A risk matrix for storm-initiated forestry-related landslides and debris flows in the Gisborne region

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Contents

Summary

Project and client

- Following a 2016 workshop in Gisborne on the impacts of storms on forestry, Gisborne District Council (GDC) approached Landcare Research to follow up on recommendations in the report that documented the workshop.
- One of those recommendations was to develop a risk matrix, in association with the forestry sector, to help understand and manage the consequences of storm-initiated landslides and debris flows associated with forestry.

Objectives

- In association with GDC and the Forestry Focus Group, to develop and prepare a draft risk matrix suitable for the Gisborne − East Coast region.
- To assist the Forestry Focus Group and GDC with the implementation of the risk matrix.
- To prepare a final report by 30 November 2016.

Methods

- A workshop was held in Gisborne on 20 October 2016 to discuss and develop a draft risk matrix that could be used by forest land managers to assess the risks associated with storm-initiated landslides and debris flows within plantation forests.
- A brief literature search was undertaken and a report produced to complement the workshop.

Findings

- There was general acceptance that a risk matrix could provide a level of consistency in approach across the region, although there were concerns that its use might become part of a resource consent process.
- The draft matrix was discussed and tested in a field situation, and feedback was provided to the authors for incorporation into the final report.

Results

- A risk matrix for assessing storm-induced post-harvest landslides and debris flows was developed in consultation with forestry representatives and GDC staff at a workshop, subsequently tested, and revised based on feedback.
- The spread-sheet-based 5 x 4 risk matrix incorporates factors contributing to landslide/debris flow susceptibility, likelihood of occurrence, and the potential consequences should such an event occur.

- Recommendations pertaining to high-risk areas were produced.
- Further work is needed to develop both the range of options and how a matrix could be incorporated into a tool such as a phone app.

Recommendations

- Trial the risk matrix for a period of 6 months and report back on its usefulness to the Forestry Focus Group.
- Assess the need for any updates and modifications after 6 months and collaboratively develop a mechanism to implement these.
- Following general agreement on the utility of such an approach, incorporate the risk matrix as part of normal forest management procedures.
- In parallel, begin to consider the suite of possible actions beyond those suggested in this report that might be taken for areas assessed by the matrix as high risk.
- The Forestry Focus Group and GDC should explore funding sources (e.g., Forest Growers Levy Trust Research Fund, Envirolink Tools) for further development of a tool that could be used in the field. An app was suggested in the feedback.

1 Introduction

In many countries, floods, debris flows, landslides and rockfalls cause damage every year, affecting property values, infrastructure, forestry and agriculture. Collecting information on such events in a systematic way is needed for hazard mapping and analysis to underpin decision-making that recognises these hazards. This information can provide answers to questions related to the spatial and temporal distribution of damage, natural hazard processes, and the corresponding weather conditions that trigger such events (Sklar et al. 2017).

Plantation forestry is a significant land use in the Gisborne − East Coast Region, providing a number of benefits, including soil conservation (Dominati et al. 2014; Marden 2012), improved water quality, employment and economic value. However, there are a number of issues associated with forestry, particularly during and after harvest, that have an impact on both the environment and the communities of the region. Among these is the issue of storm-induced, post-harvest shallow landslides and debris flows, which mobilise slash (harvesting residue) on slopes and in channels and deliver it to neighbouring properties, river flood plains and the coast, where it ends up on beaches. It also poses a risk to infrastructure such as culverts, bridges, roads and rail, and farm floodgates.

A number of incidents within the last 5 years have raised the ire of coastal communities, iwi and the farming community and have resulted in many letters to the local paper and pressure on GDC to 'tackle the issue'. Of particular importance to GDC will be the need to avert any potential damage to the Gisborne water supply pipeline following harvesting of forests near the water supply catchments. In addition, extensive areas of forest in the Waimata catchment are all due for harvesting in the next few years, with potential impacts to urban areas, the harbour, and roads and bridges. Some issues have occurred associated with earlier harvesting in this catchment.

This is not an issue unique to this region, but it is one that occurs in many other parts of New Zealand, where it also receives attention from councils, communities and forestry companies. Recent and legacy articles, reports and Environment Court evidence suggest this phenomenon is not new and will continue in the future wherever forests are harvested from steep, erosion-prone land subject to large rain storms (e.g., Wohl et al. 2017; Coulthard & Van De Wiel 2017; NZ Forest Owners Association 2011; Marden & Rowan 2015; Phillips et al. 2012).

The North Island and the top of the South Island appear more vulnerable to rainstorm events that trigger landslides, slash mobilisation and debris flows, but these phenomena can occur on steep land anywhere in New Zealand. The nature of the issue, what science has been done to address it, general observations, and recommendations for future work are described in the papers cited above and are summarised in a 2016 report (Phillips et al. 2016). Some of this material is expanded on below.

2 Background

Many regional councils have developed erosion and sediment control guidelines for forestry operations, and the forest industry has developed an environmental code of practice for forestry operations and a road engineering manual (NZ Forest Owners Association 2011). These largely focus on erosion and sediment control for forest infrastructure (roads, landings, culverts, etc.) and provide less guidance on how to best manage clear-felled slopes. Some forestry companies have started to develop operational-level hazard identification and risk management approaches to try to better manage the risk of shallow landslides, woody residue mobilisation and debris flows. However, further work is required to develop improved quantitative hazard identification and risk management methods that can be widely applied, either regionally or nationally.

Incorporation of woody residue into landslides is a major contributor to the off-site effects of debris flows from forests. Management of post-harvest woody residue is complex, with a balance needed between retaining woody residue for its beneficial effects (e.g., intercepting sediment on slope; providing shade in first order streams) and avoiding the adverse effects in large storm events. Understanding the nature of the risk associated with the window of vulnerability following harvesting and the steps taken to reduce it are key to providing a sound basis for forest planning and regulation.

Several recommendations for future work were made in a report in 2016 (Phillips et al. 2016), including the following.

- Regional landslide thresholds should be established based on knowledge of past events and forestry company records. These rainstorm–geology–steepness–landslide threshold relationships are fundamental to being able to provide a consistent quantitative assessment of risk for different regions of New Zealand.
- Terrain hazard zoning or risk management approaches should be investigated to assist forest managers and harvest planners to minimise the risk of landslides and debris flows during the post-harvest window of vulnerability. This information would then help both forest managers and owners to understand this additional element of their forests' risk profile, and would also assist regulators by providing a more evidence-based approach for setting policy and the resource consent process for the forest industry.
- The forest industry should develop a consistent set of protocols to deal with the consequences should an event occur, since it will not be possible to entirely avoid slope failures and debris flows following harvesting, even with risk management and good management practices in place. This could include rapid response and help with clean-up operations, proactive communication with neighbours and the media, and implementation of remediation plans for any infrastructure that is damaged. Many forestry companies will already have some of these activities included as part of their environmental management systems (EMS).
- A risk matrix should be developed that would help with decision-making for all forestry managers and land users in the Gisborne region (Tier 1 companies, investment forests and woodlot owners). This was a recommendation from the joint

GDC−Forestry Industry workshop in 2015 (Phillips et al. 2016). There was also support for soliciting the interest of other councils in pursuing a joint Envirolink Tools project to develop a national risk matrix or similar tool that could provide information to meet a broader national need but that was adaptable to local conditions. The value of a risk matrix might be to increase the visibility and hence overall understanding of the issue rather than provide a definitive solution.

This report builds on those recommendations and is the first step towards developing a local risk management framework for plantation forestry in the Gisborne − East Coast region.

3 Objectives

- In association with GDC and the Forestry Focus Group, to hold a workshop to develop and prepare a draft risk matrix suitable for the Gisborne − East Coast region.
- To assist the Forestry Focus Group and GDC with the implementation of the risk matrix.
- To prepare a final report that complements Part 1 of this project on protocols for monitoring and data capture by 30 November 2016.

4 Methods

4.1 Literature review

4.1.1 What do we mean by ‘susceptibility’, ‘hazard’ and ‘risk’?

The use of the terms ‘susceptibility’, ‘hazard’ and ‘risk’ in relation to natural and anthropic processes are often confused and may have either generic or specific definitions depending on the context in which they are used. In terms of landslides and debris flows:

risk = susceptibility x probability of occurrence x consequences.

Susceptibility is the quantitative or qualitative assessment of the type of failure, its size (volume or area) and its spatial distribution. It includes both intrinsic susceptibility and preparatory factors (such as vegetation removal). Probability of occurrence of failure (type and size) within a specified time period and a given area amounts to what is generally referred to as hazard. Consequences can be on-site or off-site. So risk is the expected losses due to a failure type within a specified period of time and a given area.

Landslides and debris flows are typically triggered when a rainfall threshold is exceeded. Research suggests that the relationships between rainfall intensity, rainfall duration, antecedent rainfall and landslide occurrence are complex and can only be characterised probabilistically rather than mechanistically. There have been several attempts in New Zealand to define thresholds for shallow landslides using any – or combinations – of the above parameters, though none are in current use.

4.1.2 What is a risk matrix?

A landslide risk matrix is a common way to assess the relationship between susceptibility to a landslide, the probability it will occur and the magnitude of its impact in physical, social and economic terms (i.e. risk). Risk matrices are widely used to objectively and transparently assess risk, assist management decision-making, and meet community expectations.

Typically these matrices are constructed in a semi-quantitative way, comprising a measure of severity (the physical, social and economic effects) and a measure of the likelihood of a triggering event. Measures of severity would consider the extent of exposure of the different receptors identified (e.g. people, infrastructure, stream habitat). Likelihood of the impact occurring would be something like the probability of a storm occurrence (annual exceedance probability, or AEP) coinciding with a recently harvested area that is susceptible to landsliding. While commonly used, such matrices are not without their problems (see, e.g. Cox 2008), most of which are associated with the categorisation and quantification of thresholds between classes.

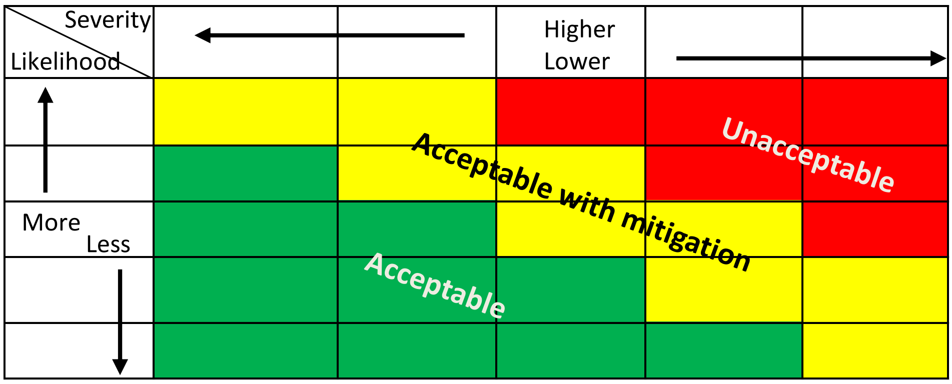

Figure 1 An example of a generic risk matrix. The terms used are often changed for specific purposes.

In the present case, criteria (categorisation and boundary thresholds) would need to be developed that were suitable for use in the Gisborne region. The risk matrix would need to consider downstream effects resulting from the failure of any one of multiple source sites. Detailed mapping might also be needed to effectively implement a risk management matrix operationally. At the 2015 workshop (Phillips et al. 2016) there was discussion on a more generic national approach, such as that proposed in the earlier version of the National Environmental Standard for Plantation Forestry, which could then be 'tweaked' for any local conditions.

There was also discussion on the need to develop criteria for identifying areas that might not be replanted due to an unacceptably high risk following harvesting, based on factors such as poor tree survival, poor growth (i.e. misshapen trees), difficulty of harvest, and a higher risk of generating debris flows. If a risk matrix was used, some foresters were concerned about the public reaction that might occur if or when the response of the landscape to a storm was greater than the risk classification suggested.

There was, however, general agreement that this would be a useful avenue to pursue and that the approach should have some common elements applicable to all forestry land users (Tier 1 companies, investment forests and woodlot owners), and should allow room to 'personalise' the matrix so that particular forest companies can meet their own requirements. Discussion on how this might be developed, what the class descriptors and thresholds might be, and how the information was to be managed and collated was limited at that earlier workshop.

4.1.3 International and New Zealand examples

Risk matrices have been developed in a number of international settings to assess the risks of landslides generally, or of those specifically associated with harvesting or post-harvest (e.g. Canada). These generic approaches are considered to be applicable to New Zealand.

Bloomberg et al. (2011) considered erosion risk related to plantation forestry as part of their development of an erosion susceptibility classification underpinning the National Environmental Standard for Plantation Forestry. They recommended that detailed assessments of landslide hazards and downslope consequences be conducted at 1:10,000 and 1:5,000, and that this range of scales be adopted for planning, consent and operational management of erosion hazards for plantation forests.

An example of a decision matrix integrating the erosion susceptibility classification with the likelihood of triggering rainfalls is shown in Figure 2 (Bloomberg et al. 2011), supported by a process to assess landslide risk (Figure 3, Saunders and Glassey 2007). This approach is based on the Australian/New Zealand Risk Management Standard AS/NZS 4360:2004 (now superseded by AS/NZS ISO 31000:2009) and was primarily aimed at assessing risk to buildings, but in principle the same type of approach is relevant to forestry risks. It has three components: erosion susceptibility, frequency of triggering events, and consequences of an erosion event (Figure 3).

Decision Matrix proposed by Bloomberg et al. (2011) for determining level of risk analysis required

Erosion Susceptibility Class	<0.08	0.08 - 0.12	0.12 – 0.21	0.21 – 0.30	>0.30	AEP
	>12	8	4.3	2.8	<2.8	ARI (yrs)
Low	NA	NA	NA	NA	NA	
Moderate	NA	NA	SA	SA	SA	
High	SA	SA	FA	FA	FA	
Very High	FA	FA	FA	FA	FA	

NA = No risk analysis required to proceed
SA = Some risk analysis required
FA = Proceed under stringent conditions only if full risk analysis indicates risk can be managed to be acceptable

Figure 2 An example of a risk matrix developed as part of the National Environmental Standard for Plantation Forestry (Bloomberg et al. 2011).

1 – Measures of Likelihood

Level	Descriptor	Description	Indicative Probability (Return Period)
A	ALMOST CERTAIN	The event is expected to occur (during life of buildings).	~1 – 10 years
B	LIKELY	The event will probably occur under adverse conditions.	~10–100 years
C	POSSIBLE	The event could occur under adverse conditions.	~100–1,000 years
D	UNLIKELY	The event might occur under very adverse circumstances.	~1,000–5,000 years
E	RARE	The event is conceivable under exceptional circumstances.	~5,000 – 10,000 years
F	NOT CREDIBLE	The event is too rare to be considered	>10,000 years

Note: "~" means that the indicative value may vary by say ½ of an order of magnitude, or more.

2 – Measures of Consequences to Property

Level	Descriptor	Description
1	CATASTROPHIC	Structure destroyed or large scale damage requiring major engineering works for stabilisation.
2	MAJOR	Extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works.
3	MEDIUM	Moderate damage to some of structure, or significant part of site requiring large stabilisation works.
4	MINOR	Limited damage to part of structure, or part of site requiring some reinstatement / stabilisation works.
5	INSIGNIFICANT	Little damage.

Note: "The Description" may be edited to suit a particular case.

3 – Risk Analysis Matrix — Level of Risk to Property

LIKELIHOOD	CONSEQUENCES TO PROPERTY				
	1: CATASTROPHIC	2: MAJOR	3: MEDIUM	4: MINOR	5: INSIGNIFICANT
A – ALMOST CERTAIN	VH	VH	H	M	L
B – LIKELY	VH	H	H	M	L
C – POSSIBLE	H	H	M	L–M	VL–L
D – UNLIKELY	M–H	M	L–M	VL–L	VL
E – RARE	M–L	L–M	VL–L	VL	VL
F – TOO RARE TO BE CONSIDERED	VL	VL	VL	VL	VL

4 – Risk Level Implications

Risk Level		Example Implications
VH	VERY HIGH RISK	Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to acceptable levels; may be too expensive and not practical.
H	HIGH RISK	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.
M	MODERATE RISK	Tolerable provided treatment plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options.
L	LOW RISK	Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk.
VL	VERY LOW RISK	Acceptable. Manage by normal slope maintenance procedures.

Note: "The Description" may be edited to suit a particular case.

Figure A3-2 Summary of the main steps for qualitative landslide risk assessment and process: (1) Likelihood terms and criteria; (2) Measures of consequence; (3) Risk analysis matrix; (4) Implications of different risk levels (AGS, 2000)

Figure 3 Risk assessment process at an operational scale (Saunders & Glassey 2007). Note that this process is appropriate for urban landslide risks and would need to be adapted for use in a rural context.

Such a risk matrix has been used by Nelson Forests Ltd to assist with harvest planning of a block of trees adjacent to a state highway. The contributing factors considered in this case included geology, slope, catchment size and proximity to streams. This was then related to the probability that landsliding could occur (hazard) and included hourly and daily rainfall intensity, AEP, and observed frequency of landslides. The consequences were assessed in relation to people, property, ecology, cost and reputation. Combining susceptibility and hazard allowed an estimate of the likelihood of landslides entering streams ranging from rare to almost certain, and then, combined with consequences, the overall risk was assessed from negligible to high (Figure 3).

4.1.4 The case of debris flow fans and downstream consequences

One particular aspect of a risk matrix that needs to be considered is the assessment of likelihood that a triggered landslide will result in a debris flow that causes the transport of sediment and debris to depositional environments such as floodplains and beaches, and much more significant damage downstream. As a consequence, the literature suggests that several factors can be assessed to determine the risk of such phenomena. However, there is no approach that provides certainty, and a probabilistic approach is required.

The factors assessed include many of the main driving factors that go in to landslide assessment, such as slope steepness, high rates of sediment supply and high rainfall. The presence of topographic features such as the morphology of fans and other catchment factors have been used to distinguish fans susceptible to debris flows from those that aren’t. One of the common methods in use is the Melton Ratio (Wilford et al. 2004), and this is expanded on in section 5.

4.2 Workshop with forestry companies to ‘road test’ the concept of a risk matrix

A workshop to determine the information required from forestry and GDC staff to develop a risk matrix for the Gisborne – East Coast area was timetabled for 20 October 2016. A questionnaire (Appendix 1) was circulated to prompt consistent input. A ‘straw man’ draft risk matrix by the report’s authors was also prepared for discussion at the workshop.

Following a general introduction to the project, the main focus of the workshop was to get participants discussing and providing feedback on two areas:

- factors contributing to susceptibility to landslides and debris flows
- consequences should such events happen.

Following the workshop, a draft risk matrix was prepared based on what was discussed, and this was circulated back to participants for feedback. Based on this feedback, a final version was drafted and is contained in this report.

5 Findings

5.1 Landslide hazard assessment – a part of the solution

In broad terms, landslides in plantation forests are not currently amenable to hazard assessment because there is insufficient information to accurately determine the probability of landslides occurring within a given time period. Hazard assessments are estimations of an area's susceptibility to landslides based on a few key factors. These are each capable of being mapped and allow land areas to be evaluated based on their relative susceptibility to landslides (Glade 2001).

Glade (1998) essentially provided a first-order landslide hazard analysis for New Zealand. However, the data upon which he based his assessment lacked the quality and consistency needed to develop a robust and detailed approach at the forestry operational scale. His studies did, however, indicate that collecting more and better data on landslide occurrence was necessary for the development of a useful landslide hazard map for the country.

Three principles guide landslide hazard assessment.

- Landslides in the future will most likely occur under geomorphic, geologic, topographic and climatic conditions that have produced past and present landslides.
- The underlying conditions and processes that cause landslides are understood.
- The relative importance of conditions and processes contributing to landslide occurrence can be determined and each assigned some measure reflecting its contribution (Schmidt et al. 2008; Hungr et al. 2014). The number of conditions present in an area can then be factored together to represent the degree of potential hazard present.

Landslide hazard has been determined with a high degree of reliability only for a few locations in the past, although this is increasingly becoming more important, particularly in urban areas. However, the key point to these hazard assessments is the requirement for *high-quality landslide data* (Basher 2015). Such assessments have required careful, detailed study of the interaction of pertinent permanent and variable conditions in the target area. This can be a very expensive and time-consuming process that is not justified for the purpose of broad-scale development planning and for forest harvest planning. Landslide hazard zonation or terrain assessment (e.g. terrain stability zoning – Phillips & Pearce 1984a, b) is one technique that could be used in the early stages of estate or harvest planning.

Most assessment procedures for landslide hazard zonation employ a few key or significant physical factors to estimate relative landslide hazard. The method described here requires a minimum of three of the four factors mentioned earlier: distribution of past landslides, type of bedrock, and slope steepness; a fourth, hydrologic or climate factor, may be added (Schmidt et al. 2008; USGS 1982).

Significant effort has also been carried out to determine the rainfall threshold conditions for triggering shallow landslides and debris flows in many countries or regions (e.g. Berti &

Simoni 2005; Harrison et al. 2012; Iadanza et al. 2016)). These approaches use a combination of statistical methods to analyse information in national databases and landslide inventories to derive relationships between several key parameters in order to construct spatial hazard maps or indices. The approaches rely heavily on good-quality post-storm information, which, again, is variable from country to country. However, while such approaches are useful in a general sense to understand the nature of the hazard and the conditions that create it, none appear to be specifically related to forestry and the forest cycle.

Basher (2015) reviews a number of approaches used to assess erosion susceptibility in New Zealand (e.g. Schicker & Moon 2012; England 2011). However, there is no approach that is in consistent current usage. We do not see any significant advances being made in the next 5 years in terms of data collection that would significantly improve the calculation of landslide hazard.

5.2 Landslide hazard assessment

Basher (2015) reviewed a number of approaches to landslide hazard assessment trialled in New Zealand (e.g. Dellow et al. 2010; Schmidt et al. 2008). Some of these use empirical landslide data collected via inventories from previous events to develop probabilistic rainfall-driven hazard models. There has also been a model developed and trialled for use within forests aimed at assessing post-harvest landslide risk (Harrison et al. 2012). The approach uses a factor of safety analysis of slope stability implemented in GIS. One of the issues of such approaches is that they require a large number of parameters for which data are not generally readily available and which in steep land terrain have high local variability.

5.3 Rainfall thresholds for landsliding

Landslides are typically triggered when a rainfall threshold is exceeded. Basher (2015) reviews the various attempts to define rainfall thresholds for landsliding as they relate to New Zealand and concludes that the frequency of triggering events is one of the key factors that needs to be incorporated into any risk management approach for plantation forestry. While variation in intensity–frequency–duration relationships of rainfall can be well characterised spatially using NIWA's HIRDS, and the effect of climate change can be calculated (see http://hirds.niwa.co.nz/), improved quantitative and spatial data on landslide and debris flow occurrence would assist in better defining thresholds for triggering landslides and debris flows. This is in line with recommendations made by Phillips et al. (2012).

While there is variation in thresholds and the conditions required at a locality to trigger a landslide, Hicks (1995) has suggested that minimum thresholds for inducing widespread landsliding are 60 mm in 12 hours, 80 mm in 24 hours, 100 mm in 48 hours, 110 mm in 72 hours and 200 mm in 120 hours. More discussion on this can be found in section 5.4.2.

The frequency of triggering events is also a key factor that needs to be incorporated into any risk management approach for plantation forestry. Previous research also suggests that relationships between rainfall intensity, rainfall duration, antecedent rainfall and landslide occurrence are likely to be complex and should be characterised probabilistically rather than mechanistically (Basher 2015). Bloomberg et al. (2011) suggest that rainfall thresholds for initiating landsliding and debris flows are likely to vary according to the underlying erosion susceptibility, emphasising the importance of evaluating landslide susceptibility independently of the frequency of triggering events.

5.4 Workshop

5.4.1 General comments

Twenty participants attended the workshop. Representation from forestry interests in the region was good across both large commercial companies and smaller organisations (details of workshop are in Appendix 1).

There was general acceptance by workshop participants that a tool such as a risk matrix could provide a level of consistency in approach across the region. Some concerns were raised that it might shift from being a harvest-planning tool to a formal requirement of the resource consent process. Attendees commented that landslide risk has been an issue they have dealt with individually with communities, and a wider collaborative approach that could demonstrate that due consideration of the hazards and consequences would be useful and might help GDC educate the public when such incidents occurred.

The workshop break-out groups addressed three topic areas: factors contributing to susceptibility to landslides/debris flows, the likelihood of an event occurring, and the consequences should such an event occur. These were then discussed in a general forum and form the basis of the draft risk matrix.

5.4.2 Susceptibility factors relevant to the Gisborne – East Coast area and likelihood of occurrence

Geological

Geology or rock type is one of the key factors considered in all landslide hazard assessments (Crosson 1997). The nature of the Gisborne – East Coast geological setting and its past history is one of the reasons erosion rates in this area are some of the highest in New Zealand (e.g. White et al. 2009; Phillips et al. 2013; Marden et al. 2014). Workshop feedback indicated that there were certain rock types that are more susceptible to shallow landslides, such as mudstones, banded mudstones and thick tephra-covered slopes. Overall geology was felt by most to be not as strong a driver as slope in terms of attributes to be used in the matrix.

Other geological factors such as the presence of fault zones, dip and structural alignment relative to slope and aspect, and the degree of weathering were also seen as being locally important but not relevant as high-level drivers for the matrix. However, the authors consider that a distinction between harder, more lithified rocks (sandstone, argillite, greywacke) and softer rocks (mudstone and banded mudstone) might provide a level of differentiation in terms of susceptibility, and so these have been included in the draft matrix. Also, tephra-covered slopes, particularly where they coincide with break points from convex to concave slopes, were also highlighted as a contributing factor that workshop participants felt was important.

Slope

Slope steepness is one of the other key factors driving susceptibility to erosion through shallow landslides and other mass wasting processes (Chowdhury & Flentje 2003; Thompson et al. 2012). Generally, the steeper the slope, the more susceptible it is to shallow landslides. There is often an upper limit at which the number of landslides drops off, largely because on very steep slopes there is only residual soil left as most has been removed by or during former events.

Feedback from participants indicated that most landslides commonly occur on slopes between 30° and 35°, and that it is the upper part of a slope that fails, especially where there is a change in slope profile between convex to concave or a flexure point often coinciding with the thinning of tephra cover. Slopes much steeper than this don't generate many landslides, largely because soils are remnant and skeletal, and historical failures have already removed soil and tephra cover. Once slopes are below 25° the number of failures decreases. The ability to transport wood left on the cutover by landslides also reduces as slope declines.

The role of aspect is often also considered in landslide susceptibility assessment (Meals et al. 2012). Anecdotal evidence from some workshop participants indicated that northerly aspect slopes appeared more susceptible to failure than those of other aspects. Whether this is related to the physical factors of slopes with this aspect or is a function of the prevailing direction in which many storms track is unknown. For this reason, aspect has not been included as a key factor in the risk matrix.

Connectivity/channel conveyance

Unlike in other regions such as Nelson, workshop participants did not feel that slope length or distance from streams is a useful indicator of susceptibility, or something that could be assessed to provide any degree of differentiation in terms of risk. Similarly, the size of the harvest area was not deemed to be a significant contributing factor to susceptibility. Proximity to high-value areas such as marine reserves and downstream communities with a known history of past events etc. were considered by several participants to be important factors to consider. Watershed area has been correlated with observed debris flows in places such as Canada (Wilford et al. 2003, 2004), where debris flows were generated in watersheds with an average size of 1.3 km^2 and a range of 0.25 to 4.1 km^2.

Some views were expressed that a measure of the ability or type of channel to convey landslide and woody debris would be useful to explore, with or without consideration of channel gradient changes and the presence of locations to capture debris. Morphometric parameters such as basin area (watershed area), Melton ratio (an index of basin ruggedness that normalises basin relief by area or the size of a watershed area relative to its steepness – Welsh & Davies 2011) and watershed length have been identified in the literature as reliable predictors for differentiating between debris flow- and non-debris flow-dominated watersheds and their respective fans, though there are some reservations about their global utility. However, some workshop participants felt these approaches had promise, particularly as many companies regularly use GIS and may have Lidar coverage from which these metrics could be generated. The Melton ratio (R) (Wilford et al. 2004; Equation 1) (watershed relief divided by square root of watershed area) is used to differentiate between flooding (R < 0.3) and debris flow (R > 0.6).

Equation 1: ***Melton ratio (R)*** = $H_b A_b^{-0.5} = H_b / \sqrt{A_b}$

H_b denotes basin relief (difference between maximum and minimum elevations in the basin) and A_b the total area of the basin

The Melton relief ratio (watershed relief divided by watershed length) is also a useful measure to differentiate between the processes of flooding and debris floods. Debris floods are generated in larger watersheds with an average size of 7 km^2 and floods are generated in the largest watersheds with an average of 34 km^2. This suggests that it is the steepest, smallest sub-catchments that are likely to generate landslides and resultant debris flows. Debris-flow-dominated basins have generally been found to be smaller in size than those dominated by fluvial activity (Westoby et al. 2012; Wilford et al. 2004), although these vary considerably between regions and no universal upper threshold has as yet been determined to allow identification of debris flow basins in different geographic regions, casting some doubt on the overall usefulness of the Melton relief ratio (on its own) for the recognition of basins susceptible to debris flows. The Melton ratio approach was successfully used in the Coromandel region (Welsh 2008; Welsh & Davies 2011), where R values > 0.6 related to debris flow watersheds, all debris flood watersheds had R values between 0.3 and 0.6, and all fluvial watersheds plotted below 0.30.

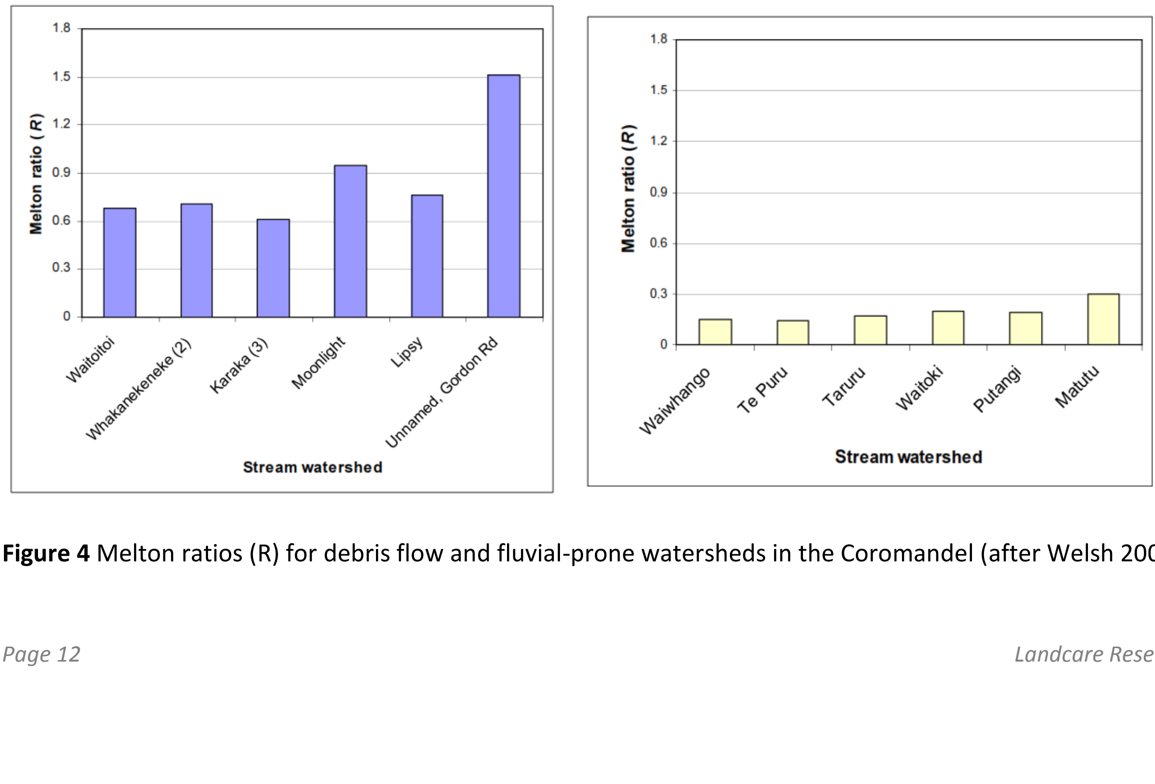

Figure 4 Melton ratios (R) for debris flow and fluvial-prone watersheds in the Coromandel (after Welsh 2008).

Fan gradient, particularly when combined with Melton's R value, has also proven useful for distinguishing debris flow from fluvial basins (James et al. 2016; de Scally et al. 2010). We have included the Melton ratio as a factor to be used in the matrix.

Rainfall

Apart from the physical landscape properties that contribute to a location's susceptibility to landslide erosion, the other key factor contributing to susceptibility is climate, particularly rainfall. The total amount and intensity of rainfall (expressed as annual exceedance probability or annual recurrence interval) and antecedent conditions are important in determining if a locality is going to fail or not (e.g. Glade 1998; Basher 2013; Guzzetti et al. 2008) or if it will trigger debris flows (Nikolopoulos et al. 2014). Some forestry companies use estimates of the probability of particular rainfall events as part of their harvest or road-planning processes, but usually in relation to the sizing of culverts and related infrastructure. These details are calculated or obtained from various methods such as the 'rational method', a widely used technique in engineering hydrology, although it is known to produce results that have large uncertainty (see Gadi et al. 2016).

Hicks (1995) has suggested that landslides occur on average every 3–6 years somewhere in the Gisborne – East Coast region. Based on historical flood records and associated landslides, Kelliher et al. (1995) suggested that there was a 97% probability that a landslide event would occur somewhere in the Gisborne – East Coast region in a 10-year period, and that this dropped to 82% for a 5-year period (based on the Waipaoa River's flood record as at 1995). On this basis, we suggest that rainfall intensities to be used in the draft risk matrix be based on 10-year return period rainfall and the values be derived from NIWA's HIRDS model (High Intensity Rainfall Design System, Thompson 2011). The data from HIRDS suggests that for a given return period and duration, rainfall tends to increase up the coast and towards the western ranges, though the northerly trend is stronger. The values we have chosen are hourly intensities greater than 30 mm/hr, with an AEP (annual exceedance probability) less than 0.1 and/or > 130 mm/24 hr, and also with an AEP less than 0.1. Data related to a specific locality (e.g. from farmer rain gauges) is also useful in determining the probability of a rain event that could trigger landslides and debris flows.

Past event frequency

The last factor deemed to be useful is the observed frequency of occurrence of past events (i.e. if events have happened in the locality in the past). If events were known to occur in a particular locality, then it was suggested that the risk of future events is higher than in an area that has not had any observable occurrence. The scientific basis for this is unknown. However, if factors exist in a locality that predispose it to an event, and that event happens, there may be other areas in the immediate vicinity that have some of the same factors and hence are likely to respond similarly in future. There is also some evidence to suggest that if storms similar to those that trigger widespread shallow landsliding occur, they do not trigger the same slope response (i.e. the same number of landslides): the focus shifts towards more channel processes and removal of stored material Phillips 1988, 1989).

5.4.3 The consequences of landslide/debris flow events

People

The primary consequence of the realisation of a natural hazard is its effect on people and the likelihood of harm or death. The workshop largely focused on the number and frequency of individuals affected should a landslide happen.

Property

This consequence is largely focused on buildings, dwellings, roads, flood gates and bridges on the floodplains at the bottom of the catchment or below where harvesting is taking place. Infrastructure in its broadest definition includes public roads, highways, bridges, rural buildings and dwellings. It also includes things like fences on both neighbouring and downstream properties. A 4-year period is designed to capture the cumulative effects of multiple operations over several years (and the potential for elevated flood risk). We have also chosen 'property within a 5 km threshold' rather than the 3 km used in Nelson, because the population and rural dwelling density is lower than in Nelson.

Four years was chosen as the post-harvest period during which the risk of damage to property is the greatest. This links with the observational view that at this time the canopy is closing and the risk is likely to reduce. This 4-year duration also links to the concept of 'catchment constraints' employed by some companies and regional councils in relation to harvest plan consent conditions (i.e. only 25% of a catchment can be harvested in any one year, so a whole catchment should be harvested over a 4-year period).

Ecology

This factor deals with the impacts of sediment on ecology, including aquatic habitat, through elevated sediment inputs or burial of the river bed, but also the scouring of channels by debris flows. It may also include damage to other habitats, such as that of Hochstetter's frogs. However, there is a lack of scientific evidence on the specific impacts of sediment and landsliding and forest harvesting in the Gisborne – East Coast region, which means it is difficult to be specific in many instances about what might be affected. Impacts on areas such as coastal marine reserves as well as on the freshwater/awa mauri of receiving environments was raised during the workshop, but rather than a generic condition this would be covered under a 'specific location' provision in the matrix. There are also potential culturally significant impacts through either loss of mauri or loss of habitat for mahinga kai.

Economics

This includes the direct cost of clean-up for the forestry company but not the total cost to the community. It could include the loss of productivity for future crops through continued loss of soil, which is known to affect both total volume and wood quality (Heaphy et al. 2014). There may also be a loss of land in estate (if decisions are taken not to replant because of high harvesting costs, high health & safety risks, etc.), which may lead to future investment issues or problems in terms of future forestry as opposed to tree saleability.

Associated with clean-up costs are liabilities (moral, ethical and legal). If there is an event that causes issues, current practice within the forestry industry is to help out with machinery (diggers and wood-handling machinery) to help repair or remove debris. Legal liability may also relate to consent conditions, causal links to 'blame' or the direct attribution of impacts, all of which have implications for owners and shareholders and which can impinge on the next factor. The workshop participants felt that costs of $250,000 were regarded as highly significant.

Reputation

Participants felt that reputation has two components. The first is the reputation of the forest company itself and the value of this to the company and its shareholders, which from Forest Stewardship Council or other accreditation schemes could be significant. The other element is a much wider regional factor, in terms of the reputation of the district as a whole, which could be affected by adverse publicity.

There was a general feeling from the forestry representatives that where there is a sensitive community or landowner, they tend to take a more conservative stand and are generally proactive in terms of communication about harvesting. The issue of wood on beaches, which in many ways kicked off the need to conduct this work, is one that is not going to disappear, and participants felt that a wider public education programme was needed to reduce the public's perception of 'who is to blame' and the level of control the forestry companies have on reducing the incidence of wood and debris versus the soil conservation value provided to the community by the forests on the hillsides.

Archaeological/cultural sites of significance

As mentioned under 'Ecology' above, the likely impacts to freshwater, coastal or terrestrial sites of importance to tangata whenua constitute another key factor. This issue is likely to be specific to localities rather than generic. Currently forestry companies do have a level of understanding of archaeological sites within their estates, but consideration also needs to be given to sites beyond the forest boundary.

5.4.4 Outstanding issues after the workshop

For the record, there were several issues raised by workshop participants concerning the general approach and its potential future use; in particular, how the risk matrix was going to be used, particularly by GDC. Concerns were expressed by forestry interests about the details to be provided and the possibility of making the risk matrix a mandatory part of a consent condition rather than being a tool to help assess the potential risks of harvesting. It was beyond the scope of the current contract to delve deeper in to this, but it was suggested that if a risk matrix were found to be useful, then its ongoing development should be something the Forestry Focus Group and GDC work through.

Similarly, concerns were expressed about liabilities (both current and future) and exposure to legal action should the use of the matrix suggest a low level of risk and a storm causing more damage than that that level of risk would indicate.

5.5 Draft risk matrix

5.5.1 General comments

Using the criteria outlined above, a spreadsheet-based risk matrix based on the Nelson Forests Ltd example discussed at the workshop was constructed. Workshop discussion suggested that the number of likelihood categories be reduced from five to four, with the removal of the ‘possible’ category because the distinction between ‘possible’ and ‘likely’ was unclear. The draft risk matrix and the process on how to use it are outlined in Appendix 2. The draft risk matrix was circulated for comment early in November, and it was also ‘field tested’ following a visit by Forestry Focus Group members to the Wharerata Ranges south of Gisborne.

5.5.2 Feedback from workshop participants, and responses

Feedback was positive and fell into several broad areas. The detailed feedback is listed in Appendix 3. Following are the key points.

- Forestry members would find the matrix valuable and agreed in principle with the concept. It was viewed as a pilot project, with the draft risk matrix as the first stage in a wider development project with the eventual aim of producing a commercial app.
- A description of what, why and how this tool could be used should be provided. (This report meets that need and should provide the necessary background and evidence base for the tool.)
- The matrix as it stands is reasonably subjective. (The authors acknowledge this. This report, which should accompany the spreadsheet, provides background information and outlines the paucity of information and data for many of the factors used in the matrix. While it is acknowledged as a subjective process, the available evidence and experience used to separate the various factors ensure that there is a degree of consistency and objectivity.)
- As it now stands the spreadsheet was seen by some to be arduous and costly to complete. (We acknowledge that using the tool will take a little getting used to, but it is a simple approach to assessing a multitude of factors and arriving at a determination that follows a well-established procedure. The intent of this project was to produce something that could be built upon and refined in future rather than a ‘finished’ product [i.e. an iterative process]. We recommend that it be further tested, refined, and if funding can be found then the development of an app would be a logical next step. GDC also holds historical aerial photographs and can provide slope and geological information on request, and is keen to assist here.)

6 Summary and conclusions

In response to requests for a pathway to try to resolve issues arising from post-harvest landslide and debris flow generation, a draft risk matrix was devised based on discussions with forestry and district council staff at a workshop. This draft was circulated for feedback and a final version was then created (Appendix 2). Following feedback from the Forestry Focus Group, the general view was that the matrix will provide sound judgement as a 'guidance tool to inform decision making' in harvest management, with the intended outcome being to mitigate/reduce environmental harm or intrusion.

The risk matrix developed as part of this project is a first step towards addressing a difficult and complex problem. It will require ongoing dialogue and fine-tuning, and experience in its use will highlight where sticking points or improvements can be made. Any improvements or modifications should be agreed by the Forestry Focus Group in consultation with GDC. We suggest a 6-month trial implementation period be instigated and then a meeting convened to determine any issues arising from its use.

7 Recommendations

- Trial the risk matrix for a period of 6 months and report back its usefulness to the Forestry Focus Group.
- Assess the need for any updates and modifications after 6 months and develop a mechanism to implement these.
- Following general agreement on the utility of such an approach, incorporate the risk matrix as part of normal forest management procedures.
- In parallel, begin to consider the suite of possible actions (beyond those suggested in this report) that might be taken for areas assessed as high risk by the matrix.
- Pursue avenues for future funding to take the concept of this risk matrix and develop it into a simple app.

8 Acknowledgements

We thank Gisborne District Council staff (Lois Easton and Kerry Hudson) for the opportunity to carry out this project. We gratefully acknowledge the input and work of the workshop attendees for their openness and willingness to contribute to the development of the draft risk matrix and the subsequent feedback received. Ian Lynn kindly reviewed the report.

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Appendix 1: Agenda and questions for workshop

Gisborne – East Coast forestry risk matrix workshop

Thursday 20 October, 2016

Venue: Board Room. Level 4 74 Grey Street (Ernslaw One building)

0830-1230 Morning Tea provided.

Background

This workshop is a follow-on from several earlier discussions on the topic of post-harvest landslides and debris flows in the Gisborne-East Coast (GEC) region. Gisborne District Council commissioned Landcare Research to determine if a risk matrix to assess post-forest harvest landslide/debris flow could be developed that incorporates susceptibility factors and consequences relevant to this region. In developing the agenda for day we have made a number of assumptions:

Assumption 1: We are developing a risk matrix for harvesting with the intention that it is used as part of the harvest planning phase to define management measures or approaches that aim to reduce the likelihood of impacts.

Assumption 2: Focus is predominantly on shallow landslides that lead to debris avalanches and debris flows rather than on other processes (gully, earthflow, surface erosion) as these processes are the ones that cause the "problem".

Assumption 3: The hazard remains for 5 years after re-planting at "normal" planting regimes/stocking, i.e. the landscape will continue to be susceptible to rain events until canopy closure and assumes that stocking and survival is uniform.

Assumption 4: We can agree on an ARI that we should be managing for, i.e. same as infrastructure design 1 in 10, 1 in 20 etc.

Assumption 5: watershed area is the area of harvest and catchment refers to the broader area downstream that could be impacted.

The workshop is short. In 4 hours we would like to get to a point where participants can agree that a risk matrix offers a useful and consistent approach to assess the nature of the hazard of landslides occurring post-harvest, the likelihood they will occur, and the consequences that might ensue if the hazard is realised. This will lead to a deeper understanding of the nature of the issue and the subsequent measures and management approaches that can reduce either the hazard or the consequences of such events. It will not ever be feasible to reduce the hazard to zero.

Provisional agenda

Time	What	Who/Output
0830-0900	Introductions, purpose of workshop, assumptions, expectations	LR –Chris Phillips All – Big group
0900-0930	Brief refresher – background, questions	LR – Les Basher
0930-0955	Susceptibility & probability factors	All – small group task, use prepared materials
0955-1020	Consequences	All – small group task, use prepared materials
1020-1030	Report back and get agreement on factors (exception reporting)	Big group
1030-1045	Morning tea	
1045-1200	Populate the matrix	All
1200-1215	Note any sticking points – right way forward	LR
1215-1230	Wrap up, next steps, who	All

What to bring

1. Open mind and willingness to <u>rapidly</u> work as a group towards an 80:20 solution – a risk matrix that <u>could</u> work for GEC.
2. Knowledge, information, data from personal, company or institutional observation or recording that relates to the incidence and triggering of landslides/debris flows and their consequences. This will be used in the short group sessions.

Specific information sought from workshop participants:

1. What "geology" or rock types have the most problems or incidents of landslides and debris flows?

1. Are particular slope classes more vulnerable than others? Do these vary across your estate? Do you have data on these? What do you use to derive slope – Lidar, National DEM, Map contours, field measurements?
2. Are observed landslides more likely on upper, mid or lower slopes?

3. What rainfall drives the incidence of observed landslides? Do you have any details/data of rainfall intensities and durations for the events that caused landslides on your estate? Is it the short local intense storm cells (weather bombs) or the large more regional events that cause the issues? What information do you have about these events? Do you have rain gauges? Do you use NIWA's HIRDS or any other forecasting as part of day to day or harvest planning operations?
4. What sort of "event" are companies currently managing for now in terms of planning or infrastructure development? What would a sensible ARI be? Are there differences across the region even within the same Company?
5. From your experience, should a risk matrix be developed for all erosion processes or should the focus be on shallow landslide and debris flows as we have assumed?, i.e. are there similar issues with other erosion processes?
6. What current stocking rates are being used? Do these vary across the region, within the same forest or Company and why?
7. Are decisions being made to re-plant or not harvest? What kind of factors are currently used now that influence a decision not to harvest or to re-plant?
8. Are there any catchment constraints existing either as a consent condition or within a company's planning conditions?
9. Anything else you think is relevant…….

Appendix 2: Draft risk matrix

The draft risk matrix is a spreadsheet that has three components that relate susceptibility and likelihood of landsliding and debris flows to consequence factors to provide a rating of likelihood and severity. This spreadsheet has been provided separately to GDC and the Forestry Focus Group.

An outline of what the spreadsheet contains is shown in Figure A1 and the process for using it in Figure A2.

Tab 1	**Read me**	General instructions on how the risk matrix works and the process to use it
Tab 2	**Check list**	A checklist of things to consider. Meant to be a first-cut assessment rather than a detailed list covering all aspects. Could be both qualitative or quantitative. Currently incomplete and would require more work to devise a rating scheme if it was felt that was a useful thing to do.
Tab 3	**Risk assessment**	Overall place/process to see the connections between the factors giving rise to the hazard and the consequences should the hazard eventuate. Helps inform the degree of risk (Green, Yellow, Orange, Red) and then leads to the options needed to manage the risk (Brown Tab).
Tab 4	**Options**	Some of the potential options to mitigate the risk or actions to take once risk identified (not exhaustive at this stage) and would expect this to grow and have more detail. It may end up being tailored by individual companies.
Tab 5	**Feedback and action plan**	This is where specific actions and details about who has done what or will do what, may include maps and other descriptions of the harvest plan etc. Likely to be linked to forest company records in some way.
Tab 6	**Background notes**	Brief summary information to explain factors used in the risk matrix. More complete information will be in the accompanying Landcare Research contract report (still in progress due to be completed end of November and submitted to GDC)

Figure A1 Screen shot of the "Read me" tab in the draft risk matrix spreadsheet

Suggested process for using the "Matrix"	
Step 1	Go to the **Check List** (Green Tab) and think about the factors and try and rate them - either by colour or by a score out of 10. If the risk/total risk is above moderate and the consequences are likely to be high then go to the **Risk Assessment** (Red Tab) and determine which cell the location sits in on the Susceptibility Table.
Step 2	Determine which cell the location sits in on the Susceptibility Table in the **Risk Assessment** (Red Tab) then determine the nature of the possible consequences for each of the Consequence Factors. Choose the <u>highest</u> consequence factor and align with the Susceptibility Factor Cell to determine if the location sits in Green, Yellow, Orange or Red.
Step 3	If risk is <u>high</u> (Red or Orange) then go to the **Options** (Brown Tab) and think about courses of action that could be taken to reduce/manage the risk.
Step 4	Begin to work up an **Action plan** on the Blue Tab - keep details of who is doing what, or what needs to be done, link to other records as required etc.
Step 5	Go back to the **Risk Assessment** tab and <u>summarise</u> the various details in top left hand part of spreadsheet - this tab should provide an overall assessment and summary of the whole situation.

Figure A2 Screen shot of the suggested process to use the draft risk matrix

The following screen shots (Figures A3–A6) illustrate each of the components that the user would assess in completing the process to determine the nature of the risk.

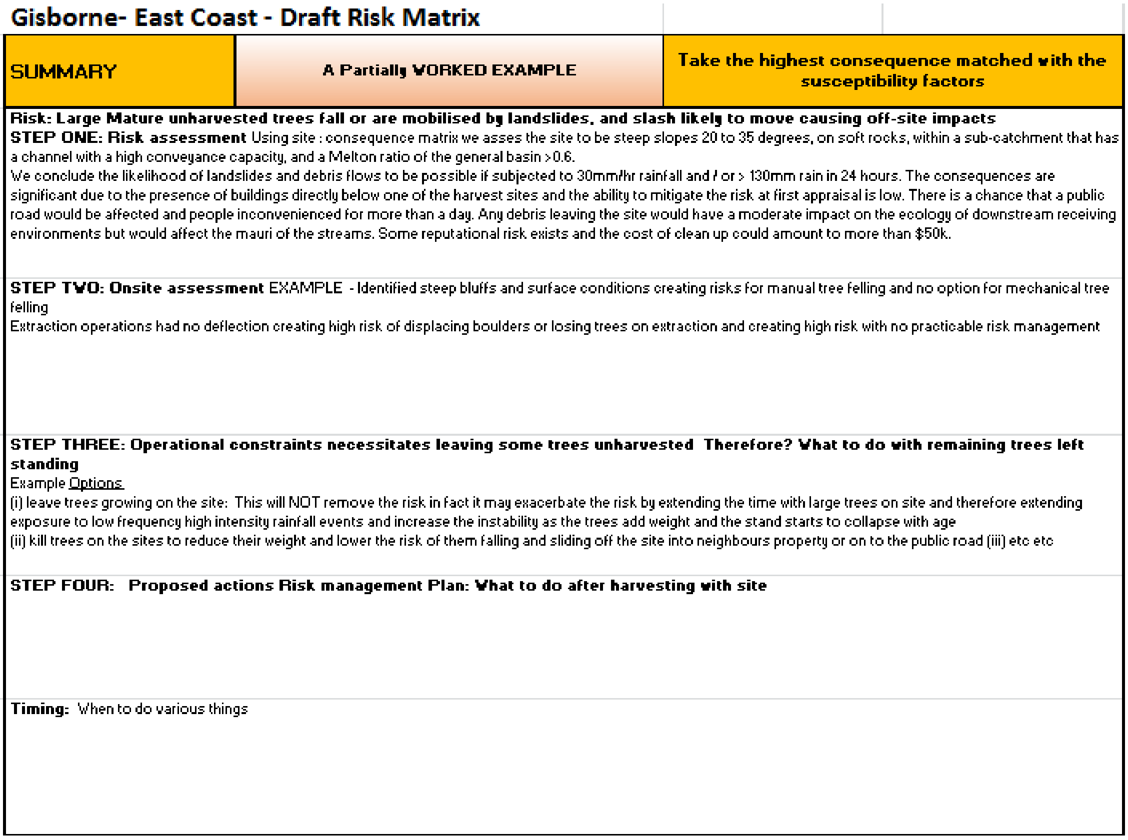
	Susceptibility: Geology, slope & channel factors			Rainfall/probability	Observed Frequency	
	Hard rocks	Soft rocks	Tephra mantled HC			
Likelihood of Landslides entering streams	Majority of slopes >35 Connected to high conveyance channel Melton ratio >0.6 No floodplain or option to mitigate	Majority of slopes >30 Connected to high conveyance channel Melton ratio >0.6 No floodplain or option to mitigate	Majority of slopes >25 Connected to high conveyance channel Melton ratio >0.6 Change of slope convex to concave common No floodplain or option to mitigate	> 30mm/hr intensities AEP less than 0.1 > 130mm /24hr. AEP less than 0.1 OR specific locations in region	Has occurred at more than once in last 5-10 years	Almost certain
	Majority of slopes 25 to 35° Connected to high conveyance channel Melton ratio >0.6	Majority of slopes 20 to 30° Connected to high conveyance channel Melton ratio >0.6	Majority of slopes > 25° Connected to high conveyance channel Melton ratio >0.6	> 30mm/hr intensities AEP less than 0.1 > 130mm /24hr. AEP less than 0.1 OR specific locations in region	Has occurred but no more than once in last 15 years	Likely
	Majority of Slopes 20-25° Not connected to high conveyance channel Melton Ratio 0.3-0.6	Majority of slopes 20 to 30° Not connected to high conveyance channel MR 0.3-0.6	Majority of slopes < 20° Not connected to high conveyance channel MR 0.3-0.6	> 30mm/hr intensities AEP less than 0.1 > 130mm /24hr. AEP less than 0.1 OR specific locations in region	Records or local knowledge indicates an occurrence in last 30 years	Unlikely
	Majority of Slopes <20° Not connected to high conveyance channel MR 0.3-0.6	Majority of Slopes <20 Not connected to high conveyance channel MR 0.3-0.6	Majority of Slopes <20 Not connected to high conveyance channel MR 0.3-0.6	> 30mm/hr intensities AEP less than 0.1 > 130mm /24hr. AEP less than 0.1 OR specific locations in region	No record of it having ever occurred in last 50 years	Rare

Figure A3 Screen shot of the susceptibility factors leading to the likelihood rating

	Consequence of landslides (entering streams) --> debris flows				
People	No roads or buildings on floodplain < 5 km below site No-one affected	Rarely used (< monthly) access tracks or buildings exist on floodplain < 5km below site Minor inconvenience to a few people	Infrequently used (< weekly) access tracks or buildings exist on floodplain < 5 km below site Inconvenience to a few people Low potential for injury -first aid treatment	Regularly used (daily) tracks or buildings exist on floodplain <5km below site Inconvenience to several people Moderate Injury potential – treatment by medical practitioner	Dwellings directly below site without reliable mitigations (barriers) High risk of major injury or fatality
Property (buildings, bridges)	No roads or buildings in floodplain < 5km below the site: Nothing affected	< 2 properties below ALL sites within the catchment to be harvested over 4 yr period AND only fence lines and farm tracks likely to be affected Public roads not impacted	< 5 properties below ALL sites within the catchment to be harvested over 4 yr period AND bridges and farm buildings possibly affected Public roads unlikely to be impacted	>5 properties below ALL sites within the catchment to be harvested over 4 yr period AND bridges, roads and farm buildings likely to be affected Public roads likely to be impacted	Presence of buildings or infrastructure directly below the site with no reliable mitigation available: significant potential damage Public roads closed
Ecology	No soil or debris from the site has potential to directly enter streams or marine environment	Soil and debris from the site could directly enter a stream or receiving environment Low level of impact on channel or receiving environment	Soil and debris from the site could directly enter a permanent stream or receiving environment Moderate level of impact on channel or receiving environment	Soil and debris from the site could directly enter a high value stream or receiving environment High level of impact on stream or receiving environment	High value receiving environments directly below the site where ecological loss is reasonably expected to occur (dead fish, major impacts on bed of stream or sea)
Economics	Only routine maintenance within forest required <NZD$10,000 clean up costs No Legal liability	Routine maintenance within forest >NZD$10,000 clean up costs No Legal liability	Some action taken to assist clean up outside of forest >NZD$10,000 clean up costs No Legal liability	Targeted actions taken to clean up within and outside of forest >NZD$50,000 clean up costs Legal liability moderate	Significant contribution to clean up costs Potential for > NZD $250,000 of offsite damages Legal liability high
Reputation	Nothing visible from neighbours or public (contained within forest	A few landslides visible to public and no debris flows (contained within forest) Unlikely to trigger an internal incident report	Numerous visible landslides and occasional debris flows across private land Triggers internal incident report Some reputational risk	Widespread visible landslides and several debris flows across public or private land EMS triggered Neighbour/council response Moderate reputational risk	Consequence of landslides/debris flows at this location is likely to generate Regional concern and adverse media High reputational risk
Archaelogical/cultural	No archaeological or cultural sites of significance present Impacts on mauri low	Unknown archaeological or cultural sites of significance present Impacts on mauri low	Presence of cultural sites of significance directly below site with reliable means of mitigation available Potential impacts on mauri	Presence of cultural sites of significance directly below site with some reliable means of mitigation available. Likely impacts on Mauri	Presence of cultural sites of significance directly below site with no reliable means of mitigation available. Certain impacts on Mauri
	Insignificant	Negligible	Moderate	Extensive	Significant

Figure A4 Screen shot of the consequence factors leading to the severity rating

Figure A5 Screen shot of the relationship between susceptibility and severity to give rating of negligible to high risk (green, yellow, orange, red)



Gisborne- East Coast - Draft Risk Matrix

SUMMARY	A Partially WORKED EXAMPLE	Take the highest consequence matched with the susceptibility factors

Risk: Large Mature unharvested trees fall or are mobilised by landslides, and slash likely to move causing off-site impacts
STEP ONE: Risk assessment Using site : consequence matrix we asses the site to be steep slopes 20 to 35 degrees, on soft rocks, within a sub-catchment that has a channel with a high conveyance capacity, and a Melton ratio of the general basin >0.6.
We conclude the likelihood of landslides and debris flows to be possible if subjected to 30mm/hr rainfall and / or > 130mm rain in 24 hours. The consequences are significant due to the presence of buildings directly below one of the harvest sites and the ability to mitigate the risk at first appraisal is low. There is a chance that a public road would be affected and people inconvenienced for more than a day. Any debris leaving the site would have a moderate impact on the ecology of downstream receiving environments but would affect the mauri of the streams. Some reputational risk exists and the cost of clean up could amount to more than $50k.

STEP TWO: Onsite assessment EXAMPLE - Identified steep bluffs and surface conditions creating risks for manual tree felling and no option for mechanical tree felling
Extraction operations had no deflection creating high risk of displacing boulders or losing trees on extraction and creating high risk with no practicable risk management

STEP THREE: Operational constraints necessitates leaving some trees unharvested Therefore? What to do with remaining trees left standing
Example Options
(i) leave trees growing on the site: This will NOT remove the risk in fact it may exacerbate the risk by extending the time with large trees on site and therefore extending exposure to low frequency high intensity rainfall events and increase the instability as the trees add weight and the stand starts to collapse with age
(ii) kill trees on the sites to reduce their weight and lower the risk of them falling and sliding off the site into neighbours property or on to the public road (iii) etc etc

STEP FOUR: Proposed actions Risk management Plan: What to do after harvesting with site

Timing: When to do various things

Figure A6 Screen shot of summary of assessment and options for taking action

Appendix 3: Feedback from FFG – provided by Prue Younger, Eastland Wood Council

The general feedback to the matrix was:

1. EWC members would find this valuable and agreed in concept with the Matrix
2. Suggest an intention/description of what, why and how this tool is to be used
3. See it as a planning tool – pre/during/post-harvest which can then be used to compare between sets
4. Suggested wording like: "The matrix will provide sound judgement as a guidance tool to inform decision making'' in harvest management with the outcome to mitigate/reduce environmental harm or intrusion
5. Believe the information needs to be well validated: the matrix as it stands is very subjective
6. Therefore not to be used for regulatory or compliance purposes
7. Some of the Likelihood/Susceptibility criteria would be a visible assessment, measurable?
8. In the format presented it is not user friendly and could be arduous and costly to complete
9. Design an APP or alternate tool

The Concept of the APP

1. It's user friendly
2. It's accessible to anyone
3. It's quantitative (less subjective)
4. It's 21st Century technology
5. Likelihood/Susceptibility criteria would have pre-determined rankings
6. Followed by Consequences which may also have predetermined rankings i.e. Within public view 1: NO 5: at least 5 people sight it every day OR 10: yes on main highway
7. Provided platform which link to existing programmes i.e. GDC Rainfall & GIS, NIWA – HIRDS, LIDAR, Tairawhiti Maps
8. Automatically tallies the rankings for both and plots against the matrix
9. Build in mitigation list – check list or tick list
10. Build in comments option so that new mitigations can be shared etc.
11. Factor in the economic implication of not harvesting an area or partial area
12. Have industry assist in the design of criteria – predetermined rankings

NB: The risk assessment across an entire forest would be quite different to an assessment for say a single water catchment and would change again if narrowed down per harvest setting

What GDC may consider:

1. View it as a pilot project
2. Maybe adapt for other land use
3. Consider NES when setting criteria
4. How is the matrix going to be used effectively?
5. Ensure there is consideration around economics compared to practicalities

What would also be of value:

1. Restrict certain criteria like age of forests which may be sensitive to some companies – private access
2. Build a database of information
3. Re-assess that information after 2nd rotation
4. Meet Forest Stewardship Council & National Environment Standard for Plantation Forestry criteria for the future which will be audited
5. EWC & GDC lead the way
6. Roll it out nationally, retaining ownership – commercial product
7. Available when land is sold on

We would certainly see the proposed matrix format, as the first stage.

Stage 2. would see further development of the APP

Stage 3. Pilot trial for 1-2 years

Stage 4. Review

Stage 5. Roll out as commercial product