The impact of forests and forest management on slope stability

Can CCF management improve slope stability?

Summary

There is a large amount of evidence to suggest that forest cover increases slope stability compared to lower-growing vegetation types such as grassland or scrub. However, while this is true for undisturbed or natural forests, the evidence is less clear for managed forests. Road building and harvesting operations that are essential for forest management reduce the stabilizing effect of forest cover, increasing both surface erosion and landslide frequency. Clear felling has the largest detrimental effect on slope stability, with shelterwood systems and selection systems offering progressively more protection; the latter two can provide conditions of continuous cover (CCF). Careful management using selection systems and a well designed road network may offer a similar amount of stability to unmanaged or natural forest systems. Management systems used in Alpine protection forests can redirect rock fall and reduce damage by dissipating energy. Model simulations suggest that conversion of forested slopes to other vegetation types is likely to increase landslide frequency in the short-term, while afforestation of grassland or scrub slopes may increase slope stability.

Introduction

There are two main types of slope instability which are closely linked; surface erosion and landslides. Surface erosion is a water-driven process, occurring largely during and after periods of intense rainfall, while landslides are gravity-driven (although they are often exacerbated by heavy rainfall).

Surface erosion

During heavy rainfall events, forests have a higher interception rate than other vegetation types, thereby reducing the amount of rainfall reaching the soil surface (Calder et al., 2003; Keim and Skaugset, 2003). The surface soils of forests also tend to have a high organic matter content compared with other vegetation types and hence have a high infiltration capacity, or ability to absorb and hold water (Schoenholtz et al., 2000). Surface flow is therefore rare in most forest soils and surface erosion is low in unmanaged forests compared to other vegetation types (e.g. Sidle et al., 2006).

Landslides

Landslides occur when sub-surface water flow accumulates at particular points on a slope (due to topography or soil hydrological pathways, Anderson and Kneal, 1982). On steep slopes or where there is a relatively impermeable substrate, further heavy rainfall will trigger a landslide of saturated soil, i.e. the soil slips downhill over the rock substrate. On steep slopes, forests reduce the risk of landsliding in three ways. Firstly, and most importantly, they stabilize soils and increase shear strength with a deep and strong network of living and dead root material (e.g. Gray and Megahan, 1981). Secondly they reduce soil water content by taking up large quantities of water through evapotranspiration compared to other vegetation types (McNaughton and Jarvis, 1983). Thirdly they may increase secondary permeability in the soil by forming preferential drainage paths and networks through the soil and substrate (e.g. Chandler and Bisogni, 1991).

However, although unmanaged forested slopes experience fewer landslides than slopes of other vegetation types, there is some evidence that average soil volumes exceed those of grassland landslides. The explanation for this is that trees are deeper rooted and therefore if a landslide occurs a greater depth of soil is removed (Amaranthus et al., 1985; Reneau and Deitriech, 1987). There is also likely to be tree debris contained within the landslide, further increasing damage. Landslides on forested slopes can also be triggered by windthrow and uprooting of trees. Soil type, rooting type and depth, and species choice can all influence stability of forests (Nicoll et al., 2006) and hence stability of slopes.

Road building

Road building can have a damaging effect as on steep slopes usual practice is to gouge deeply into the sub-soil and parent material. This removes down-slope support and roads are often surfaced with heavy additional stone-based material (Rice, 1977;

Megahan and Kidd, 1972; Larsen and Parks, 1997; Zeigler et al., 2000). Roads also modify hydrological pathways and channel excess water, increasing the risk of both surface erosion and landslides (Sidle et al., 2006). Drainage systems on forest roads such as ditches and outlets can reduce risks, but if poorly located can often be the site of landslide initiation (Sidle et al., 1985; Wemple et al., 1996). Landslide erosion caused by forest roads has been shown to be at least 25 times higher than landslide erosion in unmanaged forests (e.g. Amaranthus et al., 1985; Sidle et al., 2006).

Harvesting operations

Although less damaging than road building, harvesting operations also increase the risk of surface erosion and landslides by reducing the beneficial effects of tree cover (Keim and Skaugset, 2003; Bathurst et al., 2007) and by damaging the soil structure. Soil infiltrability is reduced and run-off is increased by compaction, disturbance of organic horizons and exposure of bare ground as a result of harvesting machinery and skidding (e.g. Chatwin and Smith, 1992; Jakob, 2000; Williamson and Neilsen, 2000).

Thinning of stands also increases the risk of wind damage and associated slope instability, particularly in mature stands with high canopies (Hibberd, 1991). Thinning of stands on slopes in high wind-risk areas should be practised with care, and in some areas lower stature native woodlands, may be more appropriate.

Therefore, while unmanaged forests have a strong stabilizing effect on steep slopes compared with other natural vegetation types, the necessity of a road network and harvesting operations in regularly managed forests increases the risk of surface erosion and landslides.

Impact of different forest management systems on slope stability

The impact of forest management operations on slope stability differ greatly depending upon the type of management being carried out.

Clearfelling

Clearfelling has the most detrimental effect on slope stability because tree removal and potential soil damage occur simultaneously over the entire harvested area, reducing slope stability and resulting in a greater number and volume of landslides compared to other forest management systems (e.g. Rice, 1977; Dhakal and Sidle, 2003). As windthrow risk also increases with tree height and age, even-aged stands can be particularly vulnerable to catastrophic damage shortly before clearfelling (Savill, 1983) decreasing slope stability.

Shelterwood systems

Management of even-aged overstories using shelterwood systems increases slope stability compared with clearfelling because the developing regeneration increases rainfall interception and further increases soil cohesion compared to clear cut systems, which usually have minimal ground vegetation (Rice, 1977). The gradual opening of the stand increases wind stability (Gardiner et al., 2005) and may be carried out as uniform, group or strip thinnings. Strip thinning towards the prevailing wind direction may be a particularly effective method of increasing stand, and hence slope stability, depending on slope orientation (Matthews, 1989). The presence of regenerating saplings at the time of overstorey removal helps to maintain soil cohesion and transpiration uptake during the vulnerable period after harvesting.

Selection systems

Selection systems have an even less detrimental effect than shelterwood systems, as the impact of operations is distributed across the whole forest area, resulting in low levels of damage (e.g. Sidle, 1992; Sakals and Sidle, 2004). As mature trees are present across the site at all times, the beneficial effects of rainfall interception, tree rooting and evapotranspiration are continuous. Long-term modelling by Dhakal and Sidle (2003) has demonstrated that landslide frequency was minimised by the combined strategies of partial cutting, increased rotation length, provision of no-thin areas and retention of understorey vegetation. However, in both shelterwood and selection systems, regular intervention is required and a carefully planned road network is essential. There is some concern that availability of brash in CCF managed systems may be insufficient for protection of access routes in the longer term. If carefully managed, the stabilising effects of tree cover in these “close to nature” management systems may outweigh the impacts of a well designed road system, resulting in slopes which are more stable than for other vegetation covers.

Protection forestry

In protection forestry systems, commonly seen in Alpine regions, forests are managed with the primary objective of increasing stability of high-risk slopes. Tree species that are particularly resistant to rockfall damage (such as stem-snap, uprooting and crown damage) and hence able to dissipate most energy, are planted where they can help to control and reduce rockfall (e.g. Dorren et al., 2005). Such stands are managed by increasing surface roughness, leaving felled snags and logs unharvested, and positioning woody material where it may “catch” or redirect falling material towards a less-damaging route (e.g. Kupferschmid Albisetti et al., 2003; Norris et al., 2008).

Changing vegetation type

Very few direct comparisons of slope stability have been published for slopes with different vegetation types because the effect of the vegetation cover cannot be separated from that of the soil type that has developed on the slope. Therefore, because soils differ, it is difficult to compare the stability of, for example, an unmanaged forested slope and a grassland slope.

Indirect comparisons of stability can be made when changes to vegetation occur. Gabet and Dunne (2002) report that the process of conversion of deep-rooted scrub vegetation to shallow-rooted grassland resulted in an increase in landslide risk in the short term. They conclude that shallower rooting grassland plants did not bind the soil to the required depth, resulting in increased frequency of landslides until rooting was well developed. It seems probable that this process would also occur during conversion of forests to scrub, or forests to grassland, with lower rainfall interception rates and reduced soil rooting depths. This is supported by model simulations in which replacement of forest cover by grassland showed an increase in landslides for a catchment in the Spanish Pyrenees (Bathurst et al., 2007). Similarly, simulated targeted reforestation of high-risk areas of a river basin in Ecuador increased root cohesion and reduced number of landslides by two-thirds (Bathurst et al., 2010).

Conclusions

The available evidence suggests that managed forests can provide less stability to slopes than unmanaged forests. However, selection and shelterwood systems, both of which provide conditions of continuous cover, offer more protection than clearfelling. Careful management using selection systems may offer a similar amount of slope stability to unmanaged or natural forest systems. Model simulations suggest that conversion of forested slopes to other vegetation types is likely to increase landslide frequency in the short-term, while afforestation of grassland or scrub slopes may increase slope stability.

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