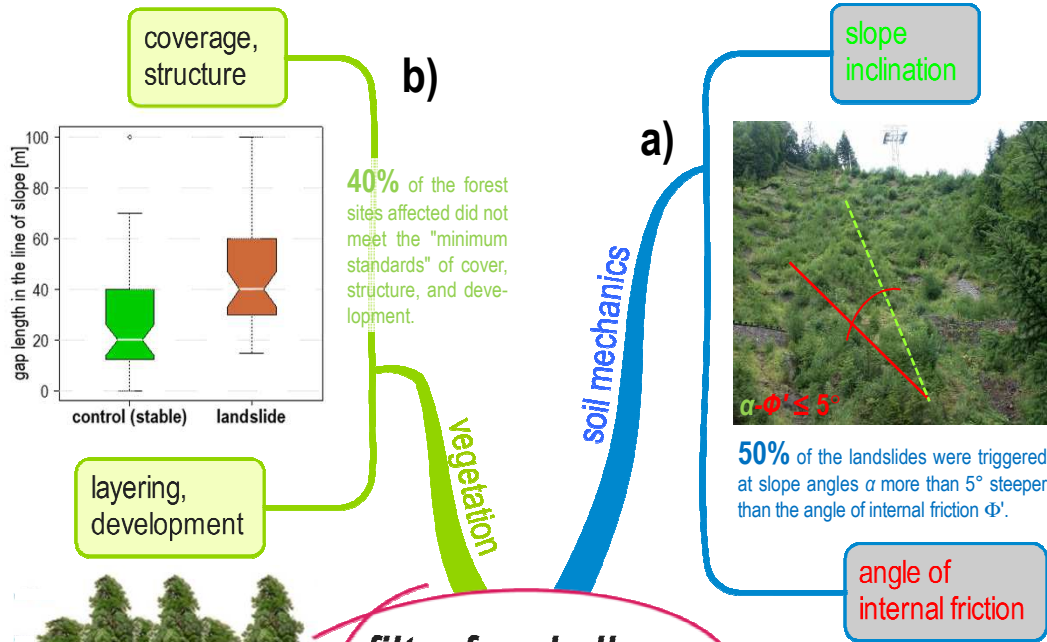


The "3-step-filter"

Retrospective analysis of 218 shallow landslides from forests (Sachseln1997; Napf, Appenzell 2002; Entlebuch, Napf, Prättigau 2005) with a serially applied "3-step-filter" explained ~97% (212) of the events. The filter consists of a **soil mechanics** (a), **vegetation** (b), and **topographic** (c) part:

- slope angle $\alpha \leq$ angle of internal friction $\Phi' + 5^\circ$
- diverse, multi-layered forest with canopy >40% and total cover >70%, gap-length < 20 m, and different succession stages
- terrain morphology **not** flat-convex (6), concave-flat (8), concave-convex (9)



curvature	profile in the line of slope			
	concave	flat	convex	
transverse profile	convex	1	2	3
	flat	4	5	6
concave	7	8	9	

c) 7% of the remaining events occurred in terrain highly susceptible to shallow landslides (types 6, 8, 9).

slope-transverse profile

The probability approach based on the "3-step-filter"

In Sachseln (1997) only 7 out of 107 landslides occurred in optimally maintained forests and these all on slopes steeper than $40^\circ - 42^\circ$ in other forests. A preliminary statistical approach based on normal distribution applied to slope inclination α and shear angle Φ' suggests that optimally maintained forests have high protection potential – optimally in this context means after Nais (Frehner *et al.* 2005) and SOSTANAH (Graf *et al.* 2017, in print).

An exemplary calculation, suggests that less than 20 of the 107 landslides would have been triggered and only about 80 ha of forest area affected compared to 400 ha (Fig. 1). Thus, it can be speculated that about 80% of the landslides could have been prevented, provided the forests fit the requirements.

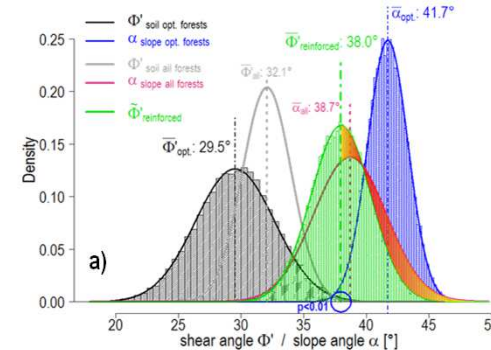


Figure 1a: Normal distribution of slope inclination α and friction angle Φ' of shallow landslides triggered in forests during the Sachseln 1997 event:
 - black: Φ' of landslides with optimally maintained forests
 - grey: Φ' of all landslides triggered in forests
 - blue: α of slope inclination of landslides with optimally maintained forests
 - violet: α of slope inclination of all landslides triggered in forests
 - green: hypothetical "reinforced" Φ' for optimally maintained forests $\rightarrow \mu = \Phi'_{\text{reinforced}} = 38.0^\circ$, assumed for $\alpha < 38.0^\circ$ the probability of shallow landslides with optimally maintained forests is <1%.
 $\sigma[\Phi'_{\text{reinforced}}] = \mu[\sigma[\Phi'_{\text{soil opt. forests}}], \sigma[\alpha_{\text{slope opt. forests}}]]$
 heat-coloured area: relative complements of $\alpha_{\text{slope opt. forests}}$ and $\Phi'_{\text{reinforced}}$ above $\Phi' = 38.0^\circ$.

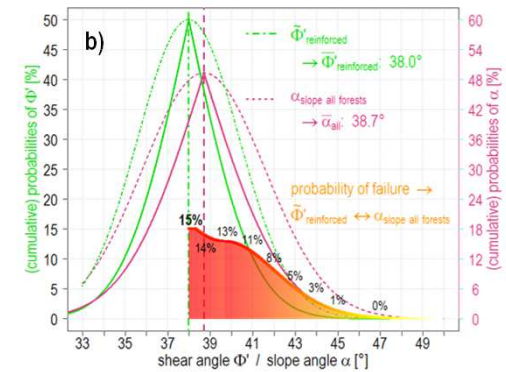


Figure 1b: Distribution (dot-dashed) and cumulative probability curves (solid) of slope inclination $\alpha_{\text{slope all forests}}$ ($\alpha_{\text{all}} = 38.7^\circ$) of all landslides and the hypothetical "reinforced" friction angle for optimally maintained forests $\Phi'_{\text{reinforced}}$ ($\Phi'_{\text{reinforced}} = 38.0^\circ$). The heat-coloured area indicates the cumulative probability with percentages for shallow landslides above a certain slope inclination.

The costs for "optimal" forest management

The approximate costs for forest management, given the specific characteristics of Sachseln and starting from an almost uncovered landslide area up to a mature protection forest (120 years), are estimated at about 35'000 CHF ha⁻¹, yielding yearly 300 CHF ha⁻¹ (price basis: 2016). In the case of Sachseln, this amounts to about 12 Mio CHF for the area of 400 ha affected in 1997 and a 100-year period. The total damage of the 1997 event in Sachseln, with an estimated return period of 100 years, exceeded 120 Mio CHF (Tab. 1).

Table 1: Cost estimates for forest management related to optimal protection against shallow landslides based on price basis 2016 and recommendations of BAFU (2008).

	costs [ha ⁻¹ year ⁻¹]	costs [400 ha ⁻¹ year ⁻¹]	costs [400 ha ⁻¹ 100 years ⁻¹]	percentage of damage sum of CHF ~120 Mio.
price basis 2016 (Sachseln)	CHF 300	CHF 120'000	CHF 12 Mio.	~10 %
BAFU 2008 (maximum amount)	CHF 800	CHF 320'000	CHF 32 Mio.	~25 %

Further investigations will show the suitability of this approach ...

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