EFFECTS OF VEGETATION ON SHALLOW LANDSLIDES: AN ANALYSIS OF THE EVENTS OF AUGUST 1997 IN SACHSELN, SWITZERLAND

Christian Rickli, Peter Zimmerli and Albert Böll
Swiss Federal Institute for Forest, Snow and Landscape Research WSL
CH-8903 Birmensdorf
tel.: ++41 1 739 24 03; Fax: ++41 1 739 24 88; e-mail; rickli@wsl.ch

ABSTRACT

An extreme thunderstorm with heavy rainfall triggered a large number of shallow landslides in the region of Sachseln, Switzerland. These events provided an opportunity to investigate the effects of different types of forest management and land use on landslide activity. A number of 280 shallow landslides were analysed in the field. The results show that beside hydrological, geological and geotechnical parameters, vegetation is a decisive factor.

INTRODUCTION

On the evening of 15 August 1997 heavy rainfall occurred in and around the village of Sachseln, Switzerland. Radar measurements showed an estimated total rainfall of 120 - 150 mm within 2 hr (1). This is among the heaviest precipitation ever recorded in Switzerland (Fig. 1) and statistically has a return period of well over 100 years. Within the catchment areas of the various local torrents, covering an area of some 20 km^2, more than 400 shallow landslides occurred. A large amount of the landslide material reached the torrent channels, which led to intense sediment transport. Masses of slope material and tree trunks were deposited on the fan and caused great damage in the populated areas.

Comprehensive risk management involves not only the identification of hazard zones and the implementation of technical protection structures but also includes measures effective over larger areas, and here the vegetation plays an important role. Given the events at Sachseln, the question arose whether different types of forest management and land use can influence the triggering of shallow landslides.

The immense number of landslides within such a small area offered a unique opportunity to investigate triggering processes and learn more about the key factors. Moser (2) studied similar events, for example, the numerous slope collapses in Austria in 1966 and 1975, which were also set off by heavy rainfall. He established that forest definitely has a positive influence in impeding small landslips both in terms of number and area. As far as larger landslides were concerned, no influence could be registered. Aleotti et al. (3), analysing weather damage events in Piedmont (I), found that about half of the landslides started inside the forest. Other research in North America, Australia and New Zealand has indicated that forest, as compared to open land, generally has a positive influence on slope stability (4). Regrettably, none of these studies includes details on the study area (e.g., forest/open land distribution, forest condition). In connection with the influence of forest management on landslide risk, O'Loughlin et al. (5) found that clear cutting greatly increase the risk of landslides.

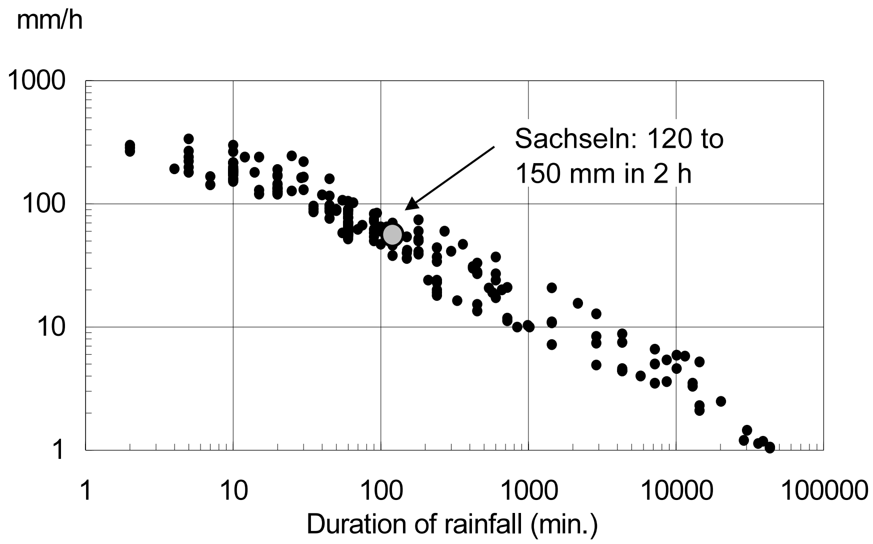


Fig.1 The rainfall of 15 August 1997 in Sachseln compared to the heaviest on record in Switzerland, after Geiger et al. (6).

In the Swiss alps no other interdisciplinary studies have been made so far that investigate the decisive triggering factors within a clearly defined research framework. Furthermore, little is known about the influence of the forest condition and/or forest management as essential factors for shallow landslides in general. This article presents some findings from the investigations of the landslide processes which occurred at Sachseln.

METHODS

The site and volume of landslides within an area under heavy rainfall are influenced by many factors. A comprehensive documentation of all landslides therefore requires the recording of all relevant factors. Beside the triggering rainfall event, these include the condition and management of the vegetation cover, the characteristics of the soils, loose material and bedrock, slope inclinations and certain aspects of the geomorphology. In our case, the study area, which is 50% forested, includes four catchment areas covering a total of 8.2 km^2 (Fig. 2). Within this zone, all landslides with a volume of at least 20m^3 were investigated. For a total of 280 slides, 136 in forested areas and 144 in open land, the following parameters were recorded:

- over an area of about 50 x 50 m^2 around the line of release, the type and condition of the vegetation, the geomorphology and other site characteristics;
- within each slide, a profile was taken in the vicinity of the line of release to record the decisive parameters of the soil and bedrock, and the parameters of the slide (length, breadth, thickness, inclination etc.) and the actual water situation was documented.

To supplement, check and calibrate the field results, soil samples were analysed (pH, density, distribution of grain size, limits of plasticity). In addition, the basic parameter set for the total study area was analysed with a geographical information system (GIS): 10 x 10 m^2 digital height model, vegetation and stand maps, and a geological-geotechnical map. Furthermore, the condition of the forest was assessed from aerial photographs.

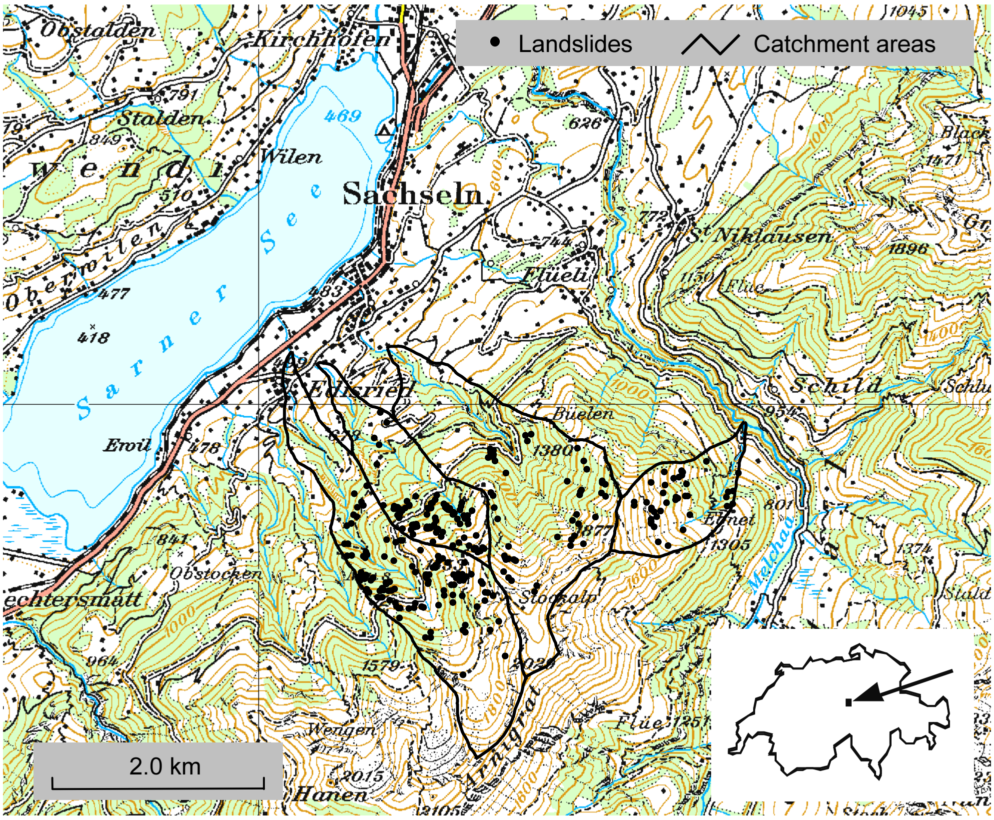


Fig. 2 The study area, which encloses four catchment areas. The black dots show the location of the landslides with a volume ≥ 20 m^3 which occurred in August 1997 and were documented in the study.

RESULTS

Precipitation

The distribution of precipitation over the study area was estimated through the analysis of radar images (1). The amount of rainfall was computed for different parts of the study area and plotted against the number of landslides per hectare (L/ha). The slide activity increased with increasing amount of precipitation. In areas receiving less than some 80 mm of rain in 2 hr hardly any landslides occurred (Fig. 3). It must, however, be mentioned that there was great uncertainty in the analysis of the radar images, so that Fig. 3 is to be understood as showing trends rather than exact values.

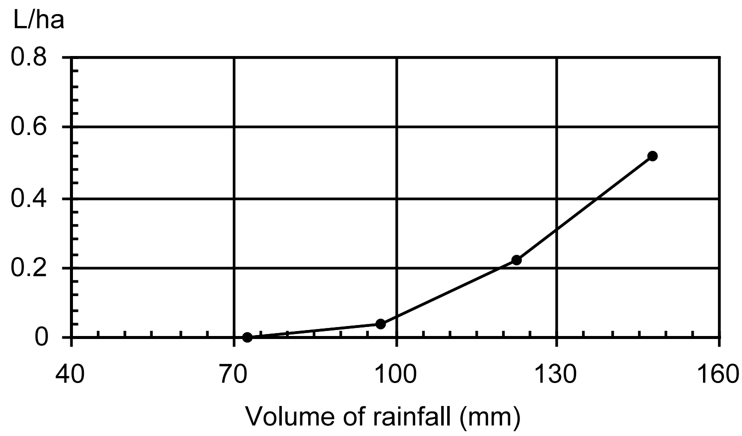


Fig. 3 Influence of volume of rainfall on landslide activity (Landslides/ha).

The landslides at Sachseln on 15 August 1997 were set off by heavy rainfall and it is clear that precipitation was the major triggering factor. Nevertheless, it is other factors which explain why landslides occurred at some points but not at others only a few metres away, for the same rainfall conditions.

Slope inclination

The number of landslides in areas of both forested and open land was recorded, and on the basis of the GIS the relevant areas were allocated to classes of inclination (Fig. 4).

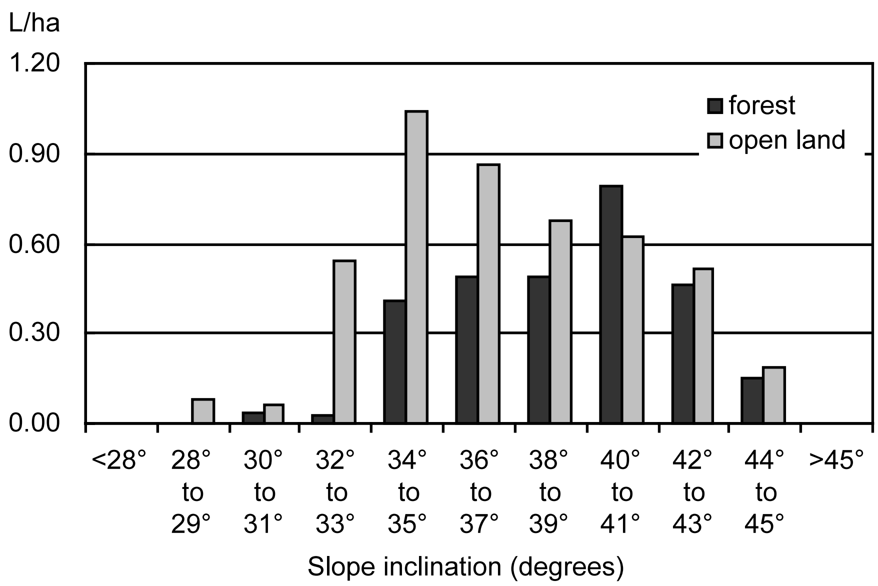


Fig. 4 Landslides per ha (L/ha) in relation to slope inclination.

The slides occurred on slopes with an inclination between 28° and 45° (Fig. 4). The absence of slides on steeper slopes can mainly be explained by the fact that in comparison to the roughness of the rock surface there were only very thin, discontinuous layers of till without any appreciable proportion of fine material. Landslides did not occur on slopes with an inclination lower than 28° because of the strength parameters and driving forces within the study area.

On slopes with an inclination of up to 37° the landslide activity (number of slides per ha) was noticeably greater on open land than on forested sites (Fig. 4). In steeper areas there was no clear difference. This finding indicates that forest enhance the stability of moderately steep slopes, but this effect is not unlimited: in very steep areas the forest has no greater influence on landslide activity than the vegetation on open land.

Volume

Larger landslides occurred less frequently (Fig. 5). Some 80% of the slides had a volume of less than 200 m^3. In the lower range of volume, landslides on open land were predominant while on average those under forest had greater volumes. The average (median) volume was 100 m^3 for slides under forest and 72 m^3 on open land. The largest landslide involved a volume of 2430 m^3.

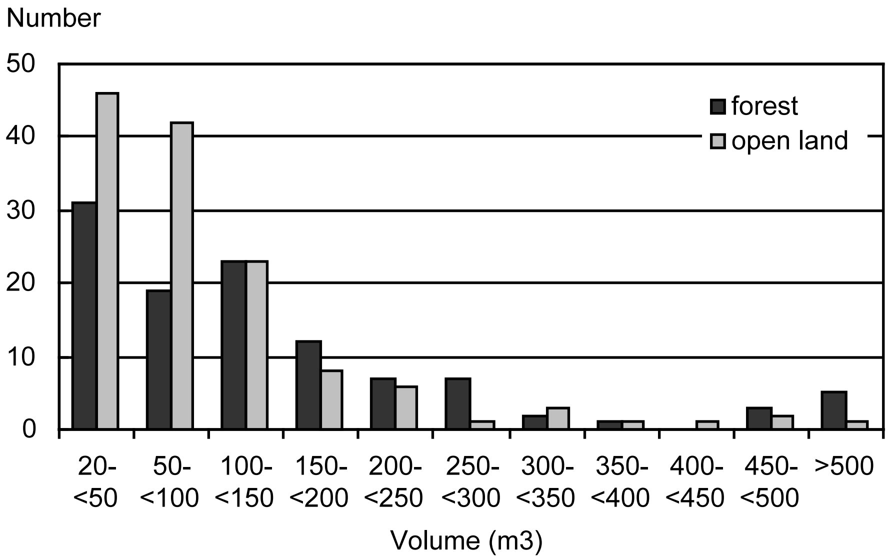


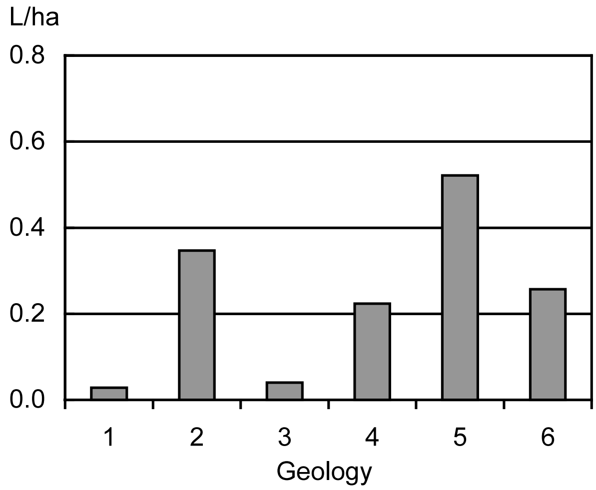
Fig. 5 Number of landslides in volume classes.

Geology

The study area lies on the northern edge of the Swiss Alps within the area of the Helvetian nappes. The bedrock is predominantly marl-like (Amden marl, Wild flysch), sometimes with alternating layers of limestone (Drusberg layers) or mixed with sandstones (Gault). Portions of calcareous rock occur only rarely (siliceous limestone, Seewen limestone). The bedrock is generally covered by a thin layer of quaternary soil (0.5 - 2.0 m) and is most frequently exposed to the surface only above an elevation of 1800 m a.s.l.

In each landslide the type of bedrock and soil, the subsurface water, and the orientation of the layers were, as far as possible, determined. In 212 of the slides the bedrock was exposed, so that direct identification was possible. A new, detailed geological map of the area was constructed, from which the geological sublayers of the other 68 landslides were deduced (7).

The Drusberg layers suffered the severest disturbance through the landslides (Fig. 6). Considering the comparatively low mean slope inclination, landslides were also quite frequent in the layers of Amden marl. Siliceous limestone and Gault experienced fewer slides, while in Wild flysch and Seewen limestone there was very little activity with only one slide occurring on each.



1: Wild flysch (32,7°)
2: Amden marl (32,3°)
3: Seewen limestone (38,8°)
4: Gault (37,4°)
5: Drusberg layers und Schratten limestone (37,6°)
6: siliceous limestone (35,5°)

Fig. 6 Number of landslides per hectare (L/ha) in relation to geology and average slope inclination of each type of bedrock (in brackets).

The soil cover had a mean thickness of 0.5 m to 2.0 m. It was in turn covered by a layer of humus from 0.1 m to 0.5 m thick. The overwhelming majority of the slides (82%) occurred in talus (8). In about 15% of the landslides a much sandier moraine material with little clay was found under the talus. In 18%, a thin layer of humus lay directly on the bedrock. The field investigations clearly showed that in this type of landscape the characteristics of the soil (thickness, distribution of grain size and underlayer of morainic material) do not vary with differences in the underlying bedrock.

During the field investigations the occurrence and rate of subsurface water flow in the vicinity of the landslides were also recorded. Such flow was observed in only 11% of the slides. Considering the rather rare occurrence of subsurface water, no close correlation between water flow under normal conditions and landslide activity under extreme conditions could be deduced.

Shape of terrain

The shape of the terrain was recorded in the field in profile to the line of fall and in transverse profile parallel to the contour lines. The part of the terrain investigated for each landslide covered some 30 to 50 m to either side of the centre of the scarp.

In 86% of the landslides the slide slopes had a flat profile to the fall line and 59% showed a flat transverse profile (Fig. 7). This finding does not agree with those of Aleotti (3) or Moser (2), who reported that depressions and the edges of terraces are particularly at risk. However, a valid report on whether this factor affects landslide activity would require documentation of the occurrence of the various shapes of terrain within the entire study area, which has so far not been the case.

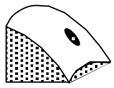
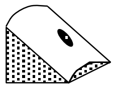
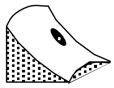
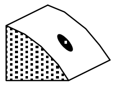
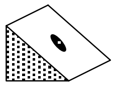
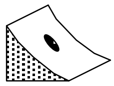
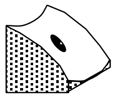
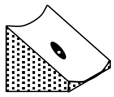
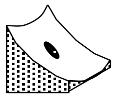
	Fall line profile convex (7 %)	Fall line profile flat (86 %)	Fall line profile concave (7 %)
Transverse profile convex (21 %)	 2 %	 19 %	 0 %
Transverse profile flat (59 %)	 3 %	 52 %	 4 %
Transverse profile concave (20 %)	 2 %	 15 %	 3 %

Fig. 7 Percentage of landslides in relation to shape of terrain.

Comparison of landslide activity under forest and in open land

Considering the entire study area, approximately as many landslides occurred under forest as in open land (Tab. 1). Those under forest, however, carried a larger volume of material than those in open land which means that over the study area as a whole the volume set in motion per unit area was larger under forest than in open land.

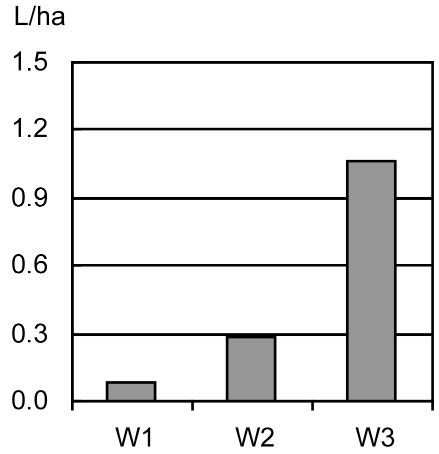
Tab. 1 Comparison of sliding activity under forest and in open land for the entire study area, for the elevation 1200 - 1500 m a.s.l. and for slope inclination 32° - 39°.

	Entire study area		Elevation 1200 - 1500 m ü.M.		Inclination 32° bis 39°	
	forest	open land	forest	open land	forest	open land
Area	414 ha	408 ha	125 ha	90 ha	210	145
No. of slides	136	144	58	71	79	114
Slides per ha	0.33 L/ha	0.35 L/ha	0.46 l/ha	0.79 L/ha	0.38 L/ha	0.79 L/ha
Vol. per slide	100 m^3	72 m^3	97 m^3	81 m^3	116 m^3	81 m^3
Vol. per ha	33 m^3/ha	25 m^3/ha	45 m^3/ha	64 m^3/ha	44 m^3/ha	64 m^3/ha

An important consideration in comparing the landslide activity under forest and in open land is that the forest stands on more vulnerable terrain. Taking the study area as a whole, the slope inclination under forest is, at an average of 38° considerably greater than that in open land, where the average was 32°. Furthermore, the forest occurs mainly at medium elevations, where according to the radar images the sum of rainfall was greatest. If only sites with comparable elevation and range of inclination are analysed, the results per unit area give fewer slides and a smaller volume of material shifted under forest (Tab. 1). This indicates that forest vegetation furnishes better protection than that of open land.

Influence of forest condition

To examine the question of whether forest condition affects landslide activity, three categories of forest condition, W1 - W3, were defined (see Fig. 8) and plots of 50 x 50 m adjacent to the slide accordingly classified. Further, using the same criteria of assessment, the forested areas of the entire study area were similarly allotted to one of these categories on a stand by stand basis. The findings indicate that the condition of the forest has a considerable effect on landslide activity (Fig. 8).



	Description of forest condition classes	Area (ha)	No. of landslides
W1	Species and stand-structure suitable for site, few gaps	163	13
W2	Species and stand-structure not suitable for site, many gaps	184	52
W3	Parts previously damaged, loose stands	67	71

Fig. 8 Number of landslides per hectare (L/ha) in relation to forest condition.

DISCUSSION AND CONCLUSIONS

Landslides frequently occurred in Drusberg layers and Amden marl in particular. Between the bedrock of these two types of marl-like rock and the loose material thin layers of heavy weathered bedrock were often observed. As these layers are both decarbonised and have a high water content they exhibit unfavourable geotechnical characteristics and thus decrease slope stability. In general the soil covering the underlying bedrock is mostly composed of clayey talus deposited at its present site through mass movement processes and, consequently, does not vary with the geological sublayer.

In the slides on marl-like rock, subsurface water occurred somewhat more frequently than in others (storage horizon). This, however, may not have played a significant role during the event, as the rainfall was so heavy that it saturated the entire soil layer. Wild flysch only occurred below 800 m a.s.l., where less rain fell. The Seewen limestone in the terrain occurs mostly as steep rock walls, which explains the low number of landslides on these geological units.

On the basis of a geological model it can be assumed that the Drusberg layers frequently have the same orientation as the slopes, i.e. that the orientation of the layers is the same as that of the slope (8). Soil mechanics dictate that the presence of such a sliding surface increases the risk of landslides.

Subsurface water is often mentioned as an important factor in slope stability. It is assumed that wet places and features of the relief, such as hollows, where water can collect and infiltrate the soil are especially vulnerable. In this study the geomorphological analyses and observations of subsurface water reveal that these factors only slightly influence slide activity. It is hypothesised that the activity of shallow landslides – triggered off by severe but short-lived rainfall events – is only negligibly influenced by the levels of saturation. It is rather to be assumed that all soil profiles over practically the whole affected area become saturated and that consequently it is rather the strength parameters, in particular the shearing angle ϕ' of the soils, that become the decisive factors for the release of a landslide at a certain point. It must, however, be emphasised that these comments refer to the extreme but short-lived rainfall of the storm at Sachseln. In long-lived severe precipitation events or intensive snow melt processes other aspects, such as the form of the terrain tend to play the leading role.

The data compiled show that landslides under forest were rather fewer but of greater volume than those in open land. Moser (2) and Crozier (9) report similar findings. Analysis including only sites which are comparable in elevation and range of slope inclination indicated that forest vegetation has a greater impeding effect on slide release than that of open land. However, even forest vegetation cannot completely prevent landslides. One explanation may be the very extreme rainfall of the event at Sachseln, as it can be assumed that any hindering effects of vegetation decrease with increasing intensity and duration of rainfall. Another explanation however, may lie in the fact that the influence of the vegetation decreases with increasing thickness of the slide material, so that in the case of large slides the impeding influence of forest does not develop to the full.

In the study area at Sachseln the condition of the forest was found to have affected the landslide activity. Markedly more slides occurred in stands with damage - by windthrow or bark beetles for instance - than in stands in better condition. The stable stands adapted to the site and with few gaps obviously had a positive influence on slope stability during the rainfall event of August 1997 in Sachseln. This indicates that appropriate silvicultural measures can help to reduce the activity of shallow landslides, even during extreme events.

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