What do we need for a risk management approach to steepland plantation forests in erodible terrain?

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Abstract

The on-site and off-site effects of landslides in erodible steeplands remain a significant issue for plantation forestry management. The Erosion Susceptibility Classification (ESC) developed for the proposed National Environmental Standard (NES) for Plantation Forestry provides a coarse screening tool, but improved tools are needed for risk analysis at the scale of forestry operations.

Introduction

About one-third of the New Zealand plantation forest estate is located on erodible steeplands, with many of the forests having originally been planted as erosion control forests. The erosion problems associated with harvesting these forests have been the subject of a number of papers in this Journal recently (Bloomberg & Davies, 2012; Phillips et al., 2012; Marden et al., 2015). While it is acknowledged that it will be impossible to completely avoid slope failures (see first photo) and debris flows (see second photo) following harvesting (Phillips et al., 2012), the forest industry needs tools to improve risk assessment for better management of the incidence and consequences of these events. The current Growing Confidence in Forestry's Future (GCFF) research programme aims to address this issue by providing improved risk assessment and mitigation options to maintain long-term productivity on sites where erosion risk is high, and to reduce the likelihood of off-site damage from debris flows.

What we know about erosion risk management

Reduction of the risk from landslides, and associated debris flows, requires that the landslide hazard be recognised and the risk assessed. A risk-based approach to managing landslides and debris flows associated with plantation forests requires three components to be addressed (Saunders & Glassey, 2007; Bloomberg et al., 2011) that link underlying susceptibility to erosion with the consequences of erosion:

- *Erosion susceptibility* – determined by intrinsic predisposition to erode (a function of rock type, soil and topography) and preparatory factors (such as forest harvesting, drainage modification, and slope modification by earthworks)
- *Frequency of triggering events* – frequency and magnitude of climatic or seismic events that trigger landslides and debris flows
- *Consequences of an erosion event* – the damage that occurs on-site (loss of productivity and soil moisture storage capacity) or off-site (debris flow damage to houses, infrastructure, farmland or waterways).

Any assessment of risk is underpinned by an analysis of erosion susceptibility, for which there is no generally accepted approach in New Zealand. Both landslide/debris flow susceptibility and the frequency and magnitude of triggering events will need to defined before addressing the question of the acceptable level of risk that can be managed by the industry.

Extensive rainfall triggered landslides after harvesting, Bay of Plenty

Debris flow deposition below mature forest, Nelson

The ESC developed for the proposed NES for Plantation Forestry (Bloomberg et al., 2011) is a start to analysing erosion susceptibility. However, it has limitations of the scale and objective description of the metric (potential erosion derived from the New Zealand Land Resource Inventory or NZLRI) used for characterising erosion susceptibility (Marden et al., 2015). Other approaches that have been used in New Zealand include:

- Terrain stability mapping based on rock type, geomorphic characteristics and evidence of past erosion (Pearce, 1977; Phillips & Pearce, 1984a, 1984b, 1986; Bloomberg, 2013; Marden et al., 2015)
- The Highly Erodible Land model (Dymond et al., 2006), a simple bivariate model that identifies highly erodible land using a combination of NZLRI data, a slope map derived from a digital elevation model (DEM), and a land cover map
- Regional analyses of landslide susceptibility derived quantitatively from underlying information on rainfall, rock type, soil, slop, and land cover using bivariate and multivariate statistical techniques (Wilson, 2003; England, 2011; Schicker & Moon, 2012)
- Spatially detailed modelling using both factor-of-safety analysis of slope stability, implemented in the SINMAP model, and a statistical non-linear regression approach based on defining the probability of landsliding based on rainfall, soil, slope and vegetation factors (Harrison et al., 2012).

In addition, landslide forecast models have been developed (Schmidt et al., 2008; Dellow et al., 2010), and there have been initial attempts to identify alluvial fans susceptible to debris flow hazards (Welsh & Davies, 2011; Page et al., 2012).

None of these approaches were specifically developed for the forest industry, apart from the modelling of Harrison et al. (2012). While this approach shows promise, the statistical model under-predicted landsliding from steeper slopes when run on terrain different to the calibration catchment, indicating a need for calibration to different terrain. The calibration process requires new areas to have a high-resolution DEM and data on landslide occurrence during storm events. These data are rare and difficult to acquire as there is currently no coordinated collection of shallow landslide erosion data in New Zealand. Similarly, the factor-of-safety model requires historical landslide data for accurate prediction. So while both models proved good predictors of shallow landslide risk, they can only perform well with an abundance of input data and need recalibration for new areas.

What we are doing

As part of the GCFF programme we have been attempting to build a picture of the spatial patterns, magnitude and frequency of occurrence of landslides and debris flows by compiling available information from published and unpublished sources, including environmental incident reports held by forestry companies. We have also been reviewing the local and international literature on erosion and debris flow risk management in the forestry industry with a view to defining how to progress development of a risk management approach.

In related work funded by the Ministry for Primary Industries as part of the proposed NES for Plantation Forestry we have revised the ESC of Bloomberg et al. (2011) to identify and reclassify misclassified Land Use Capability (LUC) units (see Figure 1). The changes have reduced the area in the High ESC class by 635,000 ha and the area in Very High by 1,684,000 ha (Basher et al., 2015a). Changes to the High and Very High classes were mostly in Canterbury and Otago, with significant changes also in Hawke's Bay and Northland. We have also developed a proposed process for managing future changes to the ESC class related to scale or misclassification errors in the ESC (Basher et al., 2015b).

What still needs to be known

What is required is a screening tool to determine where detailed site-level risk assessment is required, and development of accepted methodology for site-level risk assessment. The current ESC (Bloomberg et al., 2011) derived from regional scale data provides a coarse screening tool, and even with current work to reassess the classification of some LUC units, it will still have the limitations of scale and the subjective description of potential erosion (Basher et al., 2015a, 2015b). It could be substantially improved by developing a fit-for-purpose landslide/debris flow susceptibility methodology at operational scale and improved understanding of the magnitude and frequency of triggering events.

If a fit-for-purpose erosion susceptibility methodology were developed there appears to be three choices – it could be based on quantitative landslide/debris flow susceptibility zoning, mechanistic modelling (e.g. SINMAP) or terrain stability analysis by suitably qualified personnel. Whatever approach is used, landslide susceptibility (a measure of the spatial variation of landslide occurrence based on land characteristics such as rock type, soils and slope) should be evaluated independently of the frequency of triggering events (Bloomberg et al., 2011). The two can then be combined to provide a measure of erosion hazard – the probability of occurrence of landslides of a particular type and size within a specified period of time and in a given area. Such a methodology could form the basis of an explicit expression of the level of risk being managed.

Landsliding, and debris flows, are typically triggered when a rainfall threshold is exceeded. There have been numerous attempts to define rainfall thresholds using approaches ranging from empirical relationships based on annual rainfall (Omura & Hicks, 1992; Hicks, 1995) or storm rainfall (Reid & Page, 2002), to analyses combining daily rainfall, antecedent moisture conditions, water loss through drainage, soil water storage and evapotranspiration (Crozier, 1999; Glade, 2000). While variation in intensity-frequency-duration relationships

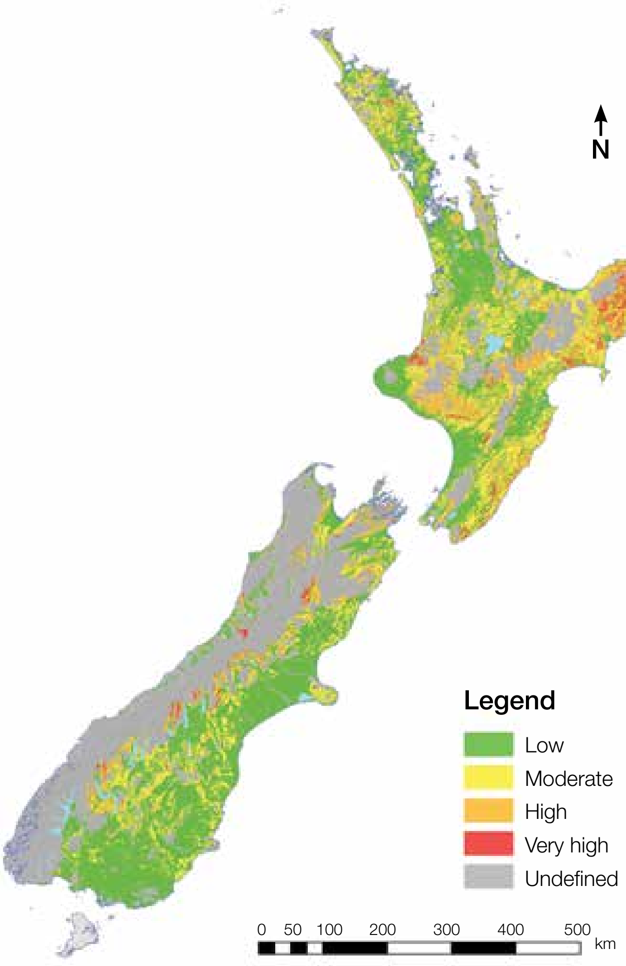

Figure 1: Map of revised Erosion Susceptibility Classification (Basher et al., 2015a)

of rainfall can be well characterised using NIWA's High Intensity Rainfall Design System (HIRDS), and the effect of climate change can be calculated (see http://hirds.niwa.co.nz/), the lack of quantitative data on landslide and debris flow occurrence precludes a better definition of thresholds for triggering landslides and debris flows. Previous research suggests that relationships between rainfall intensity, rainfall duration, antecedent rainfall and landslide occurrence are likely to be complex and should be characterised probabilistically.

Whatever approach is used for defining the risk of landslides and debris flows, spatial and temporal data on landslide and debris flow occurrence is needed to underpin landslide susceptibility modelling, debris flow prediction, and a better understanding of rainfall thresholds for landslides and debris flows, and their frequency of occurrence in different parts of New Zealand. There are few high-quality historic datasets for this purpose and currently this type of data is not routinely collected by any agency. Geonet (www.geonet.org.nz) collects some post-storm landslide data from large storm events but data analysis is very limited (M. Page, pers. comm., March 2015), while regional councils and forest companies also collect limited data.

LiDAR-derived data is increasingly being used in mapping landslides and modelling erosion susceptibility (e.g. McKean & Roering, 2004; Schulz, 2007; Chen et al., 2013), primarily through the use of DEMs to produce accurate slope data and textural analysis to identify landslides. The collection of LiDAR data has become increasingly common within the New Zealand forest industry, with the data being used to predict tree productivity and forest inventories, and also to create high resolution DEMs, which are used in the design of forest infrastructure. The use of LiDAR has the potential to improve the predictive ability of erosion susceptibility modelling.

While LiDAR-derived data provides high precision slope data, it needs to be matched with accurate landslide inventories and detailed data on variables such as rock and soil type and accurate rainfall data. An additional issue with LiDAR is the high cost of data acquisition, and new photogrammetric techniques remain an option for the creation of very high resolution DEMs at considerably less cost (Stumpf et al., 2015). LiDAR does have the advantage of being able to penetrate the tree canopy to allow landslide mapping as well as the creation of DEMs.

Implications for inter-rotational forest planning

Formalising risk analysis would allow explicit identification of the level of erosion/debris flow risk that can be managed and identify areas that may be impacted by events in excess of an accepted design threshold. Risk analysis would be mostly used for underpinning decisions on areas not to be replanted and for harvest planning, including identifying areas particularly susceptible to harvesting and roading impacts, and for considering alternative species options. This type of analysis should be completed well in advance of harvesting to allow a rapid transition from harvest to re-establishment of the next rotation.

At present different companies are taking different approaches to assessing the risk of landsliding and debris flows, ranging from terrain stability zoning to slope stability analysis. If the NES is implemented a consistent approach will be needed nationally. We suggest that what is needed is further discussion with the forest industry to gauge the level of support for a fit-for-purpose ESC and to define the preferred option.

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