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TopFlowDF - A SIMPLE GIS BASED MODEL TO SIMULATE DEBRIS-FLOW RUNOUT ON THE FAN

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ABSTRACT

Typically runout prediction methods - either based on empirical or on dynamical approaches - are applied to delineate possible debris-flow inundation zones on the fan for hazard mapping purposes. However, several case studies indicate that empirical relations may be valid only for situations which are similar to those represented by the data used for their development, and that a more accurate description of the debris-flow depositional process requires dynamical parameters which are often not easily constrained. In this study we propose that the topography of the potential deposition area has a major influence in the runout of a debris flow. We combine a random based flow algorithm, generating a maximum simulation perimeter on the fan, with the simple dynamical approach of a constant discharge model to predict the maximum runout on the fan. The program called TopFlowDF simulates deposition zones, associated deposition heights and a spatial distribution of the maximum flow velocities. The GIS-based simulation model runs with high resolution (2.5 m x 2.5 m) digital elevation models, generated for example from LiDAR data, and is tested with debris-flow events from Switzerland and South Tyrol. The predicted runout patterns of TopFlowDF are further compared with the empirical runout prediction method TopRunDF.

Key words: *debris flow, predictive modelling, GIS*

INTRODUCTION

Throughout the world, debris flows endanger settlements and infrastructures - often with disastrous effects for the affected communities. It is therefore not surprising that the risk concept for natural hazards (e.g. Heinimann *et alii*, 1988; Glade & Grozier, 2005) was also extended to debris-flow processes within the last decades (Fuchs *et alii*, 2008). Subsequently, this approach causes a demand for reliable debris-flow runout prediction methods, especially when delineating hazardous areas on the fan. To describe the depositional characteristics and runout behaviour of debris flows, several approaches, either based on empirical-statistical or dynamical methods, have been developed during the last decades. The complexity of prediction methods for debris-flow runout on the fan vary from simple one-dimensional topographical approaches to two-dimensional numerical continuum models. An overview of recent debris-flow runout models can be found in Rickenmann, 2005; Hürlimann *et alii* 2008; Scheidl & Rickenmann, 2010 and Rickenmann & Scheidl, in press.

However, practical application, respectively the selection of adequate runout prediction models, is mainly based on their availability and on the requirements of local hazard assessments. In Austria for instance, the criterion to delineate hazardous zones for potential debris-flow events is based on the maximum runout distance or maximum inundated area on the fan (e.g. Schmid, 2005). To investigate the similar spatial relevant area in Switzerland, it is necessary to estimate the maximal runout respectively lateral spreading and the intensity (flow height, flow velocity), of the potential debris-flow event (BWW/BRP/BUWAL, 1997). These examples may justify different approaches to predict the mobility of debris-flow events.

In this study we present TopFlowDF, an uncomplex, GIS based model to simulate debris-flow runout on the fan. The delineation of deposition zones, simulated with TopFlowDF, includes a physical and empirical component since the model combines the simple dynamical constant discharge model (Hungr *et alii*, 1984; Takahashi, 1991) with the flow paths simulation, implemented in TopRunDF (Scheidl & Rickenmann, 2010). The study further describes the basic concepts and verifies respectively evaluates the model against observed debris-flow events in Switzerland and Northern Italy (South-Tyrol). The resistance to flow parameters, obtained by several applications of the constant discharge model, are discussed and further compared with back-calculated friction parameters of TopFlowDF simulation results. Finally we compare the results of TopFlowDF with results of the empirical based runout model TopRunDF for Swiss debris-flow events.

FRAMEWORK OF TOPFLOWDF MODEL

CONSTANT DISCHARGE MODEL

Hungr *et alii* (1984) and Takahashi (1991) described a dynamical model to estimate the runout on the fan (L_f), based on the work of Takahashi & Yoshida (1979). This one-dimensional model assumes a constant discharge from upstream and that deposition starts at the place where the channel abruptly levels out, it is therefore also denoted as leading-edge model (VanDine, 1996; Prochaska *et alii*, 2008). The profile of such a debris flow at time *t* and *t+Δt* is modelled by the trapezoidal shape, shown in Fig. 1 (Takahashi, 1991).

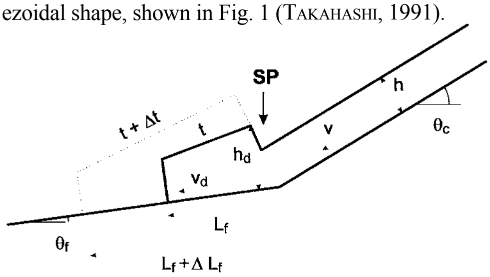

Fig. 1 - Process of stoppage of forefront of a debris flow (Takahashi, 1991); SP denotes the starting point of the deposition, the flow parameters are described in the text

For a constant flow-width, the linear runout distance on the fan L_f can analytically be estimated under consideration of mass- and momentum-conservation, using:

$$L_f = \frac{U^2}{G} \tag{1a}$$

with

$$U = v\cos(\theta_c - \theta_f)\left[1 + \frac{gh\cos\theta_c}{2v^2}\right] \tag{1b}$$

$$G = g(S_{fric}\cos\theta_f - \sin\theta_f) \tag{1c}$$

Equation (1b) describes the driving component of a debris flow mass, based on the flow velocity (v) and the flow height (h) above the starting point of the deposition (with the velocity at deposition v_d and the deposition height h_d), as well as the mean angle of the approach channel (θ_c) and mean angle of the fan (θ_f). The resistance to flow is described by Eq. (1c) with the friction slope (S_{fric}) accounting only for sliding friction.

Resistance to flow approaches

Equation (1a) can only yield to plausible results (positive L_f), if the friction slope exceeds the average mean angle on the fan (Eq. 2).

$$S_{fric} = K_{fric}\tan\theta_f \text{ with } K_{fric} > 1 \tag{2}$$

Studies show that the frictional slope S_{fric} is very close to the mean angle of the fan θ_f generated by debris flows.

Based on five Canadian debris-flow events, Hungr *et alii* (1984) found reasonable agreement between observed runouts on the fan and those predicted by Eq. (1a) by assuming a constant friction slope (S_{fric} = tan 10°). They obtained the flow parameters v and h from design discharge by means of empirical equations.

Based on 14 debris-flow events at the Kamikamihori valley in Japan (Okuda & Suwa, 1984), Rickenmann (2005) reported better predictions of L_f with S_{fric} = 1.12 tanθ_f instead of S_{fric} = tan 10°. He further found reasonable predictions of runout length for twelve Swiss debris-flow events of 1987 with S_{fric} = 1.08 tanθ_f.

D'Agostino *et alii* (2010) found a K_{fric} value of 1.072 based on investigations of six debris-flow events in the Dolomites (Eastern Italian Alps).

Rickenmann & Scheidl (2010) found a significant correlation between the friction slope S_{fric} and the average fan slope θ_f. Based on observed debris-flow runout distances in Northern Italy (South Tyrol) and Switzerland, they proposed:

$$S_{fric} = 1.29 \sin\theta_f \tag{3}$$

FLOW ROUTING ALGORITHM

The two-dimensional runout model TopFlowDF combines the simple physical approach of the constant discharge model with a random based flow algorithm which is also implemented in the empirical runout prediction model TopRunDF (Scheidl & Rickenmann, 2010).

In a first step, TopFlowDF automatically estimates the maximum extent of the simulation perimeter $B_{perimeter}$ due to topographical conditions. The quantity of this simulation perimeter is derived by an area-volume relation, which was first proposed by Iverson *et alii* (1998) to delineate lahar-inundation hazard zones. $B_{perimeter}$ is estimated with a user defined mobility coefficient k_B (e.g. Scheidl & Rickenmann, 2010) and a debris-flow event volume V.

$$B_{perimeter} = k_B V^{2/3} \quad (4)$$

Based on the topography and the maximum expected areal extent ($B_{perimeter}$), TopFlowDF simulates lateral flow patterns by using a D8 single flow-algorithm combined with a Monte Carlo technique as described in Hürlimann *et alii* (2008) and Scheidl & Rickenmann (2010). Figure 3 illustrates the effect of lateral enlargement of the simulation perimeter, which is based on multiple (n) individual flow paths(i) with constant flow width b (= gridsize of the input DTM) and a probability $p(cell_j)$ of each overflowed cell within each flow path(i). Terminal conditions for the individual flow pathways are set by the perimeter of the elevation model or by adverse slopes.

The input parameters of the first step of TopFlowDF consist of a debris-flow volume, a mobility coefficient, a starting point of the deposition (fan apex) and a digital terrain model of the fan area. The

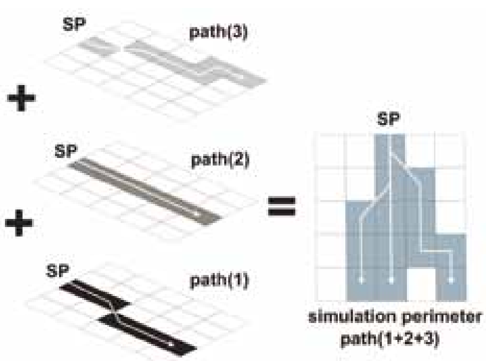

Fig. 3 - Estimation of the simulation perimeter with multiple individual flow pathways. SP denotes the user defined start point

simulated maximum extent of $B_{perimeter}$ provides the basis for the two-dimensional simulation of the final flow-height and flow-velocity patterns in step two.

In the second step the approach of the constant discharge model is applied in a differential form to each individual flow path(i):

$$\frac{dv}{dt} = \frac{U}{t} - G - \frac{1}{t}v \quad (5)$$

In Eq. (5) the driving component U of a debris-flow mass and the resistance component G are calculated by Eqs. (1b) and (1c). The resistance to flow is described by a user defined friction coefficient (k_{fric}) according to Eq. (2). The maximum runout, for each individual flow path(i) is then estimated from the predefined starting point of the deposition (SP) assuming uniform discharge. For this reason the input peak discharge (Q_p) has to be partitioned, related to the length of each individual flow path(i) and probability of each overflowed cell p($cell_j$), associated with the flow path(i). The sub-discharge, $Q_{path(i)}$ with m the number of cells within each path(i) and n the number of all flow paths, is then estimated by:

$$Q_{path(i)} = \frac{Q^*_{path(i)} Q_p}{\sum_{i=1}^{n} Q^*_{path(i)}} \quad (6)$$

with

$$Q^*_{path(i)} = \frac{\sum_{j=1}^{m} p(cell_j) Q_p}{m} \quad (7)$$

and

$$\sum_{i=1}^{n} Q_{path(i)} = Q_p \quad (8)$$

Knowing the uniform sub-discharge $Q_{path(i)}$, a maximum runout distance for each flow path(i) is estimated by means of Eq. (5), and is reached when the calculated flow velocity over time equals zero. Instead of a constant friction slope, the user needs to define a friction coefficient (k_{fric}; Eq. 2). This approach results in a variable resistance to flow during simulation, depending on the slope gradient between the actual outflow- and inflow-cell. It further prevents the flowing mass to accelerate on the simulated fan. Therefore the highest velocities exist at the starting point of the deposition (simulation). The simulations of the deposition heights are based on the distribution of the total volume in proportion to the overflow probability $p(cell_j)$ of each cell.

As an example, Fig. 4 shows the predicted deposition- and velocity-pattern for the 2005 debris-flow event at the Glattbach - torrent in Switzerland.

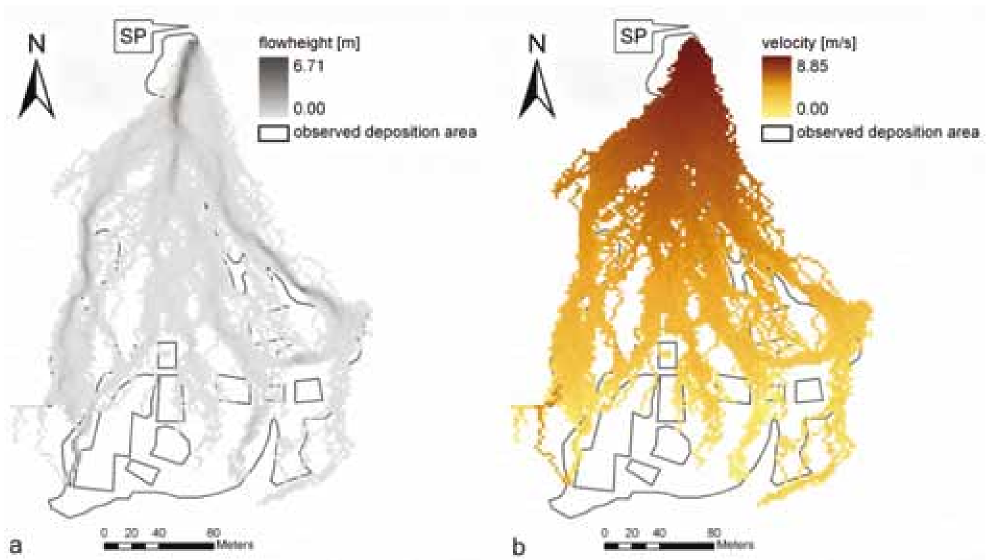

Fig. 4 - Simulation results of TopFlowDF for the Glattbach debris-flow event. a) predicted deposition zones, b) predicted velocity pattern. SP denotes the starting point of the simulation Contour interval is 1 m

The input parameters for the second step of TopFlowDF consist of peak discharge, flow-height and flow-width as well as average channel slope above the starting point and a friction coefficient.

For the simulations within this study, peak discharge Q_p and flow height h were estimated with empirical equations proposed by RICKENMANN (1999):

$$Q_p = 0.1V^{5/6} \tag{10}$$

$$v = 2.1 Q_p^{1/3} S_c^{1/3} \tag{11}$$

$$h = \frac{Q_p}{v \cdot b} \tag{12}$$

The flow width b at the starting point as well as the average channel slope S_c were measured directly from the LiDAR DTM, areal photographs and on 1:25,000 scale topographic maps.

TopFlowDF runs with high resolution (2.5 m x 2.5 m) digital elevation models, written in VB.NET©. The executable program as well as the source-code can be downloaded for free, after registration from *www.debris-flow.at*

ANALYSIS OF RESULTS

To test the dynamical approach of TopFlowDF, we compared the analytical (Eq. 1a) and differential (Eq. 5) solutions of the constant discharge model for an observed Swiss debris-flow event at the Glattbach torrent in 2005 (Figure 5).

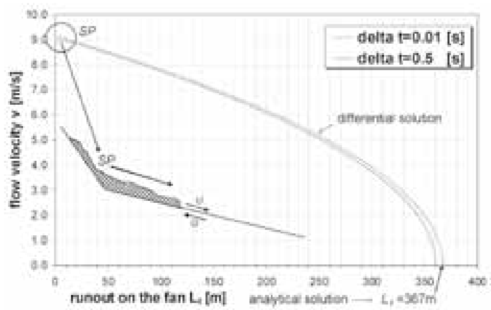

Fig. 5 - Comparison between analytical (Eq. 1a) and differential (Eq. 5) solution of the constant discharge model for the observed debris-flow event at the Glattbach (Switzerland)

The flow parameters at the fan apex, for the example in Fig. 4, are estimated with v = 8.84 m/s and h = 1.01 m based on the observed Volume (V = 8,800 m^3). The mean angle of the fan respectively channel are θ_f = 8.40 (S_f = 0.15) and θ_c = 20.72 (S_c = 0.38). The analytical solution of the runout distance for the Glattbach debris-flow event results to 367 m, based on a friction slope of S_{fric} = 0.17. With a selected time interval of Δt = 0.5 s the differential solution stops the debris-flow after 80 seconds reaching a distance of 360 meters. With a smaller time interval, Δt = 0.01, the estimated distance reaches 367 m (in 80 s). The differential approach shows more precise results if we use smaller timesteps. Therefore, TopFlowDF uses a pre-defined time interval of Δt = 0.01.

event name	region	V_{obs} [m³]	k_{Bobs} [-]	S_c [-]	Q_p [m³/s]	v [m/s]	b [m]	h [m]
Glattbach	CH	8,800	76	0.58	197	8,84	22.00	1.00
Rotlauibach	CH	50,000 (399,000)*	14	0.65	824	17.06	21.00	2.30
Schwendibach	CH	11,000	58	0.52	233	10.38	24.00	0.94
Blauseeligraben	CH	2,000	35	0.54	56	6.54	13.00	0.66
Gonerli	CH	5,000	33	0.30	121	6.96	9.00	1.93
Piz Caral	CH	3,000	29	0.77	79	8.25	12.00	0.80
Richleren	CH	9,000	92	0.42	197	9.15	9.00	2.40
Heugandtal	CH	7,000	47	0.56	160	9.40	15.00	1.14
Brichboden	CH	4,000	52	0.53	100	7.88	8.00	1.59
Val Mera 1	CH	2,000	29	0.37	56	5.80	6.00	1.62
Gerental 3B	CH	33,000	19	0.57	583	14.52	12.00	3.34
Ri di Gallinoso	CH	4,000	53	0.26	100	6.26	9.00	1.78
Ri di Sozz	CH	3,000	38	0.50	79	7.13	13.00	0.85
Saasbach	CH	50,000 (180,000)*	14	0.21	824	11.65	25.00	2.79
Arundakopfbach	ST	15,000	58	0.50	300	11.27	10.00	2.70
Draunbergerbach	ST	2,000	19	0.56	56	6.74	7.00	1.20
Fanatjoch	ST	5,000	36	0.48	121	7.89	9.00	1.70
Klammbach	ST	30,000	30	0.39	538	13.06	18.00	2.40
Koglbach	ST	15,000	38	0.39	302	10.66	16.00	1.90
Seefeldbach	ST	50,000 (70,000)*	37	0.49	538	14.45	22.00	1.69

Tab. 1 - Input process parameters for the TopFlowDF simulations of observed debris-flow events in Switzerland (CH) and South-Tyrol (ST)

For this study, the runout on the fan of 14 debris-flow events in Switzerland and 6 debris-flow events in South Tyrol were simulated and evaluated with the observed deposition patterns. For the modelling of the individual simulation perimeters a back-calculated mobility coefficient (k_{Bobs}) is used, based on the observed deposition area (B_{obs}) and the observed event volume (V_{obs}) (SCHEIDL AND RICKENMANN, 2010).

$$k_{Bobs} = B_{obs} / V_{obs}^{2/3} \qquad (13)$$

Table 1 lists the used input parameters for all TopFlowDF simulations in this study.

Analysis of a large Swiss debris-flow event in the Varuna catchment, with a total volume of 214,000 m³, an upper limit of 50,000 m³ for a single-surge volume was estimated in relation to the documented peak discharge (VAW, 1992). We therefore limited the "input-volume" to 50,000 m³ for the simulation procedure for debris-flow events exceeding a total volume of 50,000 m³. This concerned the debris-flow events at the Rotlauibach, Saasbach and Seefeldbach, marked with a * in Table 1.

The following evaluation concept of TopFlowDF is based on a methodology used in SCHEIDL & RICKENMANN (2010) and first described by CARRANZA & CASTRO (2006). Three different area-accuracies (denoted as α, β and γ) are determined, based on the relations:

- $\alpha = \dfrac{\text{predicted deposition zones}}{\text{observed deposition areas}}$
- $\beta = \dfrac{\text{predicted deposition zones}}{\text{non-deposition areas}}$
- $\gamma = \dfrac{\text{non-predicted deposition zones}}{\text{observed deposition areas}}$

Similar the positive (ε) and negative (φ) volume-prediction accuracies are defined. Here ε is defined as the relation of the total volume within the predicted deposition zones related to the observed deposition areas, and φ is defined as the inverse value of the positive volume-prediction accuracy. The overall evaluation factor (Ω) is then calculated as:

$$\Omega = \alpha - \beta - \gamma + \varepsilon \qquad (9)$$

within a range of $-2 \leq \Omega \geq 2$.

The best fit simulation is characterized by $\Omega = 2$, then the simulated deposition pattern equal the observed deposition pattern. On the contrary, a value of $\Omega = -2$ implies no overlapping between the simulated and observed deposition area.

event-name	region	α [-]	β [-]	γ [-]	ε [-]	φ [-]	Ω [-]	$k_{fric(sim)}$ [-]
Glattbach	CH	0.62	0.39	0.38	0.71	0.29	0.56	1.075
Rotlauibach	CH	0.54	0.26	0.46	0.91	0.09	0.72	1.072
Schwendibach	CH	0.73	0.28	0.27	0.57	0.43	0.76	1.082
Blauseeligraben	CH	0.69	0.27	0.31	0.84	0.16	0.96	1.109
Gonerli	CH	0.80	0.26	0.20	0.89	0.11	1.22	1.070
Piz Caral	CH	0.65	0.28	0.35	0.78	0.22	0.79	1.043
Richleren	CH	0.72	0.13	0.28	0.81	0.19	1.13	1.035
Heugandtal	CH	0.50	0.38	0.50	0.59	0.41	0.21	1.045
Brichboden	CH	0.46	0.41	0.54	0.67	0.33	0.19	1.025
Val Mera I	CH	0.66	0.37	0.34	0.68	0.32	0.63	1.040
Gerental 3B	CH	0.63	0.36	0.37	0.84	0.16	0.75	1.165
Ri di Gallinoso	CH	0.62	0.37	0.38	0.57	0.43	0.45	1.042
Ri di Sozz	CH	0.87	0.15	0.13	0.97	0.03	1.55	1.072
Saasbach	CH	0.64	0.16	0.36	0.97	0.03	1.08	1.060
Arundakopfbach	ST	0.53	0.50	0.47	0.72	0.28	0.28	1.035
Draunbergerbach	ST	0.60	0.42	0.40	0.71	0.29	0.49	1.200
Fanatjoch	ST	0.49	0.52	0.51	0.79	0.21	0.26	1.044
Klammbach	ST	0.78	0.22	0.22	0.89	0.11	1.24	1.082
Koglbach	ST	0.49	0.32	0.51	0.90	0.10	0.50	1.044
Seefeldbach	ST	0.59	0.42	0.41	0.36	0.64	0.11	1.084
Mean		**0.63**	**0.32**	**0.37**	**0.76**	**0.24**	**0.70**	**1.070**
SD		**0.11**	**0.11**	**0.11**	**0.16**	**0.16**	**0.40**	**0.044**

Tab. 2 - Accuracies and adapted friction coefficients for the simulated debris-flow events with TopFlowDF. The possible range of Ω is [-2,2]; SD denotes standard deviation,CH is for Swiss debris-flow events, whereas ST stands for South-Tyrolean (Italy) debris-flow events

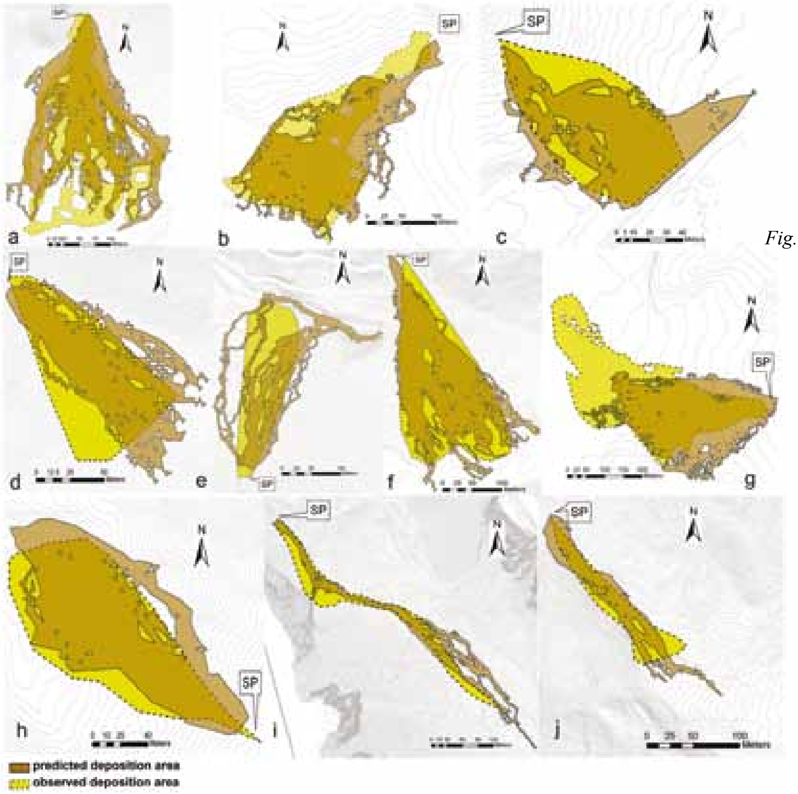

Fig. 6 - Comparison of observed deposition areas and predicted deposition zones with TopFlowDF a) Glattbach, b) Schwendibach, c) Blauseeligraben, d) Piz Caral, e) Heugandtal f) Richleren, g) Rotlauibach, h), Gonerli, i) Brichboden, j) Val Mera 1. SP denotes the starting point of the deposition. Contour-interval is 1 m

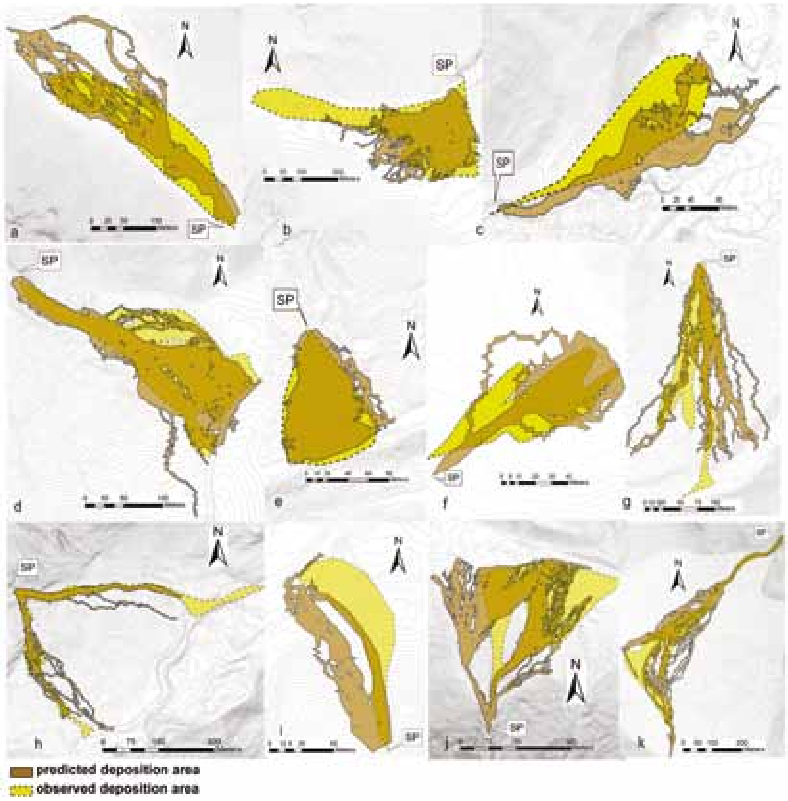

Fig. 7 - Comparison of observed deposition areas and predicted deposition zones with TopFlowDF a) Gerental 3B, b) Saasbach, c) Ri di Gallinoso, d) Klammbach, e) Ri di Sozz; f) Draunbergerbach, g) Fanatjoch, h) Koglbach, i) Seefeldbach, j) Arundakopfbach. SP denotes the starting point of the deposition. Contour-interval is 1 m

The simulation results of the back-calculated debris-flow events used for this study are shown in Figs. 6 and 7. If the simulated deposition area differed from the observed deposition area (agreement of surface area), the pre-defined friction coefficient was adapted ($k_{fric(sim)}$, Eq.2) until the simulated zones equalled to the observed deposition area. The accuracies as well as the best-fit $k_{fric(sim)}$ values are listed in Table 2.

On average, and for all used debris-flow events in this study, TopFlowDF predicted 63 % of the observed area and 76 % of the observed volume, compared to the observed deposition zones. 37 % of the area and 24 % of the volume were predicted outside the observed deposition zones. The average friction coefficient amounts to 1.070 +/- 0.044.

DISCUSSION AND CONCLUDING REMARKS

TopFlowDF simulates the maximum flow velocities and maximum deposition heights on the fan, based on the constant discharge approach (Equations 1a-1c). Therefore, starting flow parameters - flow-height, maximum discharge as well as flow width - need to be estimated based on empirical relations or on field data. Further, a suitable coefficient for k_{fric} of the friction slope in Equation 2 has to be selected, based on a correlation between the friction slope S_{fric} and the fan slope S_f. The existence of such a correlation can be explained by rheological characteristics of debris-flow events. Studies of Jackson *et alii* (1987), Marchi & Tecca (1995), Chau *et alii* (2000) and Rickenmann (2005) imply that granular flow behavior will lead to a higher roughness and friction during depositional flow, resulting in steeper fan slopes on average and in a smaller mobility. A more viscous or muddy flow behaviour, on the other hand, shows higher mobility and results in smoother and flatter fans. However, the back-simulated friction coefficients in this study ($k_{fric(sim)}$) are based on a reach wise estimation of the resistance to flow during deposition of 14 debris-flow events. Future back-simulations are necessary to test the difference between a reach wise estimation (as implemented in TopFlowDF) of the friction coefficient and a resistance coefficient, which is constant along the entire flow path on the fan, as used together with the analytical solution in Equation 1a.

Since the lateral spreading of the simulation perimeter $B_{perimeter}$ is controlled by the same approach as applied in TopRunDF, the presented model TopFlowDF behaves similarly, regarding the selection of a starting point of the simulation and the use of the Monte-Carlo-Iteration number (MCI). The starting point corresponds to a single DTM cell within a cross-section of the channel close to the fan apex and is sensitive to the level of detail of the digital terrain model. Using LiDAR data with an orthogonal gridsize of 2.5 m a maximum difference of 10 m was determined between the user defined start point and the observed start point of the deposition for the simulated debris-flow events in this study.

Scheidl & Rickenmann (2009) found an optimised iteration number MCI = 50, based on 14 simulations of Swiss debris-flow events. This number was also used for the simulation in this study. A detailed discussion of the MCI number and its influence on the simulation results is given in Scheidl & Rickenmann (2010) and Rickenmann & Scheidl (2010).

For large debris-flows, material may be deposited on the fan outside of the main channel. In such a case TopFlowDF is capable to estimate lateral runout on the fan. In contrast to the similar two-dimensional model TopRunDF (Scheidl & Rickenmann, 2010), TopFlowDF is not only based on an empirical approach but include also a simple dynamical runout model. Hence, higher uncertainties of the simulation results of TopFlowDF may originate from the selection of input flow parameters and due to the separation of the start momentum into multiple flow paths.

Comparing the simulation results of TopFlowDF with TopRunDF (Scheidl & Rickenmann, 2010) a larger standard deviation of the resulting accuracies and a lower average overall evaluation factor (Ω) for the results with TopFlowDF are noticed. Table 3 lists all area- and volume-accuracies as well as the total evaluation factors for the simulation results of TopFlowDF and TopRunDF respectively, for the 14 Swiss debris-flow events used in Scheidl & Rickenmann (2010). It appears that for most of the debris-flow events simulated with TopRunDF, more accurate results can be achieved, compared to the simulation results of TopFlowDF. However, the difference between the mean values of Ω and Ω* remains small, compared to its possible range between -2 to 2. Moreover, the quality of the visual evaluation of the predicted deposition zones of TopFlowDF compared to the observed deposition areas (Figures 6 and 7) appears to be similar.

	α	α*	β	β*	γ	γ*	ε	ε*	φ	φ*	Ω	Ω*
Glattbach	0.62	0.68	0.39	0.32	0.38	0.32	0.71	0.73	0.29	0.27	**0.56**	**0.77**
Rotlauibach	0.54	0.81	0.26	0.15	0.46	0.19	0.91	0.88	0.09	0.12	**0.72**	**1.35**
Schwendibach	0.73	0.68	0.28	0.32	0.27	0.32	0.57	0.80	0.43	0.20	**0.76**	**0.84**
Blauseeligraben	0.69	0.71	0.27	0.24	0.31	0.29	0.84	0.88	0.16	0.12	**0.96**	**1.06**
Gonerli	0.80	0.61	0.26	0.46	0.20	0.39	0.89	0.79	0.11	0.21	**1.22**	**0.55**
Piz Caral	0.65	0.79	0.28	0.08	0.35	0.21	0.78	0.94	0.22	0.06	**0.79**	**1.44**
Richleren	0.72	0.79	0.13	0.17	0.28	0.21	0.81	0.90	0.19	0.10	**1.13**	**1.31**
Heugandtal	0.50	0.62	0.38	0.28	0.50	0.38	0.59	0.74	0.41	0.26	**0.21**	**0.70**
Brichboden	0.46	0.59	0.41	0.41	0.54	0.41	0.67	0.75	0.33	0.25	**0.19**	**0.52**
Val Mera 1	0.66	0.64	0.37	0.33	0.34	0.36	0.68	0.70	0.32	0.30	**0.63**	**0.65**
Gerental 3B	0.63	0.64	0.36	0.35	0.37	0.36	0.84	0.69	0.16	0.31	**0.75**	**0.62**
Ri di Gallinoso	0.62	0.68	0.37	0.07	0.38	0.32	0.57	0.89	0.43	0.11	**0.45**	**1.18**
Ri di Sozz	0.87	0.77	0.15	0.25	0.13	0.23	0.97	0.86	0.03	0.14	**1.55**	**1.15**
Saasbach	0.64	0.66	0.16	0.29	0.36	0.34	0.97	0.74	0.03	0.26	**1.08**	**0.77**
Mean	0.65	0.69	0.29	0.27	0.35	0.31	0.77	0.81	0.23	0.19	**0.79**	**0.92**
SD	0.11	0.07	0.09	0.12	0.11	0.07	0.14	0.08	0.14	0.08	**0.38**	**0.32**

*Tab. 3 - Comparison of TopFlowDF and TopRunDF based on the accuracies of predicted deposition zones.The results based on TopRunDF (Scheidl & Rickenmann, 2010) are denoted with **

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