Future-proofing erosion-prone hill country against soil degradation and loss during large storm events: have past lessons been heeded?

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Abstract

The two damaging storms that struck the Manawatu and Bay of Plenty regions in 2004 serve to remind us of the occurrence of similarly damaging events in 1988 (East Coast) and 1977 (Wairarapa), both of which had severe and long-term economic and societal consequences. The most significant physical impacts common to storm events of this magnitude (approximate 100-year return interval) are the on-site damage caused by erosion, in particular soil loss from pastoral hill country, and the resultant off-site impact of sediment on downstream infrastructure. Research has shown that a closed-canopy forest cover is effective in reducing the on-site risk of erosion during these large-magnitude events.

This article presents examples where reforestation of previously eroded pastoral land has successfully mollified those factors that contribute to risk of landsliding, gully erosion and earthflow movement and poses the question: why have we not future-proofed more of our hill country against inevitable soil degradation and soil loss in future storms?

Introduction

Erosion processes, where they are frequent and widespread, present a major obstacle to the continuation of existing pastoral land use practices, and potentially threaten the economic and social structure of specific regions of this country. Much of this erosion occurs in steep hill country, on land classes widely recognised as being vulnerable to slope failure during major storm events. Erosion is predominantly storm-driven. Over the past four decades, and largely as a consequence of historical storms, continued mass erosion and soil loss with a consequential decline in productivity have forced a change from the present intensive pastoral farming regime to plantation forestry over significant areas of North Island hill country.

Research shows that a closed-canopy forest cover contributes to an increase in slope stability and a significant reduction in erosion, even during large-magnitude storm events. It seems a logical extension, therefore, that where an erosion risk exists, forest vegetation might be employed in some manner to reduce that risk. This article highlights examples where a forest vegetation cover has been successful in mollifying those risk factors that contribute to erosion by shallow landsliding, gully erosion and earthflow movement.

In view of the occurrence of significant, large-magnitude storm events in Wairarapa (1977), Cyclone Bola in the East Coast Region (1988), and more recently the two storms impacting on the Manawatu and the Bay on Plenty regions (2004), the obvious question is will individual landowners, regional councils and central government finally acknowledge the inappropriate use of some of our hill country areas for pastoralism and expend more funds and effort towards future-proofing those areas at greatest risk?

Role of forest vegetation in modifying erosion processes

The understanding of how vegetation contributes to slope stability and erosion control is relatively well advanced. In general terms, above-ground components of vegetation (the canopy) reduce the ability of rainfall to cause slope failure through the processes of interception and evaporation while below-ground components (the roots) provide mechanical reinforcement and are the means by which trees extract soil moisure from the soil to reduce pore water pressures. Our current understanding of these processes in respect to shallow landsliding, gully erosion and earthflows is largely based on studies initiated following Cyclone Bola and undertaken in the East Coast Region, North Island.

Shallow landslides

The effectiveness of *Pinus radiata* for protection against shallow landslides in New Zealand is well documented (O'Loughlin 1984; Phillips *et al.* 1990; Marden *et al.* 1991). Less well known is the role that kanuka (*Kunzea ericoides* var. *ericoides*), a species endemic to New Zealand and an early coloniser of harsh sites, plays in soil conservation and erosion prevention.

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In recent years, and largely since Cyclone Bola (1988), researchers have attempted to quantify the effectiveness of different vegetation types in mitigating the impact of relatively infrequent but large-magnitude storms against landslide initiation. Much of this research focused on *P. radiata* and kanuka, the two species used most widely for erosion control in this region. The following is a summary of those findings.

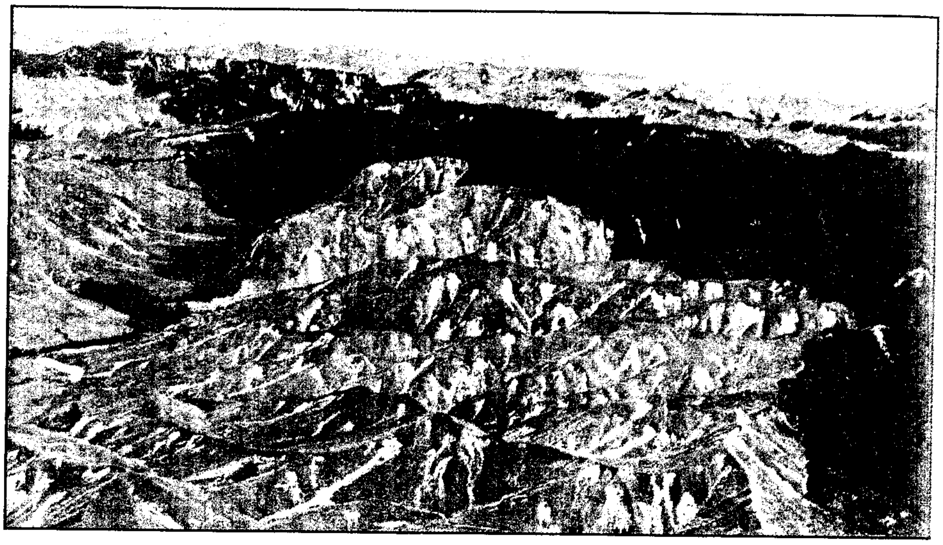


Fig. 1: Contrasting densities of shallow landslides initiated during Cyclone Bola (1988) in native forest and pasture. Photograph courtesy of Don Miller.

Comparisons of storm-initiated landslide densities in different vegetation types showed there is little difference in protective value between different closed-canopy forest types but that forest age has a significant effect on the number of landslides initiated. For example, during Cyclone Bola, areas under indigenous forest or exotic plantations > 8 years old were 16 times less susceptible to landsliding than both pasture and exotic pines <6 years old, and four times less susceptible than regenerating scrub and exotic pines 6–8 years old (Marden & Rowan 1993).

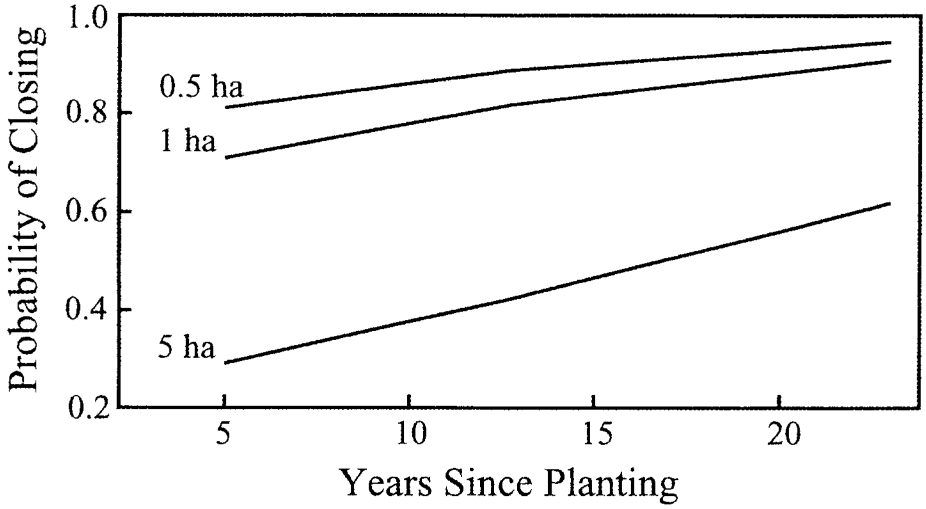
In another East Coast study of landslide damage to fully stocked stands of reverting manuka scrub of known age, damage to 10-year-old stands was estimated to be 65% less than that sustained by pasture and damage in 20-year-old stands 90% less (Bergin *et al.* 1993, 1995). More recently and following the Manawatu storm (2004), landsliding under forest was 90% less than that under pasture and 80% less under scrub (Dymond *et al.* in press).

These figures show that a forest cover affords considerable protection against the initiation of landslides and are consistent with process-based research showing little difference in the magnitude of interception loss, as a percentage of rainfall, across different, closed-canopy vegetation communities (Rowe *et al.* 1999). Soils under a forest cover will therefore be less prone to rainfall-induced landslides than similar soils under pasture and other vegetation types with an open or partial canopy, including young stands of pines and scattered, regenerating scrub. Fig. 1 shows contrasting landslide densities on pasture and closed-canopy forest (indigenous) following Cyclone Bola.

Within forested areas, and particularly during extreme rainfall events, factors additional to the soil-water regime are also likely to influence landslide initiation. These include stand density, root system dimensions, and the magnitude of root–soil reinforcement. Comparisons of excavated root systems of kanuka and *P. radiata*, revealed that, although the roots of *individual* kanuka were smaller than those of *P. radiata* at all stages of growth, the difference in total root mass was more than compensated for by the higher stand densities of the kanuka. Thus, the annual rate of root production of *stands* of regenerating kanuka exceeds that of *P. radiata* for the first 9 years of growth (Watson *et al.* 1995). As a consequence, the calculation of slope safety factors (a measure of a slope's resistance to failure) showed that slopes with a dense stand of regenerating kanuka were less likely to fail than similar slopes in *P. radiata*, at least for the first 9 years after establishment. Thereafter, older-aged stands of both species afforded a high and comparable level of slope resistance against landslide initiation (Ekanayake *et al.* 1997).

In a study of the relationship between soil erosion and farm conservation plantings (predominantly poplar and willow) it was concluded that the effectiveness of the plantings was contingent on correct planting and maintenance. Appropriate plantings reduced erosion by 75% compared with similar unplanted slopes whereas if improperly installed and maintained their effectiveness declined to 10%. The same study concluded that properly installed farm conservation trees (planting density unspecified), close afforestation with pines, and reversion to native scrub all reduced erosion (erosion type not specified) by about the same amount (Hicks 1991).

Fig. 2: Predicted probability of gully-stabilisation plotted against years since planting for 0.5-ha, 1-ha, and 5-ha sized gullies.



Gully erosion

Gully erosion has been prevalent in the headwater reaches of many East Coast catchments since the indigenous forest was cleared and the land converted to pasture in the first quarter of the 20th century. By 1939, three or four decades after deforestation, gullies in the headwater reach of one of these catchments, the Waipaoa, occupied ~2% of the 14 km^2 study area. By the early 1960s the area affected by gullies increased to a maximum of ~4%, but 24 years after reforestation with exotic species this had decreased by ~64%, to 1.5% of the study area.

The key determinants affecting whether or not reforestation can facilitate stabilisation are the size and shape of each gully at the time of planting; linear gullies are more likely to become stable than their amphitheatre-shaped counterparts. Probabilities that reforestation will be effective range from >80% for gullies <1 ha in area to ~60% for gullies between 1 and 5 ha in area. Gullies of 5 ha have an even chance of stabilising over the time frame of a single rotation (Fig. 2).

Erosion in the larger gully complexes (if >10 ha in area prior to planting) is generally too far advanced to be mitigated by reforestation. However, although none of the gullies larger than 10 ha stabilised within this 28-year reforestation period (1960–88), several had at least halved in size as a direct result of reforestation. It was concluded that the overall success of reforestation in ameliorating gully erosion was attributed to the selection of a fast-growing tree species, ideal growing conditions, and the planting strategy adopted. That is, gully stabilisation was achieved, first, by planting as much of the gully watershed area as physically possible and, second, by delaying within-gully plantings until there was a noticeable reduction in runoff and sediment supply to the channel as evidenced by channel incision and fan abandonment (Fig. 3). This usually coincided with canopy closure, ~ 8 years after planting.

Fig. 3 shows a medium-sized gully in Te Weraroa Stream, Mangatu Forest, prior to reforestation (1961) and post-reforestation (1972, 2004). The history of treatment that led to the closing-down of sediment production from this gully began with the planting (1962) of *Pinus nigra* on the lesser-eroded interfluves

Fig. 3: Pre- (1961) and post-reforestation (1972, 2004) photos of a medium-sized gully, Mangatu Forest. Before planting, this gully was 7.6 ha in size, and by 1988 reforestation had reduced the area of active erosion to 0.8 ha. The 1961 and 1972 photography was taken by J. Johns and the 2004 photograph was supplied by R. Hambling.

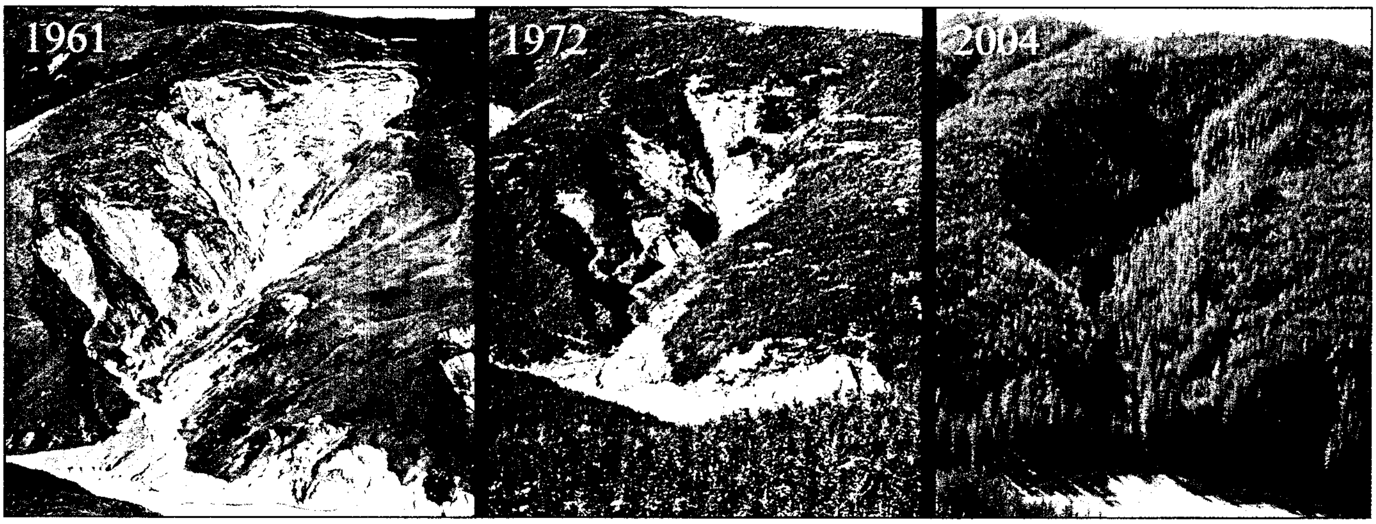


Fig. 4: Pre- (1983) and post-refforestation (2004) photography of "Wether Run" earthflow, Mangatu Forest. Surface displacement of this 29-ha earthflow slowed within 4 years of replanting (1987). Tree survival and the presence of a closed canopy (2004 photo) are indications that reforestation has been successful in arresting surface displacement. The origin of the 1983 photo is unknown. The 2004 photo was courtesy of R. Hambling.

surrounding this gully and *P. radiata* on the steeper and more severely eroding slopes immediately flanking the gully and within the gully itself. Within 10 years (1972) these plantings had effectively reduced sediment input into the channel and the channel responded by incising below the level of the fan at the mouth of the gully. Further within-gully plantings (1974) of *P. radiata* were undertaken on the remainder of bare slopes and of the fan itself. Before planting, this gully was 7.6 ha in size, and by 1988 reforestation had reduced the area of active erosion to 0.8 ha. The latest photograph shows that in spite of a major cyclonic event in 1988 (Cyclone Bola) this and similarly reforested gullies of this size have remained stable. For scale, the elevation difference between stream level and the ridge at the head of this gully is 280 m.

In the coming years, several large gully complexes will continue to dominate the sediment supply to the headwaters of the Waipaoa River and the sediment generated by them together with that from 420 currently untreated and necessarily expanding gullies could have a deleterious effect on the capacity of the Waipaoa Flood Control Scheme, which protects high-value agricultural land further downstream (on the Poverty Bay Flats) from flooding. However, the requirement to upgrade the flood control scheme by raising the height of the existing artificial levées (stopbanks) could potentially be obviated by a targetted reforestation programme that would involve additional exotic plantings totalling ~15 400 ha. It is estimated this would produce a >64% reduction in sediment production from gullies on pastoral slopes within one forest rotation (~24 years) (Marden *et al.* in press).

Earthflows

There can be little doubt that the removal of the original indigenous forest cover increased the risk of earthflow initiation and that the absence of a forest canopy and lack of a dense network of intertwining roots is directly related to today's high incidence of earthflow activity and accelerated rates of movement on pastoral hill country.

Surface movement studies of a grassed earthflow complex (Fig. 4, 1983) showed that surface displacement rates were fastest during wet periods and moderately correlated with monthly rainfall (Zhang *et al.* 1993). In an earlier study it was shown that the difference in movement rates between reforested and grassed earthflows represents an order of magnitude reduction in erosion rate by earthflows after reforestation, with interception loss by the forest canopy being the principal contributing factor (Pearce *et al.* 1987). Depending on planting density and growth rate, canopy closure, in this area, occurs within 8–10 years of planting pines. The soil water content of forested earthflows is thus dryer, for longer periods, than grassed earthflows and as a consequence surface displacement slowed appreciably (Pearce *et al.* 1987).

In addition, and at about the time of canopy closure, the root systems of pines 8–10 years old are known to develop strong lateral structural roots that may extend up to 5 m from the root bole and vertical sinker roots up to 2.1 m deep (Watson *et al.* 1999). In view of the fact that most earthflow displacement occurs along a basal shear plane typically 5–7 m below the ground surface and at a depth exceeding that of the maximum root penetration of most forest tree species, it has been suggested that where trees are planted close enough, the roots of individual trees interlock to form a large raft constituting a reinforced, semi-rigid layer that floats on the more mobile material beneath (Zhang *et al.* 1993). Surface displacement of the same earthflow pictured in Fig. 4 (1983) slowed within 4 years of planting (established at 1350 stems per hectare) and 17 years after planting a sufficient number of trees survived to achieve canopy closure and effectively stabilise this flow (Fig. 4, 2004).

Through its superior interception function, a closed canopy of evergreen forest affords the best option for stabilising an earthflow-in-motion. The space planting of deciduous poplar and willow, in sufficient numbers, has also proven to be a useful treatment option, though on account of the wide variation in plant spacings used, its effectiveness has been more difficult to quantify and is largely anecdotal. Irrespective of species, root density declines rapidly with depth and distance away from the stump. The success or otherwise of a vegetative treatment option for earthflows will therefore be determined ultimately by plant survival, which in turn (excluding factors such as plant material selection and handling, soil moisture conditions, and post-planting care) will be dictated by displacement activity of the flow at the time of planting and by the initial planting density. The denser the plantings, the greater is the probability of success.

The treatment of earthflows is often regarded as being successful if a significant reduction in surface displacement is brought about. Nonetheless, a "stabilised" earthflow can be reactivated by any number of factors, mostly climate related, but the "chance" of reactivation will be considerably less than for a grassed earthflow. Cyclone Bola caused a significant but delayed increase in movement rate on the grassed flow pictured in Fig. 4 (1983), prior to its being planted, while the "storm effect" on movement activity on adjacent forested flows was barely evident (Zhang *et al.* 1993).

Discussion

Much of New Zealand's hill country is vulnerable to storm-initiated erosion and the magnitude of damage sustained during past events has been well documented. It seems this vulnerability has not been well enough appreciated. For instance, it was unfortunate that Government policies, introduced in the 1980s, encouraged vegetation clearance, introduced stock retention schemes, and subsidised fertiliser application on "marginal land classes". It is equally unfortunate that we continue to allow the significant loss of soil from the most vulnerable hill country areas in the name of increased animal production. In the event that global warming will likely increase the frequency and magnitude of future storm events, New Zealand's pastoral hill country community can expect to sustain further loss of steep hill country soils and off-site damage to property, not only to their own but also to that of landowners downstream.

Reforestation was, and still is, considered a last-ditch option for severely eroded hill country and then only after decades of soil and nutrient loss has occurred. Traditionally we have looked at reforestation of eroding hills not for what they protect on-site but for what they protect off-site. In view of our understanding of the role of forests in ameliorating both on-site and off-site impacts of large-magnitude storms, and of the now documented financial and social consequences of past events, a review of land use regulation and current practices on erodible hill country is long overdue.

We should reverse the trend of previous decades of clearing marginal land of scrub and forest and restore these areas to a closed-canopy forest. Reforestation with exotic species has proven effective. Scrub reversion is a viable option where existing scrub coverage is sufficient to provide some initial stability and an ongoing seed source. Reversion can be relatively quick provided stock are excluded and a closed canopy could be expected to occur within 8–10 years over the most densely vegetated parts of the retired area. For those areas where no scrub cover exists, the supplementary planting of trees, exotic or indigenous, will be required. On-farm conservation plantings, if planted at spacings considered appropriate for specific erosion types and properly installed and maintained, can also afford considerable protection and enable more-sustainable pastoral farming.

If the success stories presented in this article are accepted as examples of what has been achieved for severely eroding hill country and are considered as being representative of "worst-case scenarios", then equal and better results can be expected for the lesser-eroding hill country elsewhere in New Zealand. A forest cover results in on-site benefits that include a reduction in shallow landsliding, reduced rates of earthflow displacement, the slowing of gully erosion, and the retention of soil for future productive purposes. Off-site benefits include a reduction in the amount of sediment/soil delivered to fluvial systems, thereby potentially prolonging the design life of existing flood control schemes and obviating unnecessary expenditure on new and costly stopbank construction. In addition, and in the longer term, expenditure associated with the targeted reforestation of erosion-prone hill country will be more than compensated for by a significant reduction in off-site damage with consequential savings in the cost of repair to structural utilities and clean-up costs associated with future flood events.

There is therefore an urgent need for acceptance of forests within the farming scene.

"It is no longer sufficient that we develop land-use options on the basis of a few years' projection. We need to project uses over a few hundred years, and to allow for (and hopefully modify) the inevitable catastrophic events that affect the land. Surely we have sufficient information now that, putting aside any entrenched views of land use and classic ways of land management, we can integrate farming and forestry to maintain and improve the land resource for future generations" (Nordmeyer 1978, p. 172).

Acknowledgments

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