Appendix 1: **Natural hazards**

1 Introduction

Erosion (landslides, debris flow, rockfall) is a natural geological process on mountain slopes. Even the best forest cannot fully prevent it. A stand, however, can influence the speed of such erosion and dampen the resulting energies.

This documentation is based on the current state-of-the-art, with many important questions still to be addressed through sound research. New findings may mean the recommendations will need revision.

The information provided about each natural hazard should help in the assessment and management of stands affected by these hazards.

This text does **not** cover the following topics:

- The delineation of protection forests, though the information should help to establish priorities within protection forests.
- Whether a forest is more effective in preventing floods and landslides than, for instance, a pasture, needs to be assessed separately, as does the decision to enlarge the forest area or not (e.g. high-elevation afforestation to reduce avalanche activity or forest expansion into mid-elevation pastures and meadows to reduce the risk of landslides).
- Assessing whether the protective effect of a forest is sufficient or whether further protective measures are needed may require additional investigations, depending on the case.

2 Avalanches

2.1 Target profile for avalanche protection forests

Locality	Potential contribution of the forest	Hazard-related target profile: minimum requirements	Hazard-related target profile: ideal requirements
Zone of origin Sub-alpine and upper montane coniferous forests	**Large** In **larch forests** if incline ≥ 30° (58 %) In **evergreen coniferous forests**[1] if incline ≥ 35° (70 %)	**Horizontal structure** **Incline** → **Opening length[2] in the fall line** ≥30° (58 %) → smaller than 60 m ≥35° (70 %) → smaller than 50 m ≥40° (84 %) → smaller than 40 m ≥45° (100 %) → smaller than 30 m If opening length[2] is greater than indicated above, opening width must be < 15 m Canopy cover > 50 % Minimum requirements of site-related profile accomplished	**Horizontal structure** **Incline** → **Opening length[2] in the fall line** ≥30° (58 %) → smaller than 50 m ≥35° (70 %) → smaller than 40 m ≥40° (84 %) → smaller than 30 m ≥45° (100 %) → smaller than 25 m If opening length[2] is greater than indicated above, opening width must be < 15 m Canopy cover > 50 % Ideal requirements of site-related profile accomplished
Zone of origin Broadleaved and mixed forests of the upper and lower montane zones	**Intermediate** if incline ≥ 35° (70 %)	**Horizontal structure** **Incline** → **Opening length[2] in the fall line** ≥35° (70 %) → smaller than 50 m ≥40° (84 %) → smaller than 40 m ≥45° (100 %) → smaller than 30 m If opening length[2] is greater than indicated above, opening width must be < 5 m Canopy cover > 50 % Minimum requirements of site-related profile accomplished	**Horizontal structure** **Incline** → **Opening length[2] in the fall line** ≥35° (70 %) → smaller than 40 m ≥40° (84 %) → smaller than 30 m ≥45° (100 %) → smaller than 25 m If opening length[2] is greater than indicated above, opening width must be < 5 m Canopy cover > 50 % Ideal requirements of site-related profile accomplished

An active promotion of surface roughness (e.g., leaving high stumps and lying logs) in gaps and at the edge of avalanche tracks reduces the probability of avalanche release. If the surface is sufficiently rough, the minimal target profile related to gap length in the fall line can be used as the ideal profile.

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[1] In evergreen conferous forests, the canopy cover and the general surface roughness usually prevent avalanche release unless the incline exceeds about 35°. Pure larch forests, in contrast, have often a ground vegetation rich in grass which reduces the general surface roughness. Therefore, potential release should be taken into account already at inclines of about 30°.

[2] Opening length measured from crown edge to crown edge in pole and old timber stands.

2.2 **Formation of avalanches**

In the snowpack on a slope, creeping movements occur and, depending on the characteristics of the ground-snow interface, additional gliding may take place on the ground surface. These movements can also cause the sliding of the whole snowpack, depending on:

- Slope incline
- Snow depth
- Surface roughness
- Snow consistency

Local changes in these factors cause zones of enhanced tensile, compression and shear stress in the snowpack.

Slab avalanches develop mainly in the following situation:

- Slope of at least 30° (58 %)
- Weak layers and/or gliding surface (e.g.,snow-covered hoar, smooth ground surface)
- Snow cover with continuous layers
- Snow with high cohesion
- Snowdrifts due to wind promote local snow depots and the occurrence of snow with high cohesion

Loose snow avalanches develop mainly in the following situation:

- Slope with incline between 40° (85 %) and 60° (170 %). On steeper slopes (>60°), avalanches discharge continuously
- Snow with low cohesion

Avalanches starting in the forest

If the starting zone of an avalanche is located within the forest, it is called a forest avalanche. Gap size in a stand is a decisive factor in determining the extent of snow movements. As openings are part of a near-natural stand structure and required for regeneration, especially in the sub-alpine and upper montane zones, snow movements cannot be completely excluded. This is why only incidents which are able to damage trees of at least pole size are considered forest avalanches. Trees in the new growth and sapling stages are usually damaged by snow gliding, creeping and settlement rather than by avalanches.

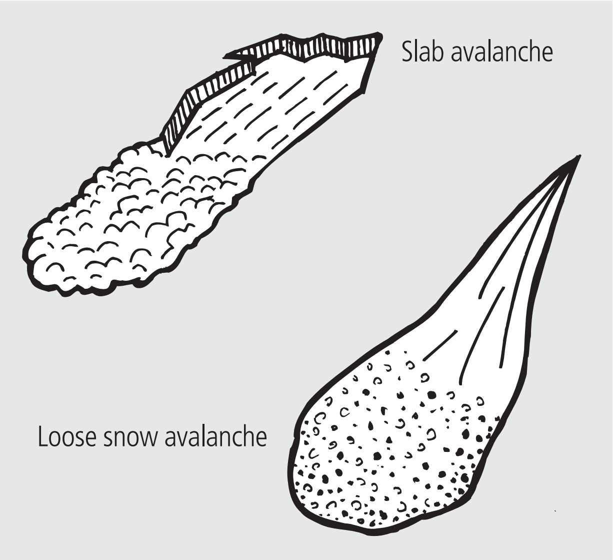

Figure 1: Avalanche types (after Salm 1982).

The following meteorological and snow conditions favour the formation of forest avalanches:

- Air temperature below –4°C, more than 80 cm new snow within 2 days, slight wind during snowfall, snow depth exceeding 120 cm, and in addition a slight increase in temperature on the day the incident happens.
- Air temperature below –4°C, more than 60 cm new snow within 3 days, slight winds during snowfall, strong warming on the day the incident happens.
- More than 50 cm new snow within 3 days, snow depth exceeding 120 cm, rain.

The colder and the less windy it is during snow fall, the less new snow is required for the release of forest avalanches.

2.3 Forests providing protection against avalanches

In regions and elevations with snow conditions which enable the development of large slab or wet snow avalanches, forests on slopes with more than a 30° (58 %) incline have the potential to provide protection against avalanches.

In the region of coniferous forests at elevations ranging from 1600 to 2200 m a.s.l., starting zones are often to be found on slopes with north-east to north-west aspects. Here, mostly dry slab avalanches are released. Often release occurs where there are changes in incline of at least 10°.

In the region of broadleaved and mixed forests below 1200 m a.s.l., wet snow avalanches or moist loose snow avalanches are released, mostly on sunny slopes.

At the upper tree line, the forest is often open and concentrated along ridges. No forest can grow in gullies be-cause of snow movements and long-lasting snow cover. The uppermost part of the forest is very important for the stability of the whole forest. The ecological conditions are mostly extreme. Regeneration is often only possible under the protection of old trees. If there is no such protection, technical measures are needed.

The situation at the tree line needs to be taken into account in deciding about the forest located below it. Under certain circumstances, high-elevation afforestation can improve the situation. At the upper tree line, the potential forest cover decreases and its protective effect against avalanches thus also tends to diminish. Below an avalanche release area located above the potential tree line, the establishment of forest is restricted to favorable sites such as ridges (see also Fig. 2).

Frey / SLF

Figure 2. Potential avalanche protection forest. On the left, a closed forest covers the slope up to the ridge, and the tree line is above the ridge. In the middle, the ridge extends over the tree line, and there is a starting zone for avalanches above the tree line. The forest is restricted to particularly favorable sites. This must be taken into account when making decisions about the forest.

2.4 **Forest influence**

The forest influences snowpack structure und thus avalanche formation by intercepting snow, maintaining a stand climate and increasing surface roughness through the presence of trees, stumps and lying logs (Fig. 3).

In the forest, an average statistical recurrence interval for avalanches of 30 years is assumed (on open land with avalanche barriers, the interval used is 100 years) since, in many cases, openings become so overgrown within 30 years that they prevent forest avalanches from releasing.

Factors impeding avalanche release

- Interception reduces snow depth in a forest in comparison to open land. The difference between the forest and open land is more pronounced during light snowfall (70 % interception) than during heavy snowfall (30% interception). If temperatures are low during snowfall, interception is less.
- In the forest, the continuous layering of the snowpack is disturbed, e.g., by snow falling to the ground or tree wells around stumps.
- Less longwave radiation is emitted particularly in evergreen forests, i.e. warming in the daytime is reduced and the longwave radiation emission at night is reduced. This leads to a special climate in the forest which influences snow transformation. Therefore, less surface hoar frost and depth hoar are built, and higher snow temperatures stabilise the snowpack. If the snow is moist, small avalanches can be released in the forest and, if the ground surface is smooth, so can wet snow avalanches.
- In the forest, wind speed is reduced close to the ground, which is why there is less wind-transported snow. In openings and at stand edges, however, the wind can result in larger snow deposits.

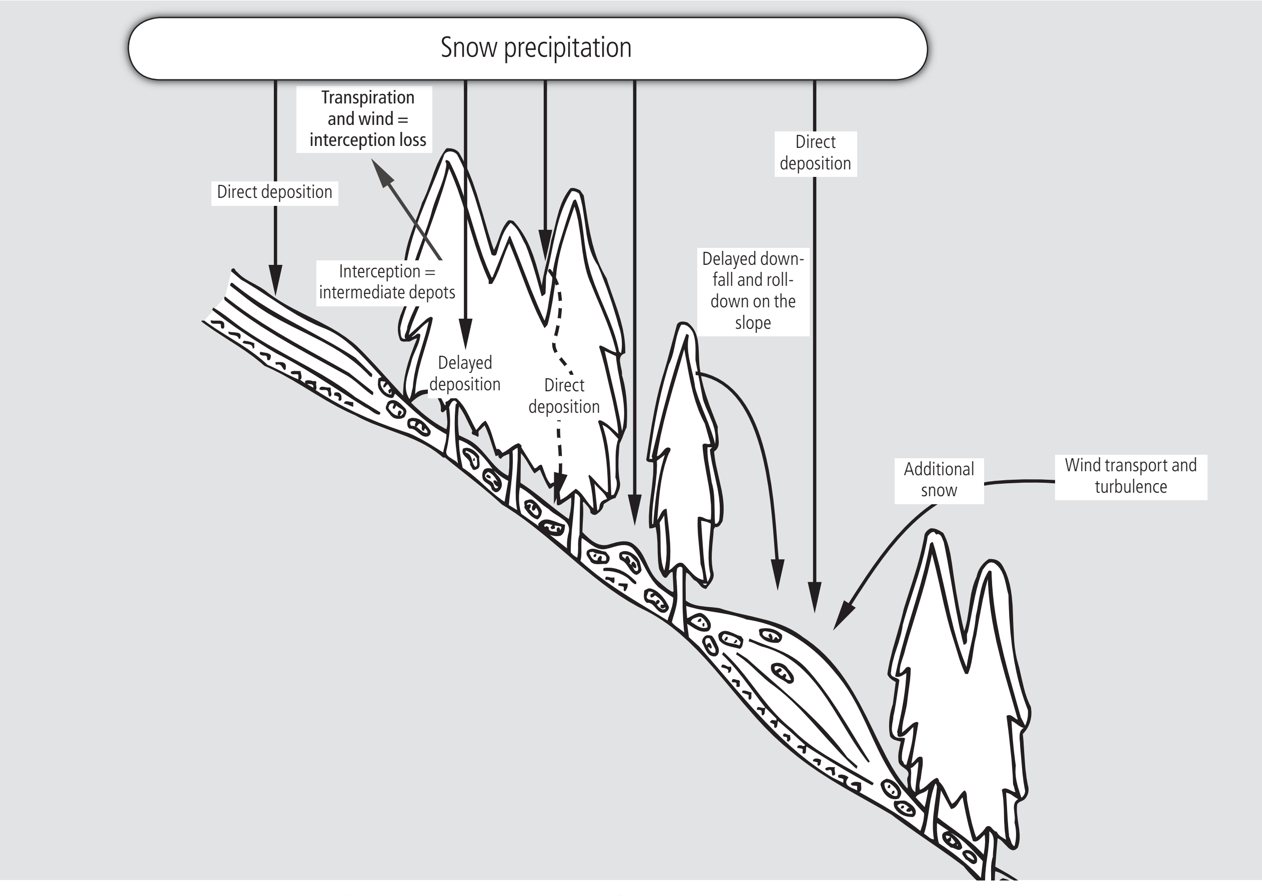

Figure 3: Sketch of snow ablation (after Meyer 1987 and Cemagref).

- In the forest, surfaces are generally rougher than in the open, which reduces the risk of snow movements.
- Upright stems and stumps, as well as lying logs, enhance surface roughness and act therefore as stabilising elements in the snowpack. The supporting effect of trees only, however, is usually insufficient to prevent avalanche release. To be effective as avalanche barriers, the following stem numbers (dbh > 8 cm) are required: 500 stems/ha at an incline of 30° (58 %), and 1000 stems/ha at an incline of 40° (84 %).

Factors promoting avalanche release

- In shady openings and at stand edges, surface hoar frost can develop and persist for a long time. When snowed on, this can promote snow gliding.

Importance of tree species and stand structure

The presence of forests generally reduces the probability of avalanche release on slopes with an incline of at least 35° (70 %). In open areas or in larch stands, the critical incline is only 30° (58 %).

Trees help to prevent avalanche release if their height is at least double the snowpack depth.

Evergreen tree species intercept more snow than deciduous trees, especially if temperatures are low. Short- and long-wave radiation emissions are reduced by up to 90% below a dense canopy of evergreen trees, but only by up to 30% under a canopy of deciduous trees. The recommended proportions of evergreens, which will depend on the site association, take this into account.

Deciduous tree species are effective in preventing avalanche release with light snowfall, but their effect is limited during heavy snowfall. Moreover, snow glides easily over beech leaves.

Small trees which are entirely covered by snow (e.g., green alder, dwarf mountain pine) can promote avalanche formation as their branches may move elastically. Moreover, such sites are prone to depth hoar. If such stands extend over vast areas, avalanches can be less frequent but larger than in open land.

Deciduous tree species often occur at the edge of avalanche tracks where evergreen tree species cannot survive as they cannot withstand the drag forces. In the central Alps, larch is often found on these sites (and the mineral soil facilitates its regeneration), whereas in the Pre-Alps sycamore maple or beech are more common. Here, evergreen tree species should not be specially promoted.

In trees with a high crown base, snow falling to the ground can cause avalanche release. In trees with branches on the lower stem (e.g., trees in clusters), this risk is smaller.

Tall trees with large crowns influence the snow cover over a larger area than small trees.

Braking effect of the forest

If the flowing depth of an avalanche is only 1–2 m and therefore only affects the stems, it can be slowed down by the forest. If the flowing depth is greater and the avalanche speed is high too (e.g., powder avalanches), a forest will be destroyed. In the deposition zone, avalanche speed is often low so that the forest is more effective in slowing it down and in diminishing its reach.

Dead wood on windthrow areas

On most uncleared windthrow areas, the timber is initially highly effective in providing protection against snow movements. The surface structures consist of snags, stumps, root plates and lying logs, which form a dense and tight entanglement. This nails the snowpack effectively to the ground and favorably affects snow deposition for several decades. For typical avalanche release zones (about 30 to 40° incline) and normal snow depth in the forest, such timber provides good protection. However, on very steep slopes and occasions with exceptionally high snow depth, the timber may be unable to resist the strain and the snowpack, including the timber, may be set in motion. As timber decays, this danger gradually increases. This should be taken into account if the damage potential is large. Clearing an area reduces the protection provided against snow movements from the beginning.

Planting was done in potential avalanche starting zones on areas devastated by the hurricane «Vivian» where there was little regeneration. This advanced the density and size of trees by at least ten years over that of newly established natural regeneration. Planting can thus shorten or even eliminate a period during which there is a lack of protective effect, which may occur if the new forest cannot compensate for the reduction in protective effect caused by timber decay. Planting is also possible in uncleared windthrow areas, although it is more difficult.

Source:

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3 Landslides, erosion and debris flows

3.1 Target profile for forests providing protection against landslides, erosion and debris flows

Locality	Potential contribution of the forest	Hazard-related target profile: minimum requirements	Hazard-related target profile: ideal requirements
Zone of origin	**Large** In the case of shallow landslides (depth of slide surface at most 2 m) and of surface erosion	**Horizontal structure** Maximum opening size[3] 0.06 ha, if secured regeneration[1] exists 0.12 ha. **Horizontal structure** Canopy cover[2] permanently ≥ 40% Minimum requirements of site-related target profile accomplished **Mixture** In areas of transition between site types, the tree species composition of the moister / wetter site should be the target	**Horizontal structure** Maximum opening size[3] 0.04 ha, if secured regeneration[1] exists 0.08 ha. **Horizontal structure** Canopy cover[2] permanently and at a small scale ≥ 60% Ideal requirements of site-related target profile accomplished **Mixture** In areas of transition between site types, the tree species composition of the moister / wetter site should be the target **Stability carriers** No heavy trees and no trees prone to windthrow
Infiltration zone	**Intermediate** In the case of intermediate to deep landslides (depth of slide surface at least 2 m), if it is possible to influence the water balance in the slide surface	**Horizontal structure** Canopy cover[2] permanently ≥ 30% Minimum requirements of site-related target profile accomplished	**Horizontal structure** Canopy cover[2] permanently ≥ 50% Ideal requirements of site-related target profile accomplished
	Small In the case of intermediate to deep landslides (depth of slide surface at most 2 m), if the potential influence on the water balance in the slide surface is small	**Regeneration** Permanent regeneration guaranteed	**Regeneration** Permanent regeneration guaranteed Ideal requirements of site-related target profile accomplished

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[1] Secured regeneration: Young growth or thickets with a mixture meeting the requirements. In the sub-alpine zone, larger areas are possible if cut in elongated form; opening width ≤ 20 m.

[2] The canopy cover is related to trees of at least pole size (i.e. young growth and thicket stages are ignored).

[3] Openings are measured from crown edge to crown edge in pole and old timber stands.

3.2 **Landslides**

The depth of the gliding surface is one way of differentiating between landslides. When considering the potential effectiveness of a forest, it is important to differentiate between shallow and intermediate to deep slides. In all types, the water infiltrating the soil is, in most cases, a very important trigger (Fig. 4).

Shallow landslides:

- Depth 0–2 m
- In most cases frequent landslide activity with short duration (minutes to months)
- Slide areas small (mostly < 0.5 ha)
- Develop mostly on slopes with incline above approx. 25°, but can also occur in clearly less inclined terrain
- Frequently with characteristic starting zone pockets from recurring landslides

WSL

Sachseln, Canton Obwalden, 15th of August 1997

- About 100 m^3 volume in each landslide
- Duration of precipitation two hours; landslides occurred within a couple of minutes
- Transition to slope debris flows due to heavy water saturation

Landslides with intermediate to large depth:

- Depth 2–10 m or > 10 m, respectively
- Landslide activity mostly in the range of cm to dm / year
- On large areas (mostly > 0.5 ha, up to several km^2)
- Landslide processes going on for years to centuries, often in phases with varying activity
- Characteristic traces in the terrain: Extensive rupture edges in the starting zone, leaning trees or trees with a bend close to the ground, soil cracks, roots under tension, compression bulges, infiltration zones for surface water, water-logged zones, roads or buildings with cracks and deformations

Thormann/SHL

Sörenberg, Canton Lucerne

- Material several million m^3 in volume
- In motion for more than 100 years; alternating active and passive phases, depending on weather conditios
- Has consequently led to additional debris flows and shallow landslides

Figure 4: Landslide examples.

Areas prone to landslides

Areas prone to landslide (in particular those with deep slide surfaces) are often well known and documented. The following documents are important for assessing landslides:

- Hazard map / hazard index map
- Map of soil and slope instabilities (map of phenomena)
- Event register/records of past incidents
- Geological map

Shallow landslides may also develop spontaneously in the interior of the forest, particularly after a complete stand collapse.

A number of factors determine whether landslides occur and, if so, where. The most important factors, however, are the slope and the type of loose material. The decisive criterion for assessing the instability of loose material is the angle of internal friction specific to each material, which designates the critical incline value of a slope.

In the following table, the types of loose material found have been roughly subdivided into three classes. For each class, a threshold value is given for the incline above which shallow landslides should be anticipated (Table 1). If a forest area is less inclined than indicated, spontaneous landslides are unlikely[3].

Table 1: Threshold values for critical incline.

Type of loose material		Threshold value for critical incline
1	Soils rich in marl Soils rich in clay	≥ 25° (47 %)
2	Intermediate soils, without signs of heavy water saturation	≥ 30° (58 %)
3	Highly permeable soils Soils with small proportion of fine-grained material (clay, silt) Sandy soils, gravel	≥ 35° (70 %)

Influence of forests on landslide release

Shallow landslides: Such landslides are located within the reach of tree roots, so that forests can greatly influence landslide intensity by:

- Mechanically reinforcing the soil throuh the root system
- Positively influencing the water balance of the soil through interception, transpiration and through enhanced soil permeability

A forest with an ideal structure can improve soil stability and thus reduce landslide activity. However, landslides cannot be completely eliminated even in an ideal forest. Moreover, the effect of the forest decreases markedly if the incline exceeds about 40°.

Large windthrown trees can tear open the soil, which in turn may increase landslide risk and surface erosion.

Strong winds can cause cracks in the soil through tree movements.

Intermediate to deep landslides: The stabilising effect of a forest through root reinforcement is of primary importance for shallow landslides, but is much less pronounced on slopes with intermediate to deep gliding surfaces. The forest has considerable indirect influence on these, however, since it creates a storage zone which prevents the infiltrating water from percolating through the soil down to a potential rupture zone. This effect, however, is lost if the soil is completely saturated with water.

For landslides with intermediate to deep surfaces, an infiltration zone can be defined. This zone encompasses the area where water infiltrates the soil and penetrates the potential sliding material. The forest can partly retain this water through storage. However, the underground water flow is often unknown, which makes it very difficult to delineate the infiltration zone. If this is the case, it must be assumed that the infiltration zone is usually the surface catchment area located directly above the slide foot.

The weight of trees does not influence landslides with intermediate to deep surfaces. «Relief cutting» is therefore not helpful.

Unstable trees, however, can cause problems in the influence zone of a channel if drift wood forms congestions (cf. target profile for torrents and floods).

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[3] Under certain circumstances, landslides can occur at smaller inclines. Special attention should be paid to previous incidents.

Importance of the tree species

Tree species able to form a deep and intensive root system are important for landslide prevention. They can not only strongly reinforce the soil but also make optimal use of the storage zone. While most tree species are able to achieve this on highly permeable soils, the species-specific reaction to clay soils, compacted soils and temporarily soaked sites is decisive. A couple of tree species root relatively deeply in compacted, wet, clay soils. These are:

Broadleaved trees: Ash, elm, oak, aspen, black alder
Coniferous trees: silver fir, Scots pine

Silver fir, as a widespread species in natural Alpine mountain forests, plays a central role here.

Importance of stand structure

Effective landslide prevention is furthered by having as deep-reaching and intensive a **rooting system** as possible.

Uneven-aged stands with the highest possible canopy cover are best at sustaining such root penetration in the long-term. A multi-layered stand structure can be assumed to be reflected in the root system in the soil. Such a structure also ensures sustainable tree regeneration, which speeds up reforestation after a potential stand destruction (e.g., by windthrow).

In contrast, **large clearcuts** are the least favourable forest condition for preventing landslide since the stabilising role of the dead roots diminishes after a few years, when the new forest is still at a young stage.

Openings should therefore be as small as possible and only as large as necessary for sufficient regeneration.

Large trees vulnerable to windthrow can negatively affect slope stability. When windthrown, they cause large soil wounds. This can increase water infiltration and intensify the weathering of the underlying material so that starting points for erosion and landslide may develop.

Effects of drainage systems

Drainage ditches can have very different effects. If an active landslide area is well-drained, this can slow down any sliding movements. Large-scale drainage systems, however, often cause other difficulties:

- Maintenance costs of drainage ditches are very high.
- Drainage systems can act counterproductively if their maintenance is neglected.
- In particular in areas with landslides with intermediate to deep surfaces, there is a high risk that the drainage system will be disrupted by slope movements.
- Large-scale drainage systems can, in certain circumstances, contribute to larger peak discharges.
- Often, the water stored cannot flow off without putting a strain on other potential landslide areas.

For these reasons, the purpose of drainage systems must be carefully considered and a maintenance plan estab-lished.

Leaving timber on site

Leaving timber on sites poses a problem in landslide areas if the timber could fall into a torrent channel where it might lead to congestion or become drift wood in debris flows (cf. the target profile for torrents and floods).

Timber harvesting

Inappropriate timber harvesting techniques can cause massive soil compaction, especially on vulnerable soils. This impairs the rooting zone, which is decisive for stand stability and thus preventing landslides, for decades. Damage caused by careless harvesting may well outweigh the intended benefit! When looking for the most cost-effective harvesting practice, a careful approach must be taken to conserve the stand and the soil. This applies in particular to salvage logging, which can do large-scale and permanent damage in a short time.

3.3 **Surface erosion**

Surface erosion is the gradual loss of loose material on the soil surface, in particular due to water. The transition between surface erosion and shallow landslide is blurred. In contrast to landslides and slope debris flows, surface erosion alone does not present a hazard potential. However, it can in the long term deposit loose material in channels which may be mobilised by debris flow. Moreover, progressive erosion of fine-grained material will reduce the water storage capacity of the soil and the rooting zone for the vegetation.

Erosion as such is a natural process which cannot be completely prevented. However, it can be speeded up or slowed down by particular forms of land use.

The positive **effect of forests** in hindering surface erosion is well known. It is essentially the result of the soil being reinforced by the root systems of the trees and other vegetation, which reduces the removal of soil material by surface runoff. Moreover, a closed vegetation diminishes the ongoing weathering and destabilisation of the granular soil. Weathering leads to a reduced shearing strength and thus promotes erosion and landslide processes.

Vegetation cover of the soil that is extensively closed is therefore of primary importance in preventing surface erosion. The **state of the forest** plays a special role in this. Thus:

- To ensure that the vegetation cover is permanently closed in the long-term, phases of stand destruction (e.g., by windthrow) must be prevented. First and foremost this means that the manager should aim for a stand which makes large-scale collapse unlikely, and here a multi-layered stand structure plays a central role.
- To prevent surface erosion, silvicultural interventions should aim to reduce the occurrence of landslides, which often initiate surface erosion.

3.4 **Debris flows**

Debris flows are rapidly flowing mixtures of water and solid components, where the proportion of solid material is about 30 to 60%. They occur often in surges in torrent channels. Typically they have a high density, sometimes with high flowing velocities, and a high transportation capacity with large volumes of solid material (with rocks several m^3 in volume) transported.

Landslides and surface erosion lead to the accumulation of loose material in torrent channels and thereby contribute to the development of debris flows. Moreover, debris flows can be triggered by slope instability as so-called slope debris flows.

The forest can influence debris flows by reducing slope processes (landslides, surface erosion) and therefore slow-ing the supply of material that could be transported by debris flow. In the deposition zone of a debris flow, a forest can also have a certain braking function by promoting debris flow drainage.

Debris flows are not explicitly considered in the target profile, but the triggering processes (landslides and surface erosion) are.

A potential negative influence of a forest on debris flow (drift wood in the channel) is considered in the target profile for torrents and floods.

Source:

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4 **Rockfall**

4.1 **Target profile of forests protecting against rockfall**

Locality	Potential contribution of the forest	Hazard-related target profile: minimum requirements	Hazard-related target profile: ideal requirements
Zone of origin	**Medium**	**Stability carriers** No unstable heavy trees	
Transit zone	**Large** Rocks up to 0.05 m^3 (diameter about 40 cm)	**Horizontal structure** At least 400 trees/ha with dbh > 12 cm	**Horizontal structure** At least 600 trees/ha with dbh > 12 cm
		Potentially also coppice shoots	
		Vertical structure Target diameter[2] appropriate	
	Rocks 0.05 to 0.20 m^3 (diameter about 40 to 60 cm)	**Horizontal structure** At least 300 trees/ha with dbh > 24 cm	**Horizontal structure** At least 400 trees/ha with dbh > 24 cm
		Vertical structure Target diameter[2] appropriate	
	Rocks 0.20 to 5.00 m^3 (diameter about 60 to 180 cm)	**Horizontal structure** At least 150 trees/ha with dbh > 36 cm	**Horizontal structure** At least 200 trees/ha with dbh > 36 cm
	Additionally for all rock sizes:	**Horizontal structure** In openings[1] in the fall line, stem distance < 20 m Lying logs and high stumps supplementing standing trees if no risk of fall	
		Minimum requirements of the site-related target profile accomplished	Ideal requirements of the site-related target profile accomplished
Run-out and deposition zone	**Large** The effective minimum diameter of trees is considerably smaller than in the transit zone, and lying logs are always effective	**Horizontal structure** At least 400 trees/ha with dbh > 12 cm	**Horizontal structure** At least 600 trees/ha with dbh > 12 cm
		Horizontal structure In openings[1] in the fall line, stem distance < 20 m Potentially also coppice shoots	
		Vertical structure Target diameter appropriate Lying logs and high stumps supplementing standing trees	
		Minimum requirements of the site-related target profile accomplished	Ideal requirements of the site-related target profile accomplished

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[1] Opening size in pole and old timber stands is measured from stem to stem.

[2] The target diameter should be chosen so as to ensure that the required stem number with trees of the minimum effective diameter is permanently achievable.

4.2 **Rockfall processes**

A rockfall process is the movement of falling rocks and their interaction with the environment. The rocks roll, bounce or slide. These movement types can be well described. In their forward movement, the rocks hit the ground or obstacles such as logs or defence structures. This causes the rocks to lose energy.

Rockfall processes occur in several distinctive areas: the zone of origin, the transit zone and the run-out and deposition zone (Fig. 5). Often, these zones overlap.

In addition to rockfall, icefall often occurs.

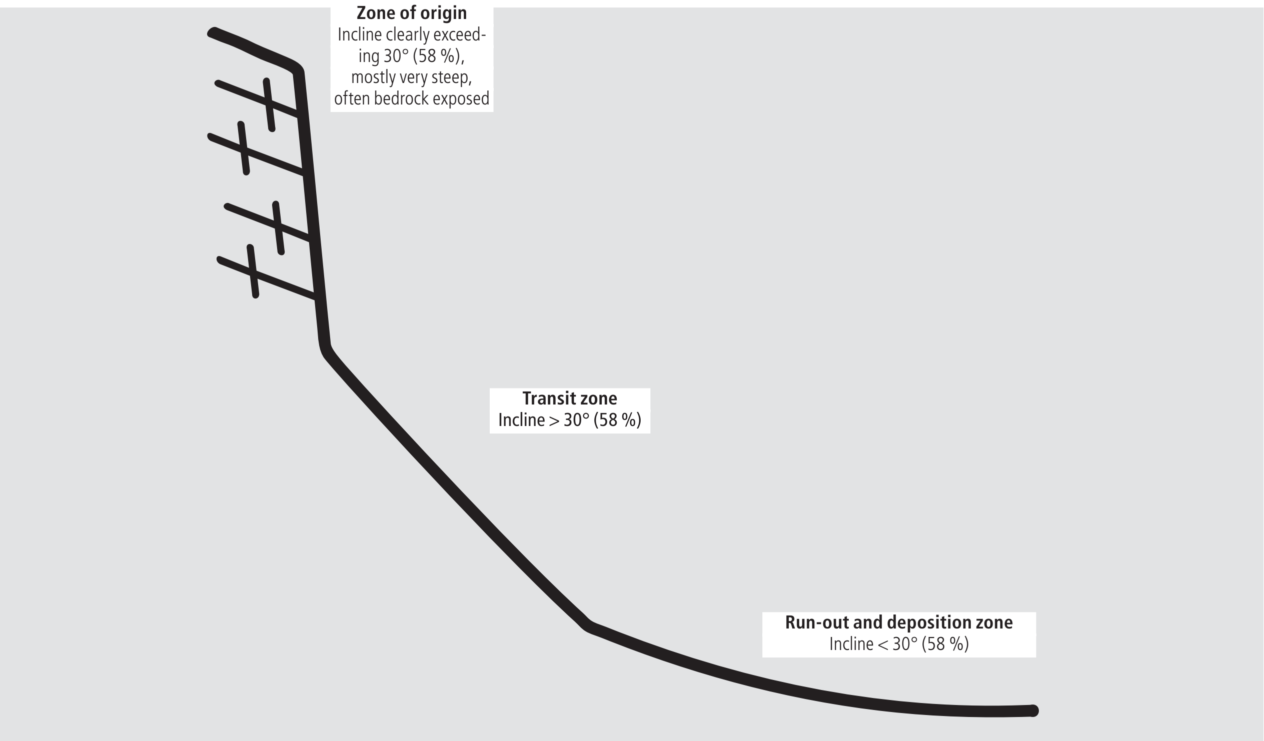

Figure 5: Schematic slope profile.

4.3 **Zone of origin**

Role in the rockfall process

In this zone rocks are released. The size and form of the rocks as well as the rockfall frequency are influenced by the bedrock type, bedrock stratification, aspect and elevation.

Forest influence

Tree roots hold rocks together. However, they can also speed up weathering since organic acids from roots and coniferous litter corrode the rocks. The roots may also grow into cracks and lead to frost wedging. If the bedrock layers are parallel to the slope, weathering processes act more strongly than if they run perpendicularly to the slope. Falling trees can also dislodge rocks. Trees, particularly those taller than 20 m, can sway in the wind to such an extent that the roots move and thus release rocks.

The effects of the forest depend on the local geology and topography, the tree species, the trees’ weight, height and centre of gravity.

Effectiveness of lying logs

Well-anchored logs hamper rockfall if there is no risk of them falling. The risk of them falling increases with increasing incline, the way logging has been done and also depends on snow conditions.

4.4 **Transit zone**

Role in the rockfall process

On slopes with inclines between 30° (58 %) and 35° (70 %), rocks roll or slide. On slopes with inclines over 35° (70 %) they can also bounce. These movements can be calculated with relatively high precision. When hitting the ground or obstacles, rocks lose energy (energy = mass x velocity^2), and they may also change their direction. It is still difficult to calculate the extent of energy loss. Rocks may be stopped as a result of such contacts, but they may also regain speed afterwards.

The following factors besides forest and protective structures will slow down rocks:

- Topography: if the topography is rugged, rocks are deflected; the gentler the terrain, the slower rocks move.
- Surface roughness: Rocks are greatly slowed down on rough surfaces, in particular if the size of the items contributing to surface roughness is of the same magnitude as that of the rocks (talus slopes).
- Damping: soft soil has a strong breaking effect on rocks.

Round rocks usually move faster than angular or elongated rocks, assuming the conditions are otherwise similar.

Forest influence

Contact with trees brakes rocks or stops them temporarily. Braking makes rocks not only reduce speed, but also bounce less high.

How large a braking effect trees will have depends on their diameter and rock size:

- Very slim trees give way if hit by rocks, so their braking effect is slight.
- Larger trees can be injured or broken by rocks, depending on the rocks' energy (which in turn depends on their velocity and size). Such contacts reduce the velocity and the energy of the rocks to a considerable extent.
- Forests are not so effective in preventing the fall of very large rocks (=boulders).
- It is not possible to calculate precisely what the minimum diameter is that a tree must have to be effective against a particular rock. We know from experiments that living trees absorb more energy than wooden beams and that rocks moving slowly contain little energy. Thus even a relatively slim tree is able to slow down small rocks.

The effective minimum diameter of a tree plays an important role since it is not always possible to sustain a stand structure which offers optimal protection against rockfall, especially if the effective minimum diameters are large.

Therefore, an important question arises: for which situation should the forest be designed? In the case of moving objects at risk (i.e. where the damage potential consists, e.g., of hikers or cars), small but frequent rocks are often a problem. In the case of a house, it is the rather rare, large rocks that are dangerous.

The effectiveness of a forest depends on the diameter and the number of trees as well as the size of gaps. Rocks can already reach maximum speed and bounce a long way after a distance of 40 m, although this varies with the terrain. This means that the forest above an opening 40 m long parallel to the slope has little influence on any rocks that move through it and then reach the forest below. The target profiles therefore limit the length of openings in the fall line to 20 m.

If the stem number is high, there will be numerous contacts between rocks and trees. However, the stem density that is permanently possible in a forest is restricted. The stem numbers given in the profiles for large rocks are in the upper range of values to be found in virgin forests. For smaller rocks, slim stems serve same the purpose. The target diameter is therefore smaller but the stem number greater than in a virgin forest.

The target diameter exceeds the effective minimum diameter. It should be selected to sustain the required stem number with trees that have the effective minimum diameter.

The values for the effective minimum diameter given in the profiles are based on experiments and experience (Table 2).

Table 2: Rock size and assumed effective minimum diameters for the target profiles.

Rock volume (m^3)	**Rock diameter (cm)**	**Assumed effective minimum diameter**
up to 0.05 m^3	up to about 40 cm	up to 20 cm dbh
0.05 m^3 up to 0.20 m^3	about 40 cm to 60 cm	20–35 cm dbh
0.20 m^3 up to 5.00 m^3	over about 60 cm	over 35 cm dbh

The transit and/or deposition zones should have a minimum length if the forest is to be effective. Should the transit zone be short, without a deposition zone, the rocks small and the tree species in place able to sprout, coppice shoots can also be recommended for regeneration (see also Chapter 4.6).

In short transit zones, potential icefall should also be taken into account.

If the transit zones are long, the stands located close to the zone of origin are particularly important in stopping stones before they reach high speeds.

Effectiveness of lying logs

Lying logs increase surface roughness. If the logs are at an angle to the fall line, rocks will normally be slowed down. Logs lying along the contour lines brake the rocks and partly stop them. If there is a dense net of logs lying along the contour line, the danger of large rock accumulations is small since the rocks are well spaced out. In contrast, if there are only a few logs lying along the contour line in a forest, large accumulations of rocks may form.

Logs lying along the contour line are recommended if there is no run-out or deposition zone above the damage potential (e.g., a road). The rocks accumulated behind these logs need to be observed, and possibly secured before the logs decay, or alternatively new logs deposited below the decaying logs. Lying logs in the transit zone can also protect the stand itself from being injured. Logs lying at an angle to the fall line can help to canalise rocks. Where logs are weakly anchored, they must be observed in case they fall. This risk increases with increasing incline, certain logging practices (debranching and bark peeling) and snow.

Piles of branches improve damping effects

Uprooted root plates increase the roughness of the terrain and therefore help, at least in principle, to prevent rockfall. Problems may arise if large rocks are attached to the root plates. Such rocks are in most cases released with increasing root decay and thus become a rockfall source (which frequently occurs in the Jura mountains). Moreover, loose root plates are set in motion. If a log is bucked so that at least 4 m of the stem remain on the stump, this problem can largely be avoided.

High stumps favour braking and help to stop rocks.

4.5 **Run-out and deposition zones**

Role in the rockfall process

The speed of a falling rock will also diminish without any contact with obstacles. At inclines between 25° (45 %) and 30° (58 %), rocks can roll over a long distance if they do not hit an obstacle. If the incline is less than 25° (45 %), rolling rocks will stop quickly. Once stopped, rocks do not usually start moving again.

Transit and deposition zones overlap.

The same factors as in the transit zone serve to slow down rocks.

Forest influence

Contact with trees slows rocks down or stops them completely. In principle, trees hit by rocks show the same reactions as those in the transit zone. As rock velocity is on average less than in the transit zone, the effective minimum diameters are accordingly smaller.

As in the transit zone, the larger the number of trees, the more contacts there will be between rocks and trees.

The stem numbers indicated in the profiles are higher than in a virgin forest, but the target diameter is accordingly smaller.

Effectiveness of lying logs

Lying timber increases surface roughness. Rocks that have stopped moving remain immobile. There is a transition in rock movement from bouncing to rolling in the run-out and deposition zones, so that logs lying in these zones will be particularly effective obstacles.

Piles of branches improve damping effects.

Dead wood on windthrow areas

On uncleared windthrow areas, the timber provides an effective protection against rockfall. For several decades, surface structures such as snags, stumps, root plates and lying logs remain densely entangled in layers several meters tall. These prevent any release of small to intermediate rocks and stop moving rocks. Only very large boulders can break through the entanglement due to their weight. Clearing considerably reduces the level of protection against rockfall.

4.6 Additional information regarding forest effects

Silvicultural interventions compared to technical protective structures

The appropriate management of forest stands can replace technical constructions or allow them to be built more cheaply to accomodate lower bounce heights and less rock energy.

Rot

Injured trees can start rotting (Norway spruce and beech after approx. 10 years). Wood grown after the injury will not be infected.

Coppice shoots

Small trees with a dbh of at least 12 cm are already effective in the run-out and deposition zones as they are with small stones in the transit zone. In these cases it can be favourable to work also with coppice shoots if appropriate tree species are present. Coppice shoots grow very fast in their youth and reach the minimum dbh for effective protection after only a few years. When coppicing, the stumps must be cut cleanly and close to the ground so that not only the shoots but also the roots can renew themselves after the cut. As the space from stem to stem should not exceed 20 m in openings in the fall line, no large coppice cuts should be made, but only strips which have a maximum length of 20 m in the fall line. Coppice forests need intensive tending. The area must be tended regularly. Natural regulating forces cannot be relied on as much as in multi-layered forests. Therefore the areas best suited for providing protection with coppice shoots are those where there is little space between the source of the rockfall and the objects at risk.

Topography

In the rockfall process the topographical characteristics must be taken into account. In the transit zone, small flat areas can be used as deposition zones. Timber left lying in these areas is particularly effective. An eye must be kept on small isolated rockfall origin zones (e.g., unstable taluses, small rocky outcrops).

Determining the effective minimum diameter

The profiles in the transition zone are based on an incline of about 35° (70 %) and average conditions in relation to rock shape, damping and surface roughness. The effective minimum diameter can be changed if these factors change, or if the tree species changes.

Factors which **increase** the effective minimum diameter:

- Incline greater than 35° (70 %)
- Round rocks
- Poor damping (e.g. rocks at the soil surface)
- Limited surface roughness
- Tree species with soft wood (e.g. Norway spruce, silver fir, alder)
- Tree species with wood that is prone to rot (e.g. Norway spruce, beech)

Factors which **decrease** the effective minimum diameter:

- Inclines below 35° (70 %)
- Angular, elongated rocks
- Good damping (e.g. soft soil, heaps of branches)
- Very uneven surfaces (e.g. talus, lying wood, high stumps)
- Tree species with heavy wood (e.g. beech, locust, hornbeam, ash, yew, oak)
- Tree species that are rot resistant (e.g. silver fir, larch, valuable broadleaved species)

Source:

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5 Torrents and floods

5.1 Target profiles in forests providing protection against torrents and floods

Locality	Potential contribution of the forest	Hazard-related target profile: minimum requirements	Hazard-related target profile: ideal requirements
Catchment area Reduction of peak water discharges in the whole catchment	**Large** On site types in class 1[1]	**Horizontal structure** Canopy cover[2] permanently ≥ 60 % Minimum requirements of site-related target profile accomplished	**Horizontal structure** Canopy cover[2] permanently ≥ 70 % Ideal requirements of site-related target profile accomplished
	Intermediate On site types in class 2[1]	**Horizontal structure** Canopy cover[2] permanently ≥ 50% Minimal requirements of site-related target profile accomplished	
	Small On site types in class 3[1]	**Regeneration** Permanent regeneration ensured	**Horizontal structure** Canopy cover[2] permanently ≥ 50% Ideal requirements of site-related target profile accomplished
	Very small On site types in class 4[1]	No requirements	
Forest on channel slopes Prevention of negative impacts of timber in the channel	**Small to large** Depends on channel characteristics (e.g., potential bottlenecks)	**Other requirements** No unstable trees or stems prone to slide	**Other requirements** No unstable trees or stems prone to slide Ideal requirements of site-related target profile accomplished Pioneer vegetation on areas which are temporarily or permanently unstocked

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[1] cf. site type classification (Appendix 1, Chapter 5.7).

[2] The canopy cover relates to trees of at least pole size (i.e. young growth and thicket stages are ignored).

In areas where there are not only floods but also landslide problems, the target profiles must be adjusted to each other. In the case of shallow landslide, as a rule, landslide profiles should have priority. In contrast, intermediate and deep landslides must be assessed from case to case.

5.2 Role of the forest in different situations

Stable forests well-suited to the site are the most favourable for utilising the soil to store as much water as possible during heavy rain. Whether the status of the forest can also have a substantial influence on the runoff in the catchment area depends on the following basic circumstances:

Proportion of forest in the whole catchment area and its location

The influence on the total runoff in a catchment area is obviously the greater the larger the proportion of forest is in the catchment area. Additionally, the location of the forested area in the catchment area must be considered. Often forest is to be found growing on areas near watercourses (slopes of streams), which make the largest contribution to the runoff. Thus the forest can have a greater impact than one would expect it to have on the basis of its area alone.

Critical precipitation event

The water regime is greatly influenced by the intensity and duration of the precipitation that occurs. Short showers in a dry period are almost completely absorbed by interception in a forest and only a small part reaches the ground. With heavier rainfall the impact of a short, heavy storm is very different from that of a long period of drizzle, even if the amount of rainfall is the same. The different intensities of the rain affect the infiltration capacity of the soil, which may be insufficient after intense rainfall so that there is surface water runoff. This is less likely in the second case.

The time distribution of precipitation before an extreme event is also very significant. Should the soil be very saturated due to snow-melt or previous precipitation, its storage capacity will be diminished.

Thus we have, to put it simply, the following three typical scenarios[3]:

1. Short intense showers on a relatively small area
2. Long periods of heavy rain over a fairly large area
3. Rain spread over a wide area on soil with high water saturation (e.g. during snow-melt)

The forest and vegetation in general have their most significant protective role when the soil-water reservoir is at its emptiest at the time of the event. In the case of scenario 1, the significance of the forest is therefore much greater than in scenario 3, with scenario 2 lying somewhere between the two.

When delineating forests that provide protection against floods, the likely scenarios for precipitation events need to be considered.

5.3 The influence of forests on the hydrologic regime

In the case of extreme precipitation, the forest has mainly an indirect impact on flooding by influencing soil characteristics and conditions in the long and medium term[4]. The soil characteristics also depend on bedrock, climate and topography. These three soil-forming factors enhance or reduce the potential influence of the forest.

The forest can have considerable impact by affecting the **intensity and depth of root penetration**. Rooting creates a finely branched system of cavities and thus promotes good soil permeability. The more intensive and the deeper the penetration of the soil is, the better the available water **storage capacity** of the soil can be utilised when precipitation is heavy.

In addition, the **conditions on the soil surface**, which affect the **infiltration capacity** of the soil, can be influenced by the forest. When the soil is compacted on the surface, (e.g. due to machine use or cattle trampling), less water can infiltrate within a useful timespan, so that the probability of surface runoff is increased. Conversely the infiltration capacity can be significantly increased by having a favourable humus and top-soil form and an intensive layer of forbs and moss.

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[3] after Zimmermann (2001), adapted

[4] While the aboveground vegetation considerably affects the annual course of discharge by interception and transpiration, its influence on individual extreme incidents is very small.

5.4 **Importance of the site**

The soil, particularly that in the rooting zone, is the key forest variable influencing the water regime. Soil characteristics can be easily determined at any point by boring or digging soil profiles, but the variations and distribution of the soil characteristics over a whole area are very difficult to determine. Every forest site type has a known range of soil characteristics, so that it can be used as a basis for assessing the soil characteristics over larger areas[5].

In this way it is possible to assess how much the state of the forest can influence flooding in a particular location and if there is a need for silvicultural action. In Figure 6 this is shown schematically: on site A there is the highest absolute storage capacity, but the influence of the forest on the storage capacity is greatest on site C. Sites of type C therefore have the highest priority in forest management. These sites are often sites which are periodically water-logged. In contrast to permeable soils where the state of the forest plays a lesser role, deep-rooting tree species can increase the storage capacity substantially on intermittent watertable soils by improving the accessibility of the available storage space. The influence of the state of the forest is marginal on shallow soils and on soils with a very permeable subsoil (type D).

5.5 **Significance of individual factors affecting the state of the forest**

Tree species

Trees have typical, site-specific rooting patterns. The rooting of different tree species in the soil can vary greatly, and also depends on the layering of the soil profile and the development of the soil characteristics.

In the literature there are only few, rather inexact data concerning rooting in different soil types given, and they have mainly to do with maximum **rooting depths**. Some tree species have the special capability of accessing intermittent watertable soils, which is decisive for water storage. Of all the main tree species of the upper and lower montane altitudinal belt, this capability is the most developed in silver fir. But beech also accesses these horizons better than Norway spruce. Of the secondary tree species, ash and maple have the best characteristics in this regard.

Regarding the species-specific **rooting intensity**, which is at least as decisive, Norway spruce also displays worse values than silver fir and beech[6].

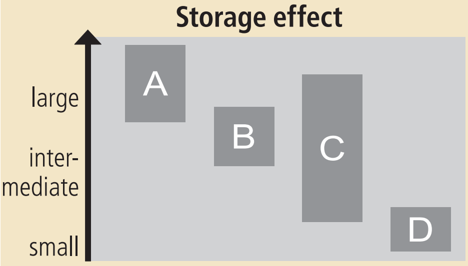
From the point of view of the **infiltration conditions**, tree species with litter that decomposes well (broadleaved trees, particularly ash and maple) are desirable. Nonabsorbant organic surface matter that hinders the penetration of the water into the soil is unfavourable.

Stand structure

Rooting intensity obviously increases in the soil with denser tree stocking. For the rooting to be as intensive as possible, a high canopy cover is best.

Additionally, an even distribution of the rooting throughout the entire potential rooting space is crucial in both horizontal as well as vertical directions.

- ▸ In the horizontal direction this implies that there are as few gaps as possible. The size of the individual gap is not very important here, but the total area of the gaps is.



A: large storage effect regardless of the state of the forest:
sites with deep soils and normal permeability.
B: intermediate storage effect regardless of the state of the forest:
sites with intermediate soil depth and normal permeability.
C: large storage effect if the state of the forest is good, and small effect if it is bad:
sites with deep soils and limited permeability.
D: small storage effect regardless of the state of the forest:
heavily water-logged, very shallow or overly permeable sites.

Figure 6: Range of storage effects in the case of heavy precipitation (schematically). The boxes designate the range for different site types: The lower edges designate the storage effect in the worst case (e.g., after large-scale windthrow), the upper edges the effects of stands with ideal structure.

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[5] Studies on windthrow areas have demonstrated that the site class is a suitable instrument to assess the formation of surface flow (Badoux et al. 2003; Hegg 2004).

[6] Lüscher (2000)

- In the vertical direction rooting should be as regular as possible throughout the whole rooting zone. Presumably multi-layered stocking that has a regular space distribution has a similar effect in the rooting space.

The ideal stand structure is one that is multi-layered on small areas with a dense canopy cover and regular distribution.

Soil compaction

The incorrect use of machines (especially during logging operations) can lead to massive compaction of the soil. This causes a long-term deterioration of the infiltration conditions, the permeability and storage capacity of the soil. The formation of continuous linear structures in the fall-line should, for example, be avoided when clearing damaged areas.

5.6 **Forests on channel slopes**

While forests have positive dampening effects on the water regime within the catchment area of a torrent, they can also act negatively through trees and wood falling in the channel. Logs within the range of a flood cross-section can be swept away by a flood or by a debris flow. At narrow points (rock spurs, stream bends, bridge culverts) congestion and bottle-necks can then occur.

Bottle-necks are particularly unfavourable because behind them bed load can accumulate, which can later be set in motion as debris flow. When a flood occurs, it can cause a channel displacement with flooding, overbank sedimentation and debris flow deposition at blockage points. For this reason bottle-necks must be avoided where there is significant damage potential.

Areas close to the stream bed

The relevant areas close to a stream bed are those which would be affected by an extreme flood or debris flow.

In most cantons monitoring these areas is the responsibility of the water board or the public works department. Measures undertaken in the immediate proximity of the stream bed must therefore be coordinated with the appropriate authorities.

Managing forests on channel slopes

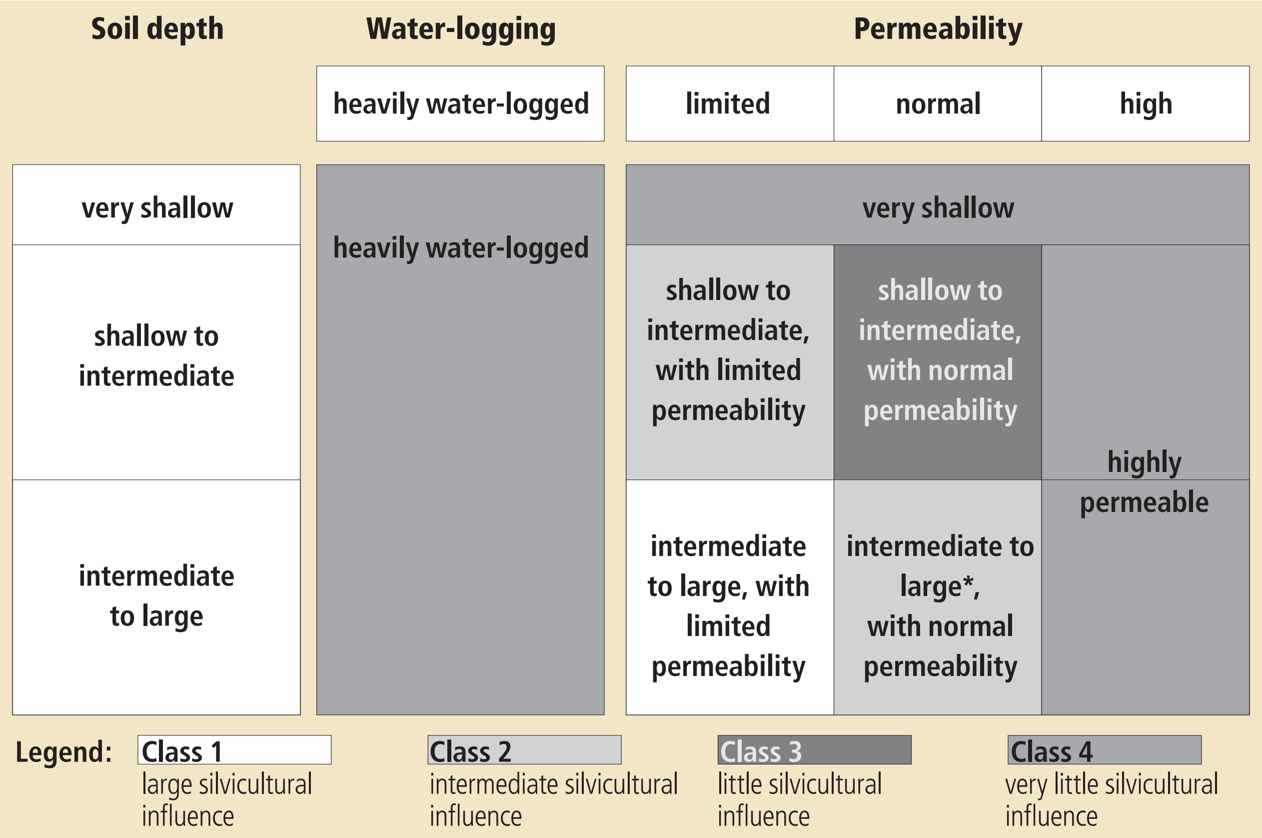
The relevant forest areas on channel slopes are those from which wood can slide or be swept into the channel itself.

On channel slopes the primary management target is to maintain stable stocking so that no wood can reach the stream bed and cause blockages. The most important measure, therefore, is the selective removal of unstable trees (and root plates). As channel slopes are usually areas that are difficult to access, an option to clearing can also be cutting logs into short pieces. The size of the pieces depends on the conditions and the possible blockage points in the stream bed.

A destabilisation of the embankment and surface erosion can often be prevented by stable stocking. In this case the target profile to prevent landslides must also be considered.

5.7 **Classification of the site types**

The site types are classified in principle according to the three soil criteria: depth, water logging and permeability (Figure 7). These are known for the soils of all site types (Table 3, the soil characteristics of each site type are described in Appendix 2A, unavailable in English):



<table>
<tr><th>Soil depth</th><th>Water-logging</th><th colspan="3">Permeability</th></tr>
<tr><td></td><td>heavily water-logged</td><td>limited</td><td>normal</td><td>high</td></tr>
<tr><td>very shallow</td><td rowspan="3">heavily water-logged</td><td colspan="3">very shallow</td></tr>
<tr><td>shallow to intermediate</td><td>shallow to intermediate, with limited permeability</td><td>shallow to intermediate, with normal permeability</td><td rowspan="2">highly permeable</td></tr>
<tr><td>intermediate to large</td><td>intermediate to large, with limited permeability</td><td>intermediate to large*, with normal permeability</td></tr>
</table>

Legend:
- **Class 1** large silvicultural influence
- **Class 2** intermediate silvicultural influence
- **Class 3** little silvicultural influence
- **Class 4** very little silvicultural influence

Figure 7: Site type classification based on soil characteristics.

* impermeable underground

In the following cases there may be some deviation from this classification:

Sites that are difficult to influence silviculturally

The possibility of influencing the water storage capacity of the soil through silviculture is not the same on all site types. At higher altitudes (sub-alpine zone) especially, the influence generally decreases. Norway spruce is usually the only tree species which can be used. The processes are generally slower, and the stand densities and, as a consequence, the rooting intensity are lower. But also on other sites (e.g. pure ash sites), the silvicultural possibilities are limited by the absence of other tree species. These sites are therefore allocated to a lower class.

Examples[7]: 26 Aceri-Fraxinetum
53 Polygalo chambaebuxi-Piceetum
57 Sphagno-Piceetum
calamagrostietosum villosae

Sites with highly variable soil

Some important and common site types have highly variable soil characteristics. One reason for this is the variation in regional (especially geological) conditions. Therefore, these site types cannot be assigned to a single class for all of Switzerland. They must be classified separately for each region, and the classification explained. Hence, they are assigned in the following list to a class of their own (class E = casewise assessment). For these site types, instructions are given in Figure 8 to explain under what circumstances they can be assigned to which class. For the definite assignment, additional investigations of the soil in the particular forest will be necessary (Hegg et al., 2004).

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[7] Numbers refer to the site type classification in Appendix 2A (see also Table 3)

Site type	Class 1	Class 2	Class 3	Class 4
7a, 8a, 18, 19, 50, 50P, 51	if there is clear evidence of water-logging (common on Flysch soils)	if there is no or almost no evidence of water-logging		
11 12S 46	if the soil is deep (common in the Plateau and in the Pre-Alps)	if the soil is shallow (common in the Jura mountains)		
12a 46M		if the soil is deep (common in the Plateau and in the Pre-Alps)	if the soil is shallow (common in the Jura mountains)	
(42)-34A Rob		on Cambisols and (humic) Podzols	on Leptosols	
49		if the proportion of indented sites (with vegetation indicating wet conditions) < 60% of the area	if the proportion of indented sites (with vegetation indicating wet conditions) > 60% of the area	if the proportion of indented sites (with vegetation indicating wet conditions) < 80% of the area

Figure 8: Classification of the site types with highly variable soil characteristics.

Tips for handling the site type classification

- If a site map exists, a priority map can be produced with the help of the four classes described above. The classes based on the site type must be weighted according to the urgency and effectivity of the silvicultural intervention in the individual stand. In this way, is is possible to determine where silvicultural interventions will have the largest influence on the storage capacity of the soil.
- When necessary, deviations from the classification according to the list can be made. This can be the case, for example, if the geology suggests there are differences in the depth of soil or the permeability of a particular site type.
- Usually not only pure units are to be found on a site map. There are often transitions or a mosaic of different site types. In this case, the different classifications of the unit must be weighted against each other.

Example: An area was mapped as transitional 18 (20). 18 (Abieti-fagetum festucetosum) can, depending on circumstances, belong to classes 1 or 2, and 20 (Abieti-fagetum polystichetosum) only to class 1. This area is therefore assigned to class 1.

When deciding on silvicultural interventions to help retain floods, it is not the single stand or the single stand type area which is important, but rather the state of the forest in the whole catchment area. Thus, as well as taking into account the site type and the forest's state, further factors, e.g. timber harvesting methods, must be considered during planning to achieve the best possible result.

Table 3: **Classification of site types in Swiss protection forests. The nomenclature follows that in Appendix 2A in the German version.**

Class 1	**Sites with large silvicultural influence**
Soils with limited permeability, intermediate to large soil depth	
7S	Galio-Fagetum stachyetosum silvaticae
8S	Milio-Fagetum stachyetosum silvaticae
8*	Milio-Fagetum blechnetosum
19f	Luzulo-Abieti-Fagetum, variant on Gleysol
20	Adenostylo alliariae-Abieti-Fagetum typicum
20E	Adenostylo alliariae-Abieti-Fagetum hordelymetosum
20*	Streptopo-Fagetum s.l. prov.

Class 2	**Sites with intermediate silvicultural influence**
Soils with limited permeability, shallow to intermediate soil depth	
9w	Pulmonario- / Lathyro-Fagetum caricetosum flaccae
10w	Pulmonario- / Lathyro-Fagetum melittetosum, variant with Carex flacca
18v	Adenostylo glabrae Abieti-Fagetum calamagrostietosum variae, variant with Carex ferruginea
18w	Adenostylo glabrae Abieti-Fagetum calamagrostietosum variae
46*	Vaccinio myrtillii-Abieti-Piceetum sphagnetosum
Soils with normal permeability, intermediate to large soil depth	
3mL-4L	Ilici-Fagetum typicum and dryopteridetosum
4	Luzulo niveae-Fagetum dryopteridetosum
9a	Pulmonario- / Lathyro-Fagetum typicum
18M	Adenostyle glabrae-Abieti-Fagetum typicum
19L	Laburno-Abieti-Fagetum typicum
25A-34mA	Cruciato glabrae-Quercetum p.p. Luzulo niveae-Tilietum
25Am-33m	Arunco-Fraxinetum typicum; Luzulo niveae-Tilietum p.p.
25AB-33B	Arunco-Fraxinetum; Luzulo niveae-Tilietum p.p.
25AF	Lunario-Acerion, Tilion, Arunco-Fraxinetum p.p.
50*	Adenostylo glabrae-Abieti-Piceetum typicum
51C	Galio-Abieti-Piceetum coryletosum
52	Adenostylo glabrae-Abieti-Piceetum caricetosum albae
55	Veronico latifoliae-Piceetum

Class 3	**Sites with little silvicultural influence**
Soils with normal permeability, shallow to intermediate soil depth	
1h	Luzulo-Abieti-Fagetum, variant poor in species
3	Luzulo niveae-Fagetum typicum
3VL	Ilici-Fagetum typicum, variant poor in nutrients
10a	Pulmonario- / Lathyro-Fagetum melittetosum
12w	Mercuriali- / Cardamino-Fagetum caricetosum flaccae
12*h	Cardamino-Fagetum veratretosum
13a	Tilio-Fagetum typicum
24*	Ulmo-Aceretum
33AV-33A	Arunco-Fraxinetum vaccinietosum
34B	Cruciato glabrae-Quercetum p.p.
36	Carpino betuli-Ostryetum
37	Fraxino orni-Ostryetum
47	Calamagrostio-villosae-Abieti-Piceetum typicum
47D	Calamagrostio-villosae-Abieti-Piceetum dryopteridetosum
47M	Calamagrostio-villosae-Abieti-Piceetum melampyretosum

Sites with little silvicultural influence, intermediate to large soil depth	
21	Aceri-Fagetum
21*	Alno viridi-Sorbetum aucupariae prov.
26	Aceri-Fraxinetum
26h	Aceri-Fraxinetum, variant in high altitude
47*	Rhododendro-Abietetum
54	Melico-Piceetum typicum
57C	Homogyno-Piceetum calamagrostietosum villosae
57M	Homogyno-Piceetum melampyretosum sylvatici
57V	Homogyno-Piceetum vaccinietosum myrtilli
59V	Larici-Pinetum cembrae vaccinietosum myrtilli
60	Adenostylo-Piceetum typicum
60A	Adenostylo-Piceetum athyrietosum distentifolii
60*	Calamagrostio variae-Piceetum

Class 4	**Sites with very little silvicultural influence**
Highly permeable soils, intermediate to large soil depth	
53	Polygalo chamaebuxi-Piceetum
53*	Erico-Piceetum
57S	Homogyno-Piceetum sphagnetosum
57Bl	Homogyno-Piceetum, variant on boulders
58	Larici-Piceetum typicum
58C	Larici-Piceetum calamagrostietosum villosae
58L	Larici-Piceetum laserpitietosum halleri
59	Larici-Pinetum cembrae typicum
59A	Adenostylo-Laricetum
59C	Cotoneastro-Pinetum cembrae
59E	Larici-Pinetum cembrae ericetosum
59J	Junipero-Laricetum
59L	Larici-Pinetum cembrae laserpitietosum halleri
59*	Rhododendro ferruginei-Laricetum
60E	Adenostylo-Piceetum equisetetosum silvaticae
72	Sphagno-Pinetum cembrae

Heavily water-logged soils	
27	Carici remotae-Fraxinetum
27h	Carici remotae-Fraxinetum, variant with Petasites albus
27*	Adenostylo-Alnetum incanae
33-27	Osmundo-Alnetum; Arunco-Fraxinetum p.p.
49*	Equiseto-Abieti-Piceetum caricetosum ferrugineae
56	Sphagno-Piceetum
71	Sphagno-Pinetum montanae

Very shallow soils	
12e	Mercuriali-/Cardamino-Fagetum caricetosum albae
12*	Cardamino-Fagetum insubricum s. l.
14	Carici (albae)-Fagetum typicum
14*	Cephelanthero-Fagetum insubricum s. l.
15	Carici-Fagetum caricetosum montanae
17	Taxo-Fagetum / Seslerio-Fagetum calamagrostietosum variae
18*	Adenostylae glabrae-Abieti-Fagetum caricetosum albae
61	Molinio-Pinetum sylvestris
62	Cephalanthero-Pinetum sylvestris
65	Erico- / Coronillo-Pinetum sylvestris
65*	Ononido-Pinetum sylvestris
67	Erico-Pinetum montanae

68	Calluno-Pinetum sylvestris
68*	Vaccinio vitis-idaeae-Pinetum sylvestris
69	Rhododendro hirsuti-Pinetum montanae
70	Rhododendro ferruginei-Pinetum montanae

Highly permeable soils, shallow to intermediate soil depth	
13e	Tilio-Fagetum caricetosum albae
13eh	Adenostylo-Fagetum seslerietosum
13h	Adenostylo-Fagetum typicum
22	Phyllitido-Aceretum
23	Sorbo-Aceretum
25	Asperulo taurinae-Tilietum typicum
25B	Asperulo taurinae-Tilietum, insubric variant s.l.
25*	Aceri-Tilietum / Asperulo taurinae-Tilietum tametosum
42R	Phyteumo betonicifoliae-Quercetum festucetosum variae; Quercion pubescenti-petraeae p.p.
42C/Q	Phyteumo betonicifoliae-Quercetum typicum
42V	Phyteumo betonicifoliae-Quercetum vaccinetosum
47H	Hypno-Piceetum
48	Asplenio-Abieti-Piceetum
55*	Luzulo niveae-Piceetum

Class E	**Sites with variable silvicultural influence (case-wise assessment)**
Soils highly variable	
7a	Galio-Fagetum typicum
8a	Milio-Fagetum typicum
11	Aro-Fagetum
12a	Mercuriali-/Cardamino-Fagetum typicum
12S	Mercuriali-/Cardamino-Fagetum circaetosum / allietosum
18	Festuco-Abieti-Fagetum
19	Luzulo-Abieti-Fagetum typicum
(42)-34A	Phyteumo betonicifoliae-Quercetum polygonatetosum multiflorii; Cruciato glabrae-Quercetum p.p.
46	Vaccinio myrtillii-Abieti-Piceetum typicum
46M	Vaccinio myrtillii-Abieti-Piceetum melampyretosum
49	Equiseto-Abieti-Piceetum typicum
50	Adenostylo alliariae-Abieti-Piceetum typicum
50P	Adenostylo alliariae-Abieti-Piceetum petasitetosum
51	Galio-Abieti-Piceetum typicum
Rob	Chelidonio-Robinion; Carpinion s. l. p.p.

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