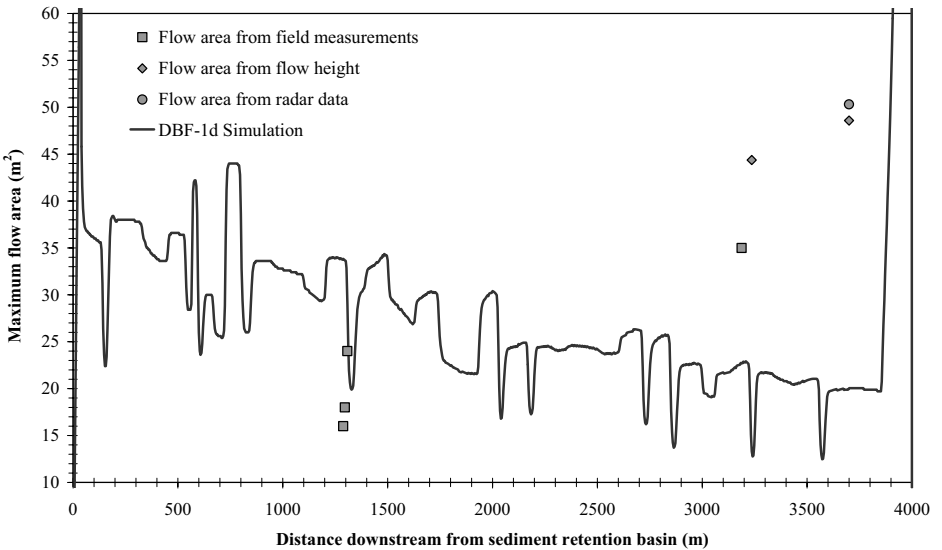


**Figure 6** Observed and simulated front trajectory data from the 28 June 2000 Illgraben event.

Figures 7 and 8 show the flow areas calculated by DBF-1D for the second surge of the Schipfenbach event and the Illgraben event, respectively. In both cases, the flow areas are underestimated, although they are slightly less so for the Schipfenbach case.

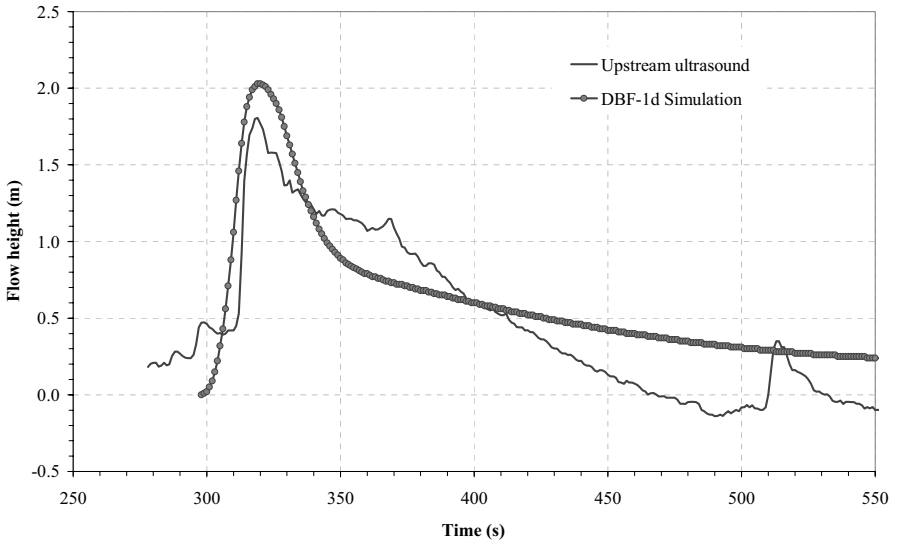


**Figure 7** Observed and simulated flow areas for the 6 August 2000 Schipfenbach debris flow (second surge). Field measured flow areas are shown with an error bar of 20 % to account for erosion.

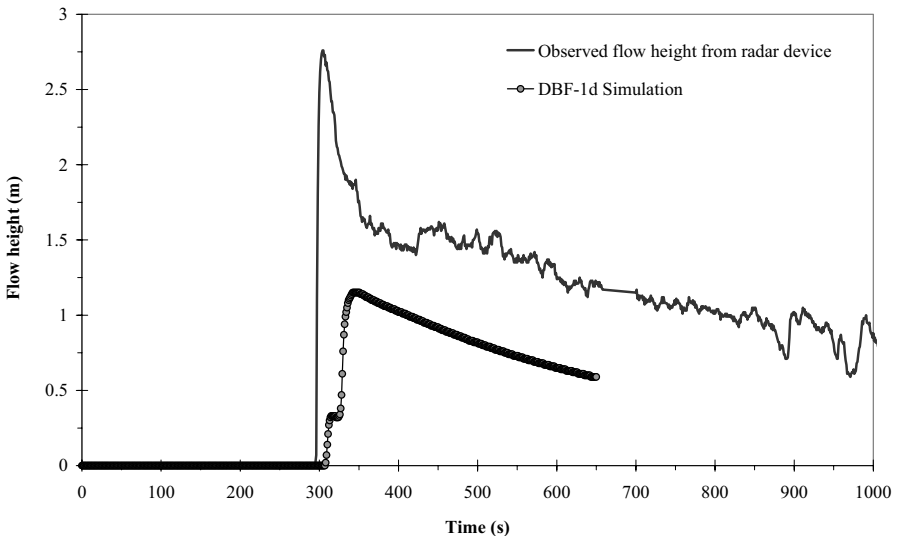


**Figure 8** Observed and simulated flow areas for the 28 June 2000 Illgraben debris flow.

Figures 9 and 10 compare the observed flow hydrographs (from ultrasonic or radar devices) at the Schipfenbach and Illgraben catchments, respectively. DBF-1d simulates flow heights at Schipfenbach reasonably well, slightly overestimating the peak height; at Illgraben, the peak flow height is underestimated.



**Figure 9** Observed and simulated flow hydrographs at the upper ultrasonic device for the 6 August 2000 Schipfenbach debris flow (second surge).



**Figure 10** Observed and simulated flow hydrographs for the 28 June 2000 Illgraben debris flow.

Systematic underestimation of simulated flow heights is, in our experience, a common problem when modeling debris flows where the parameters have been adjusted to match the observed flow velocity. For DBF-1d, the best results were obtained when the total solid friction is larger than the total fluid friction; this can be interpreted as the granular front acting like a dam, impeding the fluid phase (Parsons et al. 1999). The poor match with the flow height data at the Illgraben torrent is most likely due to the tendency of the flows to form their own channel levees at this section due to local channel widening.

## CONCLUSIONS

DBF-1D is a new tool for simulating debris flow behavior being developed at the Swiss Federal Research Institutes WSL and SLF. This two-phase approach is a simple yet physically realistic description of debris flow which can be used to provide a realistic estimation of debris flow velocities. While flow depths are currently slightly underestimated, further research into parameter combinations and the influence of channel geometry will likely improve this issue.

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