Ministry for Primary Industries
Manatū Ahu Matua

# Plantation Forestry Erosion Susceptibility Classification

## Risk assessment for the National Environmental Standards for Plantation Forestry

MPI Technical – Paper No: 2017/47

Prepared for the Ministry for Primary Industries

ISBN No: 978-1-77665-647-9 (online)
ISSN No: 2253-3923 (online)

**July 2017**

New Zealand Government

Growing and Protecting New Zealand

## Disclaimer

While every effort has been made to ensure the information in this publication is accurate, the Ministry for Primary Industries does not accept any responsibility or liability for error of fact, omission, interpretation or opinion that may be present, nor for the consequences of any decisions based on this information.

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries website at http://www.mpi.govt.nz/news-and-resources/publications/

# Contents

Page

# 1 Introduction to Erosion Susceptibility Classification development

The Erosion Susceptibility Classification (ESC) provides a threshold test for councils to implement the National Environmental Standard for Plantation Forestry (NES-PF) regulations according to the erosion risk of different landscapes over the eight forestry activities regulated under the NES-PF. The classification also gives guidance to foresters on the risks associated with planting forests.

This publication contains the four research reports that were used to develop the ESC tool for the NES-PF and the expert group conference results that occurred after the third report was released.

The four research reports that the ESC is based on are:

1. Bloomberg M, Davies T, Visser R, Morgenroth J (2011) *Erosion Susceptibility Classification and analysis of erosion risks for plantation forestry*. Report prepared by the University of Canterbury for the Ministry for the Environment, Wellington.
2. Basher L, Lynn I, Page M (2015) *Update of the Erosion Susceptibility Classification (ESC) for the proposed National Environmental Standard for Plantation Forestry – revision of the ESC*. MPI Technical Paper No. 2015/13. Prepared by Landcare Research for the Ministry for Primary Industries, Wellington (Landcare Research Contract Report LC2196).
3. Basher L, Barringer J, Lynn I (2016) *Update of the Erosion Susceptibility Classification (ESC) for the proposed NES for Plantation Forestry: Subdividing the High and Very High ESC classes – Final report*. MPI Technical Paper No. 2016/12. Prepared by Landcare Research for the Ministry for Primary Industries, Wellington (Landcare Research Contract Report LC2472).
4. Basher L, Barringer J (2017) *Erosion Susceptibility Classification for the NES for Plantation Forestry*. Prepared by Landcare Research for the Ministry for Primary Industries, Wellington (Landcare Research Contract Report LC2744).

The development of the ESC has been iterative. The initial approach and design was developed by Bloomberg et al in 2011. The authors recommended a four-class ESC where land is coded green (Low risk), yellow (Moderate), orange (High) and red (Very High risk). They based this on the potential erosion severity values identified in the New Zealand Land Resource Inventory (NZLRI) and the Land Use Capability (LUC) database. They then used data from 12 New Zealand catchments to ascertain the likelihood of rain storms severe enough to cause landslides during the four- to seven-year period it takes for a forest replanted on clear felled land to develop a full canopy. This helped compare the plantation forestry risk profile to the original erosion risk profile of the LUC system, which was developed for pastoral farming. Using this information, the authors then produced maps and tables of the ESC using Geographic Information System (GIS) analysis to cross reference the LUC system information to the forestry ESC risk.

The Bloomberg et al report was the basis for consultation on the proposed NES-PF during 2015. While there was a broad level of support for the ESC in principle, a large number of submitters believed the proposed classification was not precise enough nor completely accurate with regard to the characterisation of risk.

The Ministry for Primary Industries (MPI) commissioned Landcare Research to refine the original ESC. The initial brief was to identify LUC units in the High and Very High ESC classes that were misclassified or conservatively classified and update the ESC on the basis of any findings. Landcare Research was then asked to:

- refine the ESC so it could be used to assess erosion risk associated with plantation forestry activities in the High and Very High classes with more accuracy;
- provide descriptions of the revised classes within the High and Very High ESC classes and the erosion risk for different forestry activities so appropriate controls and conditions could be applied through the NES-PF to manage the effects of these activities.

Landcare Research, through Basher et al, produced reports in 2015 and 2016. The 2015 report saw a change of classification for about 16 percent of the LUC units, especially in Otago and Canterbury, where some land was included in a lower ESC class (for example, High to Moderate). The researchers noted that several difficulties remained in applying the ESC based on potential erosion, these included the subjectivity of the classification, the poor definition of the concept and method of assessment of potential erosion and the broad definition of some LUC units.

For the 2016 report, the research team developed a terrain classification based on dominant erosion process, rock type and topography. Land within the High and Very High classes was grouped according to the dominant erosion process, resulting in seven major groups: gullying, earthflows, landsliding, tunnel gullying, wind erosion, bank erosion and deposition.

These were then grouped according to rock types with similar strength and erodibility and the steepness of the land, resulting in 21 distinct terrains. These were then analysed regarding the impact of the eight forestry activities covered by the NES-PF, and the report provides recommendations for plantation forestry management practices to mitigate any potential effects.

The Basher and Barringer 2017 report tidied up several residual matters. These included:

- extending the ESC classification over the whole of mainland New Zealand – it had previously not covered the conservation estate;
- improving the mapping precision for the ESC along river margins, lakes and the coast – it had previously had some misalignment due to different mapping types being used in the LUC map database and the New Zealand topographical map series;
- creating overlays that identify ESC units where:
  - the primary erosion type is gully or tunnel gully erosion and of severe erosion potential or greater;
  - the primary erosion type is earthflow and the geology is crushed argillite, Tertiary mudstone or sandstone;
- separately identifying LUC Class 8e land (including compound units with a dual LUC unit).

While the 2017 report provided a systematic approach to analysing erosion type, compared with terrain, the approach it used to terrain type was less nuanced than that of the LUC system for Tertiary sediments, in particular. This resulted in some units, particularly in the hill country in the lower central North Island, not matching the risk profile that local experts would ascribe to them. In March and April 2017, a small expert group with field expertise in both LUC and plantation forestry reassessed the risk rating on the Tertiary sediment terrain. The report of this process is the final chapter of this publication.

The result of the four reports and expert review is the Erosion Susceptibility Classification May 2017, used for the gazettal of the NES-PF.

# 2 Erosion Susceptibility Classification and Analysis of Erosion Risks for Plantation Forestry, University of Canterbury - 2011

M Bloomberg [1]
T Davies [2]
R Visser [1]
J Morgenroth [1]

[1] School of Forestry, University of Canterbury
[2] Department of Geological Sciences, University of Canterbury 17 May 2011



Inquiries and requests to:
Mark Bloomberg School of Forestry
University of Canterbury PB 4800
Christchurch 8140, New Zealand
Email: mark.bloomberg@canterbury.ac.nz

## CONTENTS

## 2.1 GLOSSARY

Most technical terms in this report are defined the first time they are used in the text. This glossary contains terms which are used but not completely defined within the main report.

| | |
|---|---|
| Antecedent conditions | The conditions prevailing prior to a soil erosion or landslide event. This description is normally used to characterize basin wetness, as determined by long-duration low-intensity rainfall prior to the event. |
| Cutoffs | Raised mounds on a road surface at right angles to the grade, which direct surface runoff away from the road surface (also known as waterbars) |
| Deep disturbance | Soil disturbance leaving no surviving vegetation; surface soil removed to expose parent materials (e.g. colluvium or bedrock). |
| Dry ravel | Movement of individual particles resulting from wetting and drying, freezing and thawing, or mechanical disturbance, is considered a surface erosion process. |
| Duration | The length of time of occurrence of a rainfall event |
| Empirical model | A model, mathematical function or other description of system behaviour that is based on observation or experiment, but does not include an underlying theoretical explanation of the system |
| Fillslopes | The creation of a horizontal bench on a sloping hill surface using excavated material, usually placed and then subject to some degree of compaction |
| Outsloping | Construction of earthworks with an outwards camber so that surface water is directed away from the earthworks surface |
| Overland flow | Surface movement of rainfall-derived water, not intercepted or absorbed by vegetation or soil. |
| Polygon | Two-dimensional polygons are used in a GIS to represent geographical features that cover a particular area of the earth's surface. LUC units are represented as polygons within the NZLRI |
| Process-based model | A model, mathematical function or other description of system behaviour that is based on an underlying theoretical or “mechanistic” explanation of the system |
| Rainfall intensity | The rate at which rainfall occurs during a rainfall event (usually expressed in millimetres per hour) |
| Raster | Raster data consists of rows and columns of cells, with each cell storing a single value. This allows a spatial representation of a single variable in a GIS. |
| Sediment yield | The mean sediment (soil and rock) load carried by a watercourse, usually related to the amount of erosion occurring in the watercourse catchment |
| Shallow disturbance | Disturbance leaving ome surviving grasses/weeds; needle litter removed or reworked, topsoil scarified but largely intact |
| Slash | Residual above-ground parts of a tree crop or understorey shrub layer not removed by harvesting e.g. branches, foliage, unmerchantable parts of the tree stem. |
| Soil pore water pressure | The pressure of groundwater held within a soil or rock, in gaps |
| Undisturbed ground | Ground cover vegetation flattened but otherwise unaffected by logging operations; litter layer and topsoil intact |
| Waterbars | See “cutoffs” |

## 2.2 SUMMARY

The objective of this study is the development of an erosion susceptibility classification (ESC), which will be used to analyse the risks of erosion, sedimentation and environmental harm associated with plantation forestry activities in New Zealand.

To do this, we used a conceptual model of landslide risk where

*Erosion risk =erosion susceptibility x frequency of triggering events x downslope /downstream consequences.*

Erosion susceptibility is therefore just one component of erosion risk, which also depends on the frequency of triggering events (usually high intensity rain storms) and the nature of the downslope/downstream values impacted by the erosion (consequences).

Erosion susceptibility itself has two components, predisposing factors such as slope and lithology which determine the inherent susceptibility of a land unit to erode, and preparatory/mitigating factors, which respectively increase or reduce erosion susceptibility above or below this inherent level. Many preparatory/mitigating factors are related to plantation forest management e.g. earthworks and removal of the forest canopy by clearfell harvesting (preparatory factors), and reinstatement of a forest canopies by tree planting or forest regeneration (mitigating factor).

We review several candidate methods for estimating erosion susceptibility in New Zealand, and opt for the potential erosion severity values in the NZ Land Resource Inventory (NZLRI) and Land Use Capability (LUC) database. These erosion severities range from 0 (negligible) to 5 (extreme), and were classified into a three-class and four-class erosion susceptibility classification (ESC) as follows:

| Potential erosion severity | Three class ESC | Four class ESC |
|---|---|---|
| 0=negligible | 1 | 1 |
| 1=slight | 1 | 1 |
| 2=moderate | 2 | 2 |
| 3=severe | 3 | 3 |
| 4=very severe | 3 | 4 |
| 5=extreme | 3 | 4 |

Using this system, all map units (polygons) in the NZLRI, which covers the North and South Islands but not outlying islands, were assigned to ESC classes and GIS analysis was used to produce maps and tables depicting the spatial distribution of the ESC classes. Towns, quarries and the Department of Conservation estate were excluded from this analysis, and classed as “undefined”.

Based on this analysis we recommended a four-class ESC as it makes an important differentiation between differentiation between 1) land units which are going to be difficult to afforest without very severe adverse erosion effects, and 2) areas which, although having a severe erosion limitation to use, are more suited to conventional plantation management.

The distribution of ESC classes by regional council regions is shown in the following table:

| | Area('000 ha) | | | | | |
|---|---|---|---|---|---|---|
| **Region** | **Low** | **Moderate** | **High** | **Very High** | **Undefined** | **Total** |
| Auckland | 208 | 142 | 67 | 8 | 88 | 513 |
| Bay Of Plenty | 303 | 229 | 224 | 68 | 403 | 1228 |
| Canterbury | 1743 | 756 | 342 | 456 | 1236 | 4533 |
| Gisborne | 103 | 266 | 192 | 196 | 84 | 841 |
| Hawke's Bay | 504 | 341 | 154 | 151 | 301 | 1451 |
| Manawatu-Wanganui | 795 | 543 | 361 | 113 | 473 | 2285 |
| Marlborough | 114 | 191 | 162 | 91 | 495 | 1053 |
| Nelson | 3 | 10 | 18 | 3 | 8 | 43 |
| Northland | 450 | 266 | 318 | 50 | 190 | 1273 |
| Otago | 1307 | 565 | 471 | 193 | 663 | 3199 |
| Southland | 990 | 252 | 49 | 37 | 1705 | 3033 |
| Taranaki | 312 | 97 | 119 | 48 | 152 | 729 |
| Tasman | 109 | 87 | 114 | 27 | 642 | 979 |
| Waikato | 1077 | 547 | 307 | 53 | 465 | 2448 |
| Wellington | 306 | 194 | 88 | 57 | 169 | 816 |
| West Coast | 261 | 26 | 37 | 30 | 1982 | 2336 |
| **Total** | **8586** | **4513** | **3023** | **1581** | **9057** | **26,760** |

In the second part of this study, we made a qualitative analysis of the risks (defined as erosion susceptibility × frequency of triggering events) We reviewed the mitigating effects of afforestation on erosion susceptibility, and the preparatory effects of clearfell harvesting and associated earthworks (roads, landings and quarries). For New Zealand plantations, there is a window of between 4-7 years from the time of clearfelling until the replanted plantation crop establishes a full canopy, where plantation sites are more susceptible to erosion. Using data from 12 New Zealand catchments, the annual exceedance probability for landslide-causing rain storms was calculated for all New Zealand, using a spatial database for mean annual rainfall (MAR). This indicated there were substantial areas of New Zealand where the AEP was >0.2, so that it was likely that a landslide-causing rainfall event would occur during the 4-7 year “window of susceptibility” after clearfelling of a plantation.

In the final part of this study, we re-examined the limitations of an ESC based on 1:50,000 scale mapping, and discussed how risks from erosion in plantation forests may be managed at a more detailed scale of 1:5000 to 1:10,000, required for accurate mapping of and planning for erosion risks.

## 2.3 A. EROSION SUSCEPTIBILITY CLASSIFICATION

### *A.1 Introduction*

The objective of this study is the development of an erosion susceptibility classification (ESC), which will be used to analyse "the risks of erosion, sedimentation and environmental harm associated with plantation forestry activities in each of the classification zones" (MfE, 2011).

To do this requires an explicit model of the link(s) between erosion susceptibility and "risks of erosion, sedimentation and environmental harm". In this proposal, we use a conceptual model of landslide risk described in Saunders and Glassey (2007). A diagram of this conceptual model is in Appendix 1 to this proposal.
Briefly, there are three parts to estimation of erosion risk using the Saunders and Glassey model:

1. **Erosion susceptibility** is determined by two interacting factors—**predisposition** (of a land unit) to erode, and **preparatory factors**.
   a) **Predisposition** to erode is an intrinsic quality of a land unit determined by soil type/lithology and topographic characteristics (slope, aspect, drainage pattern, slope position or landform element).
   b) A land unit with a specific predisposition to erode may be placed at greater likelihood of erosion by **preparatory** factors. Examples relevant to forestry are removal of forest cover by land preparation or harvesting, interruption of drainage patterns and earthworks which undercut, and/or create unstable surcharge on, previously stable slopes. Examples of natural preparatory factors include undercutting of toe slopes when rivers change their course. A corollary is that management factors may **mitigate** erosion e.g by reforestation of land units previously in short pasture, or by engineering works to stabilise toeslopes or dewater slopes which are normally wet.
2. **Likelihood and severity of an erosion event**. Erosion occurs when there are **triggering events**, most commonly high-intensity rain storms but also earthquakes or volcanic eruptions. Different land units will have different probabilities of triggering events occurring, depending on local climate or proneness to earthquakes. Some erosion classification systems (e.g. the NZLRI system) bundle intrinsic erosion susceptibility with frequency of triggering events, to estimate a potential erosion severity. Others e.g NZeem (Dymond et al., 2010) explicitly model likelihood of triggering rain storms as a separate factor to the erosion susceptibility of the land unit. **Erosion susceptibility x frequency of triggering events** determines erosion hazard, an overall likelihood and severity of an erosion event.
3. **Consequences of an erosion event**. The final element in the calculation of risk is the consequences of erosion. Therefore any analysis of erosion risk must include an evaluation of these consequences i.e. **Erosion risk =Erosion susceptibility x frequency of triggering events x consequences**. These consequences usually occur "downslope" of the erosion site, although they may also occur upslope e.g where property or infrastructure is undercut by erosion. The severity of the consequences and therefore erosion risk depends on the nature of what is "downslope"—risks are higher when residential houses, valuable infrastructure or iconic waterways are "downslope", compared to farmland or unoccupied land where damage caused by erosion involves low risk to human life and is reasonably cheap to repair.

A major advantage of the Saunders & Glassey model is that it explicitly separates triggering events and downslope consequences from susceptibility (underlying predisposition to erode× preparatory and/or mitigating factors). It clearly identifies all factors that contribute to risk; in

particular, it recognises that two erosion events of equal severity may have quite different levels of risk, depending on what is located "downslope' from where the erosion occurs.
In Section A of this report, we focus on the susceptibility of land units to erode. To normalise the effect of preparatory/mitigating factors on erosion susceptibility, we will use the assumptions that the NZLRI uses in estimating potential erosion severity i.e. land is under permanent pasture vegetation and there are no soil conservation works but also no earthworks that might destabilise the land (I. Lynn pers. comm., 26 April 2011). This means that all land units are compared purely on the basis of their predisposition to erode, with a correction for differences in erosion susceptibility due to different vegetation cover , intensity of earthworks, or other preparatory factors.

Other contributing factors to erosion risk will be discussed in Section B (Analysis of Erosion Risk) i.e:

- Modifying effects of forestry earthworks and harvesting (=preparatory factors) on erosion susceptibility
- Frequency of triggering events.

Note that the brief for this study (MfE, 2011) requires only analysis of two out of three components of erosion risk - susceptibility and frequency. This analysis will not analyse consequences of erosion. Therefore, in this study the term "**erosion risk**" refers to the likely frequency of occurrence of erosion with a given severity (magnitude and/or spatial density). This definition of erosion risk is equivalent to "erosion hazard" as defined by the JTC-1 Joint Technical Committee on Landslides and Engineered Slopes (Fell et al., 2008).

## *A.2 Review of Candidate Models*

In this section, candidate models of erosion susceptibility will be reviewed for their usefulness in predicting "the risks of erosion, sedimentation and environmental harm associated with plantation forestry activities in each of the classification zones." Additional criteria in this review will be:

- Data reliability. The input data for candidate models will be assessed for reliability i.e resolution, accuracy and degree to which they have been generalised or extrapolated from original field data.
- The ECS should be understood by and acceptable to end-users.

### *A.2.1 Empirical versus process models of erosion susceptibility*

In making an ESC two methods are available:

1. Utilisation of empirical information on erosion in New Zealand acquired over the last several decades, using the NZ Land Resource Inventory (NZLRI) and the Land Use Capability (LUC) Classification derived from it; or
2. Further develop recent initiatives using process-based slope stability assessments within a GIS using topography, soils, vegetation and other land attributes available as GIS layers.

Pragmatically, we prefer the LUC classification because it uses comprehensive field assessments of actual and potential erosion over the whole of New Zealand compiled by experts. In principle, this approach is preferable because 1) it is based on observed erosion rather than on modelled/simulated/computed erosion; and 2) it requires little if any field verification, in contrast to any modelled classification which will require comprehensive field verification.

A further justification for using the first method arises from consideration of the present status of erosion susceptibility modelling in GIS (usefully summarised by Carrara and Pike, 2008). While a number of frameworks exist for applying physically-based slope stability models to spatially-varying land data, considerable reservations remain about a number of factors. In particular,

- The quality of the spatial data used in such models is very variable, and the cumulative errors in calculation of slope stability have the potential to be high.
- The resolution of the data is inevitably dependent on the mapping scale; where large areas are to be mapped, scales are small and the ability to detect severe erosion susceptibility of a small area is dubious.

Carrara and Pike (2008) note that: “It is still too early in the evolution of GIS-based landslide-hazard and risk modelling to identify any “best” approach or set of techniques”.

Thus we propose to utilise the factual information available in the NZLRI to develop an initial nation- wide set of erosion susceptibility assessments. In the future it may well be that GIS-based assessment becomes equally as reliable as the NZLRI-based method, following improvements in slope stability analysis and its application to spatially-distributed parameters; it is likely that the NZLRI data will play a crucial part in the development and validation of such models. For the present we propose to utilise the more analytically-based approaches at the second stage of this investigation, that is, in analysing risks from erosion in plantation forests.

### *A.2.2 Comparison of NZLRI, HEL and NZeem*

An ESC based on the national NZLRI database is the default option for this investigation. Other candidate models (HEL, (Dymond et al., 2006) NZeem (Dymond et al., 2010) are partially based on process models of erosion, and thus have drawbacks discussed in Section A2.1.

Furthermore, a detailed comparison of the NZLRI, HEL and NZeem for use in mapping the land susceptible to mass movement affecting soil carbon stocks was made by Basher et al. (2010). They concluded that “Of the three different approaches used to define susceptibility to mass movement, potential erosion from the NZLRI provides the most robust and defensible definition…”

In this investigation, we aim to classify land susceptibility to the same erosion types (mass movement and gully erosion) defined by Basher et al. (2010). Rather than duplicate the detailed analysis in Basher et al. (2010), we refer the reader to Section 3.4 (p.30 et seq.) in that document.

Although the preferred model for this investigation, the NZLRI has limitations as a predictor of erosion “susceptibility” (as defined by Saunders and Glassey (2007)).

1. Actual erosion severity in the NZLRI database is only a guide to erosion susceptibility, since it reflects the effects of mitigating/preparatory factors (e.g. existing vegetation cover) as well as a stochastic element (e.g. the history of triggering rainfall events for that particular NZLRI unit).
2. For all NZLRI units, potential erosion type and severity was also assessed. While this represents useful expert opinion, it is an estimate of potential erosion type and severity, rather than erosion susceptibility. It bundles intrinsic land unit predisposition to erosion with an assumed likelihood of triggering factors, which makes difficult an explicit analysis of risk using the Saunders and Glassey (2007) model. However, it does attempt

to explicitly account for preparatory factors such as existing vegetation (by assuming land cover to be pasture) and also cultivation (for arable soils). It also assumes that there are no soil conservation works and no destabilising earthworks (I. Lynn pers. comm., 26 April 2011).

3. Potential erosion severity is based on expert opinion. As such, it can be "wrong"—assessments by NZLRI surveyors of potential erosion severity can change with experience and observation over a working lifetime.

### *A.3 Estimation of Erosion Susceptibility*

Erosion susceptibility is defined as the interaction of predisposing factors and preparatory factors, determining the intrinsic susceptibility of a land unit to erode (Section A1). Susceptibility is determined, in the case of landslide erosion, by an inventory of landslides which have occurred in the past and areas with potential to experience landsliding (Cascini, 2008)—a definition is consistent with the use of potential erosion severity in the NZLRI. Within the NZLRI, erosion forms are classified as shown in Table 1:

**Table 1 Erosion Types and Symbols. Source: Table 7, Lynn et al. (2009).**

*Table 7: Erosion types and symbols (for definitions see Appendix 2).*

| Category | Erosion types | Symbol | Optional prefixes (examples) |
|---|---|---|---|
| 1. Surface erosion | Sheet | **Sh** | |
| | Wind | **W** | |
| | Scree | **Sc** | |
| 2. Mass movement | Soil slip | **Ss** | s = shallow, d = deep, r = riparian |
| | Earthflow | **Ef** | s = shallow, d = deep, r = riparian |
| | Slump | **Su** | s = shallow, d = deep, r = riparian |
| | Rock fall | **Rf** | |
| | Debris avalanche | **Da** | |
| | Debris flow | **Df** | |
| 3. Fluvial erosion | Rill | **R** | |
| | Gully | **G** | s = shallow, d = deep |
| | Tunnel gully | **T** | |
| | Streambank | **Sb** | |
| 4. Deposition | Deposition | **D** | |

However, not all erosion forms are likely to be significant in New Zealand plantation forests. There is considerable New Zealand research, reviewed in the following Sections, to show that the following are significant:

1. Landslides which includes all the mass–movement erosion types in Table 1 above.
2. Gully and tunnel gully erosion—forms of fluvial erosion.

Other forms of surface and fluvial erosion, as defined by Lynn et al. (2009) are unlikely to be significant consequences of plantation forestry management, although sheet and rill erosion can result in locally significant sedimentation from harvesting, land preparation and earthworks operations (G. Ridley, pers. comm. 29 April 2011).

#### *A.3.1 Evidence in relation to surface erosion*

*Surface erosion from harvest sites*

Marden et al. (2006) note that most research on erosion in New Zealand plantations has concentrated on effects of roading and associated mass-movement (landslide) erosion. However, Marden and co- workers also examined the amount of surface (sheet) erosion (”slopewash”) from hauler-logged sites in Mangatu Forest, Whangapoua Forest (Coromandel), Hawke’s Bay (Pakuratahi Catchment) and the northern Boundary of Kaingaroa Forest (Pokairoa Catchment) (Marden and Rowan, 1997; Marden et al.

2006; Fahey et al. 2003; Marden et al., 2007). In all these studies, harvested sites (excluding earthworks) were differentiated into the following classes:

- Undisturbed ground including stumps and rock outcrops
- Shallow disturbance, where topsoil may be scarified but is largely intact
- Deep disturbance created by soil scraping by extracted logs and cables used in hauling, where sediment is removed and redistributed on the site, and mineral soil and/or parent material is exposed.

The results of these studies are summarised below:

1. Undisturbed ground and shallow disturbance (usually 80-90% of total ground cover) had very low slopewash rates and contributed negligible sediment to stream in the study catchments. Any slopewash was usually redistributed and stored in natural depressions or trapped by vegetation downslope of the erosion area.
2. Deep disturbance areas comprised 9-15% of study areas, and contributed ~85% of total slopewash from all disturbed sites. Where deep disturbance sites (including the soil deposited by soil scraping) were connected to channels, these sites contributed to sediment loads in catchment streams.
3. Sediment contributed to streams from deep disturbance sites was small in relation to sediment contributed from landslides and gullies. Relative contributions of slopewash were 0.2% (Pokairoa), 2% (Whangapoua), but a further 26% of catchment sediment yield was due to “slope-scraping” deposits in watercourses, and 1% (Pakuratahi) of total sediment yield. The % contribution for Mangatu is not specified, but was reported to be “several orders of magnitude” lower than sediment generated from existing gully erosion in the catchment. Note that for all these studies, sediment yields are calculated from measured erosion on-site, and so give a realistic estimate of the scale of surface versus mass-movement and gully erosion.
4. Slopewash rates from deep and shallow disturbance sites declined rapidly within two years, due to revegetation of shallow disturbance sites and “hardening” of deep disturbance sites i.e all loose sediment had been entrained, leaving a resistant surface.

*Surface erosion from earthworks*
Sheet erosion can occur on cut and fill surfaces created by earthworks. On unconsolidated road fill surfaces, sheet and rill (fluvial) erosion may occur until consolidation and “hardening” occur.

As roads consolidate, there is a continuing low level of surficial erosion from road treads and water tables (Fahey and Coker, 1992).

Fahey and co-workers studied the contribution of roads to erosion and sediment yields from plantations on steep and erodible sites in the Marlborough Sounds and on the Separation Point granites in the Motueka Catchment (Coker et al., 1993; Fahey and Coker, 1989, 1992, 1993). The results from these and other New Zealand studies on granite, schist and pumice lithologies are summarised in Fransen et al. (2001). Key results are:

1. Surface erosion from roads at harvest times may increase sediment yield five-fold compared with that from pre-harvest ungraded and lightly used roads. Logging truck traffic during rainfall events can markedly increase sedimentation from road surfaces.
2. However, surface sediment yield rates from roads were generally an order of magnitude lower than estimated background catchment sediment yields. Note that these comments apply to permanent forest roads. Sediment yields from harvest (skidder) tracks may generate much higher proportions of catchment sediment yield catchment (Fransen et al., 2001).
3. Infrequent road-related mass movements are major sources of sediment within forests and have the greatest potential to affect streams. Road mass-movement erosion rates are up to three orders of magnitude greater than surface erosion rates.
4. Mass-movement erosion rates decline with road age, but may increase to earlier levels when roads are upgraded for harvesting activities, or when subject to intense storm events—such as those that caused major road-related mass movements in the Motueka Catchment in 1990 (Fahey and Coker, 1993).

*Wind Erosion*

The topic of wind erosion in New Zealand was most recently reviewed by Basher and Painter (1997). They identify the following sites where wind erosion occurs

In the North Island, wind erosion occurs locally in three main environments covering ~5% of North Island's land area:

- Mobile, coastal dunes on the west coast of Northland and the Manawatu that have not yet been afforested or have poor grass cover;
- High-altitude (>700 m) ash-mantled slopes in the central North Island that have poor vegetation cover due to strong winds and cool temperatures;
- Low-altitude hill country and alluvial terraces in the eastern North Island with low-fertility soils and severe seasonal soil moisture deficits.

In contrast, in the South Island wind erosion is widespread. Basher and Painter (1997) estimate that 19% of the South Island's land area, occurring mainly on light-textured alluvial soils and "loess-mantled terraces and slopes in low-rainfall, seasonally dry eastern regions subject to common strong foehn winds." On lowland sites, cultivation is a preparatory factor. On upland sites, vegetation depletion (due to overgrazing and fire, coupled with climatic limitations to vegetation recovery) is a preparatory factor for wind erosion.

However, Basher and Painter (1997) have recorded no wind erosion events in plantation or indigenous forests. Clearly, forest canopies create a layer of relatively "still" air even in strong wind storms, and this relatively "still" air will not have sufficient erosive power to entrain soil particles. Even during the harvest phase in plantation forests, there is sufficient harvest residue on the ground to create a boundary layer of air next to the ground with reduced wind speed, and enough residual undisturbed ground with an intact litter layer and/or topsoil to keep soil erodibility at a low level.

This absence of wind erosion is particularly important in plantations which have been widely planted in New Zealand to stabilise mobile coastal dunes. This type of terrain is typically classified as a severe or extreme potential for wind erosion in the national NZLRI database. Nonetheless, the actual risk of wind erosion of sand dunes under a normal cycle of plantation forestry is very low, (R. Cathcart (Northland Regional Council) pers. comm 20 April 2011 and Ian Moore (Ian Moore and Associates) pers.comm. 9 May 2011) and we contend that wind erosion should not be included in an ESC for forestry.

### *A.3.2 Evidence in relation to fluvial erosion*

Fluvial erosion includes gully, tunnel gully, rill or streambank erosion (Lynn et al., 2009). **Gully** and to a lesser extent **tunnel gully** erosion play a significant and well-documented role in New Zealand hill country catchments, (Marden and Rowan, 1997; Eyles, 1983) and potential severity for both erosion forms will be a criterion in the ESC.

**Rill erosion** is common on bare agricultural land, whether due to cultivation or depletion of vegetation cover. In contrast, rill erosion is negligible in plantation forests—if it does occur, it will be on unconsolidated soil deposits e.g. road fill and soil scraping (noted previously), and on exposed mineral soils subject to deep disturbance. We contend that the potential erosion severities for surface/rill erosion in the NZLRI are not an appropriate guide to the erosion susceptibility ESC of a land unit. Surface/rill erosion is specific to disturbed (earthworks, deep disturbance) sites, and is largely a function of the nature of the disturbance, not so much the predisposition to erode of the underlying unit. Therefore we propose that potential rill and sheet erosion severity should be excluded in estimating the ESC class for land units.

**Streambank erosion** may be triggered:

- Indirectly, by erosion debris originating from "upslope" plantations. However, in this case the streambank erosion is a consequence of upslope erosion, and can be mitigated by control of that upslope erosion.
- Directly, as a consequence of harvesting of forest adjacent to banks of streams. In this case, the removal of forest may be a preparatory factor which increases streambank erosion susceptibility. However, we are not aware of any published reports documenting direct effects of harvesting plantation forestry on streambank erosion in New Zealand.

We contend that streambank erosion can be excluded from the proposed ESC for plantation forestry, because streambanks can be protected from effects of harvesting by general standards (applying across all classes of the proposed ESC). These general standards would require riparian strips where forest harvesting is excluded, regardless of the erosion susceptibility of the adjoining land.

The next section outlines candidate models for a national ESC classification, in the context of the Saunders and Glassey (2007) conceptual model.

## *A.4 Proposed method for ESC classification using the NZLRI Database*

The current NZLRI database covers all areas in mainland New Zealand that are either currently plantation forests, or have the potential to be established in plantation forest. If an erosion susceptibility classification (ESC) can be specified in terms of attributes in the database, then land units can be rapidly classified using those attributes as sort variables. Notwithstanding the drawbacks of the potential erosion severity ratings in the NZLRI discussed in Section A2.2 (i.e. they are potentially incorrect, and are not estimates of erosion susceptibility as defined by Saunders and Glassey (2007)) they represent the best available data available for this investigation. They will be used in conjunction with the LUC sub-class classifications to estimate the intrinsic predisposition of land units to mass-movement and gully erosion. Note that LUC classification can be related to potential limitations or hazards to productive use as follows (Lynn et al., 2009):

LUC Classes 1-5 Negligible to slight limitations or hazards (under permanent pasture)

| | |
|---|---|
| LUC class 6 | Moderate limitations or hazards |
| LUC Class 7 | Severe limitations or hazards |
| LUC class 8 | Very severe to extreme limitations or hazards. |

Each LUC class is divided into four subclasses, depending on the dominant hazard or limitation to productive use—erosion, wetness, climate or soil, denoted by subscripts of "e", "w", "c" or "s" respectively. For example, an LUC unit with LUC class 6 and a wetness limitation to use would be denoted as 6w.

While "erosion hazard" does not necessarily directly relate to potential erosion severity, there should be some equivalence. If this is the case, then LUC subclasses 6e, 7e and 8e (where "e" denotes erosion as the dominant limitation or hazard to use) should approximately correspond with potential erosion severities of moderate, severe and very severe to extreme, respectively.

### *A.4.1 Proposed erosion susceptibility classification*

MfE (2011) suggests a three-class ESC classification, with green, orange and red colours to denote low, medium and high erosion susceptibility respectively. It also mentions the possibility of a fourth classification ("scarlet") for land with extremely high erosion susceptibility, although this may present problems, for the following reasons:

- A difficult problem with any classification is where to draw the class boundaries. Increasing the number of classes from three to four increases the number of class boundaries from two to three, increasing the potential for debate about those boundaries by 50%.
- Similarly, a resource consent application for land which straddles two or more ESC classes may have to default to the activity class assigned to the highest ESC class. Increasing the number of ESC classes increases the potential for this to occur more often.

Despite these reservations, our intention is to produce two candidate ESC classifications, one with three classes and one with four. We will examine these in terms of their ability to meet the investigation objective: to produce a classification that can be used to analyse "the risks of erosion, sedimentation and environmental harm associated with plantation forestry activities in each of the classification zones."

### *A.4.2 Classification criteria*

Potential erosion severities for mass-movement and gully erosion were sourced from published bulletins and extended legends as follows:

**Table 2 Sources of data for estimated potential erosion severities**

| NZLRI Legend | NZLRI Region | Bulletin |
|---|---|---|
| 01 | Northland | Harmsworth (1996) |
| 02 | Waikato | Page (1985) NI Correlation |
| 03 | Coromandel | Page (1985) NI Correlation |
| 04 | BoP and Volcanic Plateau | Blaschke (1985a) |
| 05 | Eastern BoP | Page (1985) NI Correlation |
| 06 | Gisborne/East Coast | Jessen et al (1999) |
| 07 | Nthern Hawkes Bay | Page (1988) |

| | | |
|---|---|---|
| 08 | Sth HB and Wairarapa | Noble (1985) |
| 09 | Wellington | Page (1995) |
| 10 | Taranaki/Manawatu | Fletcher (1987) |
| 11 | Marlborough | Lynn (1996) |
| 12 (or 00) | Sth Island | SI Extended Legend, van Berkel (ed) (1983) |

Data were listed in Excel spreadsheets, as a list of the units along with their potential erosion severity for each erosion form. Next to the unit name in the spreadsheet we listed the page reference in the appropriate bulletin, from which the estimates of potential erosion severity by erosion from were obtained. At this stage, listed data only include all Class 6 and 7 units, and all Class 8s,c,w units. Class 1- 5 and 8e are assigned default erosion susceptibilities of 0 (minimum) and 4 (maximum) respectively

For each unit in the spreadsheets, the "**maximum severity**" was calculated from the highest potential erosion severity out of those recorded for all mass movement erosion types, plus gully and tunnel gully erosion. In other words, we used the maximum for a specific erosion form, not a cumulative value for all erosion forms. In the case of the South Island, where a single potential severity value is assigned for a unit, that severity was used to calculate "**maximum severity**" if any mass-movement or gully form was recorded as a potential form of erosion. This is the same method used by Basher et al. (2010).
Note:

1. Other fluvial erosion forms and all surface erosion forms did not contribute to this maximum severity rating. For example, a coastal sand dune unit might have low erosion susceptibility because it is not prone to mass-movement or gully erosion. It might have a severe or even extreme potential wind erosion severity, but this was not counted.
2. Some LUC units are mapped as compound units, where two LUC subclasses occur in a complex within a single unit—for example, 4e6+6e20 is a compound unit composed of an arable (4e6) and a non-arable (6e20) unit. In these cases, the maximum severity was taken as the maximum severity for the LUC class with the higher potential erosion severity—in the example above, this would be the LUC class 6e20 unit.

Using a mixture of the maximum severity ratings in the spreadsheets and default values (for Classes 1-5 and 8e), LUC units were assigned to an erosion susceptibility as follows:

**Table 3 ESC classification criteria.**

| LUC Class | Erosion Susceptibility Class (ESC) Values | |
|---|---|---|
| All LUC Classes 1-5 | Default=0 | |
| All LUC Classes 6 and 7, and 8s, c, w | **Maximum potential erosion severity**<br>0<br>1<br>2<br>3<br>4<br>5 | **ESC**<br>1<br>1<br>2<br>3<br>4<br>4 |
| All LUC classes 8e | Default=4 | |
| Undefined-towns, quarries | Default=−2 | |
| Undefined-Dept of Conservation estate | Default=−1 | |

The Department of Conservation estate was excluded from the analysis, as were urban areas, quarries and other areas unclassified in the NZLRI. These were assigned negative ESC values to allow them to be identified during the spatial analysis of ESC using GIS.

There is uncertainty whether there will be a three-class or four class classification of erosion susceptibility (ESC). Therefore we have carried out both as follows:

***Three class classification***

| **Erosion Susceptibility** | **Erosion Susceptibility Classification (ESC)** |
|---|---|
| 0,1 | Low (green) |
| 2 | Moderate (orange) |
| 3,4 | High (red) |

***Four class classification***

| **Erosion Susceptibility** | **Erosion Susceptibility Classification (ESC)** |
|---|---|
| 0,1 | Low (green) |
| 2 | Moderate (yellow) |
| 3 | High (orange) |
| 4 | Very High (red) |

To normalise the effect of preparatory/mitigating factors on erosion susceptibility, we will use the assumptions that the NZLRI uses in estimating potential erosion severity i.e. land is under permanent pasture vegetation and there are no soil conservation works but also no earthworks that might destabilise the land (I. Lynn pers. comm., 26 April 2011). By doing this, we are able to rank land units in terms of their underlying **predisposition** to erode, since the effect of preparatory factors on erosion susceptibility is equal for all units. In other words, we assume that the rank order of units' ESC classifications is independent of preparatory factors. Units will therefore remain in the same ESC class when subjected to different regimes for vegetation cover, earthworks or other preparatory or mitigating factors.

### *A.5 Testing of classification*

Classification of LUC classes 1-5 and 8e is likely to be uncontroversial. The key decisions will be in relation to classification of LUC classes 6 (all subclasses), 7 (all subclasses) and 8(subclasses c, w, s). These decisions were tested in three ways:

1. Review by land management consultants with experience in land use and NZLRI mapping in their respective regions. The allocation of regions to consultants is shown in the following table. No suitable consultant was available for the Westland region.
2. The brief for the consultants required the consultant to identify any units that they believe to be misclassified. They need to justify their opinion, based on either experience (case-studies) or their assessment of susceptibility based on terrain, lithology and soils.

**Table 4. Land management consultants who reviewed the potential erosion severity values.**

| **Areas** | **NZLRI Regions** | **Consultants (Associates in brackets)** |
|---|---|---|
| Northland to East Coast and Central North Island | 1-6 | Norm Ngapo |
| Taranaki to Hawkes Bay and south to Wellington | 7-10 | Ian Moore (Lachie Grant) |

| | | |
|---|---|---|
| Nelson and Marlborough | 11 | Ron Sutherland |
| Canterbury | Pt 12 | Ron Sutherland (Phil McGuigan) |
| Otago and Southland | Pt 12 | Murray Harris (Mike Robins) |

3. After review by the panel of land management consultants, classifications were reviewed by Regional Council staff prior to a finalising a recommended ESC.
4. The final recommended ESC was peer-reviewed by panel of scientists with experience in forestry and land use capability mapping.
5. It seems sensible to provide for regular (5-yearly) review and updating of the ESC, where any new LUC mapping could be substituted for the current NZLRI data to derive more accurate mapping and estimates of potential erosion severity. However, it is necessary for some form of central quality control of LUC unit standards to be introduced if this system is to be permanently applied (G. Eyles, pers. comm 6 May 2011).

### *A.6 Results of classification*

The results of the three-class and four-class classification are shown in map form in Figures 1a and b. Detailed listings of ESC classifications for LUC units, by NZLRI regions, are in Appendix 3, which is a separate document accompanying this report. ArcMap spatial models of the three-class and four-class ESC classifications have been provided to MfE.

Figure 1 shows that a three-class classification results in equal areas of hill country in both Islands being classified as ESC=3 (High), and ESC=2 (moderate). However, under a three-class system, ESC class 3 includes both

1. Land units which are going to be difficult to afforest without severe adverse erosion effects.
2. Land units which, although having an erosion limitation to use, are more suited to conventional plantation management.

The four-class classification differentiates ESC class 3 into two types, where ESC= 4 is difficult to afforest without severe effects, and ESC 3 is possible to manage conventionally as a plantation forest, albeit with limitations. For this reason, we recommend that the four-class ESC classification is used in the NES for plantation forestry.

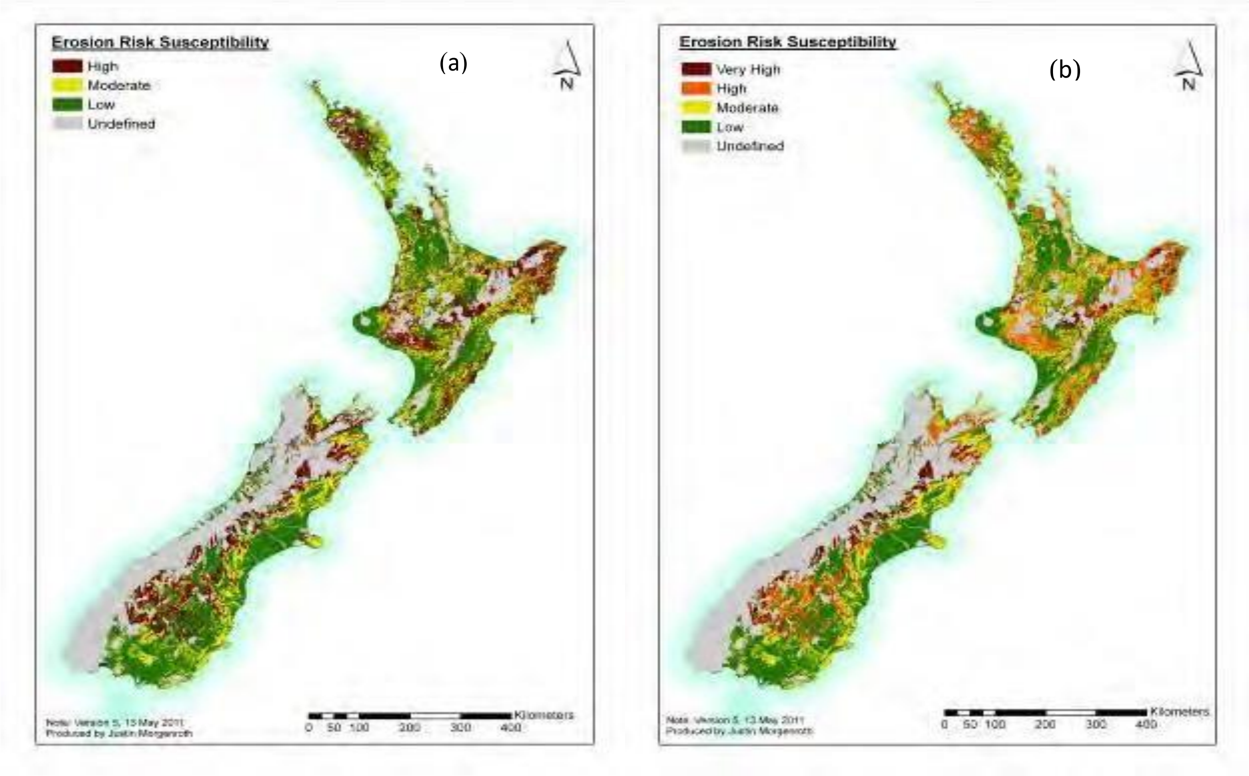



*Figure 1 Erosion susceptibility classification; (a) Three-class classification (b) Four-class-classification. Undefined areas include towns, quarries, and Department of Conservation Estate.*

The distribution of ESC classes by NZLRI regions is shown in Table 5, for the four-class ESC.

**Table 5 ESC classes by NZLRI regions. . Undefined areas include towns, quarries, and Department of Conservation Estate.**

| | Area('000 ha) | | | | | |
|---|---|---|---|---|---|---|
| **Region** | **Low** | **Moderate** | **High** | **Very High** | **Undefined** | **Total** |
| Auckland | 208 | 142 | 67 | 8 | 88 | 513 |
| Bay Of Plenty | 303 | 229 | 224 | 68 | 403 | 1228 |
| Canterbury | 1743 | 756 | 342 | 456 | 1236 | 4533 |
| Gisborne | 103 | 266 | 192 | 196 | 84 | 841 |
| Hawke's Bay | 504 | 341 | 154 | 151 | 301 | 1451 |
| Manawatu-Wanganui | 795 | 543 | 361 | 113 | 473 | 2285 |
| Marlborough | 114 | 191 | 162 | 91 | 495 | 1053 |
| Nelson | 3 | 10 | 18 | 3 | 8 | 43 |
| Northland | 450 | 266 | 318 | 50 | 190 | 1273 |
| Otago | 1307 | 565 | 471 | 193 | 663 | 3199 |
| Southland | 990 | 252 | 49 | 37 | 1705 | 3033 |
| Taranaki | 312 | 97 | 119 | 48 | 152 | 729 |
| Tasman | 109 | 87 | 114 | 27 | 642 | 979 |
| Waikato | 1077 | 547 | 307 | 53 | 465 | 2448 |
| Wellington | 306 | 194 | 88 | 57 | 169 | 816 |
| West Coast | 261 | 26 | 37 | 30 | 1982 | 2336 |
| **Total** | **8586** | **4513** | **3023** | **1581** | **9057** | **26,760** |

This classification shows the relatively high proportion of high and very high ESC classes in regions such as Northland, Gisborne and Marlborough, compared to regions with relatively high areas of low ESC, such as the Waikato and Bay of Plenty. Much of the Department of Conservation estate (undefined) would be classified as ESC class 4 under a four-class ESC classification.

## 2.4 B. EROSION RISK ANALYSIS FOR PLANTATION FORESTRY

### *B.1 Introduction*

In this section the ESC will be used to analyse the risks of erosion associated with plantation forestry activities in each of the classification zones (Request for Proposals RFP0049-01, MFE 2011).

Analysis is confined the following erosion forms in Lynn et al. (2009):

- Gully and tunnel gully erosion
- Mass movement forms i.e. soil slips, debris avalanche and debris flows, earthflows,
- slumps, and rock falls.
- Rill or sheet erosion on deeply disturbed soil or earthworks only.

Other fluvial or surface erosion forms are not included.

Erosion risk is defined as **Erosion susceptibility x frequency of triggering events** (erosion hazard in the JTC-1 terminology), an overall likelihood and severity of an erosion event.

The interaction of erosion susceptibility and frequency of triggering rainfalls can be visualised using the conceptual model advanced by Cepeda et al. (2010), as shown by Figure 2. Here the intensity-duration (I-D) threshold defines a combination of rainfall intensity (millimetres of rain per hour) and duration (hours) which will trigger landslides. The different threshold lines $Th_{susci}$ to $Th_{susc}N$ show the threshold positions for land units of increasing erosion susceptibility, and therefore decreasing threshold for rainfall intensity and duration before landsliding is initiated. Triggering rainfall events for diminishing values of saturated permeability from $_{Ep,j}$ to $E_{q,j}$ are shown by circles.

As the I-D threshold increases, the likelihood of that threshold being reached in a rainfall event decreases. Thus land with lower erosion susceptibility is less likely to be subject to a triggering rainfall, and the frequency of landslide events is lower.

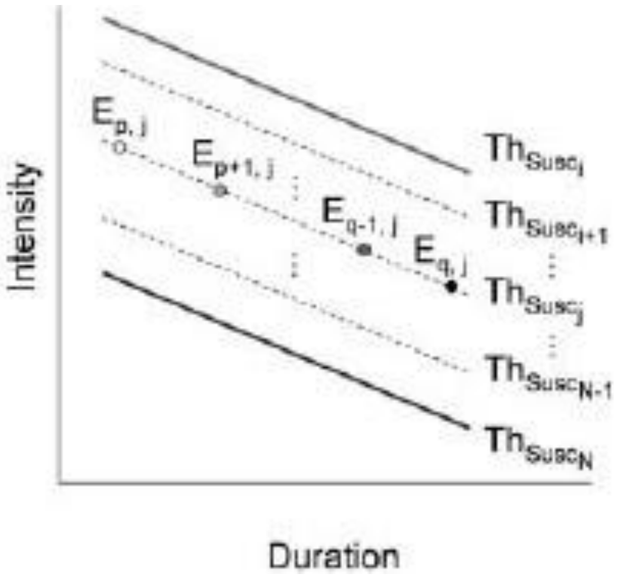



*Figure 2 Conceptual model for relationship between erosion susceptibility and rainfall intensity and duration required to trigger landslides. Source: Cepeda et al. (2010).*

### *B.2 Objectives*

The RFP (MfE, 2011) describes the risk analysis phase of the project as entailing a "qualitative (and relative) assessment of the erosion and sedimentation risks of plantation forestry activities (afforestation, harvesting, earthworks, mechanical land preparation, and quarrying) in each of the classification zones adopted."

We intend to broaden the analysis to include a written description of erosion risks, assessment of their likely frequency and severity, and recommendations for processes for assessment and management of risks.

Note that this risk analysis is not site-specific. The ESC developed in previous Sections is a "regional" (1:50,000) scale depiction of erosion susceptibility. The risk analysis for the ESC classes will explore differences in the nature of erosion risk between regions, and how these differences can be accommodated within a national environmental standard (NES) for plantation forestry.

The analysis of erosion risks for plantation forests will focus on:

1. Identifying and describing the underlying ("predisposing") factors that influence erosion susceptibility.
2. Plantation forest operations as preparatory or mitigating factors which interact with predisposing factors to determine erosion susceptibility—in particular, how forest operations can be managed so that they do not increase susceptibility of land to erosion. We believe that a national ESC and NES for forestry will only work if it is backed up by clear standards for design and execution of any forest operations which have the potential to increase erosion susceptibility.
3. Estimation of the frequency of intense, triggering rainfall events on a regional basis within New Zealand.
4. Using the frequency data for triggering events and the ESC to characterise:

   a) Differences in the nature of erosion risk between the ESC classes, and how these differences can be accommodated within a national environmental standard (NES) for plantation forestry.

b) The extent to which plantation forest operations are constrained by erosion risk within each ESC class, on a regional basis.

### B.3 Identifying and evaluating predisposing factors

**Predisposition** to erode is an intrinsic quality of a land unit determined by soil type/lithology and topographic characteristics (slope, aspect, drainage pattern, slope position or landform element).

In this study, predisposition to erode is specified by the potential erosion severity values assigned to LUC units in the NZ Land Resource Inventory (NZLRI) database. While there is no specific decision-tree or algorithm for assessing potential erosion severity, criteria listed in Lynn et al. (2009) include present erosion severity and evidence of past erosion features. Also mentioned are the dominant land use (strictly a preparatory factor rather than one related to predisposition of a unit) and "magnitude and frequency of erosion causing events" (not strictly a component of erosion susceptibility).

Present erosion severity is assessed using the guidelines in Table 8, Lynn et al. (2009), which relate to the area and depth of the erosion features, and additional criteria:

- Volume of erosion debris displaced
- Nature of the parent rock and regolith
- Failure planes, crushing, rock strength
  - Soil properties such as aggregation, slaking, fertility, porosity and drainage
  - Slope and slope length where the feature is located
- Sidewall slope of gully or other incised features, and fluvial characteristics of channels Likelihood of reactivation (e.g. by slope undercutting or triggering rainfall events)
- Ease of repair or stabilisation
- Position on hillslope and connectivity with stream channels (strictly related to downslope consequences rather than erosion susceptibility).

In summary, while the potential erosion severity values for LUC units in the NZLRI are an expert assessment of the likelihood and nature of erosion for a specific unit, they do confound factors related to erosion susceptibility (rock, regolith, slope and channel characteristics; and preparatory features such as undercutting and dominant vegetation) with other elements of erosion risk and risk management such as likely frequency of triggering events or ease of stabilisation. Pragmatically, we have chosen the LUC classification because it uses comprehensive field assessments of actual and potential erosion over the whole of New Zealand compiled by experts. In principle, this approach is preferable because 1) it is based on observed erosion rather than on modelled/simulated/computed erosion; and 2) it requires little if any field verification, in contrast to any modelled classification which would require comprehensive field verification.

A land unit with a specific predisposition to erode may be placed at greater or lesser susceptibility to erosion by **preparatory** or **mitigating factors** respectively. Preparatory and mitigating factors are discussed in the following section.

### B.4 Forest operations as preparatory or mitigating factors for soil erosion

#### B.4.1 Forest operations as mitigating factors

The role of forests in mitigating erosion and consequent sediment yield in New Zealand has been thoroughly reviewed in a contract report to the MfE by Blaschke et al. (2008). Because the report by Blaschke et al. is recent, exhaustive and has been published by MfE, we see no point in describing it in detail. Instead, we will summarise the key findings only (Section B4.1.1).

### *B.4.1.1 Summary of findings from Blaschke et al. (2008)*

The effect of vegetation cover on soil erosion and sediment yield, and in particular the contrast between pasture, plantation forest and indigenous scrub and forest, has been intensively researched in New Zealand over the last 60 years. Blaschke et al. (2008) reviewed a large number of published and unpublished studies, and augmented this review with personal communications from research scientists where necessary. Research relevant to the present study is reviewed in Chapters 3 (Physical effects of afforestation and reversion on sediment yield) and 4 (Physical effects of afforestation and reversion effects on erosion). Key findings are quoted directly:

- "Small-catchment research studies provide conclusive evidence that afforesting or reverting close to 100% of small catchments, reduces averaged annual sediment yields by at least 50% and in most instances by greater than 80%.
- Long-term sediment yield computations are available for many medium to large catchments nationwide. These indicate that high sediment yields are associated with unstable geological terrain or/and high rainfall zones. In these medium to large catchments, relative reductions of 50% or more in sediment yield, only translate to substantial reductions in absolute yield (tonnes per square kilometre per year), if afforestation and reversion are targeted onto the parts of catchments that have high sediment yields in the first place.
- Substantial reductions cannot be expected immediately. The only published large-catchment investigation of afforestation effects on sediment yield (Waipaoa), shows a time-lag of several decades for reduction to work its way from headwaters to mouth. This is due to a large volume of sediment, already in channel storage, gradually being transported downstream.
- Storm damage surveys, state of environment surveys, and soil conservation effectiveness surveys, provide enough data for us to conclude that large areas of soil can be protected from erosion by:
  - spaced planting of trees in pasture
  - close-canopy afforestation
  - scrub reversion
  - bush retention

  in the following circumstances:
  - where land is erodible
  - where sufficient trees are planted (on most or all of the unstable area) and tree or scrub cover is maintained."

Although not stated in their overall summary of findings, Blaschke et al. (2008, p31) also add the important caveat that while there is "a widespread perception that less erosion occurs in forested or scrubby terrain, than on land in pasture….bush and scrub do not provide total protection, especially in higher-intensity storms (a fact often overlooked by advocates of afforestation / reversion options." However, Blaschke et al. (2008) do not closely review the time-dependency of:

1. Erosion mitigation effects of forestry (canopy rainfall interception, litterfall, root reinforcement) which generally, but not always, increase with stand development over time.
2. The preparatory factors (earthworks, vegetation disturbance, deep soil disturbance) which are also time-dependent, typically occurring at the beginning and end of the rotation—even if the triggering event which initiates erosion occurs several years later.

The time dependency of these effects of forestry on erosion will be examined in subsequent sections (Sections B4.1.2, B4.2).

### *B.4.1.2 Time dependency of mitigating effects*

The mitigating effect of forest cover on soil erosion is due to 1) the soil reinforcing effect of the forest's root network, 2) generally lower soil water balances due to interception and evaporation of rainfall by the rough forest canopy and 3) soil building effects (litterfall, nutrient cycling, aggregate stability) of a permanent or semi-permanent forest canopy which is not disrupted by cultivation, fire or grazing.

There has been extensive research work focussed on soil reinforcement and canopy effects on evapotranspiration, both here and overseas (for a recent review, see Stokes et al., 2008). Marden (2004) reviewed studies of forest effectiveness in reducing erosion in New Zealand, and reported reductions in landslide damage consistent with those in Blaschke et al. (2008). However, Marden (2004) noted that reductions in landslide damage scaled with site occupancy by the forest— they were least during forest establishment (stand age <6 years for radiata pine) and increased with stand age due to increasing forest biomass and canopy cover. For example, after Cyclone Bola (1988) landslide susceptibility in exotic plantations >8 years old and in intact indigenous forest cover was 16 times less than for both pasture and young (< 6 years) exotic plantations.

Watson et al. (1999) published a useful paper which examined how root reinforcement by kanuka and radiata pine stands varied with stand age and stand development. An important finding was that the higher stand densities of regenerating kanuka (~104 stems/ha) resulted in more rapid development of a stabilising root network compared with radiata pine (typically planted at 833-1250 stems/ha). This was illustrated in a conceptual diagram as follows:

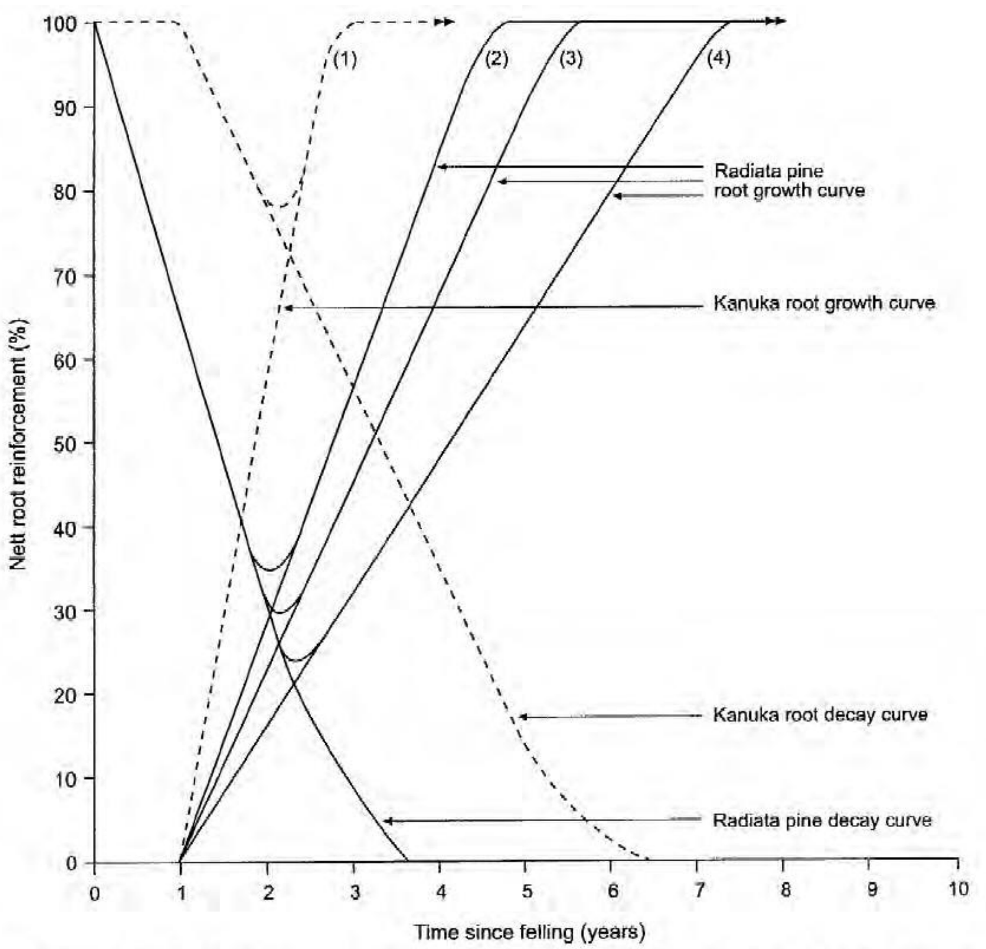



*Figure 4.* Comparative model of relative root reinforcement changes after clear felling (at year 0) and planting (at year 1) of kanuka and radiata pine. Growth curve (1) represents an initial natural kanuka establishment density of 16 000 stems $ha^{-1}$. Growth curves (2), (3) and (4) represent initial radiata pine planting densities of 1250 stem $ha^{-1}$ (a recommended slope stabilisation regime), 800 stems $ha^{-1}$ (a commercial forestry regime), and 400 stems $ha^{-1}$ (an agro-forestry regime), respectively.

*Figure 3Root reinforcement after clearfelling, radiata pine and kanuka. Source: Watson et al. (1999).*

A key feature of this figure is that the interaction of 1) the decay curve for radiata pine net root reinforcement after harvesting with 2) the root growth curve for the young replanted radiata pine stand, results in a period of reduced root reinforcement of between 4.7-7.5 years post-harvest, depending on the initial spacing of the replanted tree crop.

In Watson et al. (1999), extreme flood events were used as a surrogate for landslide-triggering extreme rainfall events. A storm frequency analysis for the Waipaoa catchment (Gisborne Region) suggested there was an 80% probability of an extreme flood event during the 4.7 year “window” when a stand replanted immediately in radiata pine at 1250 stems/ha had less than 100% net root reinforcement.

The probability of a flood event occurring during the 5.6 year “window” for a stand replanted at 800 stems/ha was 85%. The likelihood of landslide-triggering events during the “window” of reduced net root reinforcement is discussed in more detail in Section B4.2 of this study.

### *B.4.2 Forest operations as preparatory factors*

The effect of forest operations and in particular tree harvesting and associated earthworks has been extensively researched in New Zealand and overseas. This section will be based on Sidle and Ochiai’s (2006, pp 163-203) useful review of forest harvesting and earthworks effects on occurrence of mass- movement erosion. Where relevant, results from research in New Zealand plantation forests will also be cited.

#### *B.4.2.1 Harvesting*

*Loss of forest canopy and root systems*

The most obvious effect of harvesting is the felling and removal of trees, with loss of canopy effects on soil water balance and root-reinforcing effects in soils as dead tree roots decay. This process was discussed fully in Section B4.1.2 of this report. Sidle and Ochiai (2006) comment that root reinforcement effects are considered more important than canopy interception effects, and discuss mitigation of harvesting effects through:

- Re-establishment and maintenance of full canopy cover
- Alternative harvesting methods to large-scale clearfelling, such as partial harvesting, shelterwood harvests or individual tree selection. These alternative harvesting strategies are used in North America and Europe for sites with high erosion susceptibility and/or high risks associated with downslope consequences of erosion.

While the importance of rapid canopy-re-establishment is recognised in New Zealand plantation forestry, companies are reluctant to limit size of clearfelling coupes for economic and operational reasons. Nonetheless, research cited in Sidle and Ochiai (2006) and elsewhere suggests that limiting coupe sizes and or partial harvesting are highly effective ways to reduce erosion susceptibility of forest lands. Such limitations could also include exclusion of riparian areas from planting and harvesting of commercial plantation species.

*Deep soil disturbance including exposure of soil to erosion forces during harvesting (soil ploughing).*

The deep soil disturbance effects of harvesting and roading are reviewed in detail in Section A3.1. The results of New Zealand studies by Marden and co-workers are summarised below:

- Undisturbed ground and shallow disturbance (usually 80-90% of total ground cover) had very low slopewash rates.
- Deep disturbance areas comprised 9-15% of study areas, and contributed ~85% of total slopewash from all disturbed sites.
- Sediment contributed to streams from deep disturbance sites was small in relation to sediment contributed from landslides and gullies. Possible exceptions are where soil ploughed by deep disturbance is deposited in a channel and becomes entrained by streamflow during rainfall events; and where skidders or tractors are used on hillslopes and temporary contour tracks are sidecut. Effects of contour tracks are discussed below, in Section B4.2.2 (Earthworks).

*Effects of management of slash from harvesting operations*

Harvesting of trees leaves considerable quantities of small tree debris (“slash”) on the site. The optimal management of slash from an erosion mitigation perspective is a matter of debate; the debris lying on the ground has the potential to reduce the velocity of overland flow and hence to reduce surface and gully erosion, but significant accumulations of it can block small streams causing outbursts that can initiate gully erosion. Dumping slash in natural drainage channels forms traps for sediment resulting from harvest operations, reducing sediment delivery off-site; but again, larger slash can form small-scale log-jams that can sooner or later fail, releasing large quantities of stored debris and sediment downstream. At a larger scale, collapsing natural log-jams have been implicated in one of New Zealand’s worst debris-flow disasters, at Peel Forest in 1975.

In general the risk of accentuating sediment movement by retaining slash on the site is significantly lower than that of removing it (see Sidle and Ochiai (2006, pp174-176). The known situations where accentuated sediment movement has been generated by organic debris are at larger scale than is likely to result from harvesting operations, involving substantial jams of logs from mature trees. At the scale of slash any such effect is likely to be insignificant.

### *B.4.2.2 Earthworks*

In this section, earthworks include temporary and permanent roads, landings, and quarries and contour skid trails. Earthworks act as preparatory factors for erosion by:

- Altering natural drainage patterns, concentrating water onto unstable portions of the hillslope.
- Sidecutting of steep slopes leading to
  - Undercutting of unstable slopes
  - Side-casting of fill, thereby overloading and oversteepening fillslopes.
- Creation of areas where the soil is exposed or deeply disturbed.

Fillslopes may fail as slumps, debris flows or debris avalanches; dormant earthflows and deep-seated slides can be re-activated by side-cutting roads through toeslopes; and road fill material placed at the head of dormant slumps can re-activate slump erosion. Exposed road surfaces may be more susceptible to surface or fluvial erosion (Fransen et al., 2001), as well as dry ravel or debris avalanche (Sidle and Ochiai, 2006).

With careful design and drainage, erosion susceptibility of roads and earthworks can be minimised. However any earthworks involving cuts and fills necessarily decrease site stability. A general rule is that unimproved (forest) roads increase landslide erosion by approximately two orders of magnitude compared with undisturbed forests, and one order of magnitude compared with clearfell harvested catchments where earthworks are absent (Sidle and Ochiai, 2006).

Fransen et al. (2001) reviewed 12 New Zealand studies of erosion from forest roads on granite, schist and pumice lithologies. This review is discussed in detail in Section A3.1. Key results were:

- Surface erosion from roads at harvest times may increase sediment yield five-fold compared with that from pre-harvest ungraded and lightly used roads.
- Surface sediment yields from roads were generally several orders of magnitude lower than estimated sediment yields from mass movements, but surface erosion from harvest (skidder) tracks may generate much higher proportions of sediment yield.
- Infrequent road-related mass movements are major sources of sediment within forests. Mass-movement erosion rates decline with road age, but may increase to earlier levels when roads are upgraded for harvesting activities, or when subject to intense storm
- events. J.Devonport, (pers. comm. 26 April 2011) notes that forest roads on erosion-susceptible terrain in Hawke’s Bay may be an erosion hazard for up to 10 years after construction.

### *B.4.2.3 Other operations*

Other forest operations which may act as preparatory factors for erosion include vegetation management (removal of competing weeds prior to planting a forest crop), effects of initial stocking and thinning, and construction of firebreaks or fencelines. There is no published literature on the effect of these practices on soil erosion, possibly because their effects are minor compared to those arising from clearfelling and earthworks.

Vegetation management and initial stocking and thinning have effects on vegetation canopy and the live root network, and allowing for scale, have similar effects on erosion susceptibility. On land with very high erosion susceptibility, it may be desirable to manage forest canopies to maintain the mitigating effects of an intact forest. For example, plantations planted under the Government's East Coast Forestry Project grant scheme must:

*"have regular initial planting stocking densities. A grant area planted in radiata pine and Douglas fir is to be planted at a minimum stocking rate of 1250 stems per hectare"*

and must be thinned " within the following parameters:

- the mean tree height must be five metres before thinning can occur
- when the mean tree height is between five and 12 metres, the stocking rate must be at least 500 stems per hectare
- when the mean tree height is 15 metres or more, the stocking rate is to be between 250 and 500 stems per hectare." (MAF, 2007).

Effects of firebreaks or bulldozed fencelines depend on their location and width. If located on ridges, erosion effects are usually limited to surface erosion of the firebreak surface. Because firebreaks are kept permanently free of vegetation, surface erosion will continue, although declining in magnitude as erodible material is removed and a resistant surface remains ("hardening").

Where firebreaks or fencelines are bulldozed across a hillslope contour, their effects are similar to temporary tracks since they are typically not constructed to an engineering standard nor do they have any drainage apart from that afforded by techniques such as outsloping or waterbars ("cut-offs").

## *B.5 Frequency of erosion events*

### *B.5.1 Rainfall intensity/duration and landslides*

In general, erosion risk (hazard) is higher under more intense rain. However, the occurrence of long- duration, low-intensity rain can be important in preconditioning a slope for failure under later intense rain by increasing the antecedent moisture content. Recent research has suggested that long-duration, low-intensity rainfall can in fact cause slope failures under combinations of intensity and duration significantly below accepted thresholds (e.g Brunetti et al., 2010), but appears to affect low-permeability more than high-permeability soils such as found in New Zealand (Rahardjo et al., 2008); however there appears to be a need for more research into this topic (Guzetti et al., 2007). Thus while at present it appears worthwhile to include both antecedent rainfall and a measure of likely rainfall intensity in developing methods for assessing landslide susceptibility, there is continuing discussion on the role of long-duration rainfall events in the literature.

### *B.5.2 Estimating frequency of erosion events*

Mass movement erosion and gully erosion are generally triggered by intense rainfall, although wet antecedent conditions can act as a preparatory factor. The rainfall intensity and duration required to cause a soil pore water pressure sufficient to cause failure of a given slope depends on a large number of factors reviewed in Section A1; slope material and stratigraphy, slope angle(s) and planform topography, vegetation/land use, aspect, and bedrock lithology. Geotechnical modelling techniques are in principle able to predict the conditions under which a given slope will fail, but require data that are usually not available. For regional studies the critical rainfall intensity-duration combinations might be determined empirically, that is, by comparing databases of slope failures with the associated statistics of local intense rainfall (e.g. Cepeda et al., 2010), or experience in similar terrain. However without knowledge of pore water pressure, the dominating factor in slope stability, such studies may have limited reliability.

In New Zealand, some data are available on slope failure occurrences as a function of 1) catchment mean annual rainfall (e.g. Hicks, 1995), and 2) daily rainfall and antecedent rainfall (Glade, 1998; Glade et al., 2000). Intense rainfall statistics are also available (Thompson, 2011). However the required correlation between rainfall intensity and landslide hazard has not yet been analysed on a New Zealand- wide basis. We would have liked to embark on this as part of the current project, but in the timeframe available are unlikely to complete the task. Sufficient reliability for practical application would also be an issue. Thus we propose to utilise the analysis of Hicks (1995) to estimate the frequency of rainfall-triggered landslides, as it based on data covering a range of landforms in both the North and South Islands.

### *B.5.2.1 Calculation of frequency*

Hicks (1995) used landslide records for 12 major catchments in New Zealand, to estimate a relationship between the average return interval (ARI, in years ) of landslide events to mean annual rainfall (MAR, in mm). The data covered time intervals between 20 to >100 years and catchments with 500-2500 mm MAR (except for one catchment with MAR=3505 mm).

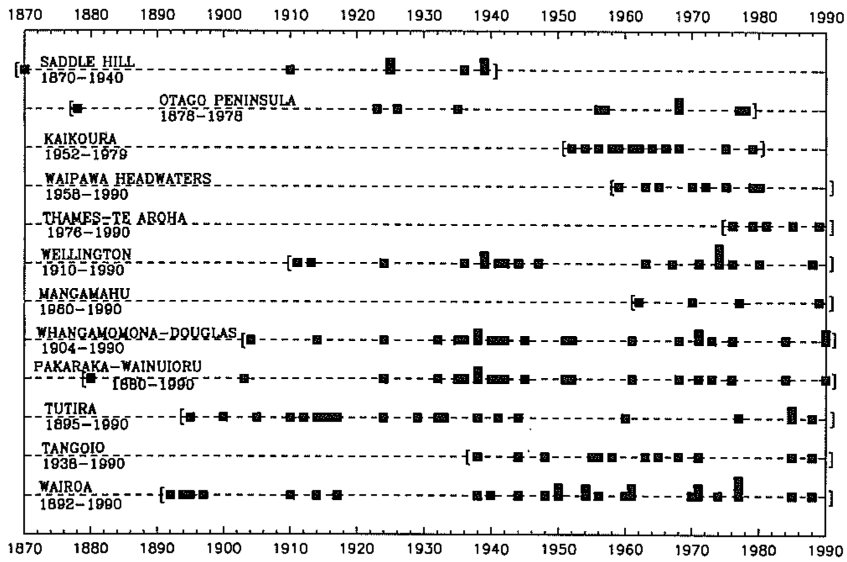



*Figure 4. Diagram showing location and timing of landslide frequency data used by Hicks (1995).*

Hicks fitted a power relationship to the data, of the form

$ARI=3009 \times MAR^{-0.894}$ (Equation 1)

as shown in Figure 5. This relationship gave a reasonable fit to a limited data set (n=12).

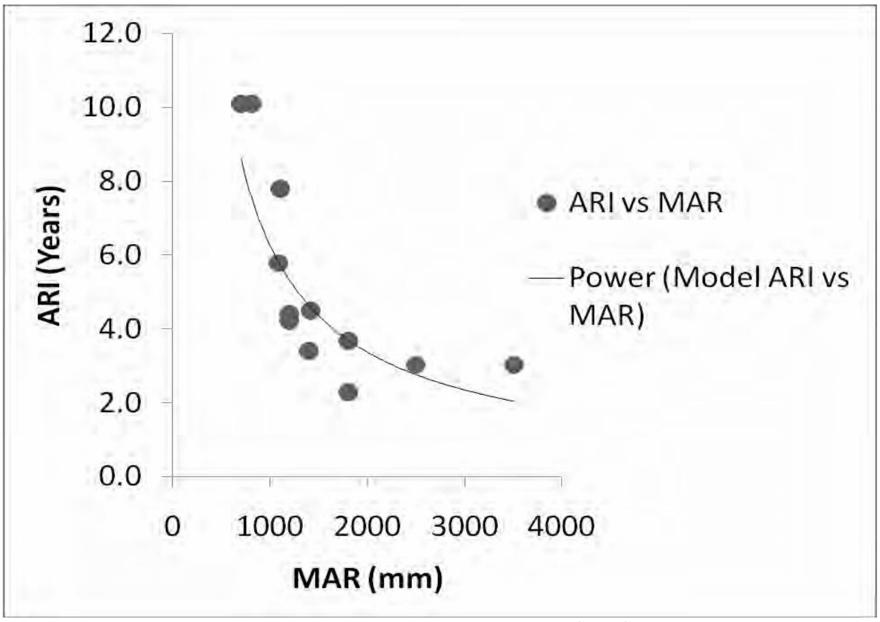



*Figure 5 Average return interval (ARI) vs mean annual rainfall (from Hicks, 1995. Data obtained by scale measurement from Figure 2).*

This relationship can be transformed so that
AEP=1−exp(−1/ARI)            (Equation 2)

where AEP= Annual Exceedance Probability, the probability that a landslide event will occur in any single year. Figure 6 shows the plot of AEP vs MAR for Hicks' data. A power function fitted to the data takes the form

AEP=0.0006 x MAR0.7974.  (Equation 3)

One advantage of transforming the relationship is that it is easier to see outliers. For Hicks' data set, one clear outlier is the data point where MAR>2500 mm; the other possible outlier is the data point for Kaikoura, which has a very high AEP (~0.35) for a relatively low MAR (~1800 mm). Hicks does caution that the ARI-MAR relationship does not apply to mountain landscapes. In the case of Kaikoura, the high probability of landslide events may be due to the rapid transition in terrain from sea level to the Seaward Kaikoura Range.

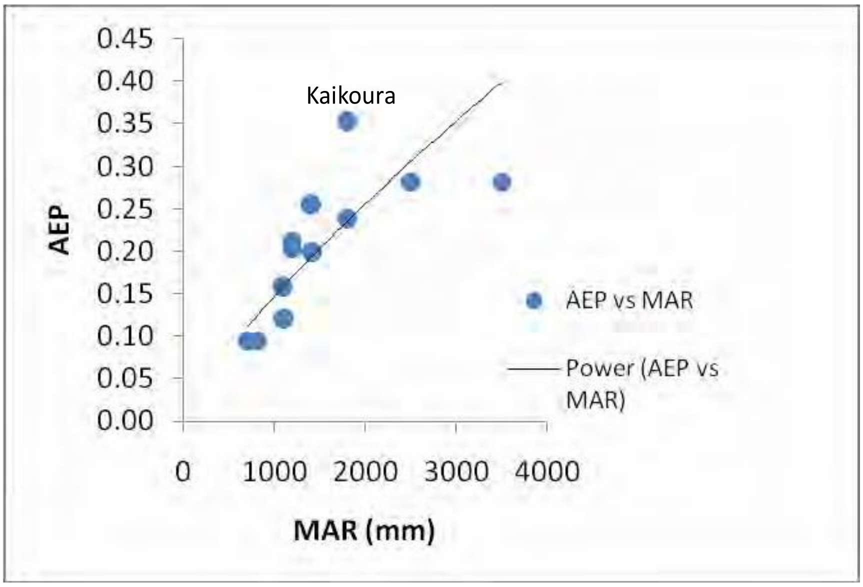


*Figure 6. Annual exceedance probability (AEP) vs mean annual rainfall (from Hicks, 1995).*

*Validation*

Hicks used data from 12 locations, 3 in the South Island. The data were limited in number, and biased towards the East Coast of the North Island and soft-rock lithologies. This precluded a formal testing of the model. However, Hicks did test the model against data for 11 catchments in the Gisborne-East Coast region, with MAR values ranging from 1231 to 2673 mm, and found good agreement between the model and observed values.

Hicks' model can also be compared with the results for the Waipaoa catchment in Watson et al. (1999), where the observed AEP (~0.25) was somewhat higher than that predicted by Hicks for Waipaoa using the MAR of 1305 mm at Mangatu Forest headquarters (0.18).

*Classification*

Hicks (1995) noted that ARI values for landslide events were scale-dependent. The larger the area relevant to each ARI data point, the higher the likelihood that there would be a landslide event somewhere within the area. He also noted that the fitted model was not likely to hold for mountainous regions where MAR>2500mm. He therefore specified that the ARI (and therefore AEP) values calculated by his model are specific to catchments of size 10-1000 km2, with MAR from 500-2500 mm.

However, if we assume that frequencies (ARI or AEP) scale with catchment area, it is possible to depict relative ARI and AEP values for all New Zealand where MAR =500-2500mm, using grid (raster) values for MAR (1950-1980) in a geospatial layer provided by NIWA (Figure 7).

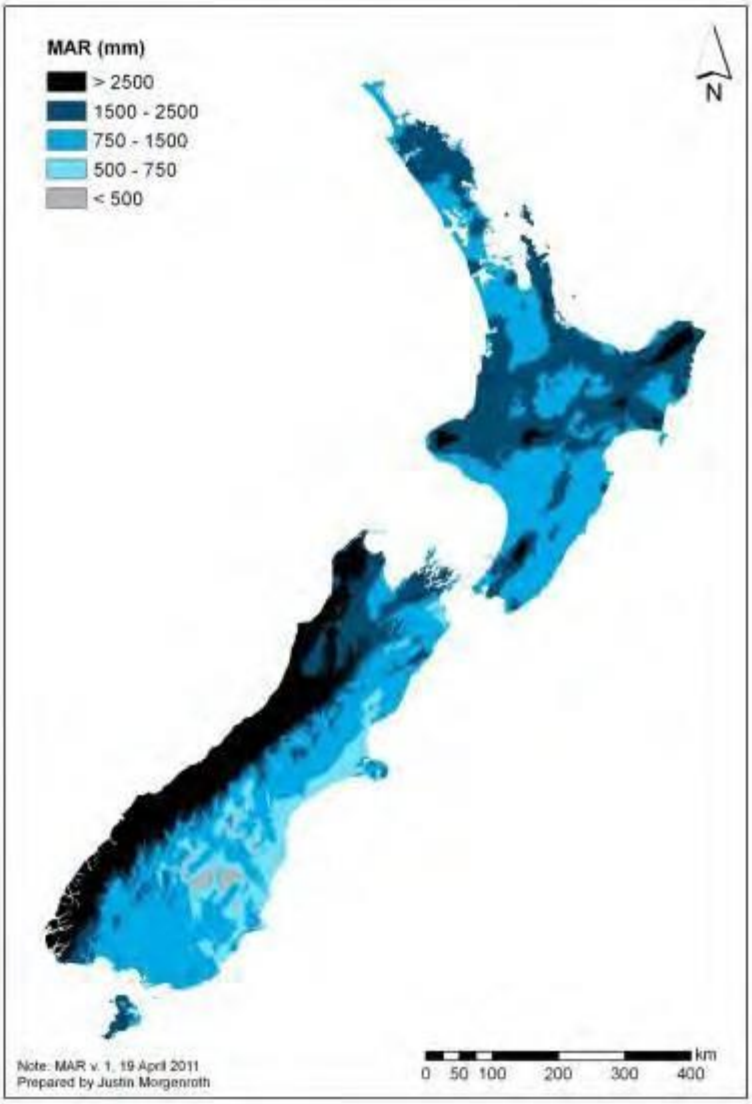



*Figure 7. Five-class classification of MAR.*

Inspection of Figure 7 suggests that a five-class classification of AEP could be based on the classification of MAR, using the intervals in Figure 7:

**Table 6. Proposed classification of AEP based on MAR**

| Class | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| MAR (mm) | <500 | 500-750 | 750-1500 | 1500-2500 | >2500 |
| ARI (years) | >11.6 | 8.1-11.6 | 4.4-8.1 | 2.7-4.4 | <2.7 |
| AEP | <0.08 | 0.08-0.12 | 0.12-0.21 | 0.21-0.30 | >0.30 |

Although the AEP values for Class 1(MAR <500mm) and Class 5 (>2500mm) cannot be inferred from Hicks' model, a reasonable assumption is that for Class 1 they are somewhat less than Class 2; and for Class 5 they are somewhat greater than Class 4.

### *B.5.3 Climate change*

The potential for significant future alteration to the climate of New Zealand is now well-appreciated. The effects that such changes may have on erosion susceptibility can be stated in general terms; for example, an increase in the frequency of intense rain may increase the probability of failure of a given a slope occurring in any given year, though this may be offset to some extent by a decrease in mean annual rainfall. However, such factors are difficult to incorporate in a current assessment of erosion susceptibility. Where the data on which the NZLRI is based are decades old, and a distinct (and long-term) change in climate has occurred, this could be borne in mind in translating the NZLRI land classifications to erosion susceptibility; however such situations are rare if not non-existent. Further, the failure of a given slope is very much a statistical event; no-one can say whether the increased high-intensity rainfall frequency will be manifest as actual storms within the next decade or not, nor whether the storms, when they occur, will cause a specific slope to fail.

Thus incorporating climate change into an ESC is difficult; in particular, for a system intended to be implemented immediately. In general, the changes in erosion susceptibility due to climate change almost certainly lie within the (quite broad) band of variability of erosion assessments, so are likely to be insignificant in the short term.

## *B.6 Assessment and management of erosion risks*

### *B.6.1 Identifying erosion risks from the ESC*

#### *B.6.1.1 Erosion hazard*

Erosion hazard is determined by erosion susceptibility of a site, and the likelihood or frequency of an erosion triggering event. Using the Hicks (1995) model, the annual exceedance probability (AEP) of a landslide triggering event is correlated with MAR (mm). An indication of erosion hazard at 1:50,000 scale can be obtained by plotting the range of MAR classes in Table 5 by the ESC. The results of this are depicted in Appendix 2, where the range of MAR classes is shown for each individual ESC class (using a four-class ESC classification).

There is an expected correlation between ESC and MAR because in New Zealand rainfall varies orographically. In general, it is steeplands that have highest MAR and because of their topography are also most susceptible to erosion. This correlation is apparent in the figures in Appendix 2, and can be explored further by plotting MAR as a function of ESC for all LUC polygons in New Zealand (Figure 8). Figure 8 depicts only a moderate correlation between ESC and AEP, and each ESC class spans at least three or more AEP classes. This suggests that:

- The erosion susceptibility of an LUC unit, as determined by slope, lithology, soils etc., exerts an effect on erosion risk that is partly independent of frequency of landslide triggering rainfalls.
- Erosion risk will require an assessment of both ESC for an LUC unit, and frequency of triggering rainfall events. Areas depicted in dark blue or black in Figure 7, where MAR>1500mm and AEP>0.21, are likely to have a greater erosion risk for a given ESC class, than the balance of New Zealand hill country where MAR is 750-1500mm.

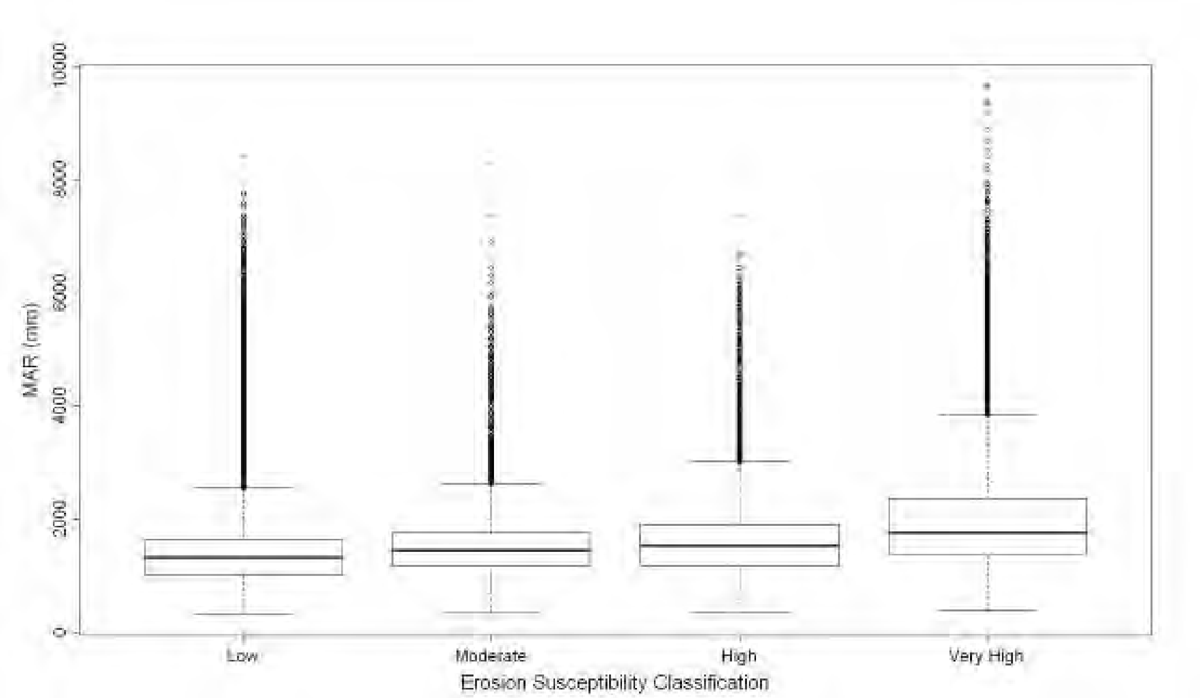



*Figure 8. MAR vs ESC for all New Zealand. Black line is the median, the box includes 25th-75th percentiles, and whiskers show "upper" and "lower" limits of data. Note that "outliers" are plotted as individual points. These occur mainly in mountainous areas and on the West Coast of the South Island.*

### *B.6.1.2 Effects of scale*

The ESC and analysis of risk in this report use spatial data at a 1:50,000 scale. Therefore the ESC derived from the NZLRI is necessarily coarse, and in some cases polygons assigned a specific ESC are likely to include a complex of sites with different erosion susceptibilities. The intention is that the ESC acts as a decision rule for the activity status of forestry operations under the Resource Management Act (RMA). The next stage involves the planning and execution of forestry operations, with an appropriate level of regulation under the RMA. At this stage more detailed consideration of local conditions of the likely effects of topography, soils, drainage and intense rainfall statistics becomes both possible and necessary to refine the larger-scale ESC classification and make operational decisions that manage risk to acceptable levels. This topic is covered in the following sections.

## 2.5 C. PROTOCOL FOR ANALYSIS AND MANAGEMENT OF EROSION RISKS AT AN OPERATIONAL SCALE

### *C.1 Introduction*

The topics covered in this section are outside the brief for the development of a national ESC (MfE, 2011). However, we believe it is important to consider the implications of an ESC within the proposed NES for plantation forestry. In particular

- The ESC is based on mapping at 1:50,000 scale. This must be supported by detailed assessment of erosion hazards and risks at a scale suitable for identifying the specific risks at a site or operational level.
- The ESC must be supported by specific standards for forestry operations that are appropriate for the level of erosion risk on a site. We suggest a set of best management practices (BMP's) which could be used for this purpose. <u>However, we emphasise that these are suggestions for discussion purposes only, not recommendations</u>.

### *C.2 Analysis of erosion susceptibility and risk*

A typical map scale for forest operations planning and management varies between 1:5000 and 1:10,000, and most forest companies have contour maps of their forest estate at this scale, with contour intervals usually between 5-20m. This scale coincides with that suitable for detailed assessment of landslide hazards and downslope consequences, usually considered to be between 1:10,000 (Saunders and Glassey, 2007) and 1:5000 (Cascini, 2008). We recommend that this range of scales be adopted for planning, consent and operational management of erosion hazards on plantation forests.

In this section we will propose how risk analysis at an operational (~1:10,000) scale might vary for the three or four different ESC Classes, and for varying levels of AEP for triggering rainfall events.

The higher the ESC class and the higher the AEP of erosion-triggering events, the greater the likelihood of significant erosion caused by harvesting, and so the more detailed and rigorous is the required risk analysis. A possible decision matrix integrating the ESC with likelihood of triggering rainfall events is shown in Table 7. Note that this decision matrix is for discussion purposes only. The actual allocation of risk analysis classes to specific cells in the matrix needs careful study, and the detail of the required risk analysis will depend on the individual situation under consideration; i.e.

- The specific types of erosion process able to occur,
- Their specific causes,
- The likely size or magnitude of erosion event,
- The proposed forestry operations and the practicable mitigation possibilities.
- The downslope consequences or receiving environment for any erosion debris originating from a specific site.

Insofar as sites on the borderline between ESC classes might well require consent conditions more severe than indicated by their ESC, it is not possible to specify in detail the risk analysis procedures for each class and frequency. Ideally, a complete protocol would be developed, based on Figure 9 (source:Figure A3.2, Saunders and Glassey (2007)). This could be applied in the first instance to all sites (except possibly those in the NA category), but particular aspects of the risk analysis could be bypassed when they are shown to be unnecessary for a particular site.

*Table 7 Decision Matrix using ESC and AEP*

| ESC | Annual Exceedance Probability (AEP) | | | | |
|---|---|---|---|---|---|
| | <0.08 | 0.08-0.12 | 0.12-0.21 | 0.21-0.30 | >0.30 |
| 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.

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

### *C.3 Management of forest operations to reduce preparatory effects on erosion susceptibility and risk*

In this section we propose a framework under the NES to mitigate the "preparatory" effects of harvesting and earthworks on erosion susceptibility. We will cover planning and design, operational management, regulation, and the role of best management practices (BMP's). We make the following preliminary comments:

- Infrastructure and harvesting effects are difficult to avoid or eliminate and most often are minimised.
- Internationally, the most common concept for managing the adverse effects of infrastructure and harvesting is the application of best management practices (BMP's).
- BMP's are considered a desirable standard of management, whereby the regulatory authority will accept unintended consequences (e.g. major erosion events) as a failure of the BMPs, not of the harvest operation.
- We recognise that there are few hard and fast rules for either infrastructure or harvesting that achieve an overall best outcome. Hence
  - BMP's are effects based, that means BMP measures can vary according to both risk and potential effects.
  - There must be an agreed resource consent process for departure from BMP's where necessary to achieve environmental standards. The consent applicant can make a technical case for design or operational standards that are lower than those in the BMP's.
- BMP's are 'live documents' with an agreed process for review and updating. As new information comes to hand standards may be changed e.g. removal (or not) of woody debris in streams.

We recommend that an NES for plantation forestry should be supported by a national set of Forestry BMP's. They should include planning, operations and monitoring/auditing components and be written in such a way that the information is readily transferable to the in-field practitioners (especially the machine operators). Documents such as the NZFOA Best Environmental Practices Guide (2008) and LIRO Forest Code of Practice (1993) could form the basis for the BMP's, but a more focussed content on technical requirements would simplify their use and implementation. Documents such as the Low Volume Roads Engineering: BMP Field Guide (Kellar and Sherar, 2003) provide a well-illustrated example of where to use and how to install BMPs. The 'Water Quality BMP's" for Montana Forests (MSU

Extension, 2001) is also a very professional document that starts at catchment scale concepts and then photographically illustrates the importance of BMP's at the operational level. It is a document often referenced for its compactness and clarity.
Note: the NZ Forest Code of Practice was written by LIRO but with major contributions from both Regional Councils and Forest Companies. In the mid-1990's it was widely considered a national document because of the absence (or in many cases the lack of development) of regional specific guidelines. The document includes systems to develop 'values' and the possible impacts on those values. It also provides a 'simple' operational section that was frequently used by many Councils as the conditions of resource consent.

For an NES it would be prudent to develop Technical Guidelines (either as appendices to Forestry BMP Guidelines or as a Field Guide). It would list specific metrics / dimensions associated with BMP practices. The Technical Guidleines will take time to develop, but a possible starting document could be:

- The Australasian Unsealed Roads Manual (ARRB, 2009) – which is used extensively by the NZ Roading Authorities.
- The new edition of the LIRO NZ Forest Road Manual (in final phase of review - due to be released soon by NZFOA). It too focuses more on the technical aspects of infrastructure construction.
- Environment BOP (2000) "Erosion and Sediment Control Guidelines for Forestry".
- Environment Waikato (2009) "Operations Earthworks - Erosion and Sediment Control Guidelines."

Note that all the above documents are relatively large as they cover all aspects from planning through to monitoring. By focussing just on the required technical aspects of BMPs it should be possible to create a focussed and condensed document.

### *C.4 Relating BMP's to the ESC*

The NES will denote risk level by erosion susceptibility class (ESC). ESC is primarily dictated by slope, soils and lithology. This is not unreasonable as slope in particular is a major driver of risk for both infrastructure and harvesting as it relates to erosion. Here are some possible BMP's and general standards that could apply in a three-class (low, medium, high) ESC:

*Risk Level 1: (low risk)*
**Rule:** General adherence to a set of national Forestry BMP's is required for both infrastructure construction and maintenance and harvesting.
**Enforcement:** System of regular audits of operations. Failure, resulting in enforcement, is triggered by actual or probable erosion effect on a receiving environment (consequence). Three prudent requirements include:

a) Requiring two members of each roading/construction/harvesting crew to complete and maintain accreditation through the completion of BMP training modules. This would be similar to the current safety rules.
b) System of regular (3-6 monthly) Council inspections/consultations, or else inspection following a complaint.
c) Pre-harvest notification, and post harvest inspection (with consultation) of all harvest areas. Harvest areas are defined as contiguous areas, or discontinuous areas grouped as agreed by Council.

Development of a standard national audit form that is aligned with the Forestry BMP guideline is required. A simple scoring system provides feedback to contractor, company and Council and provides a benchmarking system to allow both temporal and spatial analyses of results. Effective audit should include both 'intent' and 'technical compliance' components.

*Risk Level 2: (moderate risk)*
**Rule: Harvesting** – Limit of deep soil disturbance 6% by area within the harvest boundary, excluding permanent road infrastructure. Mitigation measures to control or divert water to be implemented on all areas exceeding 200 contiguous m2 that are deeply disturbed.
**Rule: Infrastructure** – Adherence to Forestry BMP Technical Guidelines, but deviation is possible with agreement from Regional Council.
**Enforcement:** System of regular audits of operations as for Risk Level 1 areas. In addition:

- **Harvesting** – Concern that harvesting exceeds 6% deep soil disturbance shall trigger an investigation using appropriate methodology (e.g. McMahon et al. 1995). Exceeding soil disturbance limits, or failure to mitigate larger contiguous areas of deep soil disturbance will trigger enforcement actions (e.g. fine, enforced mitigation requirements on timeline, or in severe cases stop work order).
  Note: McMahon et al. (1995) is a line-transect soil disturbance survey method, based in part on systems developed in Canada to inspect operations on federal lands, that has proven to be robust and pragmatic for the comparison of soil disturbance levels.
- **Infrastructure** – Post-harvest inspections to check compliance of installed infrastructure with BMPs. Failure to comply will trigger enforcement actions.

*Risk Level 3: (high risk)*

**Rule: Harvesting** – A Harvest Plan must be developed and submitted for approval. Key aspects include extraction system selection, extraction direction and the avoidance of damaging sensitive areas such as streams. Limit of deep soil disturbance 4% by area within the harvest boundary, excluding permanent road infrastructure. Mitigation measures to control or divert water to be implemented on all areas that are deeply disturbed exceeding 100 contiguous $m^2$.

**Rule: Infrastructure** – All infrastructure must be designed by, and the implementation overseen by, a registered engineer, with erosion and sediment controls designed by a suitably qualified specialist.
Design should be of a high standard that includes layout planning at a larger scale (permanence of infrastructure), minimisation of slope disturbance (through survey design), and road standards that focus on maintaining slope stability. Adherence to Forestry BMP Technical Guidelines is also required. Deviation of guidelines is only by submission and agreement of an "improved" new design and/or protocols.

**Enforcement:** System of regular audits of operations as for Risk Level 1 areas. In addition:

- **Harvesting** – Concern that harvesting exceeds 4% deep soil disturbance shall trigger an investigation using appropriate methodology. Exceeding soil disturbance limit, or failure to mitigate the larger contiguous areas of deep soil disturbance will trigger enforcement actions.
- **Infrastructure** – Compliance and post construction inspection report prepared by Registered Engineer submitted to Regional Council. Failure to comply with BMP's will trigger enforcement actions.

## 2.6 D. SUMMARY AND RECOMMENDATIONS

### *D.1 Erosion Susceptibility Classification*

A three-class and four-class ESC were derived using the potential erosion severities for LUC units in the NZLRI, mapped at 1:50,000 scale. Notwithstanding the limitations of this approach (coarse resolution of map units, lack of strict equivalence between potential erosion severity and erosion susceptibility), a four-class ESC provided a robust and sensible classification for erosion susceptibility. A three-class system did not adequately differentiate between land units which are going to be difficult to afforest without very severe adverse erosion effects, and areas which, although having an erosion limitation to use, are more suited to conventional plantation management. <u>We therefore recommend a four-class ESC classification for use within the NES for plantation forestry</u>.

The NZLRI database contains data that are now approaching 40 years old in some cases, especially in the South Island. <u>We recommend regular (5-yearly) review and updating of the ESC, where any suitable new LUC mapping could be substituted for the current NZLRI data to derive more accurate mapping and estimates of potential erosion severity</u>. However, we reiterate the need for a national set of standards for quality and for correlation of map units within the NZLRI.

### *D.2 Risk analysis*

This study focuses on erosion hazard rather than erosion risk in the strict sense, since downslope consequences were not evaluated. A key contributor to erosion risk in plantation forests are the preparatory and mitigating effects of afforestation, clearfell harvesting (including deep soil disturbance) and earthworks (roads, landings, quarries). These effects are time dependent, so that risks are greatest during a "window" of between 4-10 years exists at time of crop harvesting and establishment. Analysis of AEP for landslide-triggering storms suggests that in most hill country areas of New Zealand, there is a distinct likelihood that landslide triggering storms may occur during this "window" period where erosion susceptibility has been increased by harvesting and earthworks.

### *D.3 Risk Management*

The ESC based on 1:50,000 scale mapping is only the first step in management of erosion risks from plantation forests. In order to account for important variation in erosion susceptibility at a site level, planning and regulation at a scale of 1:5000 to 1:10,000 is required. The degree of effort required for adequate planning can be guided by the ESC, and also the AEP for landslide-triggering storms.

Site-level planning also allows for identification of consequences, downslope values that may be impacted by erosion. These include receiving water bodies, infrastructure and buildings, as well as human safety and welfare.

<u>We strongly recommend that an NES for plantation forestry will require development of site-level planning processes (including BMP's), so that operational planning and management of harvesting and earthworks are done to a uniform high standard throughout New Zealand.</u>

## REFERENCES

ARRB (2009) Unsealed Roads Manual; Guidelines to good practice 3rd edition. ARRB Group, Victoria, Australia

Basher L.R., Painter D.J. (1997). Wind erosion in New Zealand. Paper presented at the International Wind Erosion Symposium/Workshop 3-5 June 1997 Kansas State University, Manhattan, Kansas, USA.

Basher, L.R., Barringer, J., Lynn, I.H., & Page, M.J. (2010). Accounting for the effects of mass-movement erosion on soil carbon stocks: defining and mapping land prone to mass movement erosion.

Landcare Research Contract Report LC0910/086. Nelson: Landcare Research.

Blaschke P., Hicks D., Meister A. (2008). Quantification of the flood and erosion reduction benefits, and costs, of climate change mitigation measures in New Zealand. Report prepared by Blaschke and Rutherford Environmental Consultants for MfE. Wellington: Ministry for the Environment. iv + 76 p.

Brunetti, M.T., Peruccacci, S., Rossi, M., Luciani, S., Valigi, D., Guzzetti, F. (2010). Rainfall thresholds for the possible occurrence of landslides in Italy. Natural Hazards and Earth System Science 10 (3), 447-458.

Carrara, A. and Pike, R.J. (2008). GIS technology and models for assessing landslide hazard and risk (editorial). Geomorphology 94: 257–260.

Cascini, L. (2008). Applicability of landslide susceptibility and hazard zoning at different scales Engineering Geology 102, 164–177.

Cepeda,J., Höeg, K., Nadim, F. (2010). Landslide-triggering rainfall thresholds: a conceptual framework.

Quarterly Journal of Engineering Geology and Hydrogeology 2010; 43, 69-84

Coker, R.J., Fahey, B.D., Payne, J.J. (1993). Fine sediment production from truck traffic, Queen Charlotte Forest, Marlborough Sounds, New Zealand. Journal of Hydrology (N.Z.), 31, 56-64.

Dymond, J.R., Ausseil, A-G., Shepherd, J. D., Buettner, L. (2006). Validation of a region-wide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand. Geomorphology, 74(1-4), 70-79.

Dymond, J.R., Betts, H.D., Schierlitz, C.S. (2010). An erosion model for evaluating regional land-use scenarios. Environ. Model. Softw., 25(3), 289-298.

Environment BOP (2000). Erosion and Sediment Control Guidelines for Forestry. Environment Waikato (2009). Operations Earthworks—Erosion and Sediment Control.

Eyles, G. O. (1983). The distribution and severity of present soil erosion in New Zealand. New Zealand Geographer, 39(1), 12-28.

Fahey, B.D., Marden, M., Phillips, C. (2003). Sediment yields from plantation forestry and pastoral farming, coastal Hawke's bay, North Island, New Zealand. Journal of Hydrology (N.Z.), 42, 27-38.

Fahey, B.D., Coker, R.J. (1989). Forest road erosion in the granite terrain of southwest Nelson, New Zealand. Journal of Hydrology (N.Z.), 28(2), 123-141.

Fahey, B.D., & Coker, R.J. (1993). Road-related mass movement in weathered granite, Golden Downs and Motueka forests, New Zealand: a note. Journal of Hydrology (N.Z.), 31, 65-69.

Fahey, B.D., Coker, R.J. (1992). Sediment production from forest roads in Queen Charlotte Forest and potential impact on marine water quality, Marlborough Sounds. New Zealand Journal of Marine and Freshwater Research, 26, 187-195.

Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., & Savage, W. Z. (2008). Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning. Engineering Geology, 102, 99-111. Fransen, P.J.B., Phillips, C.J., & Fahey, B.D. (2001). Forest road erosion in New Zealand: overview. Earth

Surface Processes and Landforms, 26(2), 165-174.
Glade, T., Crozier, M., & Smith, P. (2000). Applying Probability Determination to Refine Landslide- triggering Rainfall Thresholds Using an Empirical "Antecedent Daily Rainfall Model". Pure and Applied Geophysics, 157(6), 1059-1079. doi:
Glade, T. (1998). Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand. Environmental Geology, 35(2), 160-174.
Guzzetti, F., Peruccacci, S., Rossi, M., Stark, C.P. (2007). Rainfall thresholds for the initiation of landslides in central and southern Europe. Meteorology and Atmospheric Physics 98 (3-4), 239-267
Hicks, (1995). A way to estimate the frequency of rainfall-induced mass movements (note). Journal of Hydrology (NZ) 33(1), pp59-67.
Kellar, G. and Sherar, J. (2003). Low Volume Roads Engineering: Best Management Practices Field Guide.
Produced for the U.S. Agency for International Development.
Lynn, I.H., Manderson, A.K., Page, M.J., Harmsworth, G.R., Eyles, G.O., Douglas, G.B., Mackay, A.D.,Newsome, P.J.F. (2009). Land Use Capability Survey Handbook - a New Zealand handbook for the classification of land (3rd ed.): AgResearch, Landcare Research, GNS Science
McMahon, S. (1995). Survey method for assessing site disturbance. Logging Industry Research Organisation Project Report 54.Rotorua, New Zealand
LIRO (1993). Forest Code of Practice. New Zealand Logging Industry Research Organisation, Rotorua, New Zealand.
MAF. (2007). East Coast Forestry Project Grant Guidelines (pp. 1-16). Gisborne: East Coast Forestry Project, MAF.

Marden, M.; Rowe, L., Rowan, D. ( 2007). Slopewash erosion following plantation harvesting in pumice terrain and its contribution to stream sedimentation, Pokairoa Catchment, North Island, New Zealand. Journal of Hydrology (New Zealand), 46(2), 73-90.
Marden, M., Rowan, D., Phillips, C. (2006). Sediment sources and delivery following plantation harvesting in a weathered volcanic terrain, Coromandel Peninsula, North Island, New Zealand. Soil Research, 44(3), 219-232. doi: doi:10.1071/SR05092
Marden, M. (2004). Future-proofing erosion-prone hill country against soil loss and degradation during large storms—have past lessons been heeded? New Zealand Journal of Forestry 11-16.
Marden, M., & Rowan, D. (1997). Vegetation recovery and indicative sediment generation rates by sheetwash erosion from hauler-logged settings at Mangatu Forest. N.Z. Journal of Forestry, 42(2), 29-34.
MfE (2011). RFP0049-01. Request for proposals for the Ministry for the Environment for development of a National Erosion Susceptibility Classification. 23 February 2011.
MSU Extension (2001). Montana State University Extension Service Water Quality BMPs for Montana Forests. Publication reference: EB158. MSU Extension Publications, Bozeman MT.
NZFOA (2008). Best Environmental Practices Guide. NZ Forest Owner's Association, Wellington, New Zealand.
Rahardjo, H., Leong, E.C., Rezaur, R.B. (2008). Effect of antecedent rainfall on pore-water pressure distribution characteristics in residual soil slopes under tropical rainfall Hydrological Processes 22 (4), 506-523.
Saunders, W., Glassey, P. (compilers) (2007). Guidelines for assessing planning policy and consent requirements for landslide prone land. GNS Science Miscellaneous Series 7.
Sidle, R.C., Ochiai, H. (2006). Landslides: Processes, Prediction, and Land Use. Water Resources Monograph, American Geophysical Union.

Stokes A., Norris, J.E., van Beek, L.P.H., Bogaard, T., Cammeraat, E., Mickovski, S.B., Jenner, A., Di Iorio, A.,Thierry Fourcaud, T. (2008). Chapter 4, How vegetation reinforces soil on slopes in J.E. Norris et al. (eds.), Slope Stability and Erosion Control: Ecotechnological Solutions. Springer, 65–118.

Thompson,C. (2011). HIRDS v3., High Intensity Rainfall Design System. http://hirds.niwa.co.nz/ Watson,A., Phillips, C., Marden, M. (1999). Root strength, growth, and rates of decay: root reinforcement changes of two tree species and their contribution to slope stability. Plant and Soil 217: 39–47, 1999.

*Figure 10 Appendix 1. Conceptual Model of Erosion Risk. After Saunders and Glassey (2007).*

***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 |

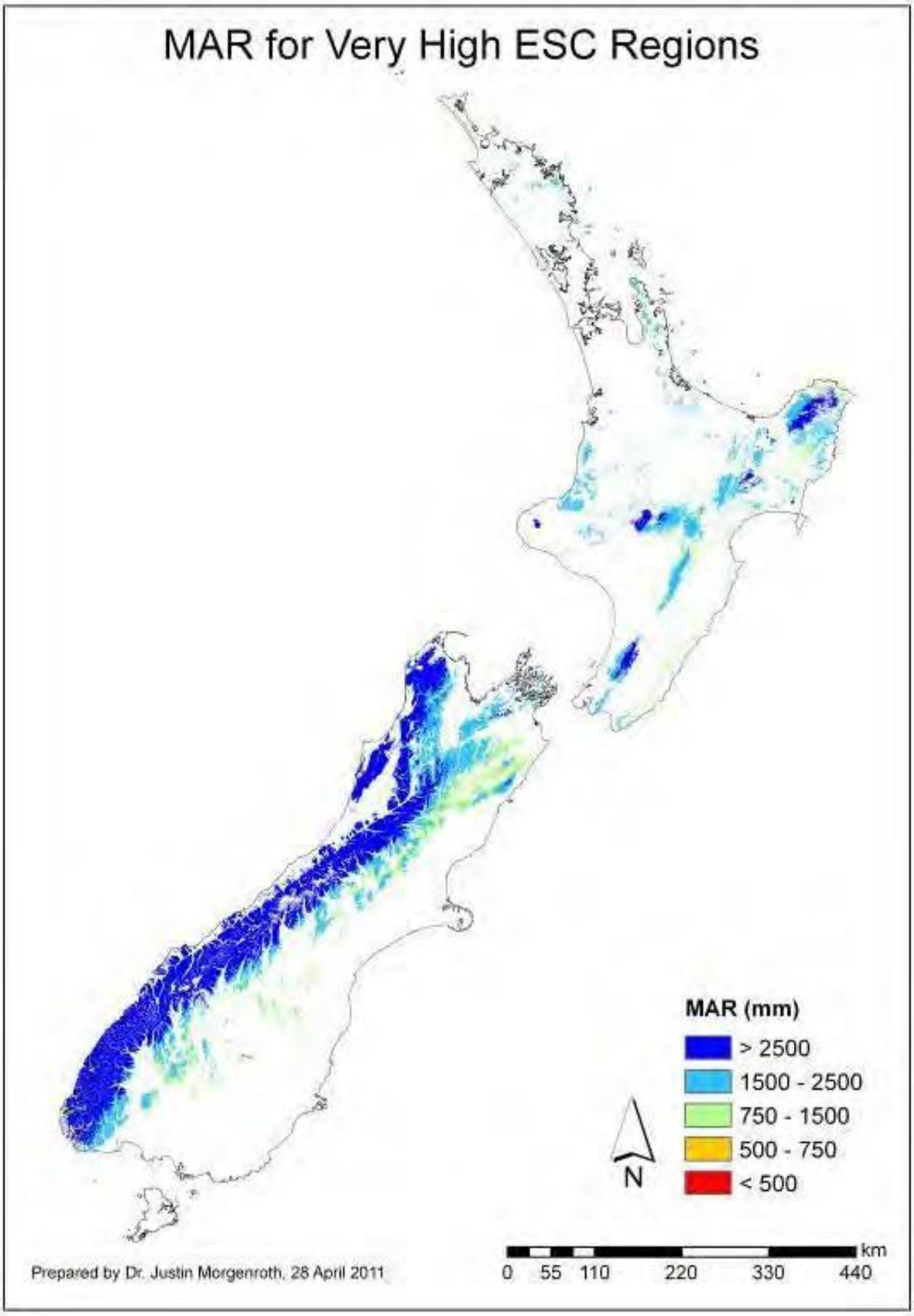
***4 – Risk Level Implications***

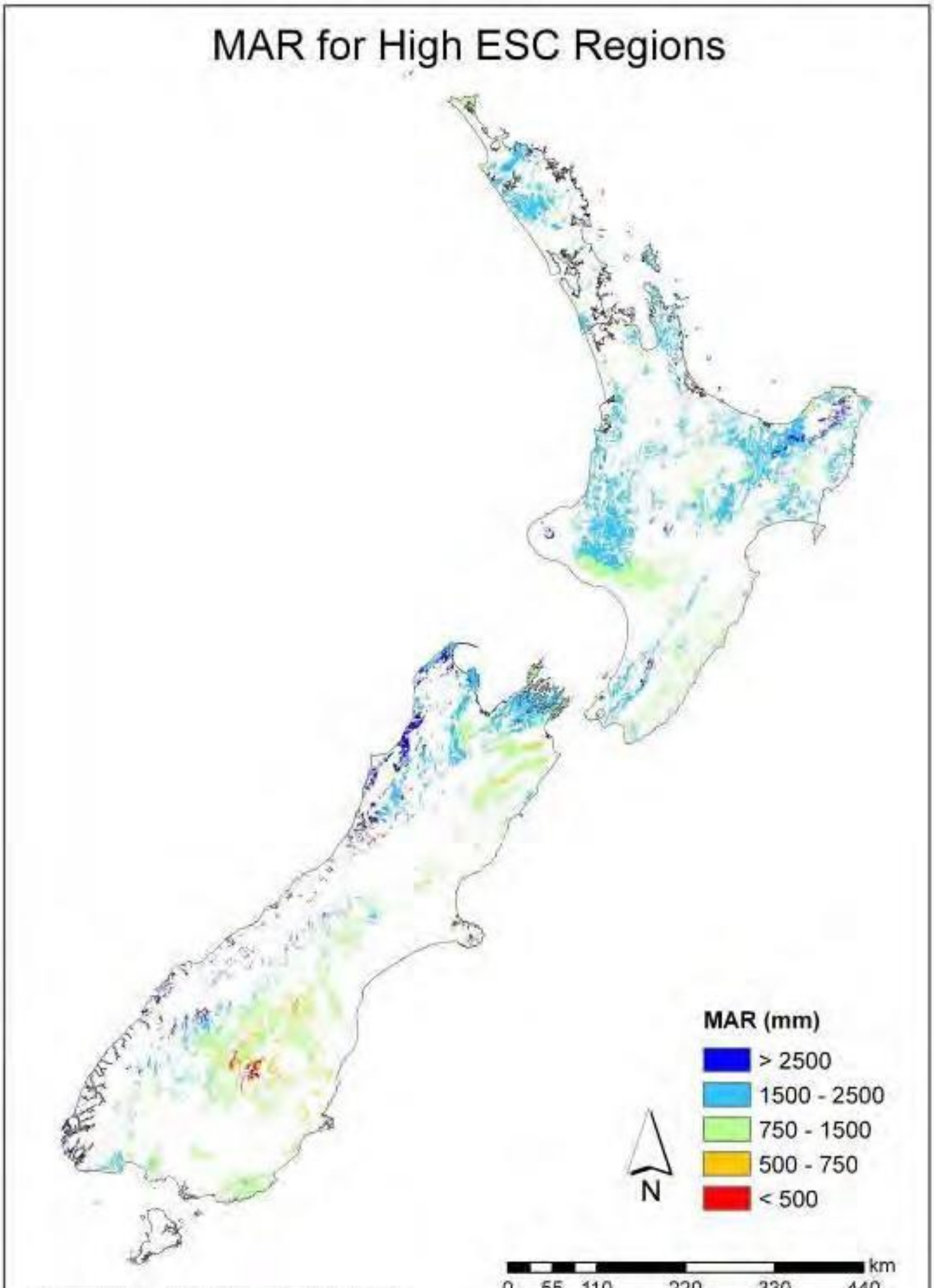
| Risk Level | | Example Implications |
|---|---|---|
| VH | VERY HIGH RISK | Extensive detailed investigation and research, planning and implementation of treatment options essential to reduce risk to acceptable levels; may be too expensive and not practical. |
| H | HIGH RISK | Detailed investigation, 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. |

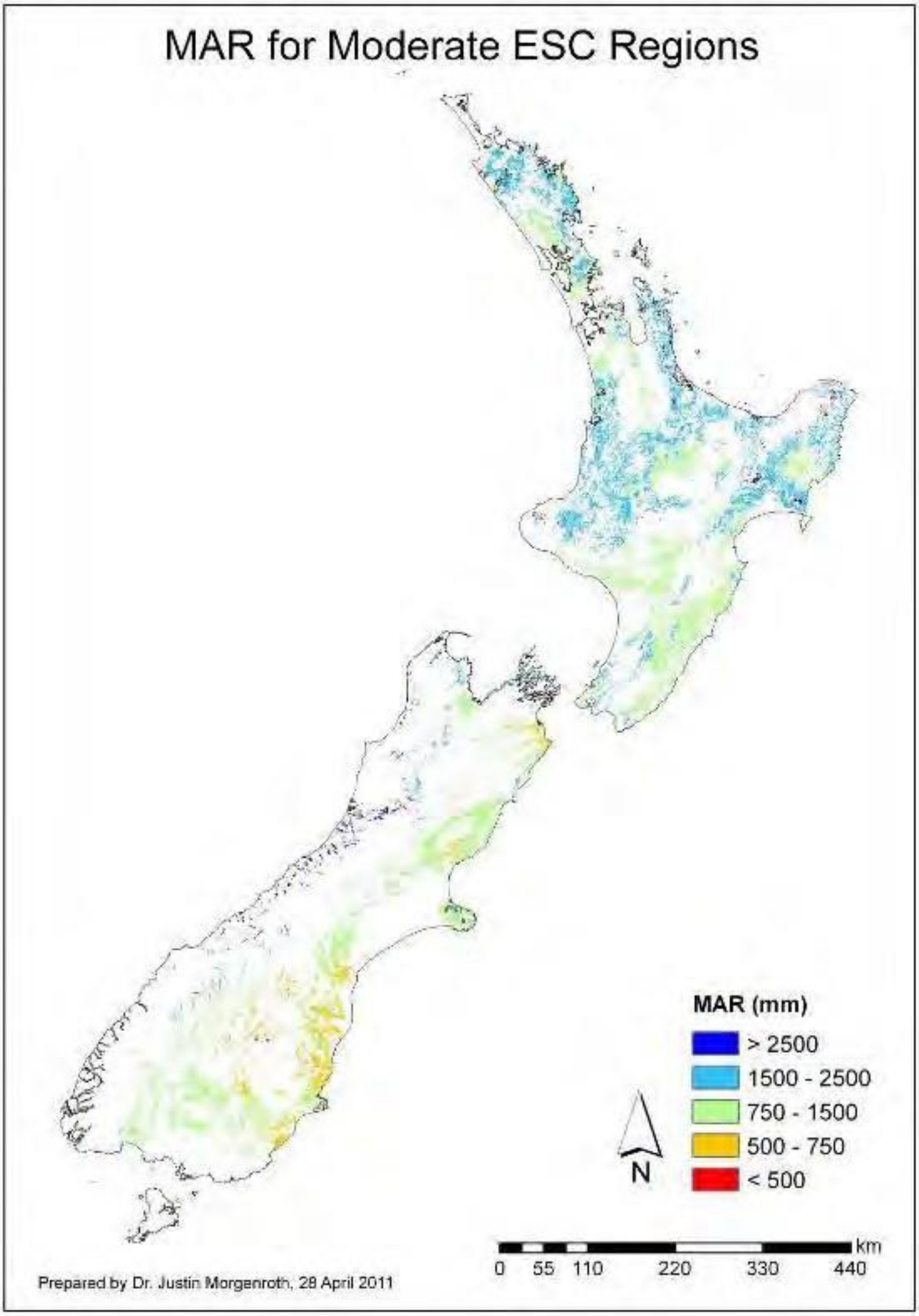
*Note: "The Description" may be edited to suit a particular case.*

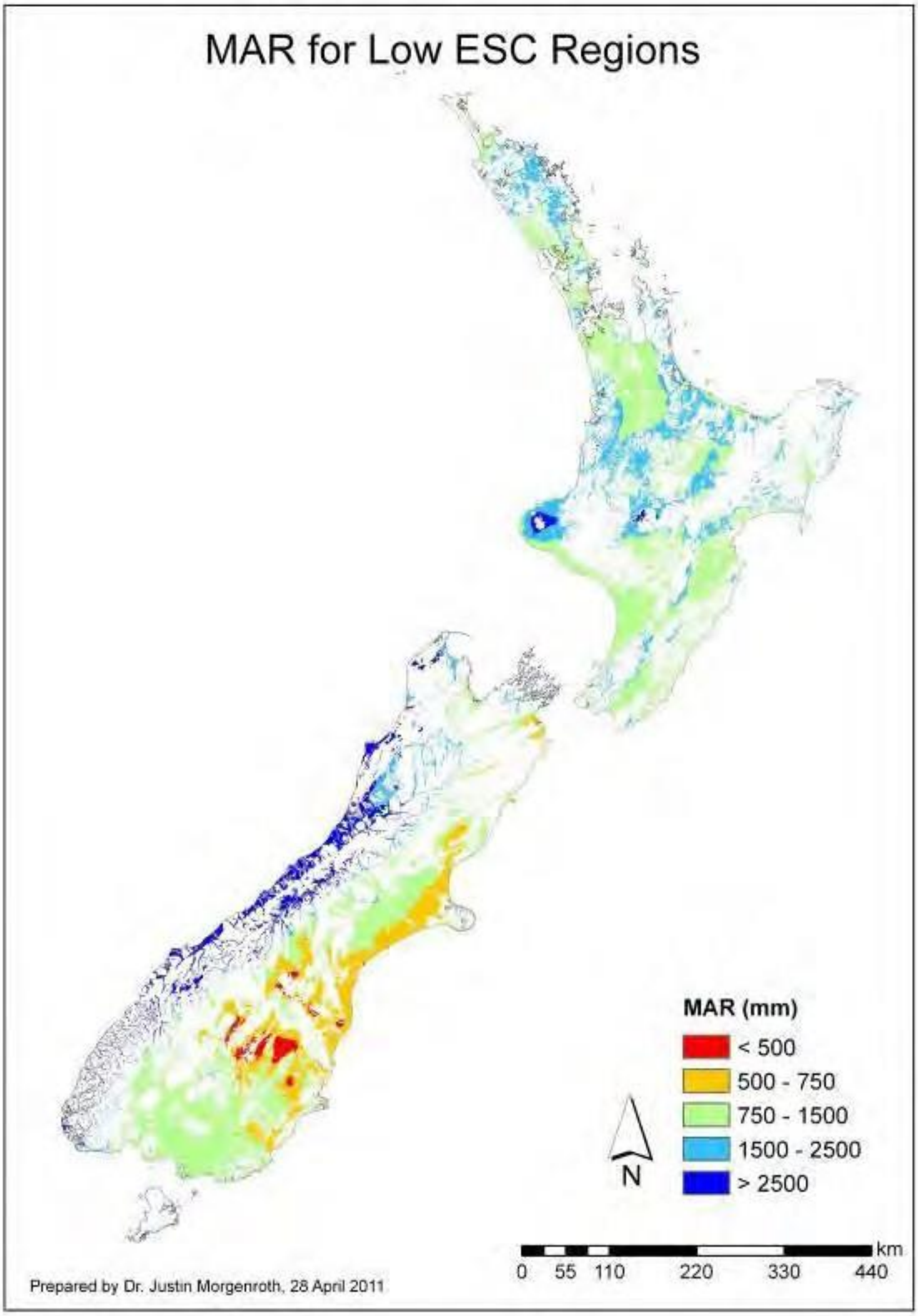
**Figure A3-2** Summary of the main steps for qualitative landslide risk assessment and process: (1) Likelihood terms and criteria; (2) Measures of consequence; (3) Risk analysis matrix; (4) Implications of different risk levels (AGS, 2000)

*Figure 11 Appendix 2. Maps of MAR plotted for a four-class ESC classification (Very high, high, moderate and low)*




MAR for High ESC Regions
MAR (mm)
> 2500
1500 - 2500
750 - 1500
500 - 750
< 500
N
km
0 55 110 220 330 440
Prepared by Dr. Justin Morgenroth, 28 April 2011


MAR for Moderate ESC Regions
MAR (mm)
> 2500
1500 - 2500
750 - 1500
500 - 750
< 500
N
km
0 55 110 220 330 440
Prepared by Dr. Justin Morgenroth, 28 April 2011


MAR for Low ESC Regions
MAR (mm)
< 500
500 - 750
750 - 1500
1500 - 2500
> 2500
N
km
0 55 110 220 330 440
Prepared by Dr. Justin Morgenroth, 28 April 2011

# 3 Update of the Erosion Susceptibility Classification (ESC) for the proposed National Environmental Standard for Plantation Forestry, Landcare - May 2015

**Les R Basher, Ian H Lynn**

*Landcare Research*

**Mike Page**

*GNS Science*

*Prepared for:*

**Ministry for Primary Industries**

25 The Terrace
PO Box 2526
Wellington 6140 New
Zealand

**May 2015**

*Landcare Research, 1st Floor, 24 Nile Street, Private Bag 6, Nelson 7042, New Zealand, Ph +64 3 545 7700,* www.landcareresearch.co.nz

*GNS Science, P O Box 30-368, Lower Hutt, New Zealand*

| *Reviewed by:* | *Approved for release by:* |
|---|---|
| | |
| James Barringer Scientist<br>Landcare Research | Chris Phillips Portfolio Leader<br>Realising Land's Potential |

*Landcare Research Contract Report:* LC2196

**Disclaimer**

*This report has been prepared by Landcare Research for Ministry for Primary Industries. If used by other parties, no warranty or representation is given as to its accuracy and no liability is accepted for loss or damage arising directly or indirectly from reliance on the information in it.*

## CONTENTS

## 3.1 INTRODUCTION

The Ministry for Primary Industries (MPI) is leading a process to deliver greater national consistency in the management of plantation forestry under the Resource Management Act (RMA) by implementing a National Environmental Standard (NES) for Plantation Forestry (hereafter simply referred to as the NES). The Erosion Susceptibility Classification (ESC) developed by Bloomberg et al. (2011), based on Land Use Capability (LUC) unit mapping, is a critical input into the proposed NES as it underpins the level of control for different plantation forestry activities. The ESC has limitations related to scale of mapping and misclassification of some land (Robson 2013; Basher et al. 2014) that will result in ongoing changes to the ESC once the NES is implemented. MPI engaged Landcare Research to refine the ESC for misclassified land and to establish a process by which changes to the ESC might be managed once the NES is implemented. The work requested includes three components:

1. Design a process by which a party can apply to have ESC units/polygons refined or reassessed, new LUC units created and where appropriate officially reclassified,
2. Reclassify those ESC units/polygons that were clearly misclassified as High or Very High under the current ESC (Bloomberg et al. 2011),
3. Apply a 'graded level of severity' classification to the High and Very High classes under the revised ESC.

This report describes work completed for the second component.

## 3.2 BACKGROUND

The ESC was developed using 'Potential Erosion Severity' (PES) data for mass movement (including gully and tunnel gully erosion)[1] published in regional LUC bulletins and extended legends (NWASCO 1975–79, 1979; NWASCA 1986a, b) that were the basis of the New Zealand Land Resource Inventory (NZLRI). The published PES ratings for each LUC unit in classes 6, 7, 8s, 8w and 8c were used to classify land into four categories of erosion susceptibility: Low, Moderate, High, and Very High (Table 1). All LUC Class 1 to 5 land was assigned to ESC class Low, while all Class 8e land was assigned to ESC class Very High.

**Table 1:** Relationship between ESC class and potential erosion severity for mass movement erosion (Bloomberg et al. 2011)

| Potential erosion severity | ESC class |
|---|---|
| 0 = negligible | 1 = Low |
| 1 = slight | 1 = Low |
| 2 = moderate | 2 = Moderate |
| 3 = severe | 3 = High |
| 4 = very severe | 4 = Very High |
| 5 = extreme | 4 = Very High |

In the source documents potential erosion was listed in the North Island and 2nd edition mapping in Marlborough for each mapped LUC unit in terms of both the type and severity of erosion, but in the remainder of the South Island a single severity category was listed for multiple erosion types. Where potential erosion severity was listed for each erosion type it took the form ‘severe earthflow, moderate gully, slight sheet’ (3Ef 2G 1Sh), whereas in the South Island mapping it was listed in the form ‘severe earthflow, gully and sheet’ (3Ef G Sh). In developing the ESC, Bloomberg et al. (2011) determined the highest severity for any form of mass movement erosion for each LUC unit. This approach could be simply applied in the North Island where each erosion type is given a severity, but is problematic in the South Island mapping where only an overall erosion severity is given for multiple erosion types. In the latter case an LUC unit mapped as, for example, severe sheet, soil slip, gully (3ShSsG) was effectively classified as severe (3) soil slip even though the inventory would suggest:

- The severity (3) was an overall assessment of all three erosion types
- The severity of any individual type is presumably <3
- The dominant erosion was sheet erosion not mass movement or gully erosion.

This approach was considered to classify ESC ‘conservatively’. Similarly, many LUC units were listed in the source documents with a range of erosion severity – see Table 2 for some examples. In most cases the highest severity ranking was used to assign ESC class (e.g. 2-3Ss would be classed as High ESC).

**Table 2:** Examples of LUC units listed with a range of potential erosion severity and their ESC class (after Bloomberg et al. 2011)

| Legend[#] | LUC unit | Potential erosion | ESC class |
|---|---|---|---|
| 00 | 7e5 | 2-4Ef Su Ss | High |
| 01 | 6e11 | 2-3Ef, 2-3Es, 2G, 2Ss, 2Sh | High |
| 01 | 7e2 | 3-4Ef, 3-4G, 2Es, 2Ss, 2Sh | Very High |
| 02 | 6e14 | 2-3Ef, 2-3Ss, 2Sh, 2G | High |
| 02 | 7e9 | 3-4Ss, 3Sh, 3Sc, 2G | Very High |
| 04 | 6e17 | 2-3G, 2Sh, 2Ss, 2Sb | High |
| 07 | 6e15 | 2-3G, 2Sh | High |
| 07 | 7e3 | 3-4Ss, 2Sh, 1G, 1T | Very High |
| 10 | 6e26 | 2-3G, 2Sb, 2Sh | High |
| 11 | 6e7 | 2-3Sh Ss | High |
| 11 | 7e15 | 2-3Sh W Ss | High |

All Class 8e land was automatically assigned to ESC class Very High without consideration of potential erosion type or severity. As a result, some Class 8 land with very low susceptibility to mass movement erosion has been assigned to ESC class Very High. In addition, many LUC polygons are mapped as compound units (e.g. 4e6+6e20) and in these cases the maximum potential erosion severity was taken as the maximum severity for the

LUC unit with the higher potential erosion severity (in the example above, this would be the 6e20 LUC unit even though the 4e6 LUC unit would be areally dominant).

As a result of these issues, and with the improved understanding of erosion processes that has occurred since the NZLRI mapping was completed, it is considered that the ESC derived by Bloomberg et al. (2011) has misclassified some LUC units. MPI has sought to re-evaluate the ESC and identify those LUC units in the High and Very High ESC classes that are misclassified.

## 3.3 OBJECTIVES

Identify LUC units in the High and Very High classes that are misclassified or conservatively classified and update the ESC.

## 3.4 METHODS

- The procedure followed for reconsidering the ESC class of LUC units involved re-examining the potential erosion data in the regional LUC extended legends and bulletins, compiling the mapped present erosion data in the NZLRI, considering the correlation of LUC units between regions, and also considering the ESC class of groups of related LUC units (suites). The following factors were taken into consideration when reviewing the ESC class of LUC units:
- The maximum mapped mass movement erosion (including gully and tunnel gully) for each unique LUC unit was compiled by querying the NZLRI.
- The potential mass movement erosion as listed in extended legends, and bulletins where available, was compiled. More reliance was placed on the bulletins because they were compiled post-mapping and better represent both what was observed during regional mapping and the interpretation of potential erosion that resulted from the mapping.
- The location of each LUC unit was plotted in GIS to observe the spatial distribution of polygons mapped within each LUC unit, and sometimes related LUC units.
- Where there was a difference between maximum mapped and assessed potential erosion, the spatial distribution of the LUC unit was examined and Google Earth was scanned for evidence of present and past erosion. The description of the LUC unit in the bulletin/extended legend was also taken into account.
- For large-scale mass movement (earthflow, slump) it was assumed that the observed extent and severity of erosion probably reflected the potential (since most of these features are ancient, long-lived landscape features).
- Consideration was given to the effect of the major factors influencing erosion susceptibility, including the relative susceptibility of different rock types (based on grouping the rock types of the NZLRI (Lynn et al. 2009) by relative rock strength), slope steepness and rainfall.
- Previous comments on the ESC made to Bloomberg et al. (2011), and subsequent feedback from regional councils as supplied by MPI and Trevor Freeman (Gisborne District Council) were taken into account.
- The correlation between regions was checked where LUC units were correlated between 2 or more legends. This followed Page (1985) and also utilised the draft National Extended Legend for LUC (Lynn in prep.). Correlation aimed to achieve consistency in ESC rating between regions, except where subtle regional differences may exist or correlations were only for part of an LUC unit.
- The relative ESC rating between related groups (suites) of LUC units (e.g. greywacke, different types of mudstone and sandstone, Taupo flow and water-sorted tephra) was examined to check for consistency.
- Those LUC units where the ESC rating was above or below the typical rating for the LUC class (e.g. most Class 6 was rated Moderate, but the least susceptible was

rated as Low and the most susceptible as High, most Class 7 LUC units were rated as High, but least susceptible was rated as Low or Medium and most susceptible as Very High) were considered more closely to evaluate if this was justifiable.

- Where possible differences between related LUC units were reflected in the susceptibility ratings (i.e. if a Class 6 LUC unit was rated as Moderate then the related Class 7 unit, which would typically have higher mapped erosion severity, was rated as High). However because the original mapping had 6 classes of erosion severity and the ESC has only 4 classes then some regrouping has occurred with the result that some related Class 6 and 7 units have the same ESC class.
- Polygons mapped with dual LUC units were treated in the same way as Bloomberg et al. (2011). That is, the ESC was derived from the LUC unit with the highest potential erosion severity in order to be able to identify those areas where some part of the polygon has higher erosion severity than the polygon as a whole. While this induces some error in the mapping it is considered this is best resolved through mapping at more detailed scale.
- The ESC for Class 8 land was analysed in exactly the same way as for Class 6 and 7 rather than automatically assigning it to the Very High class. All Class 1 to 5 land was assigned to the Low ESC class following Bloomberg et al. (2011).
- Problematic LUC units and those units where changes to the Bloomberg et al. (2011) classification were suggested were discussed in face-to-face meetings with Greater Wellington Regional Council, Horizons Regional Council, Hawke's Bay Regional Council, Gisborne District Council, Waikato Regional Council, and Northland Regional Council. Some feedback was also received from the forestry industry (Hancock Forest Management, P F Olsen Ltd, Ernslaw One).

## 3.5 RESULTS

The revised ESC for all LUC units is listed in Appendix 1 and its spatial implementation shown in Figure 1. The ESC class has been changed for approximately 16% of LUC units[2], and in most cases the revision has resulted in a lower ESC class (e.g. from High to Moderate). The reasons for each change are listed for each LUC unit in Appendix 1. Over the whole country the area classed as High has decreased by 635 000 ha and the area classed as Very High by 1 027 000 ha (Table 3). The area in the Low and Moderate classes has increased by 1 684 000 ha. Changes to the High and Very High classes are dominated by changes made in Canterbury (area of Very High decreased by 384 000 ha) and Otago (area of High and Very High decreased by 352 000 and 166 000 ha respectively). Significant changes were also made in Hawke's Bay (the area of Very High reduced by 101 000 ha and the area of High increased by 120 000 ha) and Northland (the area of High decreased by 223 000 ha). In other regions the changes were rather smaller.

For the current plantation forest estate (as defined by LCDB4) the area classed as High has decreased by 142 000 ha and the area classed as Very High by 35 000 ha (Table 4) while the area in the Low and Moderate classes has increased by 179,000 ha. Changes to the High and Very High classes in the plantation forestry estate are dominated by changes made in Northland, Tasman and Waikato, with smaller changes also made in Bay of Plenty and Hawkes Bay.

The major changes relate to:

- Reassessing LUC units in the South Island where only a single erosion severity was recorded for multiple erosion types and mass movement was a subdominant type. This has resulted in changed ESC class for 20% of South Island LUC units.

- Reassessing the relative erosion susceptibility of different rock types, in particular comparing Tertiary-age soft rocks with older and more indurated greywacke.
- It was considered that the LUC units classed as Very High in the North Island (such as the highly landslide-prone terrain on mudstone and other soft sedimentary rocks, and the extensive earthflow and gully erosion terrain on crushed argillite) were generally more susceptible to erosion than any terrain in the South Island. The most erosion- prone South Island terrain (with the exception of areas under very high rainfall) is on weathered Separation Point Granite (part LUC unit 7e9) and loess with extensive tunnel gullying (LUC unit 7e14) and these were used as the benchmark for the High class in the South Island.
- Where possible a one ESC class difference was maintained between related Class 6, 7, and 8 LUC units.

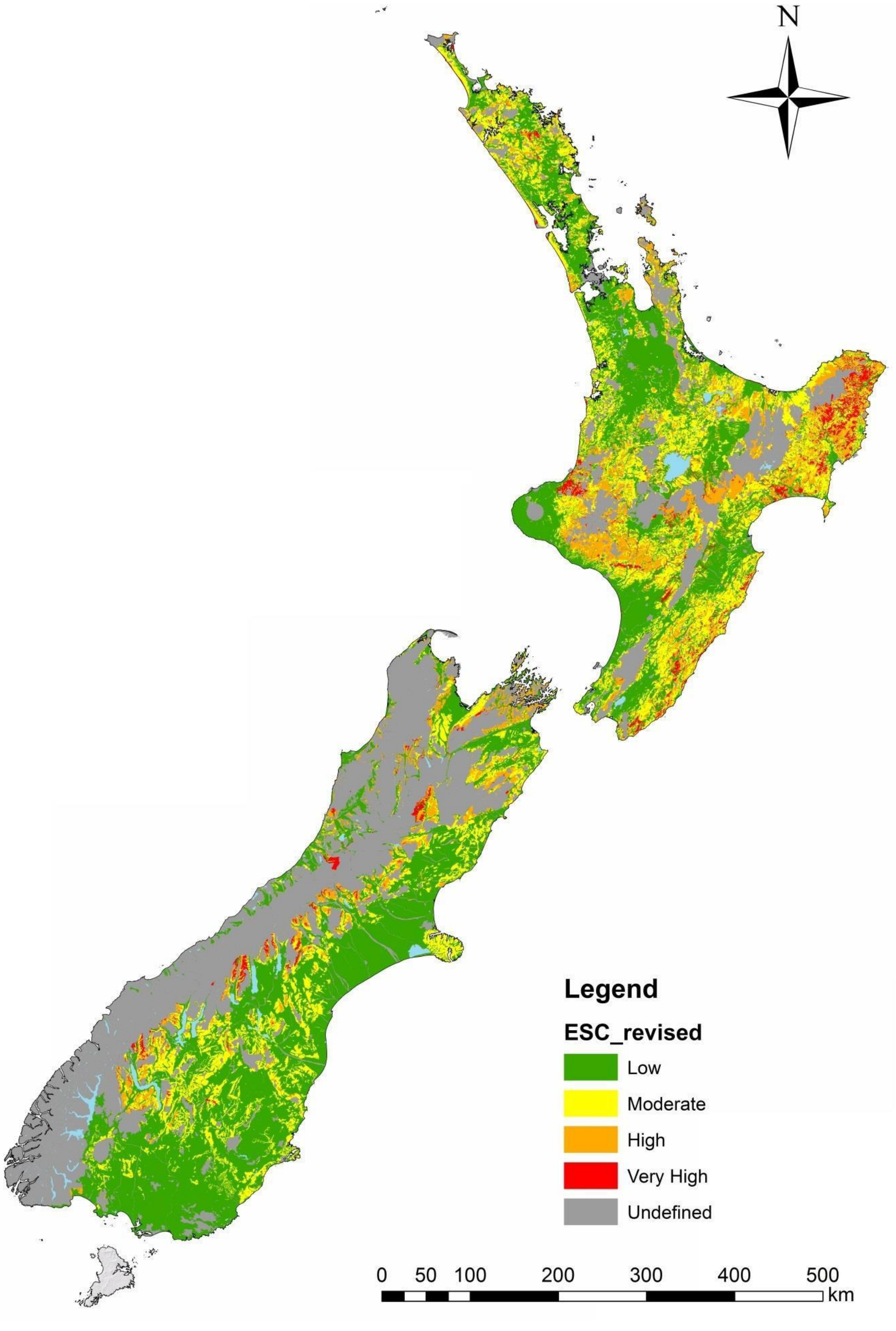



**Figure 1**: Map of revised Erosion Susceptibility Classification.

**Table 3:** Area of the four ESC classes by region. Areas in brackets are from Bloomberg et al. (2011). Undefined areas include towns, quarries, and Department of Conservation Estate

| | **Area (000 ha)** | | | | | |
|---|---|---|---|---|---|---|
| | **Low** | **Moderate** | **High** | **Very High** | **Undefined*** | **Total** |
| Auckland | 275 (208) | 99 (142) | 37 (67) | 3 (3) | 88 | 502 |
| Bay of Plenty | 326 (303) | 299 (229) | 189 (224) | 10 (68) | 403 | 1228 |
| Canterbury | 2217 (1743) | 722 (756) | 287 (342) | 72 (456) | 1236 | 4534 |
| Gisborne | 95 (103) | 266 (266) | 211 (192) | 186 (196) | 84 | 841 |
| Hawke's Bay | 463 (504) | 363 (341) | 274 (154) | 50 (151) | 301 | 1451 |
| Manawatu-Wanganui | 737 (795) | 623 (543) | 387 (361) | 64 (113) | 473 | 2285 |
| Marlborough | 277 (114) | 132 (191) | 146 (162) | 3 (91) | 495 | 1053 |
| Nelson | 6 (3) | 20 (10) | 7 (18) | 2 (3) | 8 | 43 |
| Northland | 514 (450) | 453 (266) | 95 (318) | 21 (50) | 190 | 1273 |
| Otago | 1720 (1307) | 670 (565) | 119 (471) | 27 (193) | 663 | 3199 |
| Southland | 1183 (990) | 120 (252) | 32 (49) | 3 (37) | 1705 | 3043 |
| Taranaki | 312 (312) | 98 (97) | 130 (119) | 37 (48) | 152 | 729 |
| Tasman | 166 (109) | 83 (87) | 80 (114) | 9 (27) | 642 | 979 |
| Waikato | 1209 (1077) | 562 (547) | 210 (307) | 12 (53) | 465 | 2459 |
| Wellington | 296 (306) | 211 (194) | 102 (88) | 37 (57) | 169 | 816 |
| West Coast | 261 (261) | 26 (26) | 49 (37) | 18 (30) | 1981 | 2336 |
| **Total** | 10056 (8596) | 4715 (4513) | 2388 (3023) | 554 (1581) | 9057 | 26771 |

* The undefined area was derived from the GIS data provided by Bloomberg et al. (2011).

**Table 4:** Area of the four ESC classes in the plantation forest estate (derived from LCDB4) by region. Areas in brackets are from Bloomberg et al. (2011)

| | **Area (000 ha)** | | | | |
|---|---|---|---|---|---|
| | **Low** | **Moderate** | **High** | **Very High** | **Total** |
| Auckland | 19 (8) | 26 (35) | 6 (9) | 0.7 (0.8) | 52 |
| Bay of Plenty | 120 (106) | 97 (89) | 56 (73) | 1 (6) | 279 |
| Canterbury | 96 (61) | 27 (52) | 2 (9) | 0.3 (4) | 129 |
| Gisborne | 5 (5) | 52 (52) | 48 (43) | 66 (70) | 170 |
| Hawke's Bay | 40 (45) | 73 (74) | 35 (20) | 10 (19) | 159 |
| Manawatu-Wanganui | 57 (62) | 50 (43) | 32 (38) | 10 (6) | 150 |
| Marlborough | 27 (6) | 12 (25) | 38 (43) | 0.1 (4) | 82 |
| Nelson | 2 (0.3) | 7 (3) | 3 (8) | 0 (0.1) | 11 |
| Northland | 31 (24) | 125 (73) | 20 (74) | 7 (12) | 185 |
| Otago | 103 (62) | 40 (77) | 0.2 (4) | 0 (0.6) | 145 |
| Southland | 74 (56) | 17 (35) | 3 (3) | 0 (0.6) | 95 |
| Taranaki | 7 (7) | 10 (10) | 11 (11) | 0.7 (1) | 29 |
| Tasman | 31 (8) | 44 (29) | 26 (62) | 1 (4) | 103 |
| Waikato | 124 (108) | 134 (113) | 49 (84) | 2 (5) | 312 |

| | | | | | |
|---|---|---|---|---|---|
| Wellington | 23 (24) | 26 (26) | 18 (18) | 9 (9) | 77 |
| West Coast | 24 (24) | 7 (7) | 10 (10) | 0 (0.1) | 42 |
| **Total** | 782 (604) | 738 (741) | 365 (506) | 108 (143) | 2020 |

* The undefined area was derived from the GIS data provided by Bloomberg et al. (2011).

It is considered that greywacke (along with other strongly indurated lithologies) are less susceptible to erosion than soft rocks and ESC class should reflect this. As a consequence, the rating for many greywacke units decreased. Now most Class 6 greywacke LUC units are rated Low, most Class 7 greywacke LUC units are rated Moderate and most Class 8 greywacke LUC units are rated High (see Table 5). The exceptions to this general pattern are where the rainfall is very high and/or slopes are very steep (e.g. legend 00, South Island, LUC units 8e7, 8e11), or where the greywacke is particularly crushed and shattered (such as legend 6, Gisborne-East Coast – this area is also considered to have a greater argillite component in the greywacke that makes it more susceptible to erosion). In addition, deeply weathered greywacke LUC units were considered to be more susceptible to erosion than their unweathered correlatives and generally had higher ESC class. This applied in Northland, Waikato, and parts of Coromandel.

**Table 5:** ESC class for steepland greywacke LUC units

| | ESC class | | | |
|---|---|---|---|---|
| **Legend** | **Low** | **Moderate** | **High** | **Very High** |
| 00 | 6e11, 6e14, 6e22, 6e29 | 7e2, 7e3, 7e12, 7e16, 7e21, 7e23, 7e24, 7e26 | 8e2, 8e4, 8e8, 8e9 | 8e7*, 8e11* |
| 01 | | 6e9#, 6e10#, 6e17# | 7e5#, 7e6#, part 8e2, part 8e3 | |
| 02 | 6e5, 6e6 | 6e14#, 7e2 | 6e17#, 7e8#, 7e9#, 8e2, 8e3 | |
| 03 | | part 6e7#, part 6e8#, part 6e10# | 7e1#, part 7e4#, 7e8#, part 8e2 | part 8e3*, part 8e4* |
| 04 | | | 8e3, 8e7 | 8e4* |
| 05 | | 7e2 | 8e1, 8e2 | |
| 06 | | 6e23, 6e24 | 7e11 | 8e4, 8e7, 8e8 |
| 07 | | part 7e7 | 8e5, 8e9 | 8e6* |
| 08 | 6e11 | 7e5, 7e10 | 8e5, 8e7, 8e8 | 8e6# |
| 09 | 6e6, 6e7, 6e8, 6e9 | 6e10*, 7e1, 7e2, 7e4 | 7e5*, 8e2, 8e3, 8e4 | 8e5 |
| 10 | 6e16 | 7e10 | 8e4, 8e5, 8e8 | 8e7*, 8e9* |
| 11 | 6e8, 6e12, 6e17, 6e19 | 7e7, 7e14, 7e15, 7e20, 7e23, 7e24, 7e25 | 8e5, 8e6, 8e7, 8e8, 8e9, 8e11, 8e12, 8e13 | |

The reclassification of the ESC in part reflects the relative susceptibility of different rock types, particularly the difference between young weakly to moderately indurated soft sedimentary rock types and older moderately to strongly indurated rocks (such as greywacke and schist). Table 6 shows the classification of LUC units underlain by mudstone. For this rock type ESC class is typically one class higher than for greywacke (i.e. Class 6 is mostly Moderate, Class 7 is mostly High and where the mudstone is crushed and shattered then Class 7 LUC units are Very High). A similar approach was applied to other soft rock LUC units.

The rock types of the NZLRI (Lynn et al. 2009) were grouped by relative rock strength, considered to be one of the main factors influencing erosion susceptibility (Table 7). This grouping was used to help maintain consistency between the ESC of LUC units underlain by different rock types.

**Table 6: Mudstone LUC units**
**Copy this from the original report**

**Table 7**: Relative rock strength of different unweathered rock types

| Rock strength | Rock type |
|---|---|
| Extremely weak | Ng, Rm, Ta, Sc, Lp, Kt, Tp, Ft*, Vu*, Pt, Wb, Us*, Uf* |
| Very weak | Mo, Ft*, La*, Vu*, Af, Gr*, Us*, Uf* |
| Weak | Mf, Me, Lo, Mx, Ac |
| Strong | Tb, Vb, Cl, Gl, Mm, Mb, Sm, Sb, Cw, Li* |
| Very strong | Vo, Ar, Si, Cg, Gw, Li*, Sx, Sy |
| Extremely strong | In, Gn, Um, Gs, Ma |

Other changes were made where

- LUC units on soft sedimentary rocks, volcanic rocks or loess that were mapped on fairly gentle slopes (D and E) and where the mapped severity of mass movement was very low had their ESC class adjusted down to reflect the lower slope (e.g. legend 01 6e1, legend 02 6e3; legend 3 6e3)
- LUC units characterised by earthflow erosion where the ESC class was higher than the potential erosion severity or mapped severity, and it was considered that the mapped severity represented the potential, had their ESC class adjusted down (e.g. legend 01 6e7, 6e12; legend 6 7e6)

Classification of the sand dune LUC units followed Bloomberg et al. (2011). This terrain is not susceptible to mass movement erosion but it was treated as a special case by Bloomberg et al. (2011) since some of it is highly prone to wind erosion. All sand dune LUC units were classed as Low with the exception of those on active foredunes, which are classed as Very High.

There remain a number of difficulties with applying the ESC based on potential erosion:

- The classification remains somewhat subjective. It is partly based on the NZLRI data (potential erosion and maximum mapped mass movement erosion), but also partly based on interpretation of the influence of rock type and weathering status, rainfall and topography on erosion susceptibility. These influences cannot be evaluated independently using the concept of potential erosion, nor can the role of vegetation cover, and changes of cover, be objectively evaluated.
- Part of the difficulty with classifying some LUC units was their broad definition. For example, legend 00 LUC unit 7e9 includes areas of highly erodible Separation Point Granite, but it also includes areas of weathered schist and greywacke. The ESC for this LUC unit applies to the unit as a whole, even though some parts of it are more susceptible to erosion than others.

- For some areas of the country it was particularly difficult to classify ESC class, and maintain consistency with other parts of the country, because of their rock types, climate characteristics, and vegetation cover. Chief among those was the Coromandel (legend 03) with its highly weathered and hydrothermally altered rocks, and perceived high frequency of rain storms that trigger mass movement. Similarly, a number of LUC units in the Gisborne-East Coast area (legend 6), correlated with LUC units elsewhere, were considered more susceptible to erosion because the tectonic regime has resulted in more crushed and shattered rocks in that area. In some regions there were LUC units that essentially occurred only under forest vegetation and therefore it was difficult to assess potential erosion severity because there were no areas under grassland to provide a clear baseline for their erosion response under grassland.
- Each erosion susceptibility class contains quite a wide range of terrain as a consequence of using data that originally had 6 classes for erosion severity and collapsing the data into 4 classes of erosion susceptibility. For example, in legend 00 the High ESC class includes terrain ranging from highly erodible, weathered granite (LUC unit 7e9) and loess (LUC unit 7e14) through to less erodible soft rock hill country (e.g. LUC unit 7e7) but it was considered the latter was better grouped with LUC units in the High class rather than the Moderate class. In revising the ESC subjective decisions had to be made regarding the "best-fit" groupings of ESC class. The comments column in Appendix 1 provides the rationale for these decisions.

## 3.6 CONCLUSIONS

Revision of the ESC has resulted in changes of ESC class to approximately 16% of LUC units with the area classed as High reduced by 648,000 ha and the area of Very High by 1 027 000 ha, dominated by changes made in Canterbury and Otago. The revision has focused on:

i. comparing maximum mapped mass movement erosion type and severity with the potential erosion severity listed in regional LUC bulletins,

ii. considering the effect of rock type, slope steepness, and rainfall on erosion susceptibility,

iii. correlating LUC units between different legends, and

iv. correlating the relative ESC rating between related groups (suites) of LUC units.

There remain a number of difficulties with applying the ESC based on potential erosion including the subjectivity of the classification, the poor definition of the concept and method of assessment of potential erosion, and the broad definition of some LUC units. However, the revised classification is considered an improvement on the original classification within the constraints of using potential erosion as the metric for erosion susceptibility.

## 3.7 ACKNOWLEDGEMENTS

We thank MPI for providing funding for this work and all those people who discussed potential erosion and the Erosion Susceptibility Classification with us: Dave Cameron

(Greater Wellington Regional Council), Malcolm Todd (Horizons), Campbell Leckie and James Powrie (Hawke's Bay Regional Council), Trevor Freeman and Kerry Hudson (Gisborne District Council), Alan Campbell, Grant Blackie, Vince Udy (Waikato Regional Council), Duncan Kervell, Wayne Teal , Geoff Heath, James Griffin (Northland Regional Council), and Bob Cathcart (formerly Northland Regional Council), Garth Eyles (consultant and original architect of the concept of 'potential erosion'), Robin Black (Hancock Forest Management), Kit Richards (P F Olsen Ltd), Peter Weir (Ernslaw One). James Barringer, Anne Austin and Cynthia Cripps reviewed earlier drafts of this report.

## REFERENCES

Basher L, Lynn I, Barringer J 2014. Peer review of the process proposed to update the Erosion Susceptibility Classification for the National Environmental Standard for Plantation Forestry. Landcare Research Contract Report LC1877 for Ministry for Primary Industries.

Bloomberg M, Davies T, Visser R, Morgenroth J 2011. Erosion Susceptibility Classification and analysis of erosion risks for plantation forestry. Report prepared by the University of Canterbury for the Ministry for the Environment, Wellington.

Lynn IH, Manderson AK, Page MJ, Harmsworth GR, Eyles GO, Douglas GB, Mackay AD, Newsome PJF 2009. Land Use Capability survey handbook – a New Zealand handbook for the classification of land. 3rd edn. Hamilton, AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science.

NWASCA (National Water and Soil Conservation Authority) 1986a. NZLRI worksheets (2nd edn) 1: 63 360. Wellington, National Water and Soil Conservation Authority.

NWASCA (National Water and Soil Conservation Authority) 1986b. NZLRI (2nd edn) 1: 50 000. Wellington, National Water and Soil Conservation Authority.

NWASCO (National Water and Soil Conservation Organisation) 1975–79. NZLRI worksheets 1: 63 360. Wellington, National Water and Soil Conservation Organisation.

NWASCO (National Water and Soil Conservation Organisation) 1979. 'Our Land Resources' – a bulletin to accompany NZLRI worksheets. Wellington, National Water and Soil Conservation Organisation. 79 p.

Page MJ 1985. Correlation of North Island regional land use capability units from the New Zealand land resource inventory. Water and Soil Miscellaneous Publication No. 75. Wellington, National Water and Soil Conservation Authority.

# 4 Update of the Erosion Susceptibility Classification (ESC) for the proposed NES for Plantation Forestry, subdividing the High and Very High ESC classes, Landcare - March 2016

## Final Report

MPI Technical Paper No: 2016/12

Prepared for the Ministry for Primary Industries

by Les Basher, James Barringer, Ian Lynn, Landcare Research

ISBN No: 978-1-77665-204-4 (online)
ISSN No: 2253-3923 (online)

March 2016

| **Reviewed by:** | **Approved for release by:** |
| --- | --- |
| Mike Marden<br>Scientist<br>Landcare Research | Chris Phillips<br>Portfolio Leader – Managing Land & Water<br>Landcare Research |

**Landcare Research Contract Report:** **LC2472**

# Contents

Page

## 4.1 EXECUTIVE SUMMARY


### Project and client

The Ministry for Primary Industries (MPI) is leading a process to deliver a National Environmental Standard for Plantation Forestry (NES-PF). The Erosion Susceptibility Classification (ESC) is a critical input into the proposed NES-PF as it underpins the level of resource consent control for different plantation forestry activities. Public submissions on the proposed NES-PF raised concerns about the suitability of the ESC and whether the level of control of harvesting and earthworks operations on land in the High ESC class was adequate. As a result, MPI asked Landcare Research to provide a more detailed subdivision of the High ESC class based on dominant erosion process, rock type and topography, and detail the relationship between related LUC units classed in the High and Very High ESC classes.

### Objectives

- Refine the ESC so that it can be used to assess erosion risk associated with plantation forestry activities in the High and Very High ESC classes with more accuracy.
- Provide descriptions of the revised classes within the High and Very High ESC classes and the erosion risk for different forestry activities, so that appropriate controls and conditions can be applied through the NES-PF to manage the effects of these activites.

### Methods

Subdivisions of the High and Very High ESC classes were derived from an existing “erosion terrain” classification. The revised ESC dataset was joined to the erosion terrain data (using the LegLUC field to implement the attribute join in ArcMap). The erosion terrains present in the High and Very High ESC classes were then extracted from this dataset and a pivot table used to identify which erosion terrains were present in the High and Very High ESC classes. Because the erosion terrain classification provides a very detailed subdivision of the New Zealand landscape with respect to rock type and topography they were regrouped to amalgamate terrains with similar dominant erosion process, rock types with similar erosion susceptibility, and similar topography, to provide a terrain classification relevant to forestry.

### Results

Erosion terrains in the High and Very High ESC classes were grouped by dominant erosion process to identify 6 major groupings – gullying, earthflows, landsliding, tunnel gullying, wind erosion, bank erosion and deposition. Erosion terrains were then grouped by rock types with similar strength and erodibility, and topography (hill country dominated by slopes <25° and hilly steeplands dominated by slopes >25°). A total of 21 terrains were identified.

Four classes of terrain dominated by gully erosion were recognised – terraces and fans on young flow and water sorted Taupo tephra, hill country and hilly steeplands developed on crushed argillite with large-scale gully erosion, upland plains and plateaux with tephra cover, hill country with young, deep tephra.

Two terrains dominated by earthflows occur on rolling to moderately steep hills and are formed in a range of crushed and sheared, highly erodible rock types. This terrain is also prone to gullying and large scale slumping. Both terrains have similar characteristics (slope, rock type, erosion type) with the major difference being the extent of present erosion.

Twelve terrains dominated by landsliding are recognised, with differences in underlying rock type and topography. Of these, five terrains occur in hill country dominated by slopes <25° and are formed in different rock types – weak Tertiary mudstone, weak Tertiary sandstone, weathered volcanic rocks, young tephra cover, and hard sedimentary rock. Seven terrains occur in hilly steeplands dominated by slopes >25° and are formed in different rock types – non-cohesive sands and gravels, weak Tertiary mudstone, other weak Tertiary rock types (sandstone , limestone, conglomerate, moraine, and alluvium), weathered rock types (including volcanics, greywacke, schist and granite), young tephra, old tephra cover and other volcanics, hard sedimentary, metamorphic and igneous rocks.

Three other minor terrains are recognised – steep to very steep slopes formed in deep loess highly susceptible to tunnel gully erosion, floodplains with very active bank erosion and deposition, and foredunes with severe wind erosion risk.

Management of erosion risk varies according to the dominant erosion process. In terrains at risk of gully erosion management of runoff during earthworks and harvesting is critical. In terrains underlain by tephra avoidance of compaction is important to reduce runoff generation both at harvest and throughout the forest rotation. Disturbance near existing gullies should be avoided so gullies are not reactivated. Replanting as soon as possible after harvest, or oversowing with grass, also helps manage erosion.

In terrains at risk of earthflow erosion mapping the extent and location of earthflows should be part of harvest and earthworks planning. Earthworks should avoid cuts across earthflows where possible, and runoff from roads and landings should be managed carefully to avoid increasing soil moisture on earthflows. Replanting as soon as possible after harvest helps lower soil moisture.

In terrains at risk of landslide erosion the most important issue is the occurrence of post-harvest landsliding on clearcuts and associated with earthworks. Managing cut-and-fill and runoff associated with earthworks, slash management and replanting as soon as possible following harvest helps improve slope stability and reduce soil moisture levels.

### Conclusions

- A terrain classification based on dominant erosion process, rock type and topography was developed from an existing “erosion terrain” classification. A total of 21 classes were defined and described: four terrains dominated by gully erosion; two terrains dominated by earthflows; twelve terrains dominated by landsliding; and three other minor terrains (hill country with tunnel gully erosion, floodplains with very active bank erosion and deposition, and foredunes with severe wind erosion risk. The terrain classification provides a structure for generalising the types of terrain present within the High and Very High ESC classes but ignores the detailed variability inherent in the underlying NZLRI polygon data. Management of erosion risk varies according to the dominant erosion process.

## 4.2 INTRODUCTION

The Ministry for Primary Industries (MPI) is leading a process to deliver greater national consistency in the management of plantation forestry under the Resource Management Act (RMA) by implementing a National Environmental Standard for Plantation Forestry (NES-PF). The Erosion Susceptibility Classification (ESC) developed by Bloomberg et al. (2011) from potential erosion and Land Use Capability (LUC) data associated with the New Zealand Land Resource Inventory (NZLRI) is a critical input into the proposed NES as it underpins the level of control for different plantation forestry activities. Following the intial release of the proposed NES-PF it was recognised that the ESC had limitations related to scale of the underlying NZLRI mapping and misclassification of some land (Robson 2013; Basher et al. 2014) that will result in ongoing changes to the ESC once the NES-PF is implemented.

In 2014 MPI engaged Landcare Research to refine the ESC for misclassified land and to establish a process by which changes to the ESC might be managed once the NES-PF is implemented. The work originally requested included 3 components:

1) Design of process by which a party can apply to have ESC units/polygons refined, reassessed, or new units created, and, where appropriate, officially reclassified,

2) Reclassification of those ESC units/polygons that were clearly misclassified as ‘orange’(ESC class high) or ‘red’ (ESC class very high) under the original ESC (Bloomberg et al. 2011),

3) A classification of ‘graded level of severity’ applied to the ‘orange’ category under the updated ESC.

In 2015 components 1 and 2 were completed (Basher et al. 2015a, b) and were released with the consultation document on the NES-PF (MPI 2015). The consultation document included the proposed rule set for controlling forestry activities on the 4 ESC classes of land. Public submissions raised concerns about the suitability of the ESC and whether the level of control of harvesting and earthworks operations on land in the High ESC class (the ‘orange’ zone) was adequate. In response MPI decided to complete the third component of the original work request.

## 4.3 BACKGROUND

The proposed NES-PF applies different levels of resource consent control for forestry activities (permitted, controlled, restricted discretionary) depending on the effects of the activity and the environmental risks to be managed. The draft rule set for the NES-PF sets controls for eight forestry activities – afforestation, harvesting, earthworks, mechanical land preparation, quarrying, river crossings, pruning and thinning-to-waste, and replanting. It is based on 3 principles:

- Where possible, forestry activities should be permitted, provided robust permitted activity conditions are met
- As the risk of adverse environmental effects increases (especially erosion), the requirement for resource consent becomes more likely and conditions become more stringent

– The rules should provide a consistent national approach but also reflect local conditions

The proposed NES-PF was open for public consultation between 17 June and 11 August 2015 and a large number of submissions were received. Many submissions expressed concern that the level of control applied to harvesting and earthworks operations in the High ESC zone would not adequately manage the risks of sediment generation and delivery to waterways. Harvesting and earthworks are core forestry activities and have a higher risk of adverse environmental effects in more erodible landscapes (see Fransen et al. 2001; Phillips et al. 2012).

The proposed NES-PF requires that a resource consent be obtained for harvesting and earthworks in the Very High ESC zone; however, the activities are permitted (subject to compliance with permitted activity conditions) in the High ESC zone, except for earthworks on slopes >25°, which also require a resource consent. The High ESC zone comprises c. 365 000 hectares of land under plantation forest. LUC units in the High ESC class commonly have similarities in rock type, topography, and erosion type to related LUC units in the Very High ESC class; however, generally the slopes are less steep and/or the susceptibility to erosion is lower. This report provides a more detailed subdivision of the High ESC class based on dominant erosion process, rock type and topography, and details the relationship between LUC units classed as High and Very High ESC.

## 4.4 OBJECTIVES

- Refine the ESC so that it can be used to assess erosion risk associated with plantation forestry activities in the High and Very High ESC classes with more accuracy.
- Provide descriptions of the revised classes within the High and Very High ESC classes and the erosion risk for different forestry activities.

## 4.5 METHODS

Subdivisions of the High and Very High ESC classes were derived from an existing “erosion terrain” classification held as part of Landcare Research’s Our Environment portal [1]. An erosion terrain is defined as a landtype with a unique combination of erosion processes and associated erosion rates. The spatial coverage of erosion terrains was derived by assigning LUC units from the NZLRI to produce terrains that had unique combinations of rock type, landform, slope, erosion type and severity. The full list of erosion terrains for New Zealand is given in Appendix 1. The boundaries of the erosion terrains are coincident with the ESC mapping boundaries, having been derived from the same underlying NZLRI dataset.

The revised ESC dataset (Basher et al. 2015b) provided to MPI (file name “Revised_ESC_final.shp”) was joined to the erosion terrain data (file name “nz_erosion”) using the LegLUC field to implement the attribute join in ArcMap. The erosion terrains present in the High and Very High ESC classes were then extracted from this dataset and a



[1] Available at http://ourenvironment.scinfo.org.nz/ourenvironment#layerIds=94,76,125,77,113,107,78,85,82,84,103,127,128,129,106,139&activeLayer=lri_observed_erosion&center=5409587.1080631,1588434.5102024&z=7&pq=1587108.4158835,5410905.4412552

pivot table used to identify which erosion terrains were present in the High and Very High ESC classes.

The erosion terrain classification provides a very detailed subdivision of the New Zealand landscape with respect to rock type and topography with 74 classes (Appendix 1), of which 48 were present in the High and Very High ESC classes. Therefore, the erosion terrains were regrouped to amalgamate terrains with similar dominant erosion process, rock types with similar erosion susceptibility. The erosion terrain groupings of topography were retained (Appendix 1). This reduced the total number of classes in the High and Very High ESC from 48 to 21 (Table 1). The classes are simply referred to as terrains.

The terrain class for each LUC unit present in the High and Very High ESC classes was identified. Where dual LUC units were present (e.g. 2s3+7e7) they were treated in the same way as Bloomberg et al. (2011) and Basher et al. (2015b). That is, they were allocated to the terrain class with the highest ESC rating. A full list of LUC units and their associated terrain class is given in Appendix 2.

The alternative approach of deriving a classification directly from the NZLRI data was considered but rejected for a number of reasons:

- Many polygons have multiple rock types, multiple slope classes and multiple erosion types and severity. The LUC unit description and associated erosion terrain class generalises this variability in the raw NZLRI data.
- Differences in erosion recording between South Island 1$^{st}$ edition NZLRI mapping and North Island and 2$^{nd}$ edition NZLRI mapping complicate analysis of the raw NZLRI erosion data.
- As a consequence, it was considered that a query of the raw NZLRI data would produce a complex result that would then have to be generalised to produce useful subdivisons according to erosion type and severity, dominant rock type, and dominant slope.

It was considered that utilising the erosion terrains provided a filter to generalise the detail in the individual NZLRI polygons that classified patterns of erosion type and severity and provided a boundary at 25° (separating hill country dominated by slopes <25° from hilly steeplands and mountain steeplands dominated by slopes >25°), which is used in the proposed rule set for the High ESC class under the NES-PF. However, it needs to be recognised that the erosion terrain classification provides a structure for generalising the types of terrain present within the High and Very High ESC classes but ignores the detailed variability inherent in the underlying NZLRI polygon data.

## 4.6 RESULTS

### 4.6.1 Basis of the groupings

Erosion terrains in the High and Very High ESC classes were grouped by dominant erosion process to identify 6 major groupings (Table 1) – gullying, earthflows, landsliding, tunnel gullying, wind erosion, bank erosion and deposition. Then erosion terrains were grouped by rock types with similar strength and erodibility. This grouped together erosion terrains on old hard rock types (Gw, Ar, Ma, Hs, St2, Sy, Gn, In, Vo [2]), separated weaker (Mb, Mm, Mj, Ms) from stronger (Sm, Sb, Ss, Cw, Cg, Li, Gr) Tertiary soft rock types, and identified erosion terrains on strongly weathered rock types. The last were not consistently recorded in the NZLRI inventory, therefore utilising the erosion terrain classification provided a means to identify those LUC units dominated by strongly weathered soils and regolith.

The erosion terrain classification also included a topographic subdivision between hill country (dominated by slopes <25°) and hilly steeplands (dominated by slopes >25°), which coincides with the slope threshold used to require a resource consent for earthworks in the High ESC zone. However, the erosion terrain classification also distinguished two broad groups on the basis of relief (hilly steeplands with <300 m relief and mountainous steeplands with >300 m relief). This distinction was not considered relevant in a forestry context since in high relief terrain slope length is typically broken by roads, and therefore hilly steeplands and mountainous steeplands formed on similar rock types were grouped together (Table 1).

The allocation of the erosion terrains (from Appendix 1) to terrain groupings is shown in Table 1. Maximum mapped mass movement erosion, potential erosion and revised ESC rating for each LUC unit is given in Basher et al. (2015b).



[2] Abbreviations for rock type slope, and erosion in the text follow Lynn et al. (2009) or NWASCO (1979)

*Table 8: List of LegLUC values in High and Very High ESC classes arranged according to dominant erosion process and terrain grouping*

| Dominant erosion process | Terrain grouping | High ESC class | Very high ESC class | Erosion terrains3 |
|---|---|---|---|---|
| Gullying | Terraces and fans on young flow and water sorted tephra | 047e124, 077e16, 107e19 | 048e 2, 078e 4, 108e 2 | 4.2.2, 4.2.3 |
| | Hilly steeplands developed on crushed argillite with severe gully-dominated erosion | 016e19, 067e 8 | 017e 8, 067e21, 067e22, 067e24, 068e 9, 077e15, 087e13 | 6.4.4, 7.3.2 |
| | Upland plains and plateaux with tephra cover | 047e15, 048e 5 | | 8.1.1 |
| | Hill country with deep tephra | 076e15 | | 6.2.3 |
| Earthflows | Hill country developed on crushed argillite, Tertiary-aged mudstone and sandstone with moderate earthflow-dominated erosion | 007e 5, 067e 7, 086e12, 107e 6 | | 6.4.2, 6.4.5 |
| | Hill country developed on crushed argillite, mudstone and greywacke with severe earthflow-dominated erosion | 017e 2, 027e 4, 067e 6, 067e 9, 067e12, 077e 6, 087e 7, 087e 9, 107e12 | 067e18, 067e19, 067e25, 077e10, 087e 6, 087e 8, 088e 3, 107e14 | 6.4.3 |
| Landsliding | Hill country on weak Tertiary mudstone | 076e 7 | | 6.4.1 |
| | Hill country on weak Tertiary sandstone | 007e20 | | 6.1.1, 6.4.5, 6.4.7, 6.4.8 |
| | Hill country on weathered volcanics | 016e16, 036e11 | | 6.7.2, 6.7.4 |
| | Hill country with young tephra cover; both landsliding and gullying | 047e 8, 047e13, 047e14, 077e19 | | 6.2.2, 6.2.3 |
| | Hill country on hard sedimentary rock | 007e 7, 117e26 | | 6.5.1, 6.5.2, 6.5.3 |



[3] For the complete list of erosion terrains see Appendix 1

[4] Note the LegLUC unit format is xxyyyy where xx = legend (00 = South Island 1st edition, 01 = Northland, 02 = Waikato, 03 = Coromandel, 04 = Bay of Plenty–Volcanic Plateau, 05 = Eastern Bay of Plenty, 06 = Gisborne-East Coast, 07 = Northern Hawke's Bay, 08 = Southern Hawke's Bay-Wairarapa, 09 = Wellington, 10 = Taranaki Manawatu, 11 = Marlborough), yyyy = LUC unit

| Dominant erosion process | Terrain grouping | High ESC class | Very high ESC class | Erosion terrains3 |
|---|---|---|---|---|
| | Hilly steeplands developed on non-cohesive sands, and gravels; both landsliding and gullying | 027e10 | 107e16 | 7.4.3 |
| | Hilly steeplands on weak Tertiary mudstone | 007e 4, 067e 2, 067e 3, 067e 4, 067e 5, 077e 1, 077e 2, 078e 3, 087e 1, 087e 2, 107e 1, 107e 2, 107e 7 | 067e 1, 067e23, 068e 2, 068e 3, 077e 4, 077e11, 087e12, 107e20, 118e 3 | 7.3.1 |
| | Hilly steeplands on weak Tertiary sandstone, limestone, conglomerate, moraine, alluvium | 007e13, 007e22, 017e 4, 027e 1, 027e12, 067e10, 067e14, 067e15, 067e16, 067e17, 077e 3, 077e 5, 077e 8, 077e 9, 078e 2, 087e 4, 107e 3, 107e 4, 107e 5, 107e 9, 107e11, 107e13, 107e17, 107e23, 117e 6, 117e13, 117e16 | 068e 6, 088e 1, 088e 2, 108e 3 | 7.4.1. 7.4.2 |
| | Hilly steeplands on weathered volcanics, greywacke, argillite, schist, granite | 007e 9, 017e 1, 017e 7, 026e17, 027e 8, 037e 1, 037e 2, 037e 3, 037e 7, 067e13, 117e12, 118e 4 | 068e 5 | 7.6.1, 7.6.2, 7.7.1, 7.7.2, 7.7.3 |
| | Hilly steeplands with young tephra cover; both landsliding and gullying | 047e 2, 047e 3, 047e 9, 047e11, 067e20, 077e14 | | 7.1.1, 7.1.2 |
| | Hilly steeplands with old tephra cover and other volcanics | 027e11, 047e 4, 047e 5, 048e 3 | 048e 4 | 7.1.3, 7.2.1 |
| | Hilly and mountainous steeplands on hard sedimentary, metamorphic and igneous rocks | 007e 8, 007e25, 008e 1, 008e 2, 008e 3, 008e 4, 008e 8, 008e 9, 017e 3, 017e 5, 017e 6, 018e 2, 018e 3, 027e 6, 027e 9, 028e 1, 028e 2, 028e 3, 037e 4, 037e 5, 037e 8, 037e 9, 038e 2, 047e10, 048e 6, 048e 7, 058e 1, 058e 2, 067e11, 077e 7, 078e 5, 078e 7, 078e 8, 078e 9, 088e 5, 088e 7, 088e 8, 097e 5, 098e 2, 098e 3, 098e 4, 107e18, 108e 4, 108e 5, 108e 6, 108e 8, 117e 5, 117e 8, 117e11, 117e18, 118e 1, 118e 2, 118e 5, 118e 6, 118e 7, 118e 8, 118e 9, 118e11, 118e12, 118e13 | 008e 5, 008e 7, 008e11, 038e 3, 038e 4, 068e 4, 068e 7, 068e 8, 078e 6, 088e 6, 098e 5, 108e 7, 108e 9, | 7.5.1, 7.5.2, 7.5.3, 7.5.4, 7.5.5, 8.2.1, 8.3.1, 8.3.2, 8.3.3, 8.6.1, 8.6.2 |
| Tunnel gullying | Hill country on deep loess | 007e14, 117e17 | | 6.2.1 |
| Bank erosion and deposition | Floodplains with severe bank erosion and deposition | 067e26 | 068s2 | 1.1.1 |

| Dominant erosion process | Terrain grouping | High ESC class | Very high ESC class | Erosion terrains3 |
|---|---|---|---|---|
| Wind erosion, some gullying on older dunes | Sand country, foredunes | 017e 9 | 008e10, 018e 1, 028e 4, 038e 1, 048e 1, 068e 1, 078e 1, 088e 4, 098e 1, 108e 1, 118e15 | 2.1.1, 2.1.2, 2.1.3 |

#### 4.6.2 Terrains dominated by gullying

Four classes of terrain dominated by gully erosion are recognised:

a) Terraces and fans on young flow and water sorted Taupo tephra (Tp). Class 7 LUC units are in the High ESC class and occur on flat to rolling terraces with incised gullies, and with soils developed on young, highly erodible tephra. Soils have low natural fertility, are highly permeable but have poor structure, weak soil strength, and are highly erodible if disturbed. There is a potential for very severe gully and streambank erosion, and severe sheet erosion. Related class 8 LUC units are in the Very High ESC class and occur on similar parent materials where the terraces are more dissected, slopes tend to be steeper, and present erosion is more active. These LUC units are restricted to the central North Island Volcanic Plateau.

   In this terrain runoff control is critical both at harvest and inter-rotation. In an undisturbed state the soils are highly permeable but when they are compacted infiltration is reduced to very low rates and runoff can cause severe erosion. Runoff control associated with earthworks (roads and landings) needs to be maintained throughout the forest rotation. Providing surface cover of slash can also help to reduce runoff generation and control its effects.

b) Hilly steeplands developed on crushed argillite with severe gully-dominated erosion. Moderately steep to steep terrain on highly erodible crushed argillite (Ar), greywacke (Gw), sandstone (Sm), and mudstone (Mj) with severe, large-scale gully erosion. Large-scale slump and earthflow erosion can also occur in this terrain which is some of the most naturally susceptible to erosion in New Zealand. The topography is mostly steep (F slopes dominant), but there are also significant areas of easier slope (E) included within this terrain.

   Most of this terrain is in Very High ESC class but two LegLUC units in the High ESC class tend to be less steep and have less present erosion; however, the High ESC terrain also has the potential for increased erosion if not well managed. This terrain is located mostly in the Gisborne-East Coast area, with related LegLUC units in Northland.

   In this terrain runoff control is critical at harvest, especially associated with earthworks on sloping terrain. Where possible, disturbance near existing gullies should be avoided so gullies are not reactivated. Replanting as soon as possible after harvest also helps manage erosion; however, gullies should not be replanted in a harvestable species and the gully should be allowed to revert to provide continuous cover in gullies. Earthworks should avoid existing gullies.

c) Upland plains and plateaux with tephra cover. This terrain comprises flat to rolling slopes mantled with very young tephra (mostly mapped as Ng and Ta). Because the tephra is very young it has less of a history of gully erosion than the terraces and fans on Taupo tephra; however, it is very susceptible to gully erosion if disturbed and compacted. Two related LegLUC units are both in the High ESC class.

   Runoff control critical both at harvest and inter-rotation. In an undisturbed state the soils are highly permeable but when they are compacted infiltration is reduced to very low rates and runoff can cause severe erosion. Providing surface cover of slash can also help to reduce runoff generation and control its effects.

d) Hill country with deep tephra. This occurs on rolling to moderately steep hills with a mantle of deep Kaharoa and Taupo airfall tephra (Kt) over Waimihia Lapilli (Lp). There is a potential for severe gully erosion and slight soil slip erosion. Only one LegLUC unit occurs in this terrain and it is in the High ESC class. It is located in the hill country east of Lake Taupo

   Like the other gully erosion-prone terrains formed in young tephra, runoff control is critical both at harvest and inter-rotation. Because slopes are steeper there is potential for greater erosion where runoff is generated.

Recognising the extent and location of existing gullies should be part of harvest and earthworks planning to avoid disturbing existing gullies in all the gully-erosion prone terrains. Replanting as soon as possible after harvest, or oversowing with grass, helps manage erosion

### 4.6.3 Terrains dominated by earthflows

Two terrains dominated by earthflows are recognised. Both are on rolling to moderately steep hills and are formed in a range of crushed and sheared, highly erodible rock types:

a) Hill country developed on crushed argillite (Ac), Tertiary-aged mudstone (Mj, Mb), and sandstone (Sm, Ss) with moderate earthflow-dominated erosion. All LegLUC units in this terrain are in the High ESC class.

b) Hill country developed on crushed argillite (Ac), mudstone (Mj, Me, Mb), and greywacke (Gw) with severe earthflow-dominated erosion. LegLUC units in this terrain are in both the High and Very High ESC classes

These terrains are also prone to gullying and large-scale slumping. Both terrains have similar characteristics (slope, rock type, erosion type), with the major difference being that the extent of present erosion is greater in the terrain with severe earthflow-dominated erosion. Most of the earthflow-dominated terrain is located in the Gisborne region but it also occurs in Northland, Waikato, Hawke's Bay, Taranaki, Manawatu, and there is a small area in North Canterbury.

Recognising the extent and location of earthflows should be part of harvest and earthworks planning. Earthworks should avoid earthflows where possible as this may reactivate them. Runoff from roads and landings should be managed carefully to avoid increasing soil moisture levels on earthflows. Replanting as soon as possible after harvest helps lower soil moisture levels. If necessary, springs on earthflows can be drained to help reduce soil moisture.

### 4.6.4 Terrains dominated by landsliding

Twelve terrains dominated by landsliding are recognised. They are distinguished by differences in underlying rock type and topography.

Five terrains occur in hill country dominated by slopes <25°. In order of decreasing erosion susceptibility these are:

- hill country on weak Tertiary mudstone (Mm). This terrain is dominated by E slopes but there are significant areas of F slopes in many polygons. Shallow landslides are characteristic in this terrain. It is only mapped in northern Hawke's Bay.
- hill country on weak Tertiary sandstone (Ss). This terrain is dominated by E and D slopes but there are smaller areas of F slopes in many polygons. Shallow landslides are characteristic in this terrain which is only mapped in Southland.
- hill country on hard sedimentary rock (Hs). The topography is dominated by E and D slopes but there are significant areas of F and G slopes within some polygons. This is mapped mostly in southern Marlborough, with small areas in north and south Canterbury.
- hill country on weathered volcanic rocks (Vo', Vu'). Both shallow and deep landslides occur within this terrain. It is mapped in Northland and the Coromandel. The topography is dominated by E slopes but there are significant areas of F slopes within most polygons and it could be grouped with 'Hilly steeplands on weathered volcanics, greywacke, argillite, schist, granite'. This terrain occurs in areas where high intensity storms are common and has the potential to produce large amounts of fine sediment because the soils and regolith have high clay content.
- hill country with young Tarawera (Ta), Taupo and Kaharoa (Tp, Kt) tephra cover, underlain by lapilli (Lp), older tephra (Mo) and volcanic rocks (Vo) which is prone to both landsliding and gullying. The topography is dominated by E and D slopes but there are significant areas of F slopes within some polygons. This terrain is mapped in the hill country to the east of Lake Taupo and the Rotorua lakes.

All LegLUC units in the hill country are in the High ESC class.

Seven terrains occur in hilly steeplands dominated by slopes >25° – in order of decreasing erosion susceptibility these are:

- hilly steeplands on non-cohesive sands and gravels (Us) susceptible to both landsliding and gully erosion. The rock is poorly consolidated and highly erodible while the topography is steep with mostly F and G slopes. This terrain occurs scattered through the Waikato where it is mapped in High ESC class and also in the Wanganui and Manwatu where it is mapped in the Very High ESC class.
- hilly steeplands on weak Tertiary mudstone (Mb, Mm, Mj, Ms). The topography is steep, with mostly F and G slopes, and shallow soils over weakly indurated mudstone. Extensive shallow landsliding occurs in this terrain following high intensity storms. This terrain is split between the High and Very High ESC classes but both occur on similar rock type. It is mapped extensively in the Gisborne-East Cape area, northern and Southern Hawke's Bay, Taranaki, northern Manawatu, and scattered areas of the South Island West Coast, and inland Marlborough. .
- hilly steeplands on other weak Tertiary rock types including sandstone (Sm, Sb, Ss), limestone (Li), conglomerate (Cw, Cg), moraine, and alluvium (Gr). The topography is steep, with mostly F and G slopes, and shallow soils over a range of weakly indurated rock types. Extensive shallow landsliding can occur in this terrain following high intensity storms, although it tends to be less affected than the mudstone terrain. Most of this terrain is mapped in the High ESC class with some class 8 LUC units

mapped in the Very High ESC class. It is mapped extensively in Taranaki, northern Manawatu, Gisborne-East Cape, northern Hawke’s Bay, and scattered areas in southern Northland, north Westland, Nelson, and Marlborough.

- hilly steeplands on weathered volcanics (Vu', Vo), greywacke (Gw'), schist (St2, Sy) and granite (Gn). The topography is mostly steep (F slopes dominant), although in the South Island significant areas of easier slope (E) are included. Landslides are mostly shallow but deeper landslides, and gullying, can occur within this terrain. It is mapped extensively in Northland, northern Waikato, and the Coromandel, and also in Nelson and Marlborough (including the Marlborough Sounds). This terrain also occurs in areas where high intensity storms are common and it has the potential to produce large amounts of fine sediment because the soils and regolith have high clay content. It also includes the Separation Point Granite in Nelson which produces coarse sandy sediment from landsliding. This terrain is mapped in the High ESC class except for one class 8 LUC unit mapped in the Very High ESC class in the Gisborne area.
- hilly steeplands with young Taupo and Kaharoa tephra (Kt), and older ash (Mo) susceptible to both shallow landsliding and gullying. The topography is dominated by F slopes but there are significant areas of easier (E) slopes within some polygons. This terrain is mapped in the Bay of Plenty around the Rotorua lakes and in inland Gisborne. This terrain is all mapped in the High ESC class.
- hilly steeplands with old tephra cover (Mo) and other volcanics (Vo). The topography is dominated by F and G slopes. This terrain is mapped extensively in the hilly steeplands of the Bay of Plenty and to the south-east of Lake Taupo. It is mostly mapped in the High ESC class except for one class 8 LUC unit.
- hilly and mountainous steeplands on hard sedimentary (Gw, Ar, Ma, Hs), metamorphic (St2, Sy) and igneous rocks (Gn, In, Vo). This terrain is extensively mapped through the ranges of the South and North Islands, with minor areas in the Northland and Coromandel ranges. While this terrain is steep (F and G slopes) it is mostly stable. While shallow landsliding occurs after high intensity storms the density is typically lower than in the Tertiary soft rock hill country. Most of this terrain is mapped in the High ESC class except for some class 8 LUC units which tend to be in high rainfall areas.

The LegLUC units in the hilly steeplands typically have related units in the High and Very High ESC classes and for several terrains the underlying rock type is similar to LegLUC units in the hill country (see Table 1).

For forest management the most important issue is the occurrence of post-harvest landsliding (Phillips et al. 2012). This occurs both on clearcuts and associated with earthworks. Managing cut-and-fill and runoff associated with earthworks is important for reducing the incidence of landsliding. Slash management can also help with managing debris flows associated with post-harvest landslides. Replanting as soon as possible following harvest helps improve slope stability and reduce soil moisture levels. Oversowing with grass can also help to manage erosion.

#### 4.6.5 Terrains dominated by tunnel gullying

This terrain has steep to very steep slopes (mostly E and F) formed in deep loess (Lo) over weakly indurated sedimentary (Cw, Mm) or volcanic (Vo) rocks. The loess is highly susceptible to tunnel gully erosion and is also susceptible to landslides in high intensity storms. This terrain is mapped in the Marlborough area and Banks Peninsula. Both LegLUC units are in the High ESC class.

Control of runoff is key to avoiding tunnel gully erosion. Runoff associated with earthworks needs to be managed carefully. Replanting as soon as possible following harvest helps improve slope stability and reduce soil moisture levels.

### 4.6.6 Terrains dominated by bank erosion and deposition

Two related LegLUC units with high rates of sediment delivery, deposition and bank erosion occur in rivers of the Gisborne region. One (067e26) is on flat to undulating usually extremely gravelly and bouldery, low river terraces subject to frequent flooding, gravel deposition, and persistent severe streambank erosion; and also on some extremely gravelly alluvial fans that frequently receive erosion debris from active gullies. This unit is mapped in the High ESC class. The other (068s 2) is on very active river beds also subject to frequent flooding, gravel deposition, and persistent severe streambank erosion. Land in both units is at risk of complete destruction during the lifetime of a forest rotation.

This risk can only be alleviated by not planting these areas.

### 4.6.7 Terrains dominated by wind erosion

This terrain is on undulating and rolling foredunes subject to extreme wind erosion and is mapped in most regions. This terrain was all mapped in the Very High ESC class. Also includes areas in Northland on older stable dunes (LegLUC 017e9) with strongly rolling to very steep slopes that are subject to both wind and gully erosion.

The risk of erosion can be managed by maintaining cover (including slash) and replanting rapidly.

## 4.7 CONCLUSIONS

A terrain classification based on dominant erosion process, rock type and topography was developed from an existing “erosion terrain” classification. A total of 21 classes were defined and described: four terrains dominated by gully erosion; two terrains dominated by earthflows; twelve terrains dominated by landsliding; and three other minor terrains (hill country with tunnel gully erosion, floodplains with very active bank erosion and deposition, and foredunes with severe wind erosion risk. The terrain classification provides a structure for generalising the types of terrain present within the High and Very High ESC classes but ignores the detailed variability inherent in the underlying NZLRI polygon data. Management of erosion risk varies according to the dominant erosion process. This report makes recommendations for managing risk from the dominant erosion proccesses for different forestry activities.

## REFERENCES

Basher L, Lynn I, Barringer J 2014. Peer review of the process proposed to update the Erosion Susceptibility Classification for the National Environmental Standard for

Plantation Forestry. Landcare Research Contract Report LC1877 for Ministry for Primary Industries.

Basher L, Lynn I, Barringer J 2015a. Update of the Erosion Susceptibility Classification (ESC) for the proposed NES for Plantation Forestry: Managing changes to the ESC and incorporating detailed mapping. MPI Technical Paper No. 2015/12. Wellington, Ministry for Primary Industries

Basher L, Lynn I, Page M 2015b. Update of the Erosion Susceptibility Classification (ESC) for the proposed National Environmental Standard for Plantation Forestry – revision of the ESC. MPI Technical Paper No. 2015/13. Wellington, Ministry for Primary Industries

Bloomberg M, Davies T, Visser R, Morgenroth J 2011. Erosion Susceptibility Classification and analysis of erosion risks for plantation forestry. Report prepared by the University of Canterbury for the Ministry for the Environment, Wellington.

Fransen PJB, Phillips CJ, Fahey BD 2001. Forest road erosion in New Zealand: overview. Earth Surface Processes and Landforms 26: 165–174.

Lynn IH, Manderson AK, Page MJ, Harmsworth GR, Eyles GO, Douglas GB, Mackay AD, Newsome PJF 2009. Land Use Capability Survey Handbook – a New Zealand handbook for the classification of land, 3rd ed. Hamilton, AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science.

Ministry for Primary Industries 2015. A National Environmental Standard for Plantation Forestry, Consultation Document 2015. MPI Discussion Paper No. 2015/18. Wellington, Ministry for Primary Industries.

NWASCO 1979. Our land resources. Wellington, National Water and Soil Conservation Organisation. 79 p.

Phillips C, Marden M, Basher L 2012. Plantation forest harvesting and landscape response – what we know and what we need to know. New Zealand Journal of Forestry 56: 4–12.

Robson B 2013. Updating the Erosion Susceptibility Classification – process for finer scale mapping and assessment. Report for Ministry for Primary Industries, Wellington.

# 5 Erosion Susceptibility Classification for the NES for Plantation Forestry, Landcare – March 2017


## Les Basher, James Barringer

**Landcare Research**


Prepared for:

**Ministry for Primary Industries**

Pastoral House, 25 The Terrace
PO Box 2526
Wellington 6140
New Zealand

**March 2017**


**Landcare Research, 1st Floor, 24 Nile Street, Private Bag 6, Nelson 7042, New Zealand, Ph +64 3 545 7700, www.landcareresearch.co.nz**


| Reviewed by: | Approved for release by: |
|---|---|
| Ian Lynn<br>Capability Leader<br>Landcare Research | Chris Phillips<br>Portfolio Leader – Managing Land & Water<br>Landcare Research |


Landcare Research Contract Report: LC2744

## CONTENTS

## 5.1 SUMMARY

### Project and client

- The Ministry for Primary Industries (MPI) is leading a process to deliver a National Environmental Standard (NES) for Plantation Forestry. The Erosion Susceptibility Classification (ESC) is used to identify the susceptibility of land to erosion and then to set regulatory thresholds for various plantation forestry activities. MPI engaged Landcare Research to refine the ESC for the High and Very High classes, extend the classification over the whole of mainland New Zealand, improve the mapping precision along river margins, lakes and the coast, and create overlays to identify specific erosion processes and all class 8e land.

### Objectives

- To provide a final spatial data set for the ESC and document the revision in a report.
- To extend the ESC classification over the whole of mainland New Zealand.
- To improve the mapping precision for the ESC along river margins, lakes and the coast.
- To create overlays that identify ESC units where:
    - the primary erosion type is gully or tunnel gully erosion and of severe erosion potential or greater
    - the primary erosion type is earthflow and the geology is crushed argillite, Tertiary mudstone or sandstone
    - LUC class 8e land is included (including compound units with dual LUC unit).

### Methods

- A version of the ESC data set was created that included the New Zealand Land Resource Inventory (NZLRI), potential erosion severity data (PES), the erosion terrains, and the ESC data (both the original ESC classification and the revised ESC classification).
- Boundary issues along river margins, lakes and the coastal marine area caused by the ESC mapping being based on old base maps (from the NZLRI) were corrected by an automated procedure that realigned coastlines, lake margins and river beds to currently accepted LINZ 1:50,000 scale mapping boundaries for these areas.
- The original ESC database (Bloomberg et al. 2011) was compared with the NZLRI to identify LUC units that had not previously been classified, and these units were classified following the procedure described in Basher et al. (2015a).
- The single spatial database covering all New Zealand (with the original ESC classification, the revised ESC classification, the potential erosion data and erosion terrains, and base NZLRI data) was queried to identify LegLUC units in five erosion terrains for which the ESC class was changed from High to Very High. This produced a list of LegLUC units in each erosion terrain. This list was inspected to identify LegLUC

units associated with each erosion terrain that did not require reclassification, either because their ESC class was already Very High, or was Moderate or Low. LegLUC units associated with multiple erosion terrains were also identified. Those polygons where LegLUC was associated with the relevant erosion terrain were reclassified from High to Very High.

- All polygons where PES was ≥3 were identified in the database fields G (gully) and T (tunnel gully), and fields were added for G ≥ 3 (Ggt3) and T ≥ 3 (Tgt3) with attribute values of Yes (where the polygon met the criterion PES ≥ 3) or No (where the criterion was not met).
- Polygons where the primary erosion type was earthflow and the geology was crushed argillite, Tertiary mudstone or sandstone were identified from erosion terrains 6.4.2 and 6.4.3. A field Ef_terrain was added to the database with attribute values of Yes (where the polygon met the criterion code = 6.4.2 or 6.4.3) or No (where the criterion was not met).
- All ESC units that include LUC class 8e land were identified by querying for field LegLUC LIKE '%8e%' (where % is the wildcard character). A field Class8 was added with attribute values of Yes (where the polygon met the criterion LegLUC LIKE '%8e%') and No (where the criterion was not met).

**Results**

- Realigning the NZLRI polygon boundaries to the current coastline has reduced the total mapped land area by 137,816 ha.
- Fifty-four LegLUC units were identified that were present in the NZLRI but missing from the original Bloomberg et al. (2011) ESC classification. They were mostly dual LUC units, and in most cases one of the two LUC units had already been classified.
- Eighty-nine LegLUC units were reclassified from High to Very High based on their erosion terrain. The total increase in the Very High ESC class is c. 4.5 million ha, although much of this change is due to incorporation of Crown land (Department of Conservation estate) not previously included in the analysis of ESC (c. 3.5 million ha).
- Nineteen LegLUC units were split between Very High and High ESC classes based on variation in rock type or soil within some erosion terrains.
- A total of 4,491,636 ha was identified as having severe or higher potential for gully erosion, much of which is in the Southern Alps.
- A total of 7,980 ha was identified as having severe or higher potential for tunnel gully erosion, most of which is in the North Island on areas with young tephra (5,315 ha) or the South Island on deep loess (1,639 ha).
- A total of 514,588 ha was identified with dominant earthflow erosion, mostly in the Wairarapa–Southern Hawke's Bay, Northland and Gisborne areas.
- A total of 5,571,921 ha of land contains LUC class 8 with an erosion limitation, mostly in the South Island mountainlands (83%) and the North Island axial greywacke ranges.

### Conclusions

- The ESC classification has been extended to cover all of mainland New Zealand, and a final spatial data set has been prepared as an ArcGIS shapefile.
- Polygon boundaries are now consistent with currently accepted boundaries for the rivers, lakes and the coast.

## 5.2 INTRODUCTION

The Ministry for Primary Industries (MPI) is leading a process to deliver greater national consistency in the management of plantation forestry under the Resource Management Act by implementing a National Environmental Standard for Plantation Forestry (NES-PF). The Erosion Susceptibility Classification (ESC) is used to identify the susceptibility of land to erosion and then to set regulatory thresholds for various plantation forestry activities. It was originally developed by Bloomberg et al. (2011), then revised by Basher et al. (2015a), and the types of land in the High and Very High ESC classes were further described by Basher et al. (2016). However issues remained with:

- the assigned ESC class for some land (in the High ESC class)
- the ESC not covering the whole of New Zealand
- boundary issues caused by the ESC mapping being based on old base maps inconsistent with current boundaries for river margins, lakes and the coastal marine area.

The basis of the ESC and its derivation from potential erosion and Land Use Capability (LUC) data from the New Zealand Land Resource Inventory (NZLRI) is comprehensively described in Bloomberg et al. (2011) and Basher et al. (2014, 2015a) and is not repeated here. The limitations of the ESC in terms of possible misclassification of some land and the scale of the underlying data are discussed by Basher et al. (2014, 2015a). Again this is not repeated here, but some of those limitations remain relevant to this final data set, especially related to scale and compound LUC units (i.e. where a polygon in the NZLRI has dual LUC units). In addition, there is poor registration of currently accepted river, lake and coastal boundaries (defined by LINZ) and those contained in the NZLRI.

MPI engaged Landcare Research to complete several refinements to the ESC. The specific tasks sought were to:

1. provide a final report and spatial data set for the ESC that updates the 2015 classification (Basher et al. 2015a) based on the subdivisions of the High ESC category from the 2016 erosion terrains report (Basher et al. 2016)
2. extend the 2015 ESC classification over Crown land in the spatial data set, which extends the ESC mapping over all land originally mapped as ‘Undefined’ by Bloomberg et al. (2011)
3. improve the mapping precision for the ESC along river margins, lakes and the coast
4. create overlays that identify ESC units with the following characteristics:
    a. primary erosion type is gully or tunnel gully erosion and of severe erosion potential or greater

b. primary erosion type is earthflow and the geology is crushed argillite, Tertiary mudstone or sandstone

c. all ESC units (including compound units) that include LUC class 8e land.

## 5.3 OBJECTIVES

- To provide a final report and spatial data set for the ESC that updates the 2015 classification (Basher et al. 2015a) based on the subdivisions of the 'High' ESC category from the 2016 erosion terrains report (Basher et al. 2016).
- To extend the 2015 ESC classification over Crown land in the spatial data set.
- To improve the mapping precision for the ESC by registering to modern delineation of river margins, lakes and the coast along river margins, lakes and the coast.
- To create overlays that identify ESC units with the following characteristics:
  - primary erosion type is gully or tunnel gully erosion and of severe erosion potential (3) or greater
  - primary erosion type is earthflow and the geology is crushed argillite, Tertiary mudstone or sandstone
  - all ESC units (including compound units) that include LUC class 8e land.

## 5.4 METHODS

The analysis proceeded logically by:

- creating a version of the data set that included the NZLRI, the potential erosion data, the erosion terrains and the ESC data, and both the original ESC classification (Bloomberg et al. 2011) and the revised ESC classification (Basher et al. 2015a)
- correcting the boundary issues along river margins, lakes and the coast caused by the ESC mapping being based on old base maps (from the NZLRI) that were inconsistent with current LINZ boundaries for these areas
- extending the ESC classification over all land classed as 'Undefined' in the original data set (Bloomberg et al. 2011)
- revising the classification of some land classed as High by Basher et al. (2015a) based on the erosion terrains analysis (Basher et al. 2016)
- creating overlays to identify ESC units dominated by gully, tunnel gully and earthflow erosion, and all polygons containing class 8e land.

### 5.4.1 Improving the mapping precision for the ESC along river margins, lakes and the coastal marine area

The ESC was derived from the NZLRI, which was created between the 1970s and 1990s using base maps current at that time. This means the bulk of the NZLRI was mapped on 1:63,360 base maps, and even the NZLRI second edition coverage (Wellington, Northland, Gisborne East Coast and Marlborough regions) was mapped on Topomap Edition 1 (NZMS 260). Due to both temporal change (i.e. shifting coastlines and river channels) and changes in mapping precision and accuracy (i.e. scale and projection mismatches), the NZLRI polygon boundaries no longer match the accepted topographic location of many river, lake and coast features. We devised an automated procedure to improve this shortcoming of the NZLRI data set by realigning coastlines, lake shorelines and river beds to currently accepted LINZ 1:50,000 scale mapping data sets. These were as follows:

- https://data.linz.govt.nz/layer/1153-nz-coastlines-and-islands-polygons-topo-150k/
- https://data.linz.govt.nz/layer/328-nz-river-polygons-topo-150k/
- https://data.linz.govt.nz/layer/293-nz-lake-polygons-topo-150k/
- https://data.linz.govt.nz/layer/342-nz-shingle-polygons-topo-150k/

Automated processing of this kind does carry some risk of causing errors as well as resolving them. Such errors are most commonly resolved by manual editing, and the effectiveness of the method can be judged by how much or how little manual editing is required.

This process replaced areas of the NZLRI data set with LINZ water bodies (lakes, river polygons and estuaries), areas of river bed gravel and beach gravel, and automatically reconciled the boundaries to minimise slivers. Where current lakes, rivers and estuaries overlap parts of old NZLRI polygons, these areas have been reassigned to water rather than retaining their original LUC classification and ESC rating. Where areas were previously mapped as lakes, rivers, riverbeds or estuaries in the NZLRI but are now not mapped in any of these categories (i.e. now are part of ‘land’ polygons), there is no ESC rating defined and these can only be identified as previously mapped as water bodies or shingle riverbeds with undefined ESC. Resolving these areas, probably by merging to the most suitable adjacent valid LUC polygon, would be best achieved by a manual process. While the automated process worked well, there remain some areas that are unresolved in the data set (i.e. are blank).

Realigning the coastline required a more complex process. This is because the original 1:63,360 digitised coastline in some places overlaps the current accepted LINZ 1:50,000 scale coastline (i.e. falls outside), but in others it is mapped to landward (i.e. inside) of the current coastline. To reconcile these criss-crossing coastlines, GIS topological attributes were used to identify and remove the original coastline to create a ‘coastless’ NZLRI. A 250 m buffer was created around the entire NZLRI coastline to get a new, expanded coastline guaranteed to fall outside the original NZLRI polygon.

Next, the extend line function was used to grow any ‘dangles’ (i.e. where a polygon boundary had previously intersected the coastline) from the ‘coastless’ NZLRI line work until those dangles met the new expanded coastline. Any line work that had not originally intersected the coast was left unaffected. The polygon topology was then rebuilt, and a point-in-polygon overlay used to reassign NZLRI attributes to the expanded data set. Finally, the expanded data set was clipped to the accepted current LINZ coastline. Although a more complex process, this approach did not generate a large number of incorrect outcomes, and the manual editing required to deal with incorrect attribute assignment around some more complex coastlines was manageable.

### 5.4.2 Extending the ESC land over Crown land in the data set

The original ESC database (Bloomberg et al. 2011) was compared with the NZLRI to identify LegLUC[5] units that had not previously been classified. ESC class for these units was derived using the procedure described in Basher et al. (2015a), primarily considering potential erosion data in the regional LUC extended legends and bulletins, maximum mapped mass-movement erosion from the NZLRI, correlation of LUC units between regions, and the ESC class of groups of related LUC units. For dual LUC units the ESC was derived from the LUC unit with the highest potential erosion severity. This extended the ESC classification over the land currently mapped as ‘Undefined’ (by Bloomberg et al. 2011 and Basher et al. 2015a) to cover all LUC units in New Zealand.

### 5.4.3 Updating the ESC classification based on erosion terrains

The revised ESC classification was joined in ArcGIS with a version of the NZLRI containing the potential erosion data[6] and the erosion terrains. This provided a single spatial database covering all New Zealand with the original ESC classification (Bloomberg et al. 2011), the revised ESC classification (Basher et al. 2015a), the potential erosion data and the erosion terrains, as well as the base NZLRI data. This was necessary to be able to incorporate in the analysis polygon boundaries from the NZLRI, which had been dissolved by Bloomberg et al. (2011) in the large area mapped as ‘Undefined’.

An Excel pivot table was prepared to identify LegLUC units in those erosion terrains for which ESC class was changed from High to Very High; that is:

- hilly steeplands developed on non-cohesive sands, and gravels (erosion terrain code = 7.4.3)
- hilly steeplands on weak Tertiary mudstone (7.3.1)



[5] These are unique combinations of NZLRI legend and LUC unit and are used for all queries since some LUC units occur in multiple legends but may have different definitions in each legend.
[6] Defined as ‘the potential erosion under an actual or assumed grassland cover with no soil conservation measures applied’ (NWASCO 1979).

- hilly steeplands on weak Tertiary sandstone, limestone, conglomerate, moraine or alluvium (7.4.1, 7.4.2)
- hilly steeplands on weathered volcanics, greywacke, argillite, schist or granite (7.6.1, 7.6.2, 7.7.1, 7.7.2, 7.7.3)
- floodplains with severe bank erosion and deposition (part 1.1.1).

This produced a list of LegLUC units in each erosion terrain. This list was inspected to identify LegLUC units associated with each erosion terrain that did not require reclassification, either because their ESC class was already Very High, or it was Moderate or Low (the latter mostly applied to South Island LegLUC units that were allocated to erosion terrains on the basis of soil rather than LUC). Some LegLUC units were associated with multiple erosion terrains, and the pivot table was also used to ensure that only those polygons where LegLUC was associated with the relevant erosion terrain were reclassified from High to Very High. This in effect creates a second revision of the ESC in which those parts of the five identified erosion terrains classified as High by Basher et al. (2015a) are reclassified as Very High ESC.

### 5.4.4 Overlays to identify ESC units dominated by gully, tunnel gully and earthflow erosion, and all class 8e land

Overlays were created to identify polygons where:

a. the primary erosion type was gully or tunnel gully erosion and of severe erosion potential or greater

b. the primary erosion type was earthflow and the geology is crushed argillite, Tertiary mudstone or sandstone

c. all ESC units (including compound units) that include LUC class 8e land.

This created separate fields in the ESC database that identify those LUC units and mapped polygons that meet the above criteria.

Polygons where the primary erosion type was gully or tunnel gully erosion and of severe erosion potential (3) or greater were identified using the potential erosion data set. This contained a field for each erosion type that listed the potential erosion severity (PES) from either regional bulletins or extended legends. All polygons where PES was ≥3 were identified in the fields G (gully) and T (tunnel gully) and fields added for G ≥ 3 (Ggt3) and T ≥ 3 (Tgt3) with attribute values of Yes (where the polygon met the criterion PES ≥ 3) or No (where the criterion was not met).

Polygons where the primary erosion type was earthflow and the geology was crushed argillite, Tertiary mudstone or sandstone were identified from the relevant erosion terrains:

- hill country developed on crushed Tertiary-aged mudstone, sandstone, argillite or ancient volcanic rock with moderate earthflow-dominated erosion (code = 6.4.2)
- hill country developed on crushed mudstone or argillite with severe earthflow-dominated erosion (code = 6.4.3).

Polygons were identified where the field code matched 6.4.2 or 6.4.3 and a field Ef_terrain added with attribute values of Yes (where the polygon met the criterion code = 6.4.2 or 6.4.3) or No (where the criterion was not met).

All ESC units (including compound units) that include LUC class 8e land were identified by querying for field LegLUC LIKE '%8e%' (where % is the wildcard character). A field Class8 was added with1 attribute values of Yes (where the polygon met the criterion LegLUC LIKE '%8e%') and No (where the criterion was not met).

The final GIS data set included fields that were used to develop the revised classification (erosion terrain name and code) and to develop the overlays for gully, tunnel gully and earthflow erosion, as well as class 8e land. A list of the fields included in the GIS data set is given in Table 1.

*Table 9 List of fields in the final GIS database for the ESC*

| Field name | Suggested alias | Description |
|---|---|---|
| Code | Erosion terrain code | Erosion terrain numerical code |
| Description | Erosion terrain description | Erosion terrain description |
| hectares | Hectares | Area of polygon (ha) |
| Legend | NZLRI Legend | Regional legend for NZLRI data (for key see Newsome et al. 2008) |
| LUC | Land Use Capability unit | Land Use Capability (LUC) unit derived from NZLRI |
| ESCvalue | ESC2011 class | Original ESC class (Bloomberg et al. 2011) |
| LEGLUC | NZLRI Legend and Land Use Capability Unit | Unique combination of regional NZLRI legend and LUC unit |
| ESCrevised | ESC2015 class | Revised ESC class (Basher et al. 2015a) |
| Origin | Data Origin | Origin of polygon data (classes of LUC – from NZLRI, no_LUC – from NZLRI but no associated LUC unit, DOC – from current DOC cadastral boundary (2016), shingle – from LINZ Topo 1:50k polygon, water – from LINZ Topo 1:50k River and Lake polygons) |
| ESC2017 | ESC2017 class | Current (2017) revision of ESC class |
| Gtg3 | Gully PES Greater than 3 | Polygons with PES for gully erosion (G) ≥3 (values of 'Yes' or 'No') |
| Tgt3 | Tunnel Gully PES Greater than 3 | Polygons with PES for tunnel gully erosion (T) ≥3 (values of 'Yes' or 'No') |
| Ef_terrain | Dominant Earthflow Erosion | Polygons that have dominant earthflow erosion (Ef), identified from earthflow erosion terrains (values of 'Yes' or 'No') |
| Class8 | LUC Class 8e land | All polygons that contain class 8e land (values of 'Yes' or 'No') |

## 5.5 RESULTS

### 5.5.1 Changes along river margins, lakes and the coastal marine area

The net effect of realigning the NZLRI coastline (which was based predominantly on the 1:63,360 scale NZMS1 map series available at the time of NZLRI data compilation) to the current NZTOPO50 coastline has been to decrease the total ‘land’ area in the data set by 137,816 ha (approximately 0.5%). This is the combined effect of changes in mapping scale, quality of mapping and potentially significant changes in coastal alignment due to both erosion and accretion. The NZTOPO50 coastline is approximately 16,454 km long at this scale of mapping – so a lateral error between NZMS1 and NZTOPO50 of less than 1 m on average around the entire coastline would account for much of this area. This is well within mapping precision.

The LINZ river, lake (water) polygons account for 462,945 ha, and shingle (mostly river bed) polygons account for another 163,643 ha that are not assigned an LUC in the ESC 2017 revision. In addition there are approximately 169,000 ha that are not covered by the LINZ river, lake or shingle polygon data sets that also do not have an LUC assigned. These are made up of 82,664 ha that were mapped as water or river bed areas in the original NZLRI and as a result did not have an LUC assigned to them. These differences in designation may be the result of:

- changes in river bed status (i.e. land that has been improved since NZLRI mapping and would now not be mapped as river bed)
- actual changes caused by erosion and shifting of river channels within floodplain areas
- differences in the mapping standards and conventions of the NZLRI versus LINZ TOPO50.

A further 82,747 ha are classed as ‘Other’ non-LUC units (e.g. towns, ice and quarries) that were also not assigned an LUC in the original NZLRI.

In both cases these areas that were not assigned an LUC in the original mapping cannot be automatically assigned an LUC in the 2017 revision. Any designation of LUC and/or ESC would require manual assessment. It is unlikely this could be achieved with reasonable accuracy without some field work. It is also probable that some new LUC units might have to be created to describe some of these areas that were not previously mapped.

### 5.5.2 Extending the ESC land over Crown land in the data set

Fifty-four LegLUC units were identified that were present in the NZLRI but missing from the original Bloomberg et al. (2011) ESC classification. They are listed in Table 2 with their ESC class. They were mostly dual LUC units, and in most cases one of the two LUC units had already been classified.

*Table 10 List of LUC units not included in Bloomberg et al. (2011) and their ESC class*

| Legend | LUC | ESC |
|---|---|---|
| 00 | 6e18+7e22 | High |
| 00 | 6e25+7w 2 | Moderate |
| 00 | 6s 3+7e25 | High |
| 00 | 6s 3+7w 2 | Low |
| 00 | 6s 3+8w 1 | Low |
| 00 | 6s12+6e28 | Low |
| 00 | 6s12+8w 1 | Low |
| 00 | 7e 8+6e18 | High |
| 00 | 7e17+6e29 | Moderate |
| 00 | 7e20+7s 4 | High |
| 00 | 7e20+7s 7 | High |
| 00 | 7e22+8e 1 | High |
| 00 | 7e25+6s12 | High |
| 00 | 7s 1+7e22 | High |
| 00 | 7s 4+7e20 | High |
| 00 | 7s 7+7e20 | High |
| 00 | 7s 7+7w 2 | Low |
| 00 | 7s 7+8e 3 | High |
| 00 | 7w 2+6s 3 | Low |
| 00 | 7w 2+7s 1 | Low |
| 00 | 7w 2+8w 1 | Low |
| 00 | 7w 4+7c 4 | Low |
| 00 | 8c 1+8e 3 | High |
| 00 | 8c 1+8e 7 | Very High |
| 00 | 8e 3+7e20 | High |
| 00 | 8e 3+8c 1 | High |

| Legend | LUC | ESC |
|---|---|---|
| 00 | 8e 5+8s 1 | Very High |
| 00 | 8e 7+7c 6 | Very High |
| 00 | 8e 7+8c 1 | Very High |
| 00 | 8s 1+7e25 | High |
| 00 | 8s 1+8e 3 | High |
| 03 | 4e 2 | Low |
| 03 | 7c 1 | Low |
| 04 | 3e 5+6e20 | Moderate |
| 05 | 8e 4 | High |
| 06 | 4c 1+6e23 | Moderate |
| 07 | 6e15+7e16 | High |
| 08 | 8c 1 | Low |
| 08 | 8e 9 | High |
| 10 | 6c 4+7e 8 | Moderate |
| 10 | 6e17+6w 1 | Moderate |
| 10 | 6e25+6s 6 | Moderate |
| 10 | 7e17+4w 1 | High |
| 11 | 6e17+7e24 | Moderate |
| 11 | 6e19+7e20 | Very High |
| 11 | 7e 9 | High |
| 11 | 7e25+8e11 | High |
| 11 | 7e25+8e14 | Moderate |
| 11 | 8e 8+7e23 | High |
| 11 | 8e12+7e24 | High |
| 11 | 8e12+8e 6 | High |
| 11 | 8e14+7e24 | Moderate |

### 5.5.3 Update of the ESC classification based on erosion terrains

Eighty-nine LegLUC units were reclassified from High to Very High based on the erosion terrain to which they belonged (Table 3). Appendix 1 provides a complete list of ESC classes for every LUC unit. Figure 1 shows the distribution of ESC class across New Zealand. Some LegLUC units have been split between both High and Very High ESC classes because they were classified into multiple erosion terrains: in the North Island some LUC units were allocated to different erosion terrains depending on rock type, while in the South Island the erosion terrains were based on soil and not LUC. This occurred for 19 LegLUC units (Table 4).

It is also worth noting that some of the erosion terrains that were reclassified from High ESC to Very High include a wide variety of terrain, especially the hilly steeplands on weak Tertiary sandstone, limestone, conglomerate, moraine or alluvium; hilly steeplands on weak Tertiary mudstone; and hilly steeplands on weathered volcanics, greywacke, argillite, schist or granite. Further targeted analysis of these terrains, based on the individual LUC units assigned to these terrains, might distinguish between Very High and High ESC classes (e.g. distinguish shallow soils over consolidated Tertiary sandstone that are very susceptible to landsliding from deeper soils over less consolidated Tertiary sandstone that are less susceptible to landsliding). Future changes to the ESC can be dealt with following the process described by Basher et al. (2015b).

Comparison of the areas in each ESC class with the previous versions of the ESC classification are given in Table 5. The area in the Very High ESC class has increased from c. 554,000 ha (Basher et al. 2015a) to c. 5,002,000 ha with this revision. However, much of the increase (c. 3.5 million ha) comes from incorporating the DOC estate in the analysis. A summary of ESC class by region is given in Table 6.

### 5.5.4 Overlays of ESC units dominated by gully, tunnel gully and earthflow erosion, and all class 8e land

Areas with a dominance of gully erosion with PES $\geq 3$ are shown in Figure 2. A total of 4,491,636 ha was identified as having severe or higher potential for gully erosion, much of which is in the Southern Alps, where the potential for gully erosion was probably overestimated during the compilation of the PES data. It also includes quite large areas of sand dunes in the northern North Island, where the potential for gully erosion may also have been overestimated during the compilation of the PES data.

Areas with a dominance of tunnel gully erosion with PES $\geq 3$ are shown in Figure 3. A total of 7,980 ha was identified as having severe or higher potential for tunnel gully erosion, most of which is in the North Island (5,524 ha) on areas with young tephra (5,315 ha) or loess (209 ha), with smaller areas in the South Island (2,455 ha), mostly on deep loess (1,639 ha).

Areas with a dominance of earthflow erosion (erosion terrains 6.4.2 and 6.4.3) are shown in Figure 4. A total of 514,588 ha was mapped in these erosion terrains, entirely in the North Island. The largest areas are in the Wairarapa–Southern Hawke's Bay, Northland and Gisborne areas, with smaller areas in the Waikato, Taranaki–Manawatu and Northern Hawke's Bay.

The distribution of class 8e land is shown in Figure 5. A total of 5,571,922 ha of land contains LUC class 8 with an erosion limitation. Most (83%) of this is in the South Island mountain lands and the North Island axial greywacke ranges.

*Table 11 List of LUC units reclassified from High to Very High*

| Legend | LUC unit |
|---|---|
| 00 | 6e18+7e22 |
| 00 | 6e21+8e 2 |
| 00 | 7e 4 |
| 00 | 7e 4+8e 3 |
| 00 | 7e 8+6e18 |
| 00 | 7e 9 |
| 00 | 7e 9+6e21 |
| 00 | 7e 9+8e 2 |
| 00 | 7e 9+8e 8 |
| 00 | 7e20 |
| 00 | 7e22 |
| 00 | 7e22+6e28 |
| 00 | 7e22+7s 7 |
| 00 | 7e22+8e 1 |
| 00 | 7e22+8e 3 |
| 00 | 7e25+8e 3 |
| 00 | 8e 2 |
| 00 | 8e 2+7e 9 |
| 00 | 8e 3 |
| 00 | 8e 3+7e 4 |
| 00 | 8e 3+7e20 |
| 00 | 8e 3+7e22 |
| 00 | 8e 3+7e25 |
| 01 | 7e 1 |
| 01 | 7e 7 |
| 02 | 7e 1 |
| 02 | 7e 8 |
| 02 | 7e10 |
| 02 | 7e10+3w 1 |
| 02 | 7e12 |

| Legend | LUC unit |
|---|---|
| 02 | 8e 1 |
| 02 | 8e 3 |
| 03 | 7e 1 |
| 03 | 7e 2 |
| 03 | 7e 3 |
| 03 | 7e 7 |
| 03 | 8e 2 |
| 06 | 7e 2 |
| 06 | 7e 3 |
| 06 | 7e 3+8s 1 |
| 06 | 7e 4 |
| 06 | 7e 5 |
| 06 | 7e 7 |
| 06 | 7e10 |
| 06 | 7e13 |
| 06 | 7e14 |
| 06 | 7e15 |
| 06 | 7e15+8s 1 |
| 06 | 7e16 |
| 06 | 7e17 |
| 07 | 7e 1 |
| 07 | 7e 2 |
| 07 | 7e 3 |
| 07 | 7e 5 |
| 07 | 7e 8 |
| 07 | 7e 9 |
| 07 | 7e 9+8e 2 |
| 07 | 8e 2 |
| 07 | 8e 3 |

| Legend | LUC unit |
|---|---|
| 08 | 7e 1 |
| 08 | 7e 2 |
| 08 | 7e 2+3w 1 |
| 08 | 7e 4 |
| 10 | 7e 1 |
| 10 | 7e 2 |
| 10 | 7e 3 |
| 10 | 7e 4 |
| 10 | 7e 4+3e 4 |
| 10 | 7e 5 |
| 10 | 7e 6 |
| 10 | 7e 7 |
| 10 | 7e 9 |
| 10 | 7e11 |
| 10 | 7e11+6e20 |
| 10 | 7e11+6e23 |
| 10 | 7e13 |
| 10 | 7e13+8e 3 |
| 10 | 7e17 |
| 10 | 7e17+4w 1 |
| 10 | 7e23 |
| 11 | 7e 8 |
| 11 | 7e11 |
| 11 | 7e12 |
| 11 | 7e12+4s 7 |
| 11 | 7e12+6e11 |
| 11 | 7e12+8e 4 |
| 11 | 8e 4 |
| 11 | 8e 4+7e12 |
| 11 | 8e 6+7e12 |

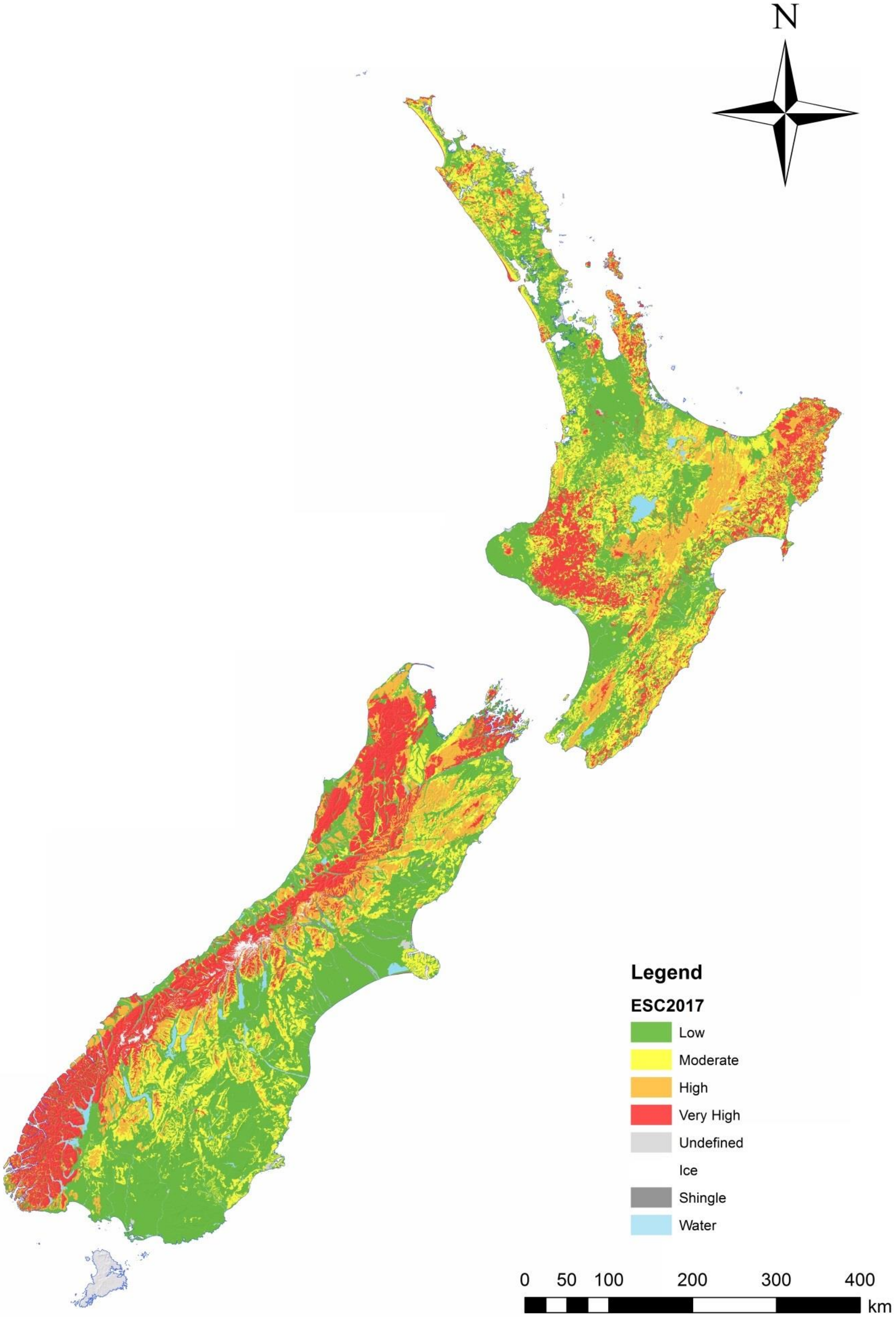



*Figure 12 Map of revised 2017 Erosion Susceptibility Classification.*

*Table 12 List of LegLUC units in both High and Very High ESC classes*

| Legend | LUC unit | ESC class | Erosion terrain Code | Erosion terrain |
|---|---|---|---|---|
| 00 | 7e 4 | Very High | 7.3.1 | Hilly steeplands developed on soft sedimentary mudstone (Ms[7]) |
| | | | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | High | 6.4.1 | Hill country developed on soft sedimentary mudstone (Ms) |
| 00 | 7e 9 | Very High | 7.6.2 | Hill country developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs)[8] |
| | | | 7.6.2 | Hilly steeplands developed on weathered, coarse-grained igneous rocks (Gn, e.g. Motueka catchment) |
| | | | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | | 8.5.1 | Mountain steeplands developed on weathered, coarse-grained igneous rocks (Gn e.g. Motueka catchment) |
| | | High | 6.5.2 | Hill country developed on hard schist rocks (St1, St2 or Sx, Sy) |
| | | | 7.5.2 | Hilly steeplands developed on hard schist rocks (St1, St2 or Sx, Sy) |
| | | | 7.5.3 | Hilly steeplands developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 8.3.1 | Mountain steeplands developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 8.3.3 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| 00 | 7e 9+8e 2 | Very High | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | High | 8.3.1 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| | | | 8.3.3 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| 00 | 7e20 | Very High | 7.4.2 | Hilly steeplands developed on soft sedimentary conglomerate (Cw) |



[7] Rock type codes from Newsome et al. (2008)
[8] This erosion terrain is misnamed in the erosion terrain database – it is a hilly steepland terrain (code starting with 7, not hill country (code starting with 6)

| Legend | LUC unit | ESC class | Erosion terrain Code | Erosion terrain |
|---|---|---|---|---|
| | | High | 5.1.1 | Downlands developed on moraine and dissected alluvium |
| | | | 6.1.1 | Hill country developed on moraine and dissected alluvium |
| | | | 6.4.1 | Hill country developed on soft sedimentary mudstone (Ms) |
| | | | 6.5.1 | Hill country developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 6.5.3 | Hill country developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| 00 | 7e22 | Very High | 7.3.1 | Hilly steeplands developed on soft sedimentary mudstone (Ms) |
| | | | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | | 7.4.2 | Hilly steeplands developed on soft sedimentary conglomerate (Cw) |
| | | High | 5.4.1 | Downlands developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 6.1.1 | Hill country developed on moraine and dissected alluvium |
| | | | 6.4.1 | Hill country developed on soft sedimentary mudstone (Ms) |
| | | | 6.4.7 | Hill country developed on soft sedimentary conglomerate Cw |
| | | | 6.5.1 | Hill country developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 6.5.3 | Hill country developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 7.5.3 | Hilly steeplands developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 8.3.1 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| | | | 8.3.2 | Mountain steeplands developed on hard schist rocks (St1, St2, or Sx, Sy) |
| | | | 8.3.3 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| 00 | 7e22+8e 3 | Very High | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | | 7.4.2 | Hilly steeplands developed on soft sedimentary conglomerate (Cw) |
| | | High | 6.5.1 | Hill country developed on hard sedimentary rocks, (Gw, Ar, Hs, Cg) |

| Legend | LUC unit | ESC class | Erosion terrain Code | Erosion terrain |
|---|---|---|---|---|
| | | | 8.3.1 | Mountain steeplands developed on hard coarse grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| 00 | 8e 2 | Very High | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | High | 6.4.1 | Hill country developed on soft sedimentary mudstone (Ms) |
| | | | 6.4.5 | Hill country developed on soft sedimentary sandstone (Ss) |
| | | | 6.4.7 | Hill country developed on soft sedimentary conglomerate (Cw) |
| | | | 7.5.1 | Hilly steeplands developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 7.5.2 | Hilly steeplands developed on hard schist rocks (St1, St2 or Sx, Sy) |
| | | | 7.5.3 | Hilly steeplands developed on hard coarse grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 8.3.2 | Mountain steeplands developed on hard schist rocks (St1, St2, or Sx, Sy) |
| | | | 8.3.3 | Mountain steeplands developed on hard coarse grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| 00 | 8e 3 | Very High | 7.3.1 | Hilly steeplands developed on soft sedimentary mudstone (Ms) |
| | | | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | | 7.4.2 | Hilly steeplands developed on soft sedimentary conglomerate (Cw) |
| | | High | 4.1.1 | Terrace and fan alluvium above the recent floodplain |
| | | | 6.1.1 | Hill country developed on moraine and dissected alluvium |
| | | | 6.4.1 | Hill country developed on soft sedimentary mudstone (Ms) |
| | | | 6.4.7 | Hill country developed on soft sedimentary conglomerate (Cw) |
| | | | 6.4.8 | Hill country developed on soft calcareous sediments and limestone (Ls) |
| | | | 6.5.1 | Hill country developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 6.5.3 | Hill country developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 7.5.2 | Hilly steeplands developed on hard schist rocks (St1, St2 or Sx, Sy) |

| Legend | LUC unit | ESC class | Erosion terrain Code | Erosion terrain |
|---|---|---|---|---|
| | | | 7.5.3 | Hilly steeplands developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 7.5.4 | Hilly steeplands developed on hard carbonate rocks (Ls, Ma) |
| | | | 8.3.1 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| | | | 8.3.3 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| 00 | 8e 3+7e22 | Very High | 7.3.1 | Hilly steeplands developed on soft sedimentary mudstone (Ms) |
| | | | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | High | 6.5.1 | Hill country developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 7.5.3 | Hilly steeplands developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| 00 | 8e 3+7e25 | Very High | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | High | 7.5.3 | Hilly steeplands developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 8.3.1 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| | | | 8.3.3 | Mountain steeplands developed on hard, coarse-grained igneous and metamorphic rocks (Gn, Gs, and ultramafic terrain) |
| 02 | 7e 1 | Very High | 7.3.1 | Hilly steeplands developed on soft sedimentary mudstone (Ms) |
| | | | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | High | 7.1.3 | Hilly steeplands developed on mid-aged (late Pleistocene/early Holocene) tephra covers |
| | | | 7.5.1 | Hilly steeplands developed on unweathered to moderately weathered greywacke/argillite |
| | | | 7.5.4 | Hilly steeplands developed on limestone |
| 02 | 8e 3 | Very High | 7.4.1 | Hilly steeplands developed on cohesive, generally weak to moderately strong Tertiary-aged sandstone |
| | | | 7.4.3 | Hilly steeplands developed on non-cohesive Tertiary-aged sandstone, and younger sandy gravels and gravelly sands |
| | | | 7.7.3 | Hilly steeplands developed on residual weathered to highly (often deeply) weathered greywacke/argillite |

| Legend | LUC unit | ESC class | Erosion terrain Code | Erosion terrain |
|---|---|---|---|---|
| | | High | 7.5.1 | Hilly steeplands developed on unweathered to moderately weathered greywacke/argillite |
| | | | 8.6.1 | Mountain steeplands developed on volcanic rocks in mountain terrains and upland hills |
| 03 | 8e 2 | Very High | 7.7.1 | Hilly steeplands developed on residual weathered to highly (often deeply) weathered ancient basalt and andesite |
| | | High | 7.5.1 | Hilly steeplands developed on unweathered to moderately weathered greywacke/argillite |
| 10 | 7e11 | Very High | 7.3.1 | Hilly steeplands developed on soft sedimentary mudstone (Ms) |
| | | | 7.4.1 | Hilly steeplands developed on soft sedimentary sandstone (Ss) |
| | | High | 7.2.1 | Hilly steeplands developed on fresh to slightly weathered welded rhyolitic rock, or bouldery andesitic lahar deposits |
| 11 | 7e 8 | Very High | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | High | 6.5.2 | Hill country developed on hard schist rocks (St1, St2 or Sx, Sy) |
| 11 | 7e11 | Very High | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | High | 6.5.2 | Hill country developed on hard schist rocks (St1, St2 or Sx, Sy) |
| 11 | 7e12 | Very High | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | High | 6.5.1 | Hill country developed on hard sedimentary rocks (Gw, Ar, Hs, Cg) |
| | | | 8.3.2 | Mountain steeplands developed on hard schist rocks (St1, St2, or Sx, Sy) |
| 11 | 7e12+8e 4 | Very High | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | High | 8.3.2 | Mountain steeplands developed on hard schist rocks (St1, St2, or Sx, Sy) |
| 11 | 8e 4 | Very High | 7.6.1 | Hilly steeplands developed on weathered hard schist & greywacke rocks (St1, St2, Sx, Sy, Gw, Marlborough Sounds, esp. lower slopes) |
| | | High | 7.5.3 | Hilly steeplands developed on hard, coarse-grained igneous or metamorphic rocks (Gn, Gs) |
| | | | 8.3.2 | Mountain steeplands developed on hard schist rocks (St1, St2, or Sx, Sy) |

*Table 13 Comparison of the area of each ESC class in this revision of the ESC with previous versions. Note that most of the change in area is caused by extension of the classification to cover all of New Zealand*

| | Area (000 ha) | | | | |
|---|---|---|---|---|---|
| | Low | Moderate | High | Very High | Undefined |
| Bloomberg et al. (2011) | 8,596 | 4,513 | 3,023 | 1,581 | 9,057 |
| Basher et al. (2015a) | 10,056 | 4,715 | 2,388 | 554 | 9,057 |
| 2017 revision | 11,259 | 5,781 | 3,621 | 5,002 | 971[9] |

*Table 14 Summary of area of ESC class by region (000 ha)*

| | Area ( ha) | | | |
|---|---|---|---|---|
| Region | Low | Moderate | High | Very High |
| Auckland | 313 | 102 | 331 | 284 |
| Bay of Plenty | 378 | 368 | 372 | 71 |
| Canterbury | 2,334 | 943 | 716 | 265 |
| Gisborne | 97 | 283 | 111 | 337 |
| Hawke's Bay | 470 | 405 | 358 | 161 |
| Manawatu–Wanganui | 816 | 687 | 160 | 537 |
| Marlborough | 335 | 232 | 287 | 178 |
| Nelson | 8 | 21 | 11 | 2 |
| Northland | 538 | 490 | 1,329 | 78 |
| Otago | 1,847 | 807 | 244 | 175 |
| Southland | 1,460 | 200 | 264 | 978 |
| Taranaki | 334 | 109 | 8 | 267 |
| Tasman | 200 | 115 | 208 | 430 |
| Waikato | 1,283 | 672 | 265 | 145 |
| Wellington | 313 | 240 | 155 | 82 |
| West Coast | 533 | 105 | 297 | 1,267 |
| Total | 11,259 | 5,781 | 3,621 | 5,002 |



[9] Includes polygons in theESC2017 field of the GIS database labelled as blank, ice, shingle, and water

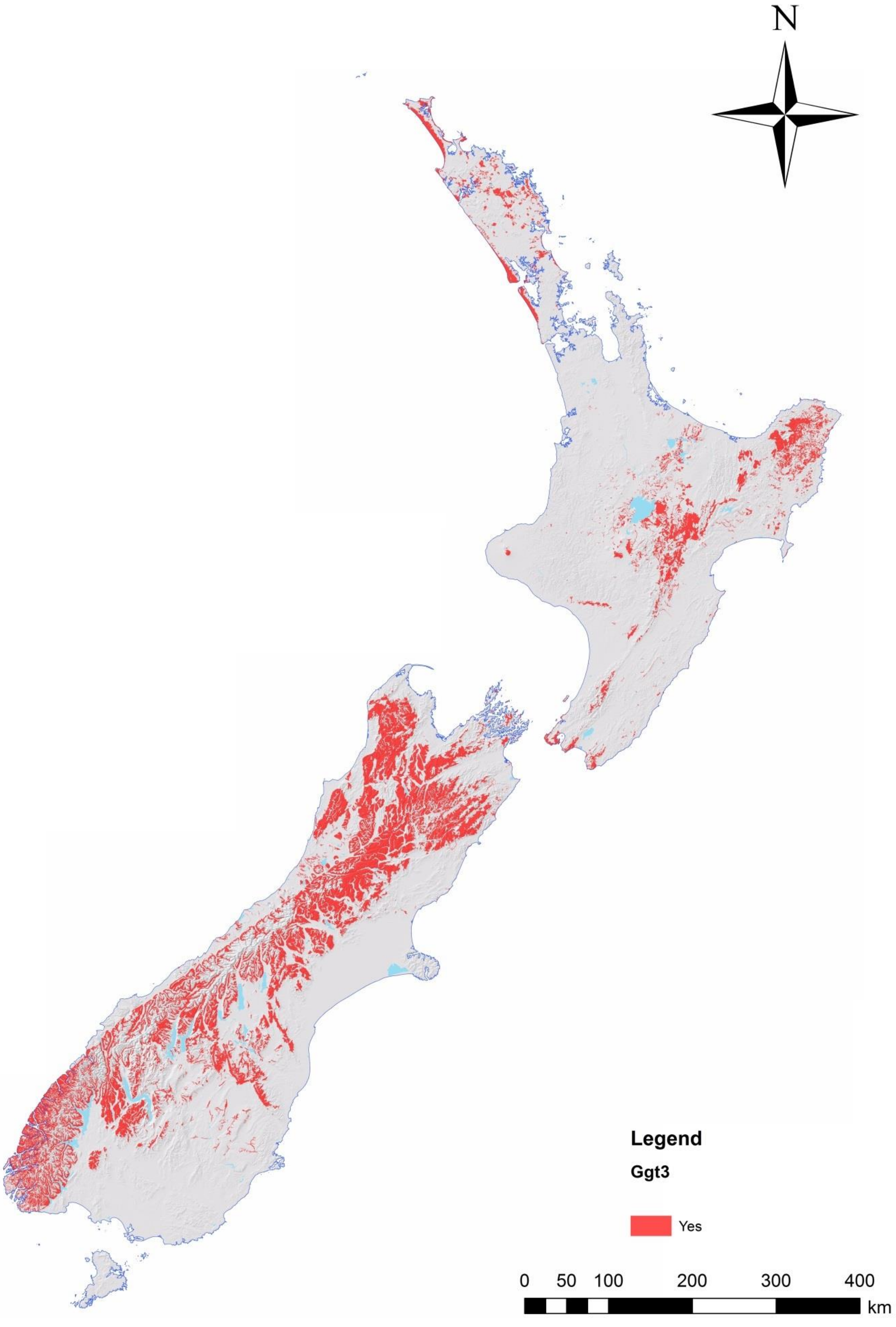



*Figure 13 Map of areas with PES ≥ 3 for gully erosion.*

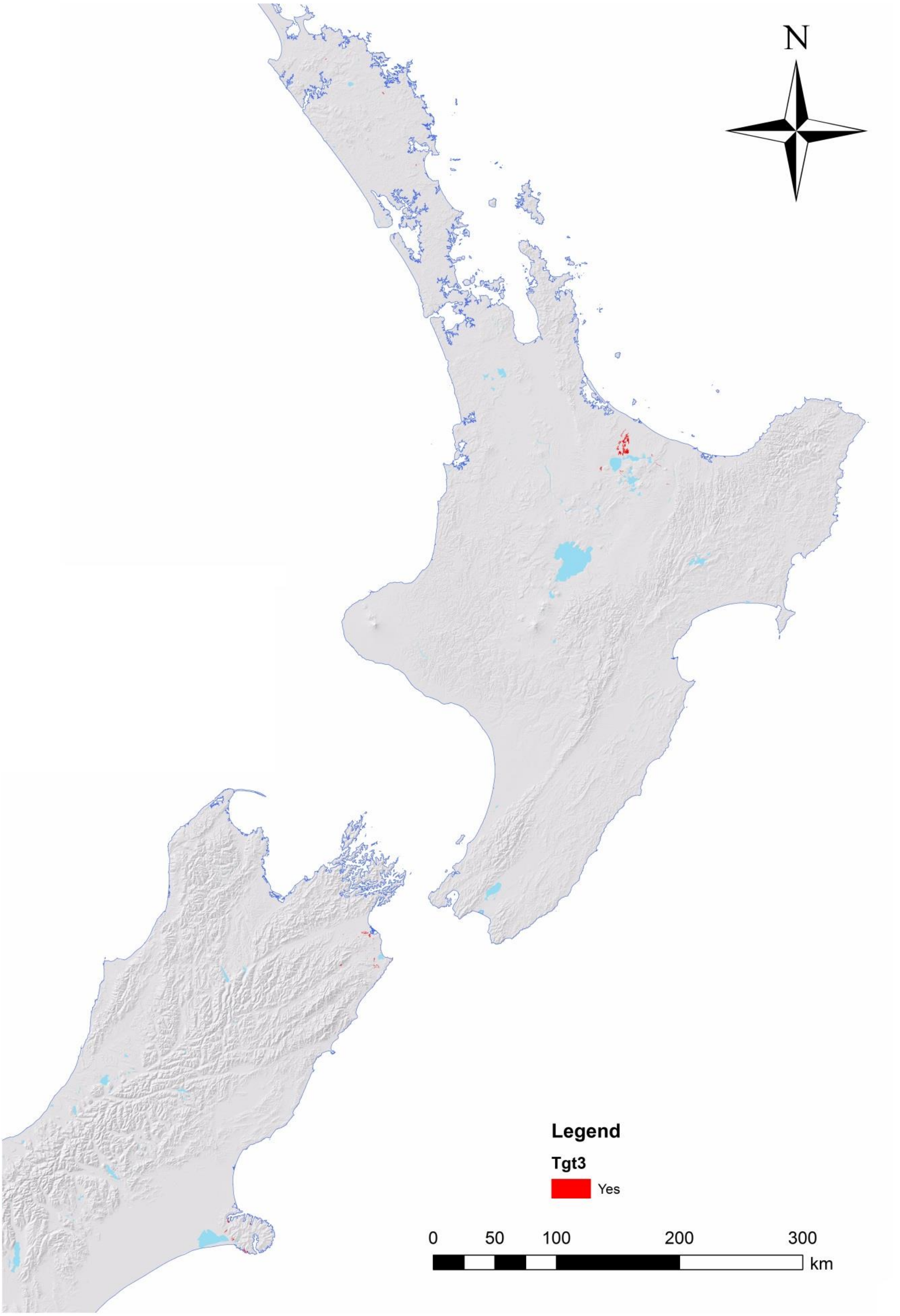



*Figure 14 Map of areas with PES ≥ 3 for tunnel gully erosion.*

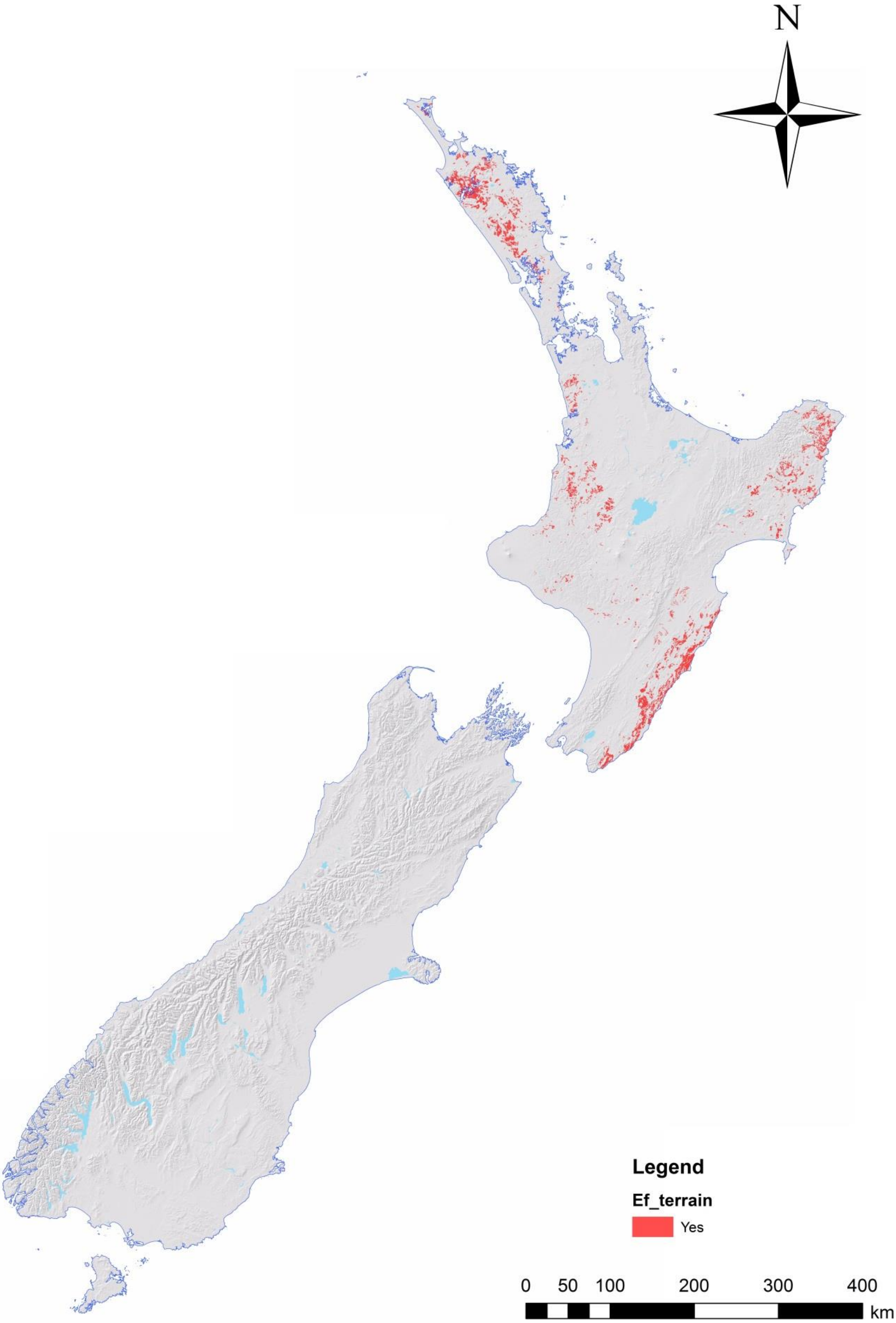



*Figure 15 Map of areas with dominant earthflow erosion.*

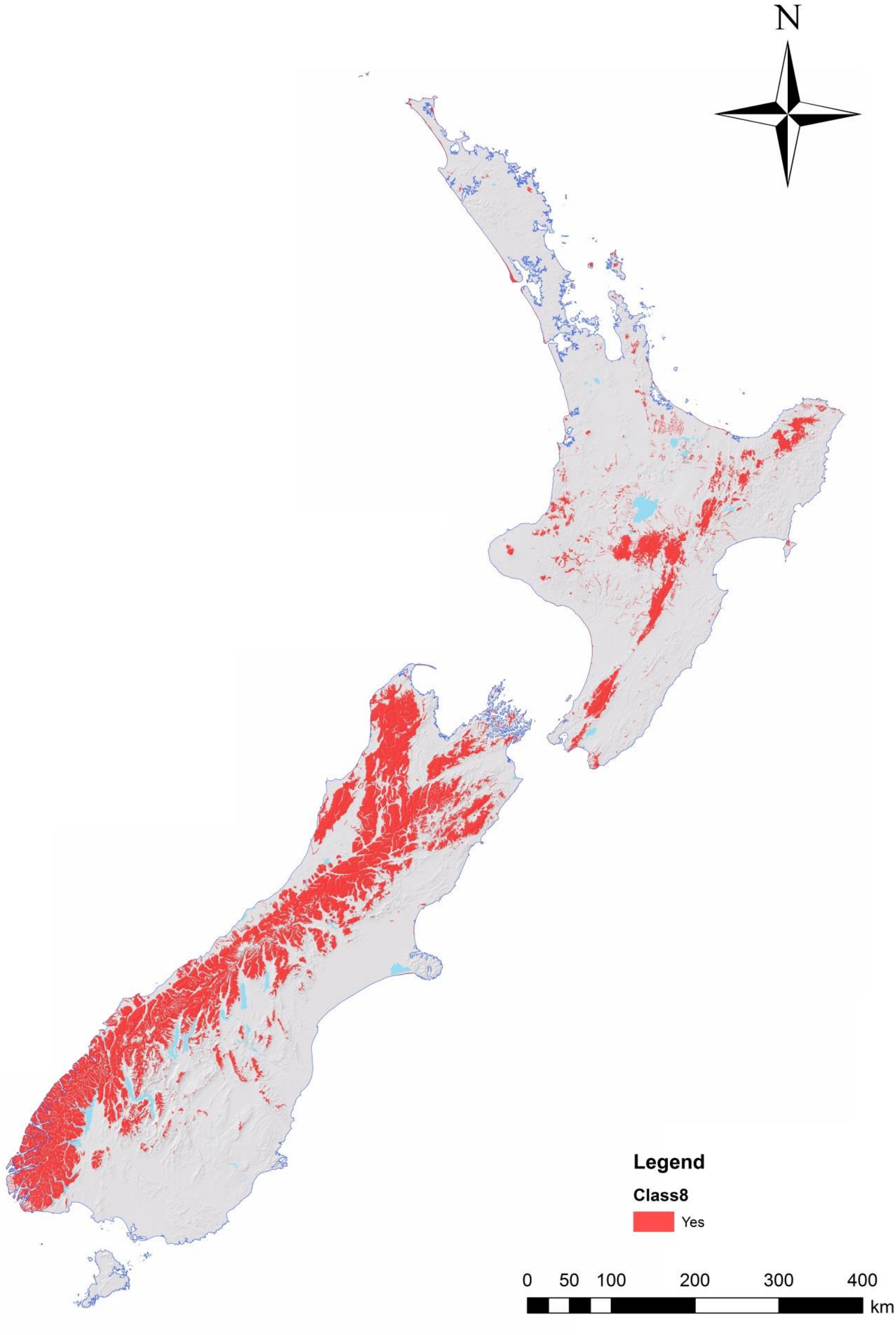



*Figure 16 Map of areas of all LegLUC units containing class 8e land.*

## 5.6 CONCLUSIONS

- The ESC classification has been extended to cover all of mainland New Zealand and a final spatial data set has been prepared as an ArcGIS shapefile.
- Polygon boundaries are now consistent with currently accepted boundaries for the DOC estate, rivers, lakes and the coast

## 5.7 ACKNOWLEDGEMENTS

We thank MPI for providing funding for this work, and Bridget Robson for providing direction and managing the project on behalf of MPI. Ian Lynn and Ray Prebble are thanked for reviews of earlier drafts of this report.

## REFERENCES

Basher L, Lynn I, Barringer J 2014. Peer review of the process proposed to update the Erosion Susceptibility Classification for the National Environmental Standard for Plantation Forestry. Landcare Research Contract Report LC1877 for Ministry for Primary Industries.

Basher L, Lynn I, Page M 2015a. Update of the Erosion Susceptibility Classification (ESC) for the proposed National Environmental Standard for Plantation Forestry – revision of the ESC. MPI Technical Paper No. 2015/13. Prepared by Landcare Research for the Ministry for Primary Industries (Landcare Research Contract Report LC2196).

Basher L, Lynn I, Barringer J 2015b. Update of the Erosion Susceptibility Classification (ESC) for the proposed NES for Plantation Forestry: managing changes to the ESC and incorporating detailed mapping. MPI Technical Paper No. 2015/12. Prepared by Landcare Research for the Ministry for Primary Industries (Landcare Research Contract Report LC2165).

Basher L, Barringer J, Lynn I 2016. Update of the Erosion Susceptibility Classification (ESC) for the proposed NES for Plantation Forestry: subdividing the High and Very High ESC classes. MPI Technical Paper No. 2016. Prepared by Landcare Research for the Ministry for Primary Industries (Landcare Research Contract Report LC2472).

Bloomberg M, Davies T, Visser R, Morgenroth J 2011. Erosion Susceptibility Classification and analysis of erosion risks for plantation forestry. Report prepared by the University of Canterbury for the Ministry for the Environment, Wellington.

Newsome PFJ, Wilde RH, Willoughby EJ 2008. Land Resource Information System Spatial Data Layers. Palmerston North, Landcare Research. Available at http://digitallibrary.landcareresearch.co.nz/cdm/ref/collection/p20022coll14/id/67

NWASCO 1979. Our land resources. Wellington, National Water and Soil Conservation Organisation. 79 p.

# Appendix 1 - List of mapped LUC units and their ESC class

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 1c 1 | Low |
| 00 | 1c 2 | Low |
| 00 | 1s 2+2s 2 | Low |
| 00 | 1w 1 | Low |
| 00 | 1w 1+2s 2 | Low |
| 00 | 1w 1+2s 3 | Low |
| 00 | 1w 1+2w 1 | Low |
| 00 | 1w 1+3s 5 | Low |
| 00 | 1w 2 | Low |
| 00 | 2c 1 | Low |
| 00 | 2c 2 | Low |
| 00 | 2c 2+3s 2 | Low |
| 00 | 2c 2+3s 5 | Low |
| 00 | 2c 2+3s 7 | Low |
| 00 | 2c 2+4s 1 | Low |
| 00 | 2e 1 | Low |
| 00 | 2e 1+2w 1 | Low |
| 00 | 2e 1+3e 8 | Low |
| 00 | 2e 1+3s 6 | Low |
| 00 | 2e 2 | Low |
| 00 | 2e 2+3e 4 | Low |
| 00 | 2s 1 | Low |
| 00 | 2s 1+3s 2 | Low |
| 00 | 2s 1+3s 3 | Low |
| 00 | 2s 1+3w 3 | Low |
| 00 | 2s 2 | Low |
| 00 | 2s 2+3s 2 | Low |
| 00 | 2s 2+3s 5 | Low |
| 00 | 2s 2+3s 9 | Low |
| 00 | 2s 2+4e 1 | Low |
| 00 | 2s 2+4s 6 | Low |
| 00 | 2s 3 | Low |
| 00 | 2s 3+1s 1 | Low |
| 00 | 2s 3+2e 1 | Low |
| 00 | 3c 4+6w 3 | Low |
| 00 | 3e 1 | Low |
| 00 | 3e 1+6e 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 2s 3+3e 8 | Low |
| 00 | 2s 3+3e12 | Low |
| 00 | 2s 3+3s12 | Low |
| 00 | 2s 3+4s 7 | Low |
| 00 | 2s 3+6e 9 | Moderate |
| 00 | 2s 3+7e 7 | High |
| 00 | 2w 1 | Low |
| 00 | 2w 1+3s 5 | Low |
| 00 | 2w 1+3s 9 | Low |
| 00 | 2w 1+4s 6 | Low |
| 00 | 2w 2 | Low |
| 00 | 2w 2+3w 3 | Low |
| 00 | 2w 2+3w 4 | Low |
| 00 | 3c 1 | Low |
| 00 | 3c 1+4s 1 | Low |
| 00 | 3c 1+4s 9 | Low |
| 00 | 3c 1+5w 2 | Low |
| 00 | 3c 1+7e11 | Moderate |
| 00 | 3c 2 | Low |
| 00 | 3c 2+3w 3 | Low |
| 00 | 3c 2+4e 3 | Low |
| 00 | 3c 2+4s 1 | Low |
| 00 | 3c 2+4s 2 | Low |
| 00 | 3c 2+4s 3 | Low |
| 00 | 3c 2+4w 1 | Low |
| 00 | 3c 3 | Low |
| 00 | 3c 3+3s 6 | Low |
| 00 | 3c 3+3w 1 | Low |
| 00 | 3c 3+4s 9 | Low |
| 00 | 3c 4 | Low |
| 00 | 3c 4+4e 3 | Low |
| 00 | 3c 4+4e13 | Low |
| 00 | 3c 4+5s 1 | Low |
| 00 | 3c 4+6e10 | Low |
| 00 | 3e10+4e 3 | Low |
| 00 | 3e10+5c 2 | Low |
| 00 | 3e10+6e 6 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 3e 2 | Low |
| 00 | 3e 2+4e 1 | Low |
| 00 | 3e 2+4e 4 | Low |
| 00 | 3e 2+6e 1 | Low |
| 00 | 3e 2+6e 2 | Low |
| 00 | 3e 3 | Low |
| 00 | 3e 3+4e 2 | Low |
| 00 | 3e 4 | Low |
| 00 | 3e 4+4e 3 | Low |
| 00 | 3e 4+4e 4 | Low |
| 00 | 3e 4+4s 3 | Low |
| 00 | 3e 4+6e 8 | Moderate |
| 00 | 3e 4+6e13 | Moderate |
| 00 | 3e 4+6s 9 | Low |
| 00 | 3e 5 | Low |
| 00 | 3e 5+4e14 | Low |
| 00 | 3e 6 | Low |
| 00 | 3e 6+4e 5 | Low |
| 00 | 3e 7 | Low |
| 00 | 3e 7+3w 3 | Low |
| 00 | 3e 7+4e 3 | Low |
| 00 | 3e 7+4e 7 | Low |
| 00 | 3e 7+4e17 | Low |
| 00 | 3e 7+4s 4 | Low |
| 00 | 3e 7+6w 3 | Low |
| 00 | 3e 8 | Low |
| 00 | 3e 8+4e 4 | Low |
| 00 | 3e 8+6e 8 | Moderate |
| 00 | 3e 8+6e 9 | Moderate |
| 00 | 3e 8+7e 7 | High |
| 00 | 3e 9 | Low |
| 00 | 3e 9+6e 3 | Moderate |
| 00 | 3e10 | Low |
| 00 | 3s 2+4s 1 | Low |
| 00 | 3s 3 | Low |
| 00 | 3s 3+2e 2 | Low |
| 00 | 3s 3+2s 2 | Low |
| 00 | 3s 3+4e 5 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 3e10+6w 1 | Low |
| 00 | 3e11 | Low |
| 00 | 3e11+4e 9 | Low |
| 00 | 3e11+4e15 | Low |
| 00 | 3e11+4s 9 | Low |
| 00 | 3e12 | Low |
| 00 | 3e12+4e 3 | Low |
| 00 | 3e12+4e 7 | Low |
| 00 | 3e12+5s 1 | Low |
| 00 | 3e12+6e15 | Moderate |
| 00 | 3e12+6e16 | Low |
| 00 | 3e12+6e17 | Moderate |
| 00 | 3e12+6s 8 | Low |
| 00 | 3e12+7e 7 | High |
| 00 | 3e12+8e 2 | High |
| 00 | 3e13 | Low |
| 00 | 3e13+4e 9 | Low |
| 00 | 3e13+4s 9 | Low |
| 00 | 3e13+6e12 | Low |
| 00 | 3e13+6e19 | Low |
| 00 | 3e14 | Low |
| 00 | 3e14+4e 3 | Low |
| 00 | 3e14+6e 7 | Moderate |
| 00 | 3e15 | Low |
| 00 | 3e15+4s12 | Low |
| 00 | 3e15+4w 3 | Low |
| 00 | 3e15+5w 2 | Low |
| 00 | 3e15+6e19 | Low |
| 00 | 3e15+6e28 | Low |
| 00 | 3e15+6s11 | Low |
| 00 | 3s 1 | Low |
| 00 | 3s 2 | Low |
| 00 | 3s 2+2s 1 | Low |
| 00 | 3s 7+4e 7 | Low |
| 00 | 3s 7+4s 1 | Low |
| 00 | 3s 7+4s 4 | Low |
| 00 | 3s 7+4s12 | Low |
| 00 | 3s 7+4w 3 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 3s 3+4s 3 | Low |
| 00 | 3s 3+8e 2 | High |
| 00 | 3s 4 | Low |
| 00 | 3s 4+3c 1 | Low |
| 00 | 3s 4+4s 6 | Low |
| 00 | 3s 4+4w 2 | Low |
| 00 | 3s 4+6s 7 | Low |
| 00 | 3s 4+6w 2 | Low |
| 00 | 3s 5 | Low |
| 00 | 3s 5+2s 2 | Low |
| 00 | 3s 5+2w 1 | Low |
| 00 | 3s 5+3e 5 | Low |
| 00 | 3s 5+4s 6 | Low |
| 00 | 3s 5+4s 7 | Low |
| 00 | 3s 5+4w 1 | Low |
| 00 | 3s 5+6e 8 | Moderate |
| 00 | 3s 6 | Low |
| 00 | 3s 6+3c 3 | Low |
| 00 | 3s 6+3e13 | Low |
| 00 | 3s 6+3w 1 | Low |
| 00 | 3s 6+4e 9 | Low |
| 00 | 3s 6+4s 6 | Low |
| 00 | 3s 6+4s 9 | Low |
| 00 | 3s 6+4s15 | Low |
| 00 | 3s 6+4w 2 | Low |
| 00 | 3s 6+6e19 | Low |
| 00 | 3s 6+6s 7 | Low |
| 00 | 3s 6+6s 9 | Low |
| 00 | 3s 6+7s 9 | Low |
| 00 | 3s 7 | Low |
| 00 | 3s 7+2c 2 | Low |
| 00 | 3w 4 | Low |
| 00 | 3w 4+7w 1 | Low |
| 00 | 4c 1 | Low |
| 00 | 4c 1+6s 4 | Low |
| 00 | 4c 1+6s12 | Low |
| 00 | 4c 2 | Low |
| 00 | 4c 2+6e10 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 3s 7+5w 3 | Low |
| 00 | 3s 8 | Low |
| 00 | 3s 8+4s 2 | Low |
| 00 | 3s 9 | Low |
| 00 | 3s 9+4s 6 | Low |
| 00 | 3s10 | Low |
| 00 | 3s10+4s 2 | Low |
| 00 | 3s10+4s 5 | Low |
| 00 | 3s11 | Low |
| 00 | 3s11+5s 6 | Low |
| 00 | 3s12 | Low |
| 00 | 3s12+2s 3 | Low |
| 00 | 3s12+3e 4 | Low |
| 00 | 3s12+4e 3 | Low |
| 00 | 3s12+4e 7 | Low |
| 00 | 3w 1 | Low |
| 00 | 3w 1+2e 1 | Low |
| 00 | 3w 1+2w 1 | Low |
| 00 | 3w 1+4s 6 | Low |
| 00 | 3w 1+4s 9 | Low |
| 00 | 3w 1+6s 8 | Low |
| 00 | 3w 1+6w 1 | Low |
| 00 | 3w 2 | Low |
| 00 | 3w 2+2w 1 | Low |
| 00 | 3w 3 | Low |
| 00 | 3w 3+2w 2 | Low |
| 00 | 3w 3+4s 1 | Low |
| 00 | 3w 3+4s 4 | Low |
| 00 | 3w 3+4s12 | Low |
| 00 | 3w 3+4w 3 | Low |
| 00 | 3w 3+7w 1 | Low |
| 00 | 4e 3+7s 4 | Low |
| 00 | 4e 4 | Low |
| 00 | 4e 4+3e 8 | Low |
| 00 | 4e 4+4e 8 | Low |
| 00 | 4e 4+6e 2 | Low |
| 00 | 4e 4+6e 8 | Moderate |
| 00 | 4e 4+6e 9 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 4c 2+6e14 | Low |
| 00 | 4c 2+6e23 | Low |
| 00 | 4c 2+6s 9 | Low |
| 00 | 4c 3 | Low |
| 00 | 4c 3+4s 5 | Low |
| 00 | 4c 3+6e25 | Moderate |
| 00 | 4e 1 | Low |
| 00 | 4e 1+5c 3 | Low |
| 00 | 4e 1+6e 1 | Low |
| 00 | 4e 1+6e 2 | Low |
| 00 | 4e 1+6e 5 | Moderate |
| 00 | 4e 2 | Low |
| 00 | 4e 2+3e 3 | Low |
| 00 | 4e 2+5c 3 | Low |
| 00 | 4e 2+6e 5 | Moderate |
| 00 | 4e 2+6e 8 | Moderate |
| 00 | 4e 2+6s 2 | Low |
| 00 | 4e 3 | Low |
| 00 | 4e 3+3e12 | Low |
| 00 | 4e 3+4s13 | Low |
| 00 | 4e 3+5c 2 | Low |
| 00 | 4e 3+6e 5 | Moderate |
| 00 | 4e 3+6e 6 | Low |
| 00 | 4e 3+6e 7 | Moderate |
| 00 | 4e 3+6e15 | Moderate |
| 00 | 4e 3+6e16 | Low |
| 00 | 4e 3+6e17 | Moderate |
| 00 | 4e 3+6e21 | Low |
| 00 | 4e 3+6e28 | Low |
| 00 | 4e 9+6e12 | Low |
| 00 | 4e 9+6e13 | Moderate |
| 00 | 4e 9+6e14 | Low |
| 00 | 4e 9+6e19 | Low |
| 00 | 4e 9+6e26 | Low |
| 00 | 4e 9+6s 7 | Low |
| 00 | 4e 9+6s 9 | Low |
| 00 | 4e10 | Low |
| 00 | 4e10+5w 2 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 4e 4+6e10 | Low |
| 00 | 4e 4+6e11 | Low |
| 00 | 4e 4+6e13 | Moderate |
| 00 | 4e 4+6e17 | Moderate |
| 00 | 4e 4+6e18 | Moderate |
| 00 | 4e 4+7e 7 | High |
| 00 | 4e 4+8e 2 | High |
| 00 | 4e 5 | Low |
| 00 | 4e 5+6e16 | Low |
| 00 | 4e 6 | Low |
| 00 | 4e 6+6e11 | Low |
| 00 | 4e 6+6e15 | Moderate |
| 00 | 4e 6+6e16 | Low |
| 00 | 4e 6+7e 7 | High |
| 00 | 4e 7 | Low |
| 00 | 4e 7+3e 7 | Low |
| 00 | 4e 7+3e14 | Low |
| 00 | 4e 7+6e 6 | Low |
| 00 | 4e 7+6e 7 | Moderate |
| 00 | 4e 7+6e10 | Low |
| 00 | 4e 7+6e15 | Moderate |
| 00 | 4e 7+6e16 | Low |
| 00 | 4e 7+6e22 | Low |
| 00 | 4e 7+7s 9 | Low |
| 00 | 4e 8 | Low |
| 00 | 4e 8+5w 2 | Low |
| 00 | 4e 9 | Low |
| 00 | 4e 9+3e13 | Low |
| 00 | 4e 9+3s 6 | Low |
| 00 | 4e16+6e27 | Low |
| 00 | 4e16+6e29 | Low |
| 00 | 4e16+6s11 | Low |
| 00 | 4e16+6s12 | Low |
| 00 | 4e17 | Low |
| 00 | 4e17+4w 3 | Low |
| 00 | 4e17+6e 5 | Moderate |
| 00 | 4e17+6s11 | Low |
| 00 | 4e17+6s12 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 4e10+5w 3 | Low |
| 00 | 4e10+6e19 | Low |
| 00 | 4e10+6e28 | Low |
| 00 | 4e10+6w 3 | Low |
| 00 | 4e10+7w 1 | Low |
| 00 | 4e11 | Low |
| 00 | 4e11+6e19 | Low |
| 00 | 4e11+6s 7 | Low |
| 00 | 4e12 | Low |
| 00 | 4e12+6e19 | Low |
| 00 | 4e12+6e26 | Low |
| 00 | 4e12+6s 7 | Low |
| 00 | 4e13 | Low |
| 00 | 4e13+3c 4 | Low |
| 00 | 4e13+4w 3 | Low |
| 00 | 4e13+6e 5 | Moderate |
| 00 | 4e13+6e 7 | Moderate |
| 00 | 4e13+6e10 | Low |
| 00 | 4e13+6e23 | Low |
| 00 | 4e13+6e28 | Low |
| 00 | 4e14 | Low |
| 00 | 4e15 | Low |
| 00 | 4e15+6e15 | Moderate |
| 00 | 4e15+6e21 | Low |
| 00 | 4e16 | Low |
| 00 | 4e16+5s 5 | Low |
| 00 | 4e16+6c 3 | Low |
| 00 | 4s 4+3w 3 | Low |
| 00 | 4s 4+4w 3 | Low |
| 00 | 4s 4+6e16 | Low |
| 00 | 4s 4+6s12 | Low |
| 00 | 4s 5 | Low |
| 00 | 4s 5+6e25 | Moderate |
| 00 | 4s 5+6s 4 | Low |
| 00 | 4s 5+6s 6 | Low |
| 00 | 4s 5+7s 8 | Low |
| 00 | 4s 6 | Low |
| 00 | 4s 6+3s 4 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 4e18 | Low |
| 00 | 4e18+2s 2 | Low |
| 00 | 4s 1 | Low |
| 00 | 4s 1+2s 1 | Low |
| 00 | 4s 1+3s 2 | Low |
| 00 | 4s 1+3w 3 | Low |
| 00 | 4s 1+4w 1 | Low |
| 00 | 4s 1+4w 3 | Low |
| 00 | 4s 1+5w 1 | Low |
| 00 | 4s 1+6s 1 | Low |
| 00 | 4s 1+6s 2 | Low |
| 00 | 4s 1+6w 2 | Low |
| 00 | 4s 1+6w 3 | Low |
| 00 | 4s 2 | Low |
| 00 | 4s 2+3s 8 | Low |
| 00 | 4s 2+4w 2 | Low |
| 00 | 4s 2+4w 4 | Low |
| 00 | 4s 2+6s 3 | Low |
| 00 | 4s 2+7w 2 | Low |
| 00 | 4s 3 | Low |
| 00 | 4s 3+2s 3 | Low |
| 00 | 4s 3+3s 3 | Low |
| 00 | 4s 3+6e16 | Low |
| 00 | 4s 3+6s 4 | Low |
| 00 | 4s 4 | Low |
| 00 | 4s 4+3e 7 | Low |
| 00 | 4s 4+3s 7 | Low |
| 00 | 4s 9+6e14 | Low |
| 00 | 4s 9+6e19 | Low |
| 00 | 4s 9+6e22 | Low |
| 00 | 4s 9+6s 7 | Low |
| 00 | 4s 9+6s 9 | Low |
| 00 | 4s 9+7c 5 | Low |
| 00 | 4s10 | Low |
| 00 | 4s10+3c 2 | Low |
| 00 | 4s10+6c 2 | Low |
| 00 | 4s10+6e21 | Low |
| 00 | 4s10+6s 6 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 4s 6+3s 6 | Low |
| 00 | 4s 6+4e 9 | Low |
| 00 | 4s 6+4w 2 | Low |
| 00 | 4s 6+6s 7 | Low |
| 00 | 4s 6+6s 8 | Low |
| 00 | 4s 6+7e 7 | High |
| 00 | 4s 6+7s 9 | Low |
| 00 | 4s 7 | Low |
| 00 | 4s 7+3s 5 | Low |
| 00 | 4s 7+6s 8 | Low |
| 00 | 4s 8 | Low |
| 00 | 4s 8+6s10 | Low |
| 00 | 4s 9 | Low |
| 00 | 4s 9+3c 3 | Low |
| 00 | 4s 9+3e11 | Low |
| 00 | 4s 9+3e13 | Low |
| 00 | 4s 9+3s 4 | Low |
| 00 | 4s 9+3s 6 | Low |
| 00 | 4s 9+4c 2 | Low |
| 00 | 4s 9+4e 9 | Low |
| 00 | 4s 9+4s15 | Low |
| 00 | 4s 9+5s 3 | Low |
| 00 | 4s 9+6c 3 | Low |
| 00 | 4s 9+6e 9 | Moderate |
| 00 | 4s 9+6e12 | Low |
| 00 | 4w 1+4e 3 | Low |
| 00 | 4w 1+4s11 | Low |
| 00 | 4w 1+5w 1 | Low |
| 00 | 4w 1+6w 1 | Low |
| 00 | 4w 1+7s 6 | Low |
| 00 | 4w 1+7w 1 | Low |
| 00 | 4w 1+7w 3 | Low |
| 00 | 4w 2 | Low |
| 00 | 4w 2+3s 6 | Low |
| 00 | 4w 2+3w 1 | Low |
| 00 | 4w 2+4s 6 | Low |
| 00 | 4w 2+4s15 | Low |
| 00 | 4w 2+5w 2 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 4s11 | Low |
| 00 | 4s11+6e24 | Low |
| 00 | 4s11+6s 5 | Low |
| 00 | 4s12 | Low |
| 00 | 4s12+3s 4 | Low |
| 00 | 4s12+5w 2 | Low |
| 00 | 4s12+6s 3 | Low |
| 00 | 4s12+6s11 | Low |
| 00 | 4s12+6s12 | Low |
| 00 | 4s13 | Low |
| 00 | 4s13+6e15 | Moderate |
| 00 | 4s13+6e21 | Low |
| 00 | 4s14 | Low |
| 00 | 4s14+6e27 | Low |
| 00 | 4s14+6s11 | Low |
| 00 | 4s14+6w 2 | Low |
| 00 | 4s14+8e 2 | High |
| 00 | 4s15 | Low |
| 00 | 4s15+3s 6 | Low |
| 00 | 4s15+6s 7 | Low |
| 00 | 4s15+7e10 | Moderate |
| 00 | 4s15+7s10 | Low |
| 00 | 4w 1 | Low |
| 00 | 4w 1+3c 2 | Low |
| 00 | 4w 1+3w 3 | Low |
| 00 | 5s 3+3s 9 | Low |
| 00 | 5s 3+4e 9 | Low |
| 00 | 5s 3+4s 3 | Low |
| 00 | 5s 3+4s 6 | Low |
| 00 | 5s 4 | Low |
| 00 | 5s 4+5w 4 | Low |
| 00 | 5s 5 | Low |
| 00 | 5s 5+5w 2 | Low |
| 00 | 5s 6 | Low |
| 00 | 5w 1 | Low |
| 00 | 5w 1+3c 2 | Low |
| 00 | 5w 2 | Low |
| 00 | 5w 2+4e12 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 4w 3 | Low |
| 00 | 4w 3+2w 2 | Low |
| 00 | 4w 3+4s 1 | Low |
| 00 | 4w 3+4s 4 | Low |
| 00 | 4w 3+7w 1 | Low |
| 00 | 4w 4 | Low |
| 00 | 4w 4+5w 4 | Low |
| 00 | 5c 1 | Low |
| 00 | 5c 2 | Low |
| 00 | 5c 2+3e10 | Low |
| 00 | 5c 2+4e 2 | Low |
| 00 | 5c 2+4e 3 | Low |
| 00 | 5c 2+4e 7 | Low |
| 00 | 5c 3 | Low |
| 00 | 5c 3+4e 1 | Low |
| 00 | 5c 3+4e 7 | Low |
| 00 | 5s 1 | Low |
| 00 | 5s 1+4e 2 | Low |
| 00 | 5s 2 | Low |
| 00 | 5s 2+2e 1 | Low |
| 00 | 5s 2+6e 4 | Low |
| 00 | 5s 3 | Low |
| 00 | 5s 3+2w 1 | Low |
| 00 | 6c 4+7c 7 | Low |
| 00 | 6e 1 | Low |
| 00 | 6e 1+4e 1 | Low |
| 00 | 6e 2 | Low |
| 00 | 6e 2+3e 1 | Low |
| 00 | 6e 2+4e 1 | Low |
| 00 | 6e 3 | Moderate |
| 00 | 6e 3+3e 9 | Moderate |
| 00 | 6e 3+6s 6 | Moderate |
| 00 | 6e 4 | Low |
| 00 | 6e 5 | Moderate |
| 00 | 6e 5+3s 3 | Moderate |
| 00 | 6e 5+4e 1 | Moderate |
| 00 | 6e 5+4e 2 | Moderate |
| 00 | 6e 5+4e 3 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 5w 2+4s 6 | Low |
| 00 | 5w 2+4w 2 | Low |
| 00 | 5w 2+6e26 | Low |
| 00 | 5w 2+6w 3 | Low |
| 00 | 5w 3 | Low |
| 00 | 5w 3+3e15 | Low |
| 00 | 5w 3+3w 3 | Low |
| 00 | 5w 3+6w 3 | Low |
| 00 | 5w 3+7w 1 | Low |
| 00 | 5w 4 | Low |
| 00 | 6c 1 | Low |
| 00 | 6c 1+4e 9 | Low |
| 00 | 6c 1+6e23 | Low |
| 00 | 6c 1+6e27 | Low |
| 00 | 6c 1+6w 3 | Low |
| 00 | 6c 1+7e21 | Moderate |
| 00 | 6c 1+7w 4 | Low |
| 00 | 6c 2 | Low |
| 00 | 6c 2+8e 2 | High |
| 00 | 6c 2+8e 3 | High |
| 00 | 6c 3 | Low |
| 00 | 6c 4 | Low |
| 00 | 6c 4+6e19 | Low |
| 00 | 6e10+3c 4 | Low |
| 00 | 6e10+4c 2 | Low |
| 00 | 6e10+4e13 | Low |
| 00 | 6e10+7e 1 | Moderate |
| 00 | 6e10+7e 3 | Moderate |
| 00 | 6e11 | Low |
| 00 | 6e11+4e 3 | Low |
| 00 | 6e11+4e 6 | Low |
| 00 | 6e11+4e13 | Low |
| 00 | 6e11+6e15 | Moderate |
| 00 | 6e11+7e 3 | Moderate |
| 00 | 6e11+7e26 | Moderate |
| 00 | 6e12 | Low |
| 00 | 6e12+4e 9 | Low |
| 00 | 6e12+4s 9 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 6e 5+4e 9 | Moderate |
| 00 | 6e 5+7e 1 | Moderate |
| 00 | 6e 5+7e 3 | Moderate |
| 00 | 6e 5+7e 8 | High |
| 00 | 6e 6 | Low |
| 00 | 6e 6+4e 3 | Low |
| 00 | 6e 7 | Moderate |
| 00 | 6e 7+3e14 | Moderate |
| 00 | 6e 7+4c 2 | Moderate |
| 00 | 6e 7+4e 7 | Moderate |
| 00 | 6e 7+4e13 | Moderate |
| 00 | 6e 8 | Moderate |
| 00 | 6e 8+3e 4 | Moderate |
| 00 | 6e 8+4e 3 | Moderate |
| 00 | 6e 8+4e 4 | Moderate |
| 00 | 6e 8+7e 7 | High |
| 00 | 6e 8+7e14 | High |
| 00 | 6e 8+8e 2 | High |
| 00 | 6e 9 | Moderate |
| 00 | 6e 9+4e 4 | Moderate |
| 00 | 6e10 | Low |
| 00 | 6e15+4e13 | Moderate |
| 00 | 6e15+4e15 | Moderate |
| 00 | 6e15+6s 2 | Moderate |
| 00 | 6e15+7e 1 | Moderate |
| 00 | 6e15+7e14 | High |
| 00 | 6e16 | Low |
| 00 | 6e16+3c 1 | Low |
| 00 | 6e16+3e12 | Low |
| 00 | 6e16+3e14 | Low |
| 00 | 6e16+4e 3 | Low |
| 00 | 6e16+4e 5 | Low |
| 00 | 6e16+4e 6 | Low |
| 00 | 6e16+4e 7 | Low |
| 00 | 6e16+6e11 | Low |
| 00 | 6e16+7e11 | Moderate |
| 00 | 6e17 | Moderate |
| 00 | 6e17+4e 3 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 6e12+7e 6 | Moderate |
| 00 | 6e13 | Moderate |
| 00 | 6e13+4e 3 | Moderate |
| 00 | 6e13+4e 4 | Moderate |
| 00 | 6e13+4e 9 | Moderate |
| 00 | 6e13+7e 1 | Moderate |
| 00 | 6e13+7e14 | High |
| 00 | 6e14 | Low |
| 00 | 6e14+4e 4 | Low |
| 00 | 6e14+4e 9 | Low |
| 00 | 6e14+6e 8 | Moderate |
| 00 | 6e14+6e11 | Low |
| 00 | 6e14+7e 2 | Moderate |
| 00 | 6e14+7e21 | Moderate |
| 00 | 6e15 | Moderate |
| 00 | 6e15+3e12 | Moderate |
| 00 | 6e15+3e14 | Moderate |
| 00 | 6e15+4e 3 | Moderate |
| 00 | 6e15+4e 4 | Moderate |
| 00 | 6e15+4e 6 | Moderate |
| 00 | 6e15+4e 7 | Moderate |
| 00 | 6e21+4s10 | Low |
| 00 | 6e21+4s13 | Low |
| 00 | 6e21+7e 9 | High |
| 00 | 6e21+7s 4 | Low |
| 00 | 6e21+8e 2 | Very High |
| 00 | 6e22 | Low |
| 00 | 6e22+6e11 | Low |
| 00 | 6e22+7e12 | Moderate |
| 00 | 6e22+7e21 | Moderate |
| 00 | 6e23 | Low |
| 00 | 6e23+4c 2 | Low |
| 00 | 6e23+4e13 | Low |
| 00 | 6e23+6c 1 | Low |
| 00 | 6e23+7e10 | Moderate |
| 00 | 6e24 | Low |
| 00 | 6e24+4s 8 | Low |
| 00 | 6e25 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 6e17+4e 6 | Moderate |
| 00 | 6e18 | Moderate |
| 00 | 6e18+7e22 | Very High |
| 00 | 6e19 | Low |
| 00 | 6e19+4e 9 | Low |
| 00 | 6e19+4e12 | Low |
| 00 | 6e19+4s 9 | Low |
| 00 | 6e19+6c 3 | Low |
| 00 | 6e19+6c 4 | Low |
| 00 | 6e19+7e 6 | Moderate |
| 00 | 6e19+7e12 | Moderate |
| 00 | 6e19+7e17 | Moderate |
| 00 | 6e19+7s 9 | Low |
| 00 | 6e20 | Low |
| 00 | 6e20+4e 9 | Low |
| 00 | 6e20+4s 9 | Low |
| 00 | 6e21 | Low |
| 00 | 6e21+4e 3 | Low |
| 00 | 6e21+4e 6 | Low |
| 00 | 6e28+7e23 | Moderate |
| 00 | 6e29 | Low |
| 00 | 6e29+4e16 | Low |
| 00 | 6e29+7e11 | Moderate |
| 00 | 6e29+7e17 | Moderate |
| 00 | 6e29+7e21 | Moderate |
| 00 | 6e29+7e23 | Moderate |
| 00 | 6s 1 | Low |
| 00 | 6s 1+4s 1 | Low |
| 00 | 6s 1+6w 3 | Low |
| 00 | 6s 1+7s 2 | Low |
| 00 | 6s 1+7w 1 | Low |
| 00 | 6s 2 | Low |
| 00 | 6s 3 | Low |
| 00 | 6s 3+4c 3 | Low |
| 00 | 6s 3+4s 5 | Low |
| 00 | 6s 3+4s12 | Low |
| 00 | 6s 3+5w 4 | Low |
| 00 | 6s 3+7e25 | High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 6e25+6s 6 | Moderate |
| 00 | 6e25+7e13 | High |
| 00 | 6e25+7w 2 | Moderate |
| 00 | 6e26 | Low |
| 00 | 6e27 | Low |
| 00 | 6e27+4e 6 | Low |
| 00 | 6e27+4e16 | Low |
| 00 | 6e27+4s12 | Low |
| 00 | 6e27+5w 2 | Low |
| 00 | 6e27+6e29 | Low |
| 00 | 6e27+6s12 | Low |
| 00 | 6e27+8s 2 | Low |
| 00 | 6e28 | Low |
| 00 | 6e28+4e 3 | Low |
| 00 | 6e28+4e10 | Low |
| 00 | 6e28+4e13 | Low |
| 00 | 6e28+6s 2 | Low |
| 00 | 6e28+6s 6 | Low |
| 00 | 6e28+6s12 | Low |
| 00 | 6s 6+7s 7 | Low |
| 00 | 6s 6+7w 2 | Low |
| 00 | 6s 6+8e 3 | High |
| 00 | 6s 7 | Low |
| 00 | 6s 7+4e11 | Low |
| 00 | 6s 7+4e12 | Low |
| 00 | 6s 7+4s 6 | Low |
| 00 | 6s 7+4s 9 | Low |
| 00 | 6s 7+6e12 | Low |
| 00 | 6s 7+6e19 | Low |
| 00 | 6s 7+6s 6 | Low |
| 00 | 6s 7+6w 3 | Low |
| 00 | 6s 7+7s 9 | Low |
| 00 | 6s 8 | Low |
| 00 | 6s 8+2s 3 | Low |
| 00 | 6s 8+4s 6 | Low |
| 00 | 6s 8+4s 7 | Low |
| 00 | 6s 9 | Low |
| 00 | 6s 9+3c 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 6s 3+7s 1 | Low |
| 00 | 6s 3+7w 2 | Low |
| 00 | 6s 3+8w 1 | Low |
| 00 | 6s 4 | Low |
| 00 | 6s 4+4s 3 | Low |
| 00 | 6s 4+4s 5 | Low |
| 00 | 6s 4+6e25 | Moderate |
| 00 | 6s 5 | Low |
| 00 | 6s 5+4s11 | Low |
| 00 | 6s 5+4w 1 | Low |
| 00 | 6s 5+7w 2 | Low |
| 00 | 6s 6 | Low |
| 00 | 6s 6+6e25 | Moderate |
| 00 | 6s 6+6e28 | Low |
| 00 | 6s 6+7c 6 | Low |
| 00 | 6s 6+7e13 | High |
| 00 | 6s 6+7e22 | High |
| 00 | 6s12+4s14 | Low |
| 00 | 6s12+4w 1 | Low |
| 00 | 6s12+5w 2 | Low |
| 00 | 6s12+6e22 | Low |
| 00 | 6s12+6e27 | Low |
| 00 | 6s12+6e28 | Low |
| 00 | 6s12+6s11 | Low |
| 00 | 6s12+6w 3 | Low |
| 00 | 6s12+7w 1 | Low |
| 00 | 6s12+8w 1 | Low |
| 00 | 6w 1 | Low |
| 00 | 6w 1+4w 1 | Low |
| 00 | 6w 1+6s 5 | Low |
| 00 | 6w 1+7w 1 | Low |
| 00 | 6w 2 | Low |
| 00 | 6w 3 | Low |
| 00 | 6w 3+4w 2 | Low |
| 00 | 6w 3+6c 1 | Low |
| 00 | 6w 3+6c 4 | Low |
| 00 | 6w 4 | Low |
| 00 | 6w 4+4e 2 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 6s 9+4s 9 | Low |
| 00 | 6s 9+6e14 | Low |
| 00 | 6s 9+6e19 | Low |
| 00 | 6s 9+7c 7 | Low |
| 00 | 6s 9+7e 6 | Moderate |
| 00 | 6s10 | Low |
| 00 | 6s10+4s 8 | Low |
| 00 | 6s10+6w 4 | Low |
| 00 | 6s10+7e15 | Low |
| 00 | 6s11 | Low |
| 00 | 6s11+4e 8 | Low |
| 00 | 6s11+4s12 | Low |
| 00 | 6s11+5w 2 | Low |
| 00 | 6s11+6w 3 | Low |
| 00 | 6s11+7s 3 | Low |
| 00 | 6s12 | Low |
| 00 | 6s12+4s 4 | Low |
| 00 | 7c 7 | Low |
| 00 | 7e 1 | Moderate |
| 00 | 7e 1+6e 5 | Moderate |
| 00 | 7e 1+6e13 | Moderate |
| 00 | 7e 2 | Moderate |
| 00 | 7e 2+8e 2 | High |
| 00 | 7e 3 | Moderate |
| 00 | 7e 3+6e11 | Moderate |
| 00 | 7e 3+8e 2 | High |
| 00 | 7e 3+8e11 | High |
| 00 | 7e 4 | Very High + High |
| 00 | 7e 4+6e18 | High |
| 00 | 7e 4+8e 3 | Very High |
| 00 | 7e 5 | High |
| 00 | 7e 6 | Moderate |
| 00 | 7e 6+6c 3 | Moderate |
| 00 | 7e 6+6e 2 | Moderate |
| 00 | 7e 6+6e19 | Moderate |
| 00 | 7e 6+7e24 | Moderate |
| 00 | 7e 7 | High |
| 00 | 7e 7+8e 2 | High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 6w 4+4s 8 | Low |
| 00 | 6w 4+4w 1 | Low |
| 00 | 6w 4+6s10 | Low |
| 00 | 7c 1 | Low |
| 00 | 7c 1+7w 4 | Low |
| 00 | 7c 2 | Low |
| 00 | 7c 3 | Low |
| 00 | 7c 4 | Low |
| 00 | 7c 4+6c 1 | Low |
| 00 | 7c 4+7e10 | Moderate |
| 00 | 7c 4+7e21 | Moderate |
| 00 | 7c 4+7w 4 | Low |
| 00 | 7c 5 | Low |
| 00 | 7c 5+6e19 | Low |
| 00 | 7c 6 | Low |
| 00 | 7e12+7e 2 | High |
| 00 | 7e12+7e24 | High |
| 00 | 7e13 | High |
| 00 | 7e13+6e25 | High |
| 00 | 7e14 | High |
| 00 | 7e15 | Low |
| 00 | 7e15+2e 2 | Low |
| 00 | 7e15+6s 7 | Low |
| 00 | 7e16 | Moderate |
| 00 | 7e17 | Moderate |
| 00 | 7e17+6e29 | Moderate |
| 00 | 7e17+6s11 | Moderate |
| 00 | 7e18 | Low |
| 00 | 7e19 | Moderate |
| 00 | 7e20 | Very High + High |
| 00 | 7e20+6e28 | High |
| 00 | 7e20+7s 4 | High |
| 00 | 7e20+7s 7 | High |
| 00 | 7e20+8e 5 | Very High |
| 00 | 7e21 | Moderate |
| 00 | 7e21+6e22 | Moderate |
| 00 | 7e21+6e29 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 7e 8 | High |
| 00 | 7e 8+6e18 | Very High |
| 00 | 7e 8+8e 1 | High |
| 00 | 7e 9 | Very High + High |
| 00 | 7e 9+6e21 | Very High |
| 00 | 7e 9+8e 2 | Very High + High |
| 00 | 7e 9+8e 8 | Very High |
| 00 | 7e10 | Moderate |
| 00 | 7e10+7c 4 | Moderate |
| 00 | 7e11 | Moderate |
| 00 | 7e11+6e16 | Moderate |
| 00 | 7e11+8e 2 | High |
| 00 | 7e12 | High |
| 00 | 7e12+6e19 | High |
| 00 | 7e12+6e22 | High |
| 00 | 7e23+8e 8 | High |
| 00 | 7e23+8e 9 | High |
| 00 | 7e24 | Moderate |
| 00 | 7e24+6e19 | Moderate |
| 00 | 7e24+6e26 | Moderate |
| 00 | 7e24+8e 4 | High |
| 00 | 7e25 | High |
| 00 | 7e25+6s 6 | High |
| 00 | 7e25+6s12 | High |
| 00 | 7e25+7s 1 | High |
| 00 | 7e25+7s 7 | High |
| 00 | 7e25+8e 1 | High |
| 00 | 7e25+8e 3 | Very High |
| 00 | 7e25+8e 5 | Very High |
| 00 | 7e25+8s 1 | High |
| 00 | 7e26 | Moderate |
| 00 | 7e26+7e12 | Moderate |
| 00 | 7e26+8e 9 | High |
| 00 | 7s 1 | Low |
| 00 | 7s 1+7e17 | Moderate |
| 00 | 7s 1+7e22 | High |
| 00 | 7s 1+7e25 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 7e21+7c 4 | Moderate |
| 00 | 7e21+8e 6 | Moderate |
| 00 | 7e21+8e 9 | High |
| 00 | 7e22 | Very High + High |
| 00 | 7e22+6e21 | High |
| 00 | 7e22+6e28 | Very High |
| 00 | 7e22+7s 7 | Very High |
| 00 | 7e22+8e 1 | Very High |
| 00 | 7e22+8e 3 | Very High + High |
| 00 | 7e22+8e 5 | Very High |
| 00 | 7e23 | Moderate |
| 00 | 7e23+6e28 | Moderate |
| 00 | 7e23+6e29 | Moderate |
| 00 | 7e23+7c 4 | Moderate |
| 00 | 7s 7+4s13 | Low |
| 00 | 7s 7+6s 6 | Low |
| 00 | 7s 7+7e20 | High |
| 00 | 7s 7+7e25 | Moderate |
| 00 | 7s 7+7w 2 | Low |
| 00 | 7s 7+8e 3 | High |
| 00 | 7s 8 | Low |
| 00 | 7s 9 | Low |
| 00 | 7s 9+3s 4 | Low |
| 00 | 7s 9+4e 9 | Low |
| 00 | 7s 9+4s 9 | Low |
| 00 | 7s 9+8s 2 | Low |
| 00 | 7s10 | Low |
| 00 | 7s11 | Low |
| 00 | 7s11+6s10 | Low |
| 00 | 7s12 | Low |
| 00 | 7w 1 | Low |
| 00 | 7w 1+4w 3 | Low |
| 00 | 7w 1+5w 1 | Low |
| 00 | 7w 1+6s 1 | Low |
| 00 | 7w 1+8w 1 | Low |
| 00 | 7w 2 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 7s 1+7w 2 | Low |
| 00 | 7s 1+8s 1 | Low |
| 00 | 7s 2 | Low |
| 00 | 7s 2+4s 6 | Low |
| 00 | 7s 2+6s 1 | Low |
| 00 | 7s 3 | Low |
| 00 | 7s 3+6e26 | Low |
| 00 | 7s 3+6s11 | Low |
| 00 | 7s 4 | Low |
| 00 | 7s 4+7e20 | High |
| 00 | 7s 5 | Low |
| 00 | 7s 5+7e 6 | Moderate |
| 00 | 7s 6 | Low |
| 00 | 7s 7 | Low |
| 00 | 8e 2 | Very High + High |
| 00 | 8e 2+6e16 | High |
| 00 | 8e 2+6s 8 | High |
| 00 | 8e 2+7e 3 | High |
| 00 | 8e 2+7e 9 | Very High |
| 00 | 8e 3 | Very High + High |
| 00 | 8e 3+7e 4 | Very High |
| 00 | 8e 3+7e13 | High |
| 00 | 8e 3+7e20 | Very High |
| 00 | 8e 3+7e22 | Very High + High |
| 00 | 8e 3+7e25 | Very High + High |
| 00 | 8e 3+7s 7 | High |
| 00 | 8e 3+8c 1 | High |
| 00 | 8e 3+8s 1 | High |
| 00 | 8e 4 | High |
| 00 | 8e 4+7e21 | High |
| 00 | 8e 5 | Very High |
| 00 | 8e 5+7e22 | Very High |
| 00 | 8e 5+7e25 | Very High |
| 00 | 8e 5+8s 1 | Very High |
| 00 | 8e 6 | Low |
| 00 | 8e 7 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 7w 2+6s 3 | Low |
| 00 | 7w 2+7s 1 | Low |
| 00 | 7w 2+8w 1 | Low |
| 00 | 7w 3 | Low |
| 00 | 7w 3+6w 4 | Low |
| 00 | 7w 4 | Low |
| 00 | 7w 4+7c 4 | Low |
| 00 | 8c 1 | Low |
| 00 | 8c 1+7e21 | Moderate |
| 00 | 8c 1+8e 3 | High |
| 00 | 8c 1+8e 7 | Very High |
| 00 | 8c 2 | Low |
| 00 | 8e 1 | High |
| 00 | 8e 1+7e 8 | High |
| 00 | 8s 1 | Low |
| 00 | 8s 1+7e25 | High |
| 00 | 8s 1+7s 1 | Low |
| 00 | 8s 1+8e 3 | High |
| 00 | 8s 2 | Low |
| 00 | 8s 3+7e24 | Moderate |
| 00 | 8w 1 | Low |
| 00 | 8w 1+7w 1 | Low |
| 00 | 8w 2 | Low |
| 00 | 8w 2+7w 3 | Low |
| 01 | 1c 1 | Low |
| 01 | 2e 1 | Low |
| 01 | 2e 2 | Low |
| 01 | 2s 1 | Low |
| 01 | 2s 2 | Low |
| 01 | 2w 1 | Low |
| 01 | 2w 1+3e 3 | Low |
| 01 | 2w 2 | Low |
| 01 | 2w 3 | Low |
| 01 | 3e 1 | Low |
| 01 | 3e 2 | Low |
| 01 | 3e 3 | Low |
| 01 | 3e 4 | Low |
| 01 | 3e 5 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 00 | 8e 7+7c 6 | Very High |
| 00 | 8e 7+8c 1 | Very High |
| 00 | 8e 8 | High |
| 00 | 8e 8+7e 3 | High |
| 00 | 8e 8+7e23 | High |
| 00 | 8e 8+8e 9 | High |
| 00 | 8e 9 | High |
| 00 | 8e 9+7e12 | High |
| 00 | 8e 9+7e21 | High |
| 00 | 8e 9+7e23 | High |
| 00 | 8e 9+7e26 | High |
| 00 | 8e10 | Very High |
| 00 | 8e11 | Very High |
| 00 | 8e11+8c 2 | Very High |
| 01 | 3w 4 | Low |
| 01 | 4e 1 | Low |
| 01 | 4e 2 | Low |
| 01 | 4e 3 | Low |
| 01 | 4e 3+6s 2 | Low |
| 01 | 4e 4 | Low |
| 01 | 4e 5 | Low |
| 01 | 4e 6 | Low |
| 01 | 4e 7 | Low |
| 01 | 4e 8 | Low |
| 01 | 4e 9 | Low |
| 01 | 4e10 | Low |
| 01 | 4e11 | Low |
| 01 | 4e12 | Low |
| 01 | 4s 1 | Low |
| 01 | 4s 2 | Low |
| 01 | 4s 3 | Low |
| 01 | 4s 4 | Low |
| 01 | 4s 5 | Low |
| 01 | 4s 5+4w 3 | Low |
| 01 | 4w 1 | Low |
| 01 | 4w 2 | Low |
| 01 | 4w 2+3s 4 | Low |
| 01 | 4w 3 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 01 | 3s 1 | Low |
| 01 | 3s 2 | Low |
| 01 | 3s 3 | Low |
| 01 | 3s 4 | Low |
| 01 | 3s 4+3w 1 | Low |
| 01 | 3s 4+4w 1 | Low |
| 01 | 3s 4+6e14 | Moderate |
| 01 | 3s 4+6w 1 | Low |
| 01 | 3s 5 | Low |
| 01 | 3w 1 | Low |
| 01 | 3w 2 | Low |
| 01 | 3w 3 | Low |
| 01 | 6e 7 | Moderate |
| 01 | 6e 8 | Moderate |
| 01 | 6e 8+4e 5 | Moderate |
| 01 | 6e 9 | Moderate |
| 01 | 6e10 | Moderate |
| 01 | 6e11 | Moderate |
| 01 | 6e12 | Moderate |
| 01 | 6e13 | Moderate |
| 01 | 6e14 | Moderate |
| 01 | 6e15 | Moderate |
| 01 | 6e15+6e 3 | Moderate |
| 01 | 6e16 | High |
| 01 | 6e17 | Moderate |
| 01 | 6e18 | Moderate |
| 01 | 6e19 | High |
| 01 | 6s 1 | Low |
| 01 | 6s 2 | Low |
| 01 | 6s 3 | Low |
| 01 | 6s 4 | Moderate |
| 01 | 6s 5 | Moderate |
| 01 | 6w 1 | Low |
| 01 | 6w 2 | Low |
| 01 | 6w 3 | Low |
| 01 | 7e 1 | Very High |
| 01 | 7e 2 | High |
| 01 | 7e 3 | High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 01 | 4w 3+4s 5 | Low |
| 01 | 4w 4 | Low |
| 01 | 5c 1 | Low |
| 01 | 5c 2 | Low |
| 01 | 5s 1 | Low |
| 01 | 6c 1 | Low |
| 01 | 6e 1 | Low |
| 01 | 6e 2 | Moderate |
| 01 | 6e 3 | Low |
| 01 | 6e 4 | Low |
| 01 | 6e 5 | Moderate |
| 01 | 6e 6 | Moderate |
| 01 | 8e 2 | High |
| 01 | 8e 3 | High |
| 01 | 8s 1 | Moderate |
| 01 | 8s 2 | Moderate |
| 02 | 1s 1 | Low |
| 02 | 1s 1+7e10 | High |
| 02 | 1w 1 | Low |
| 02 | 2e 1 | Low |
| 02 | 2e 2 | Low |
| 02 | 2e 2+3w 1 | Low |
| 02 | 2e 3 | Low |
| 02 | 2e 3+2w 3 | Low |
| 02 | 2e 4 | Low |
| 02 | 2e 5 | Low |
| 02 | 2s 1 | Low |
| 02 | 2s 1+3s 1 | Low |
| 02 | 2s 2 | Low |
| 02 | 2s 2+3w 1 | Low |
| 02 | 2s 2+4e 1 | Low |
| 02 | 2s 3 | Low |
| 02 | 2s 3+3w 2 | Low |
| 02 | 2s 4 | Low |
| 02 | 2s 5 | Low |
| 02 | 2w 1 | Low |
| 02 | 2w 1+2e 2 | Low |
| 02 | 2w 1+2s 2 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 01 | 7e 4 | High |
| 01 | 7e 5 | High |
| 01 | 7e 6 | High |
| 01 | 7e 7 | Very High |
| 01 | 7e 8 | Very High |
| 01 | 7e 9 | High |
| 01 | 7e10 | Moderate |
| 01 | 7w 1 | Low |
| 01 | 7w 2 | Low |
| 01 | 8e 1 | Very High |
| 02 | 3e 2 | Low |
| 02 | 3e 3 | Low |
| 02 | 3e 3+3e 7 | Low |
| 02 | 3e 4 | Low |
| 02 | 3e 5 | Low |
| 02 | 3e 6 | Low |
| 02 | 3e 7 | Low |
| 02 | 3s 1 | Low |
| 02 | 3s 1+7e10 | High |
| 02 | 3s 2 | Low |
| 02 | 3s 2+4e 1 | Low |
| 02 | 3w 1 | Low |
| 02 | 3w 1+2e 3 | Low |
| 02 | 3w 1+2s 1 | Low |
| 02 | 3w 1+2s 2 | Low |
| 02 | 3w 1+3e 1 | Low |
| 02 | 3w 1+6s 2 | Low |
| 02 | 3w 1+6w 1 | Low |
| 02 | 3w 2 | Low |
| 02 | 3w 2+2e 3 | Low |
| 02 | 3w 3 | Low |
| 02 | 3w 4 | Low |
| 02 | 3w 4+2e 3 | Low |
| 02 | 3w 4+2s 2 | Low |
| 02 | 3w 4+3e 3 | Low |
| 02 | 4e 1 | Low |
| 02 | 4e 1+2w 3 | Low |
| 02 | 4e 1+3w 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 02 | 2w 1+3s 1 | Low |
| 02 | 2w 2 | Low |
| 02 | 2w 2+3s 1 | Low |
| 02 | 2w 3 | Low |
| 02 | 2w 3+3e 7 | Low |
| 02 | 2w 4 | Low |
| 02 | 3e 1 | Low |
| 02 | 3e 1+2s 1 | Low |
| 02 | 3e 1+2w 3 | Low |
| 02 | 3e 1+3w 1 | Low |
| 02 | 4s 1 | Low |
| 02 | 4w 1 | Low |
| 02 | 4w 1+2e 2 | Low |
| 02 | 4w 1+4e 3 | Low |
| 02 | 4w 2 | Low |
| 02 | 5c 1 | Low |
| 02 | 5s 1 | Low |
| 02 | 5s 1+8s 1 | Low |
| 02 | 6e 1 | Low |
| 02 | 6e 1+7e 1 | High |
| 02 | 6e 1+7e 6 | High |
| 02 | 6e 2 | Low |
| 02 | 6e 3 | Low |
| 02 | 6e 4 | Moderate |
| 02 | 6e 5 | Low |
| 02 | 6e 6 | Low |
| 02 | 6e 7 | Moderate |
| 02 | 6e 8 | Moderate |
| 02 | 6e 9 | Moderate |
| 02 | 6e 9+7s 1 | Moderate |
| 02 | 6e10 | Moderate |
| 02 | 6e11 | Moderate |
| 02 | 6e12 | Moderate |
| 02 | 6e13 | Moderate |
| 02 | 6e14 | Moderate |
| 02 | 6e15 | Moderate |
| 02 | 6e16 | Moderate |
| 02 | 6e17 | High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 02 | 4e 1+6e 4 | Moderate |
| 02 | 4e 2 | Low |
| 02 | 4e 3 | Low |
| 02 | 4e 3+6e 3 | Low |
| 02 | 4e 4 | Low |
| 02 | 4e 5 | Low |
| 02 | 4e 6 | Low |
| 02 | 4e 6+6s 1 | Low |
| 02 | 7e 1 | Very High + High |
| 02 | 7e 2 | Moderate |
| 02 | 7e 3 | Moderate |
| 02 | 7e 4 | High |
| 02 | 7e 6 | High |
| 02 | 7e 7 | Moderate |
| 02 | 7e 8 | Very High |
| 02 | 7e 9 | High |
| 02 | 7e10 | Very High |
| 02 | 7e10+3w 1 | Very High |
| 02 | 7e11 | High |
| 02 | 7e12 | Very High |
| 02 | 7s 1 | Low |
| 02 | 7s 1+6e 9 | Moderate |
| 02 | 7w 1 | Low |
| 02 | 8e 1 | Very High |
| 02 | 8e 2 | High |
| 02 | 8e 3 | Very High + High |
| 02 | 8e 4 | Very High |
| 02 | 8s 1 | Low |
| 03 | 2e 1 | Low |
| 03 | 2s 1 | Low |
| 03 | 2w 1 | Low |
| 03 | 3e 1 | Low |
| 03 | 3s 1 | Low |
| 03 | 3w 1 | Low |
| 03 | 4e 1 | Low |
| 03 | 4e 2 | Low |
| 03 | 4e 3 | Low |
| 03 | 4s 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 02 | 6e19 | Moderate |
| 02 | 6e21 | Moderate |
| 02 | 6s 1 | Low |
| 02 | 6s 2 | Low |
| 02 | 6s 2+3w 2 | Low |
| 02 | 6s 2+4w 1 | Low |
| 02 | 6s 2+7w 1 | Low |
| 02 | 6w 1 | Low |
| 03 | 6e 5 | Moderate |
| 03 | 6e 6 | Moderate |
| 03 | 6e 7 | Moderate |
| 03 | 6e 8 | Moderate |
| 03 | 6e 9 | Moderate |
| 03 | 6e10 | Moderate |
| 03 | 6e11 | High |
| 03 | 6s 1 | Low |
| 03 | 6s 2 | Low |
| 03 | 6w 1 | Low |
| 03 | 7c 1 | Low |
| 03 | 7e 1 | Very High |
| 03 | 7e 2 | Very High |
| 03 | 7e 3 | Very High |
| 03 | 7e 4 | High |
| 03 | 7e 5 | High |
| 03 | 7e 6 | Low |
| 03 | 7e 7 | Very High |
| 03 | 7e 8 | High |
| 03 | 7e 9 | High |
| 03 | 7w 1 | Low |
| 03 | 8e 1 | Very High |
| 03 | 8e 2 | Very High + High |
| 03 | 8e 3 | Very High |
| 03 | 8e 4 | Very High |
| 04 | 1w 1 | Low |
| 04 | 2e 1 | Low |
| 04 | 2s 1 | Low |
| 04 | 2s 2 | Low |
| 04 | 2s 3 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 03 | 4s 2 | Low |
| 03 | 4w 1 | Low |
| 03 | 6e 1 | Low |
| 03 | 6e 2 | Low |
| 03 | 6e 3 | Low |
| 03 | 6e 4 | Low |
| 04 | 3e 3 | Low |
| 04 | 3e 4 | Low |
| 04 | 3e 4+4e 4 | Low |
| 04 | 3e 5 | Low |
| 04 | 3e 5+6e 4 | Moderate |
| 04 | 3e 5+6e20 | Moderate |
| 04 | 3e 5+7e 2 | High |
| 04 | 3e 6 | Low |
| 04 | 3e 7 | Low |
| 04 | 3e 8 | Low |
| 04 | 3e 9 | Low |
| 04 | 3e 9+6e11 | Moderate |
| 04 | 3e10 | Low |
| 04 | 3e10+8e 2 | Very High |
| 04 | 3e11 | Low |
| 04 | 3e12 | Low |
| 04 | 3s 1 | Low |
| 04 | 3s 2 | Low |
| 04 | 3s 3 | Low |
| 04 | 3s 4 | Low |
| 04 | 3s 5 | Low |
| 04 | 3s 6 | Low |
| 04 | 3s 7 | Low |
| 04 | 3w 1 | Low |
| 04 | 3w 1+6e 2 | Moderate |
| 04 | 3w 1+7e 2 | High |
| 04 | 3w 1+7e 9 | High |
| 04 | 4e 1 | Low |
| 04 | 4e 1+6e 2 | Moderate |
| 04 | 4e 2 | Low |
| 04 | 4e 2+6e 4 | Moderate |
| 04 | 4e 2+6e 6 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 04 | 2w 1 | Low |
| 04 | 3c 1 | Low |
| 04 | 3e 1 | Low |
| 04 | 3e 1+6e 2 | Moderate |
| 04 | 3e 2 | Low |
| 04 | 3e 2+6e 4 | Moderate |
| 04 | 4e 5 | Low |
| 04 | 4e 6 | Low |
| 04 | 4e 7 | Low |
| 04 | 4e 8 | Low |
| 04 | 4e 8+6e 9 | Moderate |
| 04 | 4e 9 | Low |
| 04 | 4e 9+6e11 | Moderate |
| 04 | 4e10 | Low |
| 04 | 4e11 | Low |
| 04 | 4e12 | Low |
| 04 | 4e13 | Low |
| 04 | 4e14 | Low |
| 04 | 4e15 | Low |
| 04 | 4e16 | Low |
| 04 | 4e17 | Low |
| 04 | 4e18 | Low |
| 04 | 4e18+6e12 | Low |
| 04 | 4e18+6w 2 | Low |
| 04 | 4e18+7e12 | High |
| 04 | 4s 1 | Low |
| 04 | 4s 2 | Low |
| 04 | 4s 3 | Low |
| 04 | 4s 4 | Low |
| 04 | 4s 5 | Low |
| 04 | 4w 1 | Low |
| 04 | 5c 1 | Low |
| 04 | 6c 1 | Low |
| 04 | 6c 1+7e 6 | Moderate |
| 04 | 6e 1 | Low |
| 04 | 6e 2 | Moderate |
| 04 | 6e 2+4e 1 | Moderate |
| 04 | 6e 2+8e 3 | High |

| Legend | LUC unit | ESC class |
| --- | --- | --- |
| 04 | 4e 3 | Low |
| 04 | 4e 4 | Low |
| 04 | 4e 4+6s 1 | Low |
| 04 | 4e 4+7e 9 | High |
| 04 | 6e 5 | Moderate |
| 04 | 6e 5+4e 4 | Moderate |
| 04 | 6e 5+4e 6 | Moderate |
| 04 | 6e 5+7e 1 | Moderate |
| 04 | 6e 5+7e 2 | High |
| 04 | 6e 6 | Moderate |
| 04 | 6e 6+3e 5 | Moderate |
| 04 | 6e 6+7e 5 | High |
| 04 | 6e 7 | Moderate |
| 04 | 6e 7+7e 3 | High |
| 04 | 6e 7+8e 2 | Very High |
| 04 | 6e 8 | Moderate |
| 04 | 6e 9 | Moderate |
| 04 | 6e 9+7e 6 | Moderate |
| 04 | 6e10 | Moderate |
| 04 | 6e11 | Moderate |
| 04 | 6e11+4e 9 | Moderate |
| 04 | 6e11+7e 4 | High |
| 04 | 6e12 | Low |
| 04 | 6e12+4e 5 | Low |
| 04 | 6e12+4e18 | Low |
| 04 | 6e13 | Moderate |
| 04 | 6e14 | Moderate |
| 04 | 6e15 | Moderate |
| 04 | 6e15+3e 5 | Moderate |
| 04 | 6e15+4e 5 | Moderate |
| 04 | 6e16 | Moderate |
| 04 | 6e17 | Moderate |
| 04 | 6e18 | Moderate |
| 04 | 6e19 | Moderate |
| 04 | 6e20 | Moderate |
| 04 | 6e20+3e 5 | Moderate |
| 04 | 6e21 | Moderate |
| 04 | 6e22 | Moderate |

| Legend | LUC unit | ESC class |
| --- | --- | --- |
| 04 | 6e 3 | Moderate |
| 04 | 6e 4 | Moderate |
| 04 | 6e 4+3e 2 | Moderate |
| 04 | 6e 4+3e 5 | Moderate |
| 04 | 6e24+7e12 | High |
| 04 | 6s 1 | Low |
| 04 | 6s 1+4e 4 | Low |
| 04 | 6s 2 | Low |
| 04 | 6s 3 | Low |
| 04 | 6s 4 | Low |
| 04 | 6s 4+4s 2 | Low |
| 04 | 6w 1 | Low |
| 04 | 6w 2 | Low |
| 04 | 6w 2+4e 7 | Low |
| 04 | 6w 2+4e12 | Moderate |
| 04 | 7c 1 | Low |
| 04 | 7e 1 | Moderate |
| 04 | 7e 2 | High |
| 04 | 7e 2+3e 5 | High |
| 04 | 7e 2+4e 5 | High |
| 04 | 7e 2+6e24 | High |
| 04 | 7e 3 | High |
| 04 | 7e 4 | High |
| 04 | 7e 5 | High |
| 04 | 7e 6 | Moderate |
| 04 | 7e 7 | Moderate |
| 04 | 7e 8 | High |
| 04 | 7e 8+4e 5 | High |
| 04 | 7e 9 | High |
| 04 | 7e10 | High |
| 04 | 7e11 | High |
| 04 | 7e12 | High |
| 04 | 7e12+6e16 | High |
| 04 | 7e13 | High |
| 04 | 7e14 | High |
| 04 | 7e15 | High |
| 04 | 8c 1 | Low |
| 04 | 8e 1 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 04 | 6e23 | Low |
| 04 | 6e24 | Moderate |
| 04 | 8e 3 | High |
| 04 | 8e 4 | Very High |
| 04 | 8e 5 | High |
| 04 | 8e 6 | High |
| 04 | 8e 7 | High |
| 04 | 8s 1 | Low |
| 04 | 8w 1 | Low |
| 04 | 8w 1+4s 4 | Low |
| 04 | 8w 2 | Low |
| 05 | 2e 1 | Low |
| 05 | 2w 1 | Low |
| 05 | 3e 1 | Low |
| 05 | 3w 1 | Low |
| 05 | 4e 1 | Low |
| 05 | 4s 1 | Low |
| 05 | 4w 1 | Low |
| 05 | 6e 1 | Moderate |
| 05 | 6e 1+7e 1 | Moderate |
| 05 | 6e 2 | Moderate |
| 05 | 6e 4 | Moderate |
| 05 | 6e 5 | Moderate |
| 05 | 7e 1 | Moderate |
| 05 | 7e 2 | Moderate |
| 05 | 7e 3 | Low |
| 05 | 8e 1 | High |
| 05 | 8e 2 | High |
| 05 | 8e 3 | Moderate |
| 05 | 8e 4 | High |
| 06 | 1c 1 | Low |
| 06 | 1w 1 | Low |
| 06 | 2e 1 | Low |
| 06 | 2s 1 | Low |
| 06 | 2s 1+3s 1 | Low |
| 06 | 2s 1+3w 3 | Low |
| 06 | 2s 2 | Low |
| 06 | 2s 3 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 04 | 8e 2 | Very High |
| 04 | 8e 2+4e18 | Very High |
| 06 | 2w 1 | Low |
| 06 | 2w 1+2s 2 | Low |
| 06 | 2w 2 | Low |
| 06 | 2w 2+2s 1 | Low |
| 06 | 3c 1 | Low |
| 06 | 3c 1+4w 2 | Low |
| 06 | 3c 2 | Low |
| 06 | 3c 2+6s 2 | Low |
| 06 | 3e 1 | Low |
| 06 | 3e 2 | Low |
| 06 | 3e 3 | Low |
| 06 | 3e 4 | Low |
| 06 | 3e 4+3w 3 | Low |
| 06 | 3e 5 | Low |
| 06 | 3s 1 | Low |
| 06 | 3s 1+8s 2 | Very High |
| 06 | 3s 2 | Low |
| 06 | 3s 2+2w 1 | Low |
| 06 | 3s 2+3w 3 | Low |
| 06 | 3s 2+8e 2 | Very High |
| 06 | 3s 3 | Low |
| 06 | 3s 3+3w 1 | Low |
| 06 | 3w 1 | Low |
| 06 | 3w 2 | Low |
| 06 | 3w 3 | Low |
| 06 | 3w 3+2s 1 | Low |
| 06 | 3w 3+2s 3 | Low |
| 06 | 3w 3+2w 1 | Low |
| 06 | 3w 3+3s 2 | Low |
| 06 | 3w 3+4s 1 | Low |
| 06 | 3w 3+8s 2 | Very High |
| 06 | 3w 4 | Low |
| 06 | 3w 5 | Low |
| 06 | 4c 1 | Low |
| 06 | 4c 1+6e19 | Moderate |
| 06 | 4c 1+6e23 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 06 | 4e 1 | Low |
| 06 | 4e 2 | Low |
| 06 | 4e 3 | Low |
| 06 | 4e 4 | Low |
| 06 | 4e 5 | Low |
| 06 | 4e 5+3c 1 | Low |
| 06 | 4e 5+6s 2 | Low |
| 06 | 4s 1 | Low |
| 06 | 4s 1+4w 1 | Low |
| 06 | 4s 1+7e26 | High |
| 06 | 4s 2 | Low |
| 06 | 4s 3 | Low |
| 06 | 4w 1 | Low |
| 06 | 4w 1+2s 1 | Low |
| 06 | 4w 1+7e26 | High |
| 06 | 4w 1+8s 2 | Very High |
| 06 | 4w 2 | Low |
| 06 | 6e 1 | Moderate |
| 06 | 6e 1+4w 1 | Moderate |
| 06 | 6e 2 | Moderate |
| 06 | 6e 3 | Moderate |
| 06 | 6e 4 | Moderate |
| 06 | 6e 5 | Moderate |
| 06 | 6e 6 | Moderate |
| 06 | 6e 7 | Moderate |
| 06 | 6e 8 | Moderate |
| 06 | 6e 9 | Moderate |
| 06 | 6e10 | Moderate |
| 06 | 6e10+3w 3 | Moderate |
| 06 | 6e11 | Moderate |
| 06 | 6e12 | Moderate |
| 06 | 6e13 | Moderate |
| 06 | 6e14 | Moderate |
| 06 | 6e15 | Moderate |
| 06 | 6e16 | Moderate |
| 06 | 6e17 | Moderate |
| 06 | 7e15+8s 1 | Very High |
| 06 | 7e16 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 06 | 6e18 | Moderate |
| 06 | 6e19 | Moderate |
| 06 | 6e20 | Moderate |
| 06 | 6e21 | Moderate |
| 06 | 6e22 | Moderate |
| 06 | 6e23 | Moderate |
| 06 | 6e23+6s 2 | Moderate |
| 06 | 6e24 | Moderate |
| 06 | 6e25 | Low |
| 06 | 6e25+7w 1 | Low |
| 06 | 6s 1 | Low |
| 06 | 6s 2 | Low |
| 06 | 6s 2+7w 1 | Low |
| 06 | 6s 3 | Low |
| 06 | 6s 3+4s 2 | Low |
| 06 | 6s 3+8s 2 | Very High |
| 06 | 6w 1 | Low |
| 06 | 7e 1 | Very High |
| 06 | 7e 2 | Very High |
| 06 | 7e 3 | Very High |
| 06 | 7e 3+7e23 | Very High |
| 06 | 7e 3+8s 1 | Very High |
| 06 | 7e 4 | Very High |
| 06 | 7e 5 | Very High |
| 06 | 7e 6 | High |
| 06 | 7e 7 | Very High |
| 06 | 7e 8 | High |
| 06 | 7e 9 | High |
| 06 | 7e10 | Very High |
| 06 | 7e11 | High |
| 06 | 7e11+8s 1 | High |
| 06 | 7e12 | High |
| 06 | 7e13 | Very High |
| 06 | 7e14 | Very High |
| 06 | 7e15 | Very High |
| 06 | 7e15+8e 3 | Very High |
| 06 | 8s 2 | Very High |
| 06 | 8s 2+3s 1 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 06 | 7e17 | Very High |
| 06 | 7e18 | Very High |
| 06 | 7e19 | Very High |
| 06 | 7e19+8s 2 | Very High |
| 06 | 7e20 | High |
| 06 | 7e21 | Very High |
| 06 | 7e22 | Very High |
| 06 | 7e23 | Very High |
| 06 | 7e23+7e 8 | Very High |
| 06 | 7e24 | Very High |
| 06 | 7e24+8e 7 | Very High |
| 06 | 7e25 | Very High |
| 06 | 7e26 | High |
| 06 | 7e26+8s 2 | Very High |
| 06 | 7e27 | Low |
| 06 | 7e27+6s 3 | Low |
| 06 | 7e27+7w 1 | Low |
| 06 | 7s 1 | Moderate |
| 06 | 7s 2 | Moderate |
| 06 | 7s 2+8s 1 | Moderate |
| 06 | 7w 1 | Low |
| 06 | 7w 1+6w 1 | Low |
| 06 | 8e 1 | Very High |
| 06 | 8e 1+7e27 | Very High |
| 06 | 8e 2 | Very High |
| 06 | 8e 3 | Very High |
| 06 | 8e 4 | Very High |
| 06 | 8e 5 | Very High |
| 06 | 8e 6 | Very High |
| 06 | 8e 7 | Very High |
| 06 | 8e 8 | Very High |
| 06 | 8e 9 | Very High |
| 06 | 8s 1 | Moderate |
| 06 | 8s 1+7e11 | High |
| 07 | 6e 1+4e 2 | Low |
| 07 | 6e 2 | Low |
| 07 | 6e 3 | Moderate |
| 07 | 6e 4 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 06 | 8s 2+3w 3 | Very High |
| 06 | 8s 2+6w 1 | Very High |
| 06 | 8s 2+7e26 | Very High |
| 07 | 1c 1 | Low |
| 07 | 1w 1 | Low |
| 07 | 2e 1 | Low |
| 07 | 2w 1 | Low |
| 07 | 3e 1 | Low |
| 07 | 3e 2 | Low |
| 07 | 3e 3 | Low |
| 07 | 3s 1 | Low |
| 07 | 3s 2 | Low |
| 07 | 3s 3 | Low |
| 07 | 3s 4 | Low |
| 07 | 3w 1 | Low |
| 07 | 3w 1+3s 3 | Low |
| 07 | 3w 2 | Low |
| 07 | 4c 1 | Low |
| 07 | 4e 1 | Low |
| 07 | 4e 2 | Low |
| 07 | 4e 2+6e 6 | Moderate |
| 07 | 4e 3 | Low |
| 07 | 4e 4 | Low |
| 07 | 4e 5 | Low |
| 07 | 4s 1 | Low |
| 07 | 4s 2 | Low |
| 07 | 4s 2+8e 4 | Very High |
| 07 | 4w 1 | Low |
| 07 | 4w 2 | Low |
| 07 | 5c 1 | Low |
| 07 | 6c 1 | Low |
| 07 | 6c 2 | Low |
| 07 | 6c 3 | Low |
| 07 | 6e 1 | Low |
| 07 | 7e14 | High |
| 07 | 7e15 | Very High |
| 07 | 7e16 | High |
| 07 | 7e17 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 07 | 6e 5 | Moderate |
| 07 | 6e 6 | Moderate |
| 07 | 6e 7 | High |
| 07 | 6e 8 | Moderate |
| 07 | 6e10 | Moderate |
| 07 | 6e11 | Moderate |
| 07 | 6e12 | Moderate |
| 07 | 6e13 | Low |
| 07 | 6e14 | Moderate |
| 07 | 6e15 | High |
| 07 | 6e15+7e16 | High |
| 07 | 6e16 | Moderate |
| 07 | 6s 1 | Low |
| 07 | 6s 3 | Low |
| 07 | 6w 1 | Low |
| 07 | 7e 1 | Very High |
| 07 | 7e 2 | Very High |
| 07 | 7e 3 | Very High |
| 07 | 7e 4 | Very High |
| 07 | 7e 5 | Very High |
| 07 | 7e 6 | High |
| 07 | 7e 7 | High |
| 07 | 7e 7+8e 4 | Very High |
| 07 | 7e 8 | Very High |
| 07 | 7e 9 | Very High |
| 07 | 7e 9+8e 2 | Very High |
| 07 | 7e10 | Very High |
| 07 | 7e11 | Very High |
| 07 | 7e11+8e 2 | Very High |
| 07 | 7e12 | Moderate |
| 07 | 7e12+6e16 | Moderate |
| 07 | 7e13 | Low |
| 08 | 3s 1+7e 3 | Moderate |
| 08 | 3s 2 | Low |
| 08 | 3s 2+6s 4 | Low |
| 08 | 3s 2+7e 4 | High |
| 08 | 3s 3 | Low |
| 08 | 3s 3+4e 3 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 07 | 7e18 | Moderate |
| 07 | 7e19 | High |
| 07 | 7s 1 | Low |
| 07 | 7w 1 | Low |
| 07 | 8e 1 | Very High |
| 07 | 8e 2 | Very High |
| 07 | 8e 3 | Very High |
| 07 | 8e 4 | Very High |
| 07 | 8e 4+4e 5 | Very High |
| 07 | 8e 4+4s 2 | Very High |
| 07 | 8e 4+7e16 | Very High |
| 07 | 8e 5 | High |
| 07 | 8e 6 | Very High |
| 07 | 8e 7 | High |
| 07 | 8e 8 | High |
| 07 | 8e 9 | High |
| 07 | 8e10 | Low |
| 07 | 8e11 | Low |
| 07 | 8s 1 | Low |
| 08 | 1c 1 | Low |
| 08 | 1w 1 | Low |
| 08 | 2c 1 | Low |
| 08 | 2s 1 | Low |
| 08 | 2s 1+7e 4 | High |
| 08 | 2w 1 | Low |
| 08 | 3e 1 | Low |
| 08 | 3e 2 | Low |
| 08 | 3e 2+6e 4 | Moderate |
| 08 | 3e 2+7e 4 | High |
| 08 | 3e 3 | Low |
| 08 | 3e 3+4e 3 | Low |
| 08 | 3s 1 | Low |
| 08 | 6e 7 | Moderate |
| 08 | 6e 8 | Moderate |
| 08 | 6e 9 | Moderate |
| 08 | 6e10 | Moderate |
| 08 | 6e11 | Low |
| 08 | 6e11+2s 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 08 | 3s 3+7e 1 | High |
| 08 | 3s 3+7e 2 | High |
| 08 | 3s 3+7e 4 | High |
| 08 | 3s 4 | Low |
| 08 | 3w 1 | Low |
| 08 | 3w 1+3s 3 | Low |
| 08 | 3w 1+7e 2 | High |
| 08 | 3w 2 | Low |
| 08 | 3w 2+7e 4 | High |
| 08 | 4e 1 | Low |
| 08 | 4e 1+8e 1 | Very High |
| 08 | 4e 2 | Low |
| 08 | 4e 3 | Low |
| 08 | 4e 3+3s 3 | Low |
| 08 | 4e 3+3w 1 | Low |
| 08 | 4e 4 | Low |
| 08 | 4e 5 | Low |
| 08 | 4s 1 | Low |
| 08 | 4s 1+7e 4 | High |
| 08 | 4w 1 | Low |
| 08 | 5c 1 | Low |
| 08 | 5s 1 | Low |
| 08 | 6c 1 | Low |
| 08 | 6c 2 | Low |
| 08 | 6e 1 | Moderate |
| 08 | 6e 2 | Moderate |
| 08 | 6e 3 | Moderate |
| 08 | 6e 4 | Moderate |
| 08 | 6e 5 | Moderate |
| 08 | 6e 6 | Low |
| 08 | 7e13 | Very High |
| 08 | 7e14 | Low |
| 08 | 7s 1 | Low |
| 08 | 7s 2 | Low |
| 08 | 8c 1 | Low |
| 08 | 8e 1 | Very High |
| 08 | 8e 1+2w 1 | Very High |
| 08 | 8e 1+3s 2 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 08 | 6e12 | High |
| 08 | 6e13 | Moderate |
| 08 | 6e14 | Low |
| 08 | 6s 1 | Low |
| 08 | 6s 1+3e 1 | Low |
| 08 | 6s 2 | Low |
| 08 | 6s 3 | Low |
| 08 | 6s 3+6e12 | High |
| 08 | 6s 4 | Low |
| 08 | 6s 5 | Low |
| 08 | 6w 1 | Low |
| 08 | 7e 1 | Very High |
| 08 | 7e 1+7e 8 | Very High |
| 08 | 7e 2 | Very High |
| 08 | 7e 2+3w 1 | Very High |
| 08 | 7e 3 | Moderate |
| 08 | 7e 4 | Very High |
| 08 | 7e 5 | Moderate |
| 08 | 7e 6 | Very High |
| 08 | 7e 6+7e 5 | Very High |
| 08 | 7e 7 | High |
| 08 | 7e 8 | Very High |
| 08 | 7e 8+6e10 | Very High |
| 08 | 7e 9 | High |
| 08 | 7e 9+4s 1 | High |
| 08 | 7e10 | Moderate |
| 08 | 7e10+3s 2 | Moderate |
| 08 | 7e11 | Moderate |
| 08 | 7e12 | Very High |
| 08 | 7e12+3s 4 | Very High |
| 09 | 3e 1 | Low |
| 09 | 3e 2 | Low |
| 09 | 3e 2+2c 1 | Low |
| 09 | 3e 3 | Low |
| 09 | 3e 3+2c 1 | Low |
| 09 | 3e 3+3s 4 | Low |
| 09 | 3e 3+6e 1 | Moderate |
| 09 | 3s 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 08 | 8e 2 | Very High |
| 08 | 8e 3 | Very High |
| 08 | 8e 4 | Very High |
| 08 | 8e 5 | High |
| 08 | 8e 6 | Very High |
| 08 | 8e 7 | High |
| 08 | 8e 8 | High |
| 08 | 8e 9 | High |
| 09 | 1c 1 | Low |
| 09 | 1c 1+6e 1 | Moderate |
| 09 | 1s 1 | Low |
| 09 | 1s 1+2s 1 | Low |
| 09 | 1s 1+4s 1 | Low |
| 09 | 1w 1 | Low |
| 09 | 2c 1 | Low |
| 09 | 2c 1+6e 1 | Moderate |
| 09 | 2e 1 | Low |
| 09 | 2e 1+6e 1 | Moderate |
| 09 | 2s 1 | Low |
| 09 | 2s 1+2w 1 | Low |
| 09 | 2s 1+4s 1 | Low |
| 09 | 2s 2 | Low |
| 09 | 2s 3 | Low |
| 09 | 2s 3+3s 2 | Low |
| 09 | 2s 3+3w 1 | Low |
| 09 | 2w 1 | Low |
| 09 | 2w 2 | Low |
| 09 | 3c 1 | Low |
| 09 | 4s 1 | Low |
| 09 | 4s 2 | Low |
| 09 | 4s 2+4e 1 | Low |
| 09 | 4s 2+8e 3 | High |
| 09 | 4w 1 | Low |
| 09 | 4w 1+4e 1 | Low |
| 09 | 4w 2 | Low |
| 09 | 4w 3 | Low |
| 09 | 4w 3+6s 5 | Low |
| 09 | 6c 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 09 | 3s 1+4s 1 | Low |
| 09 | 3s 2 | Low |
| 09 | 3s 2+2s 1 | Low |
| 09 | 3s 2+3w 1 | Low |
| 09 | 3s 3 | Low |
| 09 | 3s 4 | Low |
| 09 | 3s 4+1s 1 | Low |
| 09 | 3s 4+6e 1 | Moderate |
| 09 | 3w 1 | Low |
| 09 | 3w 1+2s 3 | Low |
| 09 | 3w 1+4e 2 | Low |
| 09 | 3w 1+7e 3 | Low |
| 09 | 3w 2 | Low |
| 09 | 3w 2+6s 5 | Low |
| 09 | 3w 3 | Low |
| 09 | 3w 3+6e 5 | Low |
| 09 | 3w 3+6s 4 | Low |
| 09 | 3w 3+6s 5 | Low |
| 09 | 4c 1 | Low |
| 09 | 4e 1 | Low |
| 09 | 4e 1+3s 2 | Low |
| 09 | 4e 1+4s 2 | Low |
| 09 | 4e 2 | Low |
| 09 | 4e 2+6e 1 | Moderate |
| 09 | 4e 3 | Low |
| 09 | 4e 4 | Low |
| 09 | 4e 4+6s 5 | Low |
| 09 | 4e 5 | Low |
| 09 | 6s 4 | Low |
| 09 | 6s 4+7e 3 | Low |
| 09 | 6s 5 | Low |
| 09 | 6s 5+3w 2 | Low |
| 09 | 6s 5+4e 4 | Low |
| 09 | 6s 5+4w 3 | Low |
| 09 | 6s 5+6e 5 | Low |
| 09 | 6s 6 | Low |
| 09 | 6s 7 | Low |
| 09 | 6s 7+3s 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 09 | 6c 1+6e 6 | Low |
| 09 | 6c 1+6e 8 | Low |
| 09 | 6c 2 | Low |
| 09 | 6c 3 | Low |
| 09 | 6c 3+4s 2 | Low |
| 09 | 6e 1 | Moderate |
| 09 | 6e 1+3e 3 | Moderate |
| 09 | 6e 1+3s 4 | Moderate |
| 09 | 6e 1+4e 2 | Moderate |
| 09 | 6e 2 | Moderate |
| 09 | 6e 3 | Low |
| 09 | 6e 4 | Low |
| 09 | 6e 5 | Low |
| 09 | 6e 5+3w 2 | Low |
| 09 | 6e 5+4e 4 | Low |
| 09 | 6e 5+4w 3 | Low |
| 09 | 6e 6 | Low |
| 09 | 6e 7 | Low |
| 09 | 6e 8 | Low |
| 09 | 6e 8+6c 1 | Low |
| 09 | 6e 9 | Low |
| 09 | 6e10 | Moderate |
| 09 | 6s 1 | Low |
| 09 | 6s 1+6e 2 | Moderate |
| 09 | 6s 2 | Low |
| 09 | 6s 3 | Low |
| 10 | 1c 3+3w 4 | Low |
| 10 | 1w 1 | Low |
| 10 | 1w 1+4s 2 | Low |
| 10 | 1w 2 | Low |
| 10 | 2c 1 | Low |
| 10 | 2c 1+3s 2 | Low |
| 10 | 2c 1+4e 3 | Low |
| 10 | 2c 1+8e 3 | Very High |
| 10 | 2c 2 | Low |
| 10 | 2c 3 | Low |
| 10 | 2c 3+3e 2 | Low |
| 10 | 2c 3+3s 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 09 | 6w 1 | Low |
| 09 | 7c 1 | Low |
| 09 | 7e 1 | Moderate |
| 09 | 7e 2 | Moderate |
| 09 | 7e 3 | Low |
| 09 | 7e 3+6s 4 | Low |
| 09 | 7e 4 | Moderate |
| 09 | 7e 4+8e 2 | High |
| 09 | 7e 5 | High |
| 09 | 7s 1 | Low |
| 09 | 7s 2 | Low |
| 09 | 7s 3 | Low |
| 09 | 7w 1 | Low |
| 09 | 7w 2 | Low |
| 09 | 8e 1 | Very High |
| 09 | 8e 2 | High |
| 09 | 8e 3 | High |
| 09 | 8e 4 | High |
| 09 | 8e 5 | Very High |
| 09 | 8s 1 | Low |
| 09 | 8s 1+7s 3 | Low |
| 10 | 1c 1 | Low |
| 10 | 1c 1+3s 1 | Low |
| 10 | 1c 1+5s 1 | Low |
| 10 | 1c 2 | Low |
| 10 | 1c 3 | Low |
| 10 | 2w 4 | Low |
| 10 | 3c 1 | Low |
| 10 | 3c 1+4e 6 | Low |
| 10 | 3c 1+6e 6 | Moderate |
| 10 | 3c 2 | Low |
| 10 | 3c 3 | Low |
| 10 | 3c 4 | Low |
| 10 | 3c 4+3e 6 | Low |
| 10 | 3c 4+3w 5 | Low |
| 10 | 3c 4+4e 7 | Low |
| 10 | 3c 4+4s 1 | Low |
| 10 | 3c 4+5c 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 2c 3+3w 5 | Low |
| 10 | 2c 3+4e 2 | Low |
| 10 | 2c 3+4e 3 | Low |
| 10 | 2c 3+5c 1 | Low |
| 10 | 2c 3+6e 1 | Low |
| 10 | 2e 1 | Low |
| 10 | 2e 1+3e 2 | Low |
| 10 | 2e 1+3w 5 | Low |
| 10 | 2e 2 | Low |
| 10 | 2e 2+6e 2 | Low |
| 10 | 2s 1 | Low |
| 10 | 2s 2 | Low |
| 10 | 2s 2+3e 4 | Low |
| 10 | 2s 2+6e14 | Moderate |
| 10 | 2s 2+7e 3 | High |
| 10 | 2s 3 | Low |
| 10 | 2s 3+5s 1 | Low |
| 10 | 2s 4 | Low |
| 10 | 2s 5 | Low |
| 10 | 2w 1 | Low |
| 10 | 2w 2 | Low |
| 10 | 2w 2+7e 6 | High |
| 10 | 2w 2+8e 3 | Very High |
| 10 | 2w 3 | Low |
| 10 | 3s 2 | Low |
| 10 | 3s 2+8e 3 | Very High |
| 10 | 3s 3 | Low |
| 10 | 3s 3+5s 1 | Low |
| 10 | 3s 4 | Low |
| 10 | 3s 5 | Low |
| 10 | 3s 5+6s 3 | Low |
| 10 | 3s 5+6s 5 | Low |
| 10 | 3s 6 | Low |
| 10 | 3s 6+4w 1 | Low |
| 10 | 3s 6+6e26 | Moderate |
| 10 | 3s 6+7e19 | High |
| 10 | 3s 6+8e 2 | Very High |
| 10 | 3w 1 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 3c 4+6e 6 | Moderate |
| 10 | 3e 1 | Low |
| 10 | 3e 1+6e 3 | Moderate |
| 10 | 3e 2 | Low |
| 10 | 3e 2+3w 5 | Low |
| 10 | 3e 2+5c 1 | Low |
| 10 | 3e 2+6s 6 | Low |
| 10 | 3e 3 | Low |
| 10 | 3e 4 | Low |
| 10 | 3e 4+6e 3 | Moderate |
| 10 | 3e 4+6e14 | Moderate |
| 10 | 3e 4+8e 3 | Very High |
| 10 | 3e 5 | Low |
| 10 | 3e 5+8e 3 | Very High |
| 10 | 3e 6 | Low |
| 10 | 3e 6+6e 6 | Moderate |
| 10 | 3e 7 | Low |
| 10 | 3e 7+6w 1 | Low |
| 10 | 3e 8 | Low |
| 10 | 3e 8+8e 2 | Very High |
| 10 | 3s 1 | Low |
| 10 | 3s 1+2c 3 | Low |
| 10 | 3s 1+6e 1 | Low |
| 10 | 3s 1+6s 6 | Low |
| 10 | 4e 2+2c 3 | Low |
| 10 | 4e 2+3w 5 | Low |
| 10 | 4e 2+5c 1 | Low |
| 10 | 4e 2+6e 1 | Low |
| 10 | 4e 2+6e21 | Moderate |
| 10 | 4e 3 | Low |
| 10 | 4e 4 | Low |
| 10 | 4e 5 | Low |
| 10 | 4e 5+6e17 | Moderate |
| 10 | 4e 5+6s 2 | Low |
| 10 | 4e 6 | Low |
| 10 | 4e 6+6e 3 | Moderate |
| 10 | 4e 6+6e23 | Moderate |
| 10 | 4e 7 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 3w 2 | Low |
| 10 | 3w 2+8e 3 | Very High |
| 10 | 3w 3 | Low |
| 10 | 3w 4 | Low |
| 10 | 3w 4+6e24 | Low |
| 10 | 3w 4+7e15 | Low |
| 10 | 3w 5 | Low |
| 10 | 3w 5+4e 2 | Low |
| 10 | 3w 5+5s 1 | Low |
| 10 | 4c 1 | Low |
| 10 | 4c 1+6e 7 | Moderate |
| 10 | 4c 2 | Low |
| 10 | 4c 2+6e27 | Moderate |
| 10 | 4c 3 | Low |
| 10 | 4c 3+5c 1 | Low |
| 10 | 4c 3+5s 1 | Low |
| 10 | 4c 3+6s 3 | Low |
| 10 | 4c 4 | Low |
| 10 | 4c 4+6w 1 | Low |
| 10 | 4e 1 | Low |
| 10 | 4e 1+6s 1 | Low |
| 10 | 4e 2 | Low |
| 10 | 4s 2 | Low |
| 10 | 4s 3 | Low |
| 10 | 4w 1 | Low |
| 10 | 4w 1+3e 1 | Low |
| 10 | 4w 1+7e15 | Low |
| 10 | 4w 2 | Low |
| 10 | 4w 3 | Low |
| 10 | 4w 4 | Low |
| 10 | 5c 1 | Low |
| 10 | 5c 1+2c 3 | Low |
| 10 | 5c 1+2e 1 | Low |
| 10 | 5c 1+3c 4 | Low |
| 10 | 5c 1+3e 2 | Low |
| 10 | 5c 1+3w 2 | Low |
| 10 | 5c 1+3w 3 | Low |
| 10 | 5c 1+3w 5 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 4e 7+4c 3 | Low |
| 10 | 4e 7+5c 1 | Low |
| 10 | 4e 8 | Low |
| 10 | 4e 8+6e20 | Moderate |
| 10 | 4e 8+7e 2 | High |
| 10 | 4e 9 | Low |
| 10 | 4e 9+6s 5 | Low |
| 10 | 4e10 | Low |
| 10 | 4e10+6e24 | Low |
| 10 | 4e10+6s 4 | Low |
| 10 | 4e10+7e15 | Low |
| 10 | 4e11 | Low |
| 10 | 4e12 | Low |
| 10 | 4e12+3c 3 | Low |
| 10 | 4e12+6c 3 | Low |
| 10 | 4e12+6e27 | Moderate |
| 10 | 4e13 | Low |
| 10 | 4e14 | Low |
| 10 | 4e14+6w 1 | Low |
| 10 | 4s 1 | Low |
| 10 | 4s 1+3s 1 | Low |
| 10 | 4s 1+6s 6 | Low |
| 10 | 6e 1+3e 6 | Low |
| 10 | 6e 1+4s 1 | Low |
| 10 | 6e 1+6s 6 | Low |
| 10 | 6e 2 | Low |
| 10 | 6e 2+2s 2 | Low |
| 10 | 6e 3 | Moderate |
| 10 | 6e 3+3c 4 | Moderate |
| 10 | 6e 3+4e 4 | Moderate |
| 10 | 6e 3+4e 6 | Moderate |
| 10 | 6e 4 | Moderate |
| 10 | 6e 4+4e 4 | Moderate |
| 10 | 6e 5 | Moderate |
| 10 | 6e 6 | Moderate |
| 10 | 6e 6+3c 4 | Moderate |
| 10 | 6e 6+3e 6 | Moderate |
| 10 | 6e 6+4e 7 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 5c 1+4e 2 | Low |
| 10 | 5s 1 | Low |
| 10 | 5s 1+2c 2 | Low |
| 10 | 5s 1+2s 3 | Low |
| 10 | 5s 1+3w 1 | Low |
| 10 | 5s 1+3w 5 | Low |
| 10 | 5s 2 | Low |
| 10 | 6c 1 | Low |
| 10 | 6c 1+3c 1 | Low |
| 10 | 6c 1+3w 2 | Low |
| 10 | 6c 2 | Low |
| 10 | 6c 3 | Low |
| 10 | 6c 3+4e12 | Low |
| 10 | 6c 3+7e13 | High |
| 10 | 6c 4 | Low |
| 10 | 6c 4+6e26 | Moderate |
| 10 | 6c 4+6w 1 | Low |
| 10 | 6c 4+7e 8 | Moderate |
| 10 | 6c 5 | Low |
| 10 | 6e 1 | Low |
| 10 | 6e 1+3e 6 | Low |
| 10 | 6e 1+4s 1 | Low |
| 10 | 6e 1+6s 6 | Low |
| 10 | 6e 2 | Low |
| 10 | 6e 2+2s 2 | Low |
| 10 | 6e 3 | Moderate |
| 10 | 6e 3+3c 4 | Moderate |
| 10 | 6e 3+4e 4 | Moderate |
| 10 | 6e 3+4e 6 | Moderate |
| 10 | 6e 4 | Moderate |
| 10 | 6e 4+4e 4 | Moderate |
| 10 | 6e 5 | Moderate |
| 10 | 6e 6 | Moderate |
| 10 | 6e 6+3c 4 | Moderate |
| 10 | 6e 6+3e 6 | Moderate |
| 10 | 6e 6+4e 7 | Moderate |
| 10 | 6e 6+5c 1 | Moderate |
| 10 | 6e 6+6s 6 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 6e 6+5c 1 | Moderate |
| 10 | 6e 6+6s 6 | Moderate |
| 10 | 6e 7 | Moderate |
| 10 | 6e 8 | Moderate |
| 10 | 6e 9 | Moderate |
| 10 | 6e10 | Moderate |
| 10 | 6e10+4e 7 | Moderate |
| 10 | 6e11 | Moderate |
| 10 | 6e12 | Moderate |
| 10 | 6e12+4e 3 | Moderate |
| 10 | 6e13 | Moderate |
| 10 | 6e14 | Moderate |
| 10 | 6e15 | Moderate |
| 10 | 6e16 | Low |
| 10 | 6e17 | Moderate |
| 10 | 6e17+4e 7 | Moderate |
| 10 | 6e17+4w 1 | Moderate |
| 10 | 6e17+6w 1 | Moderate |
| 10 | 6e18 | Moderate |
| 10 | 6e18+4e 9 | Moderate |
| 10 | 6e19 | Moderate |
| 10 | 6e20 | Moderate |
| 10 | 6e20+4e 1 | Moderate |
| 10 | 6e21 | Moderate |
| 10 | 6e21+4e 7 | Moderate |
| 10 | 6e21+4e 8 | Moderate |
| 10 | 6e21+4w 1 | Moderate |
| 10 | 6e22 | Low |
| 10 | 6e23 | Moderate |
| 10 | 6e23+3c 4 | Moderate |
| 10 | 6e24 | Low |
| 10 | 6e24+2w 4 | Low |
| 10 | 6e24+3w 4 | Low |
| 10 | 6e24+4e10 | Low |
| 10 | 6e24+7e15 | Low |
| 10 | 6e25 | Moderate |
| 10 | 6e25+4e 2 | Moderate |
| 10 | 6e25+6s 6 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 6e 7 | Moderate |
| 10 | 6e 8 | Moderate |
| 10 | 6e 9 | Moderate |
| 10 | 6e10 | Moderate |
| 10 | 6e10+4e 7 | Moderate |
| 10 | 6e11 | Moderate |
| 10 | 6e12 | Moderate |
| 10 | 6e12+4e 3 | Moderate |
| 10 | 6e13 | Moderate |
| 10 | 6e14 | Moderate |
| 10 | 6e15 | Moderate |
| 10 | 6e16 | Low |
| 10 | 6e17 | Moderate |
| 10 | 6e17+4e 7 | Moderate |
| 10 | 6e17+4w 1 | Moderate |
| 10 | 6e17+6w 1 | Moderate |
| 10 | 6e18 | Moderate |
| 10 | 6e18+4e 9 | Moderate |
| 10 | 6s 8+8s 1 | High |
| 10 | 6w 1 | Low |
| 10 | 6w 1+4e14 | Low |
| 10 | 7c 1 | Low |
| 10 | 7c 1+8w 1 | Low |
| 10 | 7e 1 | Very High |
| 10 | 7e 1+8e 3 | Very High |
| 10 | 7e 2 | Very High |
| 10 | 7e 3 | Very High |
| 10 | 7e 4 | Very High |
| 10 | 7e 4+3e 4 | Very High |
| 10 | 7e 5 | Very High |
| 10 | 7e 6 | Very High |
| 10 | 7e 7 | Very High |
| 10 | 7e 8 | Moderate |
| 10 | 7e 9 | Very High |
| 10 | 7e10 | Moderate |
| 10 | 7e11 | Very High + High |
| 10 | 7e11+6e20 | Very High |
| 10 | 7e11+6e23 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 6e26 | Moderate |
| 10 | 6e27 | Moderate |
| 10 | 6e27+4c 2 | Moderate |
| 10 | 6e27+4e12 | Moderate |
| 10 | 6s 1 | Low |
| 10 | 6s 2 | Low |
| 10 | 6s 3 | Low |
| 10 | 6s 3+3s 5 | Low |
| 10 | 6s 4 | Low |
| 10 | 6s 4+7e15 | Low |
| 10 | 6s 5 | Low |
| 10 | 6s 6 | Low |
| 10 | 6s 6+3s 1 | Low |
| 10 | 6s 6+4s 1 | Low |
| 10 | 6s 6+6e 1 | Low |
| 10 | 6s 7 | Low |
| 10 | 6s 7+7e 9 | High |
| 10 | 6s 8 | Low |
| 10 | 7e20+6e20 | Very High |
| 10 | 7e21 | Moderate |
| 10 | 7e22 | Moderate |
| 10 | 7e23 | Very High |
| 10 | 7e24 | Low |
| 10 | 7e25 | Low |
| 10 | 7e26 | Low |
| 10 | 7s 1 | Low |
| 10 | 8c 1 | Low |
| 10 | 8e 1 | Very High |
| 10 | 8e 2 | Very High |
| 10 | 8e 2+3s 6 | Very High |
| 10 | 8e 3 | Very High |
| 10 | 8e 3+2c 1 | Very High |
| 10 | 8e 3+2s 1 | Very High |
| 10 | 8e 3+3c 1 | Very High |
| 10 | 8e 3+3e 5 | Very High |
| 10 | 8e 3+3s 2 | Very High |
| 10 | 8e 3+3w 2 | Very High |
| 10 | 8e 3+4e13 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 7e12 | High |
| 10 | 7e13 | Very High |
| 10 | 7e13+8e 3 | Very High |
| 10 | 7e14 | Very High |
| 10 | 7e15 | Low |
| 10 | 7e15+3w 4 | Low |
| 10 | 7e15+4e10 | Low |
| 10 | 7e15+6e 4 | Moderate |
| 10 | 7e15+6e24 | Low |
| 10 | 7e15+6s 4 | Low |
| 10 | 7e16 | Very High |
| 10 | 7e17 | Very High |
| 10 | 7e17+4w 1 | Very High |
| 10 | 7e18 | High |
| 10 | 7e19 | High |
| 10 | 7e20 | Very High |
| 11 | 2s 2 | Low |
| 11 | 2s 2+4s 5 | Low |
| 11 | 2s 4 | Low |
| 11 | 2w 1 | Low |
| 11 | 2w 1+4s 8 | Low |
| 11 | 3c 2 | Low |
| 11 | 3c 3+4s 3 | Low |
| 11 | 3e 1 | Low |
| 11 | 3e 2 | Low |
| 11 | 3e 3 | Low |
| 11 | 3e 3+4e 6 | Low |
| 11 | 3e 3+6e16 | Moderate |
| 11 | 3e 4 | Low |
| 11 | 3s 1 | Low |
| 11 | 3s 2 | Low |
| 11 | 3s 2+3w 1 | Low |
| 11 | 3s 2+4s 4 | Low |
| 11 | 3s 3 | Low |
| 11 | 3s 3+2s 2 | Low |
| 11 | 3s 3+3w 1 | Low |
| 11 | 3s 3+4s 3 | Low |
| 11 | 3s 4 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 10 | 8e 4 | High |
| 10 | 8e 5 | High |
| 10 | 8e 6 | High |
| 10 | 8e 7 | Very High |
| 10 | 8e 8 | High |
| 10 | 8e 9 | Very High |
| 10 | 8e10 | Low |
| 10 | 8w 1 | Low |
| 11 | 1c 1 | Low |
| 11 | 1c 1+2s 2 | Low |
| 11 | 1w 1 | Low |
| 11 | 2c 1 | Low |
| 11 | 2e 1+2s 2 | Low |
| 11 | 2e 2 | Low |
| 11 | 2e 2+3s 6 | Low |
| 11 | 2s 1 | Low |
| 11 | 3w 1+4s 8 | Low |
| 11 | 3w 1+4w 1 | Low |
| 11 | 3w 2 | Low |
| 11 | 4e 1 | Low |
| 11 | 4e 2 | Low |
| 11 | 4e 2+6e14 | Moderate |
| 11 | 4e 3 | Low |
| 11 | 4e 4 | Low |
| 11 | 4e 4+6e 5 | Low |
| 11 | 4e 4+6e 6 | Moderate |
| 11 | 4e 4+6e12 | Low |
| 11 | 4e 5 | Low |
| 11 | 4e 5+6e 7 | Moderate |
| 11 | 4e 6 | Low |
| 11 | 4e 6+3e 3 | Low |
| 11 | 4e 6+6c 4 | Low |
| 11 | 4e 6+6e12 | Low |
| 11 | 4e 6+6e14 | Moderate |
| 11 | 4e 6+6e15 | Moderate |
| 11 | 4e 6+6e16 | Moderate |
| 11 | 4e 7 | Low |
| 11 | 4e 8 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 3s 4+4s 7 | Low |
| 11 | 3s 5 | Low |
| 11 | 3s 6 | Low |
| 11 | 3s 6+2e 2 | Low |
| 11 | 3s 6+3w 1 | Low |
| 11 | 3s 6+4e 2 | Low |
| 11 | 3s 6+4s 3 | Low |
| 11 | 3s 6+4s 5 | Low |
| 11 | 3s 7 | Low |
| 11 | 3s 8 | Low |
| 11 | 3s 8+4e 2 | Low |
| 11 | 3s 8+4e 6 | Low |
| 11 | 3w 1 | Low |
| 11 | 3w 1+3s 2 | Low |
| 11 | 4s 4+6s 1 | Low |
| 11 | 4s 4+6s 3 | Low |
| 11 | 4s 5 | Low |
| 11 | 4s 5+3w 1 | Low |
| 11 | 4s 5+6s 1 | Low |
| 11 | 4s 6 | Low |
| 11 | 4s 7 | Low |
| 11 | 4s 7+3s 4 | Low |
| 11 | 4s 7+4s 3 | Low |
| 11 | 4s 8 | Low |
| 11 | 4s 8+3s 3 | Low |
| 11 | 4s 8+4s 6 | Low |
| 11 | 4s 8+6s 4 | Low |
| 11 | 4s 9 | Low |
| 11 | 4s 9+4e 8 | Low |
| 11 | 4s 9+4w 4 | Low |
| 11 | 4s 9+6e | Low |
| 11 | 4s 9+6e12 | Low |
| 11 | 4s 9+6e22 | Low |
| 11 | 4s 9+6s 3 | Low |
| 11 | 4s10 | Low |
| 11 | 4s10+6s 2 | Low |
| 11 | 4w 1 | Low |
| 11 | 4w 2 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 4e 9 | Low |
| 11 | 4e 9+6e16 | Moderate |
| 11 | 4e 9+6e20 | Low |
| 11 | 4s 1 | Low |
| 11 | 4s 2 | Low |
| 11 | 4s 3 | Low |
| 11 | 4s 3+3s 3 | Low |
| 11 | 4s 3+3w 1 | Low |
| 11 | 4s 3+4e 2 | Low |
| 11 | 4s 3+4s 6 | Low |
| 11 | 4s 3+5s 1 | Low |
| 11 | 4s 3+6s 1 | Low |
| 11 | 4s 4 | Low |
| 11 | 4s 4+2w 1 | Low |
| 11 | 6e 3 | Moderate |
| 11 | 6e 3+6e23 | Moderate |
| 11 | 6e 4 | Low |
| 11 | 6e 5 | Low |
| 11 | 6e 5+4e 4 | Low |
| 11 | 6e 5+6c 4 | Low |
| 11 | 6e 5+6e12 | Low |
| 11 | 6e 5+7e 4 | Moderate |
| 11 | 6e 6 | Moderate |
| 11 | 6e 6+4e 4 | Moderate |
| 11 | 6e 6+4e 5 | Moderate |
| 11 | 6e 6+6e 2 | Moderate |
| 11 | 6e 6+7e 6 | High |
| 11 | 6e 6+8e 3 | Very High |
| 11 | 6e 7 | Moderate |
| 11 | 6e 7+4e 3 | Moderate |
| 11 | 6e 7+6e11 | Moderate |
| 11 | 6e 7+7e 5 | High |
| 11 | 6e 7+7e12 | High |
| 11 | 6e 8 | Low |
| 11 | 6e 8+6e 3 | Moderate |
| 11 | 6e 8+7e 7 | Moderate |
| 11 | 6e 9 | Moderate |
| 11 | 6e11 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 4w 3 | Low |
| 11 | 4w 4 | Low |
| 11 | 5s 1 | Low |
| 11 | 5w 1 | Low |
| 11 | 6c 1 | Low |
| 11 | 6c 1+6s 2 | Low |
| 11 | 6c 2 | Low |
| 11 | 6c 4 | Low |
| 11 | 6e 2 | Low |
| 11 | 6e 2+4e 1 | Low |
| 11 | 6e 2+6e 3 | Moderate |
| 11 | 6e 2+7e 3 | Moderate |
| 11 | 6e14+4e 6 | Moderate |
| 11 | 6e15 | Moderate |
| 11 | 6e15+4e 6 | Moderate |
| 11 | 6e15+7e16 | High |
| 11 | 6e16 | Moderate |
| 11 | 6e16+4e 4 | Moderate |
| 11 | 6e16+4e 6 | Moderate |
| 11 | 6e16+4e 9 | Moderate |
| 11 | 6e16+4s 3 | Moderate |
| 11 | 6e16+6e 2 | Moderate |
| 11 | 6e16+6e 4 | Moderate |
| 11 | 6e16+6s 1 | Moderate |
| 11 | 6e16+6w 2 | Moderate |
| 11 | 6e16+7e13 | High |
| 11 | 6e16+7e17 | High |
| 11 | 6e16+7s 2 | Moderate |
| 11 | 6e17 | Low |
| 11 | 6e17+7e22 | Moderate |
| 11 | 6e17+7e24 | Moderate |
| 11 | 6e18 | Moderate |
| 11 | 6e19 | Low |
| 11 | 6e19+6e 3 | Moderate |
| 11 | 6e19+7e20 | Very High |
| 11 | 6e20 | Low |
| 11 | 6e21 | Low |
| 11 | 6e22 | Low |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 6e12 | Low |
| 11 | 6e12+4e 6 | Low |
| 11 | 6e12+4e 8 | Low |
| 11 | 6e12+4s 9 | Low |
| 11 | 6e12+7e14 | Moderate |
| 11 | 6e13 | Low |
| 11 | 6e13+4e 2 | Low |
| 11 | 6e13+4e 4 | Low |
| 11 | 6e13+4e 5 | Low |
| 11 | 6e13+4e 6 | Low |
| 11 | 6e13+6s 1 | Low |
| 11 | 6e14 | Moderate |
| 11 | 6s 2+6s 3 | Low |
| 11 | 6s 2+6s 5 | Low |
| 11 | 6s 2+6w 3 | Low |
| 11 | 6s 2+7s 3 | Low |
| 11 | 6s 3 | Low |
| 11 | 6s 3+6s 2 | Low |
| 11 | 6s 3+7s 3 | Low |
| 11 | 6s 4 | Low |
| 11 | 6s 4+4s 8 | Low |
| 11 | 6s 5 | Low |
| 11 | 6s 5+6s 2 | Low |
| 11 | 6s 5+7s 4 | Low |
| 11 | 6w 1 | Low |
| 11 | 6w 1+7w 2 | Low |
| 11 | 6w 2 | Low |
| 11 | 6w 2+4w 1 | Low |
| 11 | 7c 1 | Low |
| 11 | 7c 1+7e 2 | Moderate |
| 11 | 7c 1+7w 3 | Low |
| 11 | 7c 2 | Low |
| 11 | 7c 3 | Low |
| 11 | 7e 2 | Moderate |
| 11 | 7e 2+7e26 | High |
| 11 | 7e 2+8e 7 | High |
| 11 | 7e 3 | Moderate |
| 11 | 7e 4 | Moderate |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 6e22+6e19 | Low |
| 11 | 6e23 | Moderate |
| 11 | 6e23+6e 3 | Moderate |
| 11 | 6s 1 | Low |
| 11 | 6s 1+4s 3 | Low |
| 11 | 6s 1+4s 4 | Low |
| 11 | 6s 1+7s 1 | Low |
| 11 | 6s 2 | Low |
| 11 | 6s 2+4s10 | Low |
| 11 | 6s 2+6c 1 | Low |
| 11 | 7e11 | Very High + High |
| 11 | 7e12 | Very High + High |
| 11 | 7e12+4s 7 | Very High |
| 11 | 7e12+6e11 | Very High |
| 11 | 7e12+8e 4 | Very High + High |
| 11 | 7e13 | High |
| 11 | 7e13+6e16 | High |
| 11 | 7e13+8e 3 | Very High |
| 11 | 7e14 | Moderate |
| 11 | 7e14+6s 1 | Moderate |
| 11 | 7e14+8e 9 | High |
| 11 | 7e15 | Moderate |
| 11 | 7e15+8e 1 | High |
| 11 | 7e16 | High |
| 11 | 7e17 | High |
| 11 | 7e17+4e 6 | High |
| 11 | 7e17+6e16 | High |
| 11 | 7e17+7e19 | High |
| 11 | 7e18 | High |
| 11 | 7e19 | Low |
| 11 | 7e19+7w 2 | Low |
| 11 | 7e19+8e15 | Very High |
| 11 | 7e20 | Moderate |
| 11 | 7e20+6e19 | Moderate |
| 11 | 7e20+7e23 | Moderate |
| 11 | 7e20+7e26 | High |
| 11 | 7e20+8e 7 | High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 7e 4+8e 2 | High |
| 11 | 7e 5 | High |
| 11 | 7e 6 | High |
| 11 | 7e 6+7s 1 | High |
| 11 | 7e 6+8e 3 | Very High |
| 11 | 7e 7 | Moderate |
| 11 | 7e 7+7e24 | Moderate |
| 11 | 7e 7+8e 9 | High |
| 11 | 7e 8 | Very High + High |
| 11 | 7e 9 | High |
| 11 | 7e25 | Moderate |
| 11 | 7e25+8e11 | High |
| 11 | 7e25+8e14 | Moderate |
| 11 | 7e26 | High |
| 11 | 7s 1 | Low |
| 11 | 7s 2 | Low |
| 11 | 7s 2+7s 1 | Low |
| 11 | 7s 2+8e 1 | High |
| 11 | 7s 3 | Low |
| 11 | 7s 3+6s 2 | Low |
| 11 | 7s 4 | Low |
| 11 | 7s 5 | Low |
| 11 | 7w 1 | Low |
| 11 | 7w 2 | Low |
| 11 | 7w 3 | Low |
| 11 | 8c 1 | Low |
| 11 | 8e 1 | High |
| 11 | 8e 1+7e 3 | High |
| 11 | 8e 2 | High |
| 11 | 8e 3 | Very High |
| 11 | 8e 3+7e 1 | Very High |
| 11 | 8e 3+7e 6 | Very High |
| 11 | 8e 4 | Very High + High |
| 11 | 8e 4+7e12 | Very High |
| 11 | 8e 5 | High |
| 11 | 8e 6 | High |
| 11 | 8e 6+7e12 | Very High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 7e20+8e 8 | High |
| 11 | 7e21 | Low |
| 11 | 7e22 | Moderate |
| 11 | 7e23 | Moderate |
| 11 | 7e23+8e 8 | High |
| 11 | 7e24 | Moderate |
| 11 | 7e24+6e 5 | Moderate |
| 11 | 7e24+6e17 | Moderate |
| 11 | 7e24+8e 9 | High |
| 11 | 8e 9+7e24 | High |
| 11 | 8e 9+8e11 | High |
| 11 | 8e10 | Low |
| 11 | 8e11 | High |
| 11 | 8e11+8e 9 | High |
| 11 | 8e11+8e13 | High |
| 11 | 8e12 | High |
| 11 | 8e12+7e24 | High |

| Legend | LUC unit | ESC class |
|---|---|---|
| 11 | 8e 6+7e18 | High |
| 11 | 8e 6+7e24 | High |
| 11 | 8e 7 | High |
| 11 | 8e 7+7e 2 | High |
| 11 | 8e 7+7e20 | High |
| 11 | 8e 7+7e26 | High |
| 11 | 8e 8 | High |
| 11 | 8e 8+7e23 | High |
| 11 | 8e 9 | High |
| 11 | 8e12+8e 6 | High |
| 11 | 8e13 | High |
| 11 | 8e14 | Moderate |
| 11 | 8e14+7e24 | Moderate |
| 11 | 8e15 | Very High |
| 11 | 8e16 | Moderate |
| 11 | 8s 1 | Low |
| 11 | 8w 3 | Low |

# 6 Refining Erosion Susceptibility Classification units: Field expert assessment, MPI - April 2017

## Report of the Land Use Capability expert caucusing

### 6.1 Summary

The Ministry for Primary Industries is leading a process to deliver a National Environmental Standard for Plantation Forestry (NES-PF). An Erosion Susceptibility Classification (ESC) system is an integral component of this standard because it provides a risk threshold test for various forestry activities. The March 2017 version of the ESC was assessed by a small group of experts in the use of the New Zealand Land Resource Inventory (NZLRI) and with intimate site knowledge. Some classifications, particularly in the Tertiary sedimentary geologies, were considered to be inappropriately classified, either at a Land Use Capability (LUC) to ESC correlation or at an individual LUC unit. The expert group conferred to confirm opinions on the appropriate classification, the details of which are covered in this section of the overall ESC report.

#### 6.1.1 Objectives

1. To identify LUC units that had been misclassified in the March 2017 data set.
2. To update the ESC to include these revisions before gazettal of the NES-PF in July 2017.

#### 6.1.2 Method

The March 2017 version of the ESC data set was used to assess whether, in the minds of the expert group, the characterisation of the plantation forestry activity risk was appropriate. This was cross referenced against the NZLRI.

Using knowledge of the site, the ESC rating was compared with Legend x LUC (LegLUC) units for a series of sites in the mid-to-lower North Island, with emphasis on locations where plantation forests were already present or plantation forest was regarded as being a desirable land use. This assessment produced a list of LegLUC units. This list, along with aerial and oblique photos of sites, was pre-circulated and then discussed by the group on 7 April 2017 to confirm an appropriate risk rating. This resulted in reclassification both higher and lower than that of the March ESC data set.

#### 6.1.3 Results

**Risk set too low, based on expert field knowledge**

- Two LegLUC units were reclassified from High to Very High.
- Seven full units and seven polygons of one further LegLUC unit were reclassified from Moderate to High.

**Risk set too high, based on expert field knowledge**

- Twenty-two LegLUC units were reclassified from Very High to High.
- Two LegLUC units were reclassified from High to Moderate.

#### 6.1.4 Conclusions

The ESC classification was assessed by field staff with expert field knowledge resulting in further refinements to the ESC risk rating.

A revised spatial database has been prepared and named esc_july_2017.gdb.

## 6.2 Introduction

The Ministry for Primary Industries is leading a process to deliver greater national consistency in the management of plantation forestry under the Resource Management Act 1991, by implementing a National Environmental Standard for Plantation Forestry (NES-PF). The Erosion Susceptibility Classification (ESC) is used to identify the susceptibility of land to erosion and then to set regulatory thresholds for various plantation forestry activities.

## 6.3 Background

The ESC was originally developed by Bloomberg et al in their 2011 report *Erosion Susceptibility Classification and analysis of erosion risks for plantation forestry*, which was prepared by the University of Canterbury for the Ministry for the Environment, Wellington. This was revised by Basher et al in 2015 in the report *Update of the Erosion Susceptibility Classification (ESC) for the proposed National Environmental Standard for Plantation Forestry – revision of the ESC*, and in 2016 in the report *Update of the Erosion Susceptibility Classification (ESC) for the proposed NES for Plantation Forestry: Subdividing the High and Very High ESC classes*, and by Basher and Barringer in 2017 in the report *Erosion Susceptibility Classification for the NES for Plantation Forestry*.

The erosion terrains that were reclassified from High ESC to Very High in the Basher and Barringer March 2017 report included a wide variety of terrain, especially the hilly steeplands on weak Tertiary sandstone, limestone, conglomerate, moraine or alluvium; hilly steeplands on weak Tertiary mudstone; and hilly steeplands on weathered volcanics, greywacke, argillite, schist or granite.

The Basher and Barringer 2017 report identified that further targeted analysis of these terrains, based on the individual LUC units assigned to them, might distinguish between Very High and High ESC classes (for example, distinguish shallow soils over consolidated Tertiary sandstone that are very susceptible to landsliding from deeper soils over less consolidated Tertiary sandstone that are less susceptible to landsliding).

The work to ensure that all units were in the appropriate risk category was challenging, particularly in the case of the strongly consolidated Tertiary sediments mainly found in the central North Island. Several of these had been recategorised in early 2016 to be in the High risk category. However, a collective view of both foresters and regional council land management staff was that some of these on strongly consolidated Tertiary sediments should be in the Very High risk category to ensure it correctly reflected its capacity for short rotation clearfell harvest plantation forest regimes. Landcare Research reassessed this geology as part of a body of work (Basher and Barringer 2017) that concluded with a report in March 2017.

The April–May 2017 review of the Basher and Barringer March 2017 Landcare Research report was primarily in response to the reassessment of Tertiary sediments. The March 2017 process used Landcare Research's existing model "erosion terrains" to classify soil parent material to identify the ESC units. The model developed by Landcare Research groups Tertiary sediments in a different and less nuanced way from that used by the NZLRI LUC rock type assessment. Sedimentary rock groupings in the LUC handbook distinguish between compaction level and parent material type, as listed in the table below.

| Very loose to compact sedimentary rocks | Very compact to weak sedimentary rocks |
|---|---|
| Uf – unconsolidated clays and silts | Mm massive mudstone |
| Us – unconsolidated sands and gravels | Mb bedded mudstone |

| | |
|---|---|
| | Mf frittered mudstone |
| | Me bentonitic mudstone |
| | Sm massive sandstone |
| | Sb bedded sandstone |

Use of the Landcare Research erosion terrain methodology has over-risked some of the less-consolidated Tertiary sediments, which are common in the central to lower North Island, because of its broader grouping of this geology. It resulted in 89 regional LegLUC units being reclassified from High to Very High, based on their erosion terrain, and a significant area of land in the inland Taranaki, Rangitīkei and Whanganui areas being reclassified as Very High. Nineteen LegLUC units were split between Very High and High ESC classes, based on variation in rock type or soil within some erosion terrains.

Landcare Research made the following adjustments to the ESC layer to reflect this risk assessment.

## 6.4 Method

A review of the results of the Tertiary sediment reclassification was done by a small group of field specialists in NZLRI LUC mapping from regional council and forestry company backgrounds. They assessed the ESC rating on terrain they had worked on for many years.

This assessment identified several ESC units that had been over-risked in the Basher and Barringer March 2017 report. Some assessments affected entire LUC units, which were both higher or lower risk than the field experts believed was appropriate, others identified individual units. This section of the report documents the group review exercise and the conclusions reached.

The specialists who provided initial advice and met on 7 April to confirm decisions were:

- Kerry Hudson of Gisborne District Council
- Peter Manson of Hawke’s Bay Regional Council, based in Wairoa
- Malcolm Todd of Horizons Regional Council
- Robin Black of Hancocks Forest
- Bridget Robson, contracted to Ministry for Primary Industries.

## 6.5 Results

The consensus on changes required is outlined below.

| **Legend** | Risk rated too high. Decrease… | | Risk rated too low. Increase… | |
|---|---|---|---|---|
| | to<br>ESC High (orange) | to<br>ESC Moderate (yellow) | to<br>ESC Very High (red) | to<br>ESC High (orange) |
| 01 – Northland | 7e1 and 7e8 | | | |
| 02 – Waikato | | 7e4 and 8e3 | | |
| 05 – Eastern Bay of Plenty | | | | 7e1, 7e2<br>7 polygons of 3w1>>7e1 |
| 06 – Gisborne East Coast | 7e16 | | | |

| | | | | |
|---|---|---|---|---|
| 07 – Northern Hawke's Bay | | | 7e10, 7e15, | 6e7, 6e10, 6e15, 7e9, 7e16 |
| 08 – Southern Hawke's Bay Wairarapa | 7e1, 7e2, 7e4, 7e6, 7e7, 7e8 | | | |
| 10 – Taranaki Manawatū | 7e1, 7e2, 7e3, 7e4, 7e5, 7e6, 7e9, 7e7, 7e11, 7e13, 7e23, 7e14, 7e16 | | | |

## 6.6 Detail of recommendations and sources

**Legend 01 – Northland**

LUC unit: 7e1 and 7e8 in the Northland Legend 01
**Recommendation:** Change down to High – whole of both units

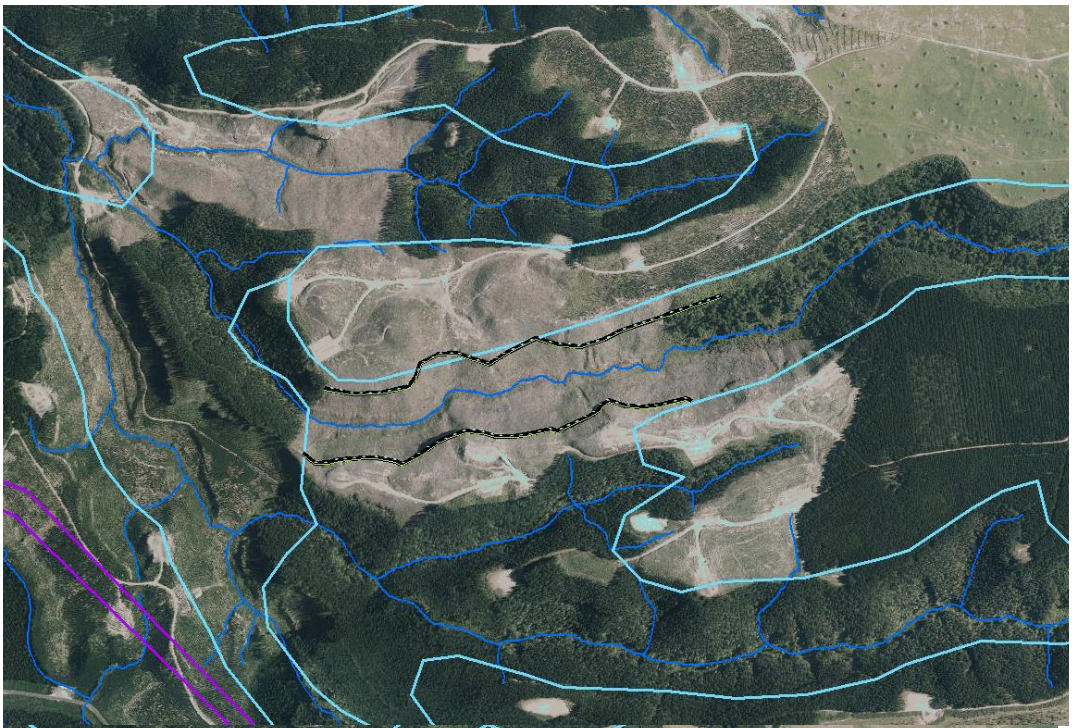
*Advice* from Robin Black email of 27/3/17
*Endorsed* by Kerry Hudson and Malcolm Todd
*Rationale*
The reasoning for calling it Very High was probably based on the appearance of widespread soil slip erosion in neighbouring farmland. That is not present in managed forest (7e1 in Whatoro, Karaka, Gammons south, Hikurangi, Pipiwai and Twin Bridges forests). The location of thrust fault boundaries has some impact but is not consistent across the mapped units.

LUC unit: 7e8 in the Northland Legend 01 (Waiomio and Rakautao forests). It is deeply weathered Waipoua basalt and is associated with a thrust fault boundary in some forests. Prior to forest establishment, soil slip and gully erosion was very obvious in farm land. The most severe potential applies to the steep gully heads only and these are only a small component of the forest area. As a mapped unit, minimal change has occurred across the pine rotation.

**Legend 02 – Waikato**

LUC unit: 7e4 in the Bay of Plenty Legend 02 (Kinleith forest)
**Recommendation:** Change down to Moderate – whole unit

*Advice* from Robin Black email of 27/3/17 and 2/3/17
*Endorsed* by Kerry Hudson and Malcolm Todd
*Rationale*
Mapped as High. This should be Moderate, because the potential for erosion is overrated on the Class 7 and 8 units on the Whakamaru ignimbrite. The actual erosion risk on 8e3 is low and is comparable to the 8s1 mapped on the same unit in other parts of Kinleith.
Class 8 is a soil (or lack of soil) issue, not erosion. That is, the very narrow band of rhyolite bluff above Ongaroto Road at the bluffs is mapped as 8s1-Low. Even Pohaturoa, as a steep rhyolite remnant, is Moderate and mapped as 7e6. Snapshots show an area largely mapped as 7e4. These units are third rotation forests with minimal erosion issues.
This next orthographic photo shows the significantly reduced area of 8e3. This is the black and yellow line. The thickness of the line is the horizontal expression of the area of Class 8. It is minimal in the rhyolite landscape. The rest of the landscape is 6e5, 7e4 and class 4.
During the evolution of the landscape, there was a Very High ESC but now it is Low.



LUC unit: 8e3 in the Bay of Plenty Legend 02 (Kinleith forest)
**Recommendation:** Change down to Moderate – whole unit

*Advice* from Robin Black email of 3/2/17
*Endorsed* by Kerry Hudson and Malcolm Todd
*Rationale*
This should either fall into 7e4 or be 8s1 if it is actually non-productive.
This Class 8 unit is not erosion prone because the rhyolite does not react like Tertiary marine sediments. Mapping inaccuracy in Kinleith shows with 8e3 covered in second and third rotation pine trees instead of being merged with 7e4. This image shows the Class 4 tops and the incised gullies mapped as 8e3.

**Legend 05 – Eastern Bay of Plenty**

LUC Units: 7e1 and 7e2 in the Eastern Bay of Plenty Legend 05 (Houpoto and Torere)

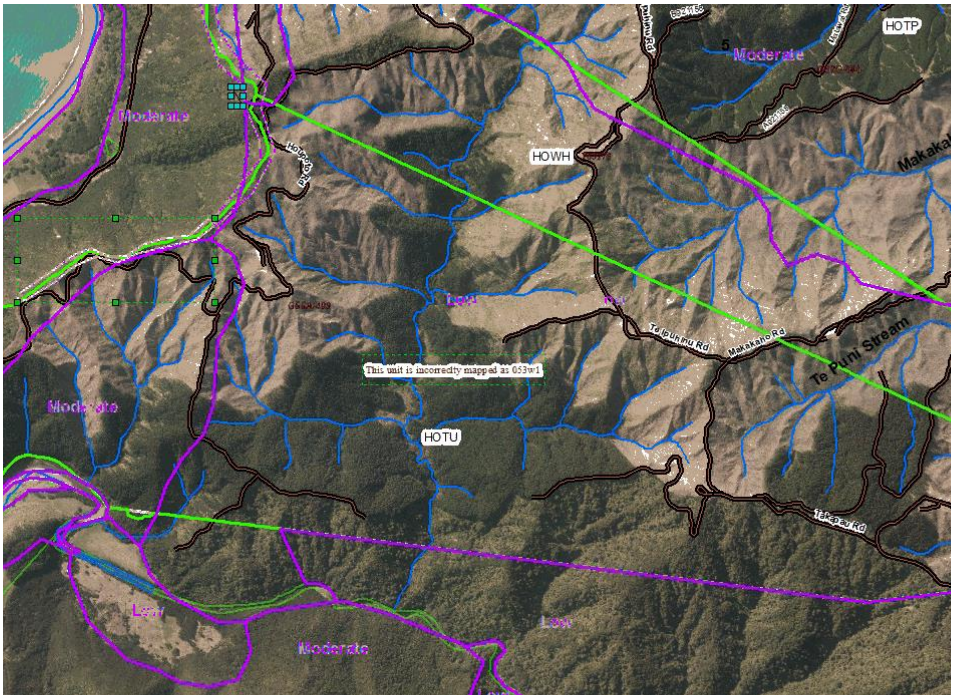
**Recommendation:** Change up to High – whole unit

*Advice* from Norm Ngapo via BOPRC exposure draft questionnaire and Robin Black email 3/2/17
*Endorsed* by Kerry Hudson
*Rationale*
The latest ESC report has not referenced the BOPRC Correlation of LUC units (Harmsworth G, Page, MJ (1993) *Correlation of Land Use Capability (LUC) Units into a Single LUC Classification for the Bay of Plenty Regional Council Area Phase Two*. Landcare Research Contract Report: LC9293/65 (Version 2)).
This document supersedes the information in the North Island Correlation of LUC units and specifically looks at the Eastern Bay of Plenty LUC units in more detail.
The ESC units in the Eastern Bay of Plenty have been classified incorrectly.
The LUC classes of 7e1 and 7e2 in the Eastern Bay of Plenty should be reclassified as orange.
This classification takes into account the nature of the terrain; steep to very steep greywacke and shattered greywacke slopes.
The slopes run from razor back ridges directly down to perennial streams, meaning, if harvesting planning was undertaken prior to planting, it would demonstrate that the areas are so difficult to harvest that substantial areas would not be planted into plantation forest.

LUC Units: 3w1 in the Eastern Bay of Plenty Legend 05 (Houpoto–Hawai catchment and Torere catchment) *[single unit cartography error?]*

**Recommendation:** Change up to High at least seven polygons on the south and east flank of Houpoto in the native forest that are incorrectly mapped as 3w1. Confirm polygons with Landcare Research.

*Advice* from Robin Black email of 3/2/17 and 22/2/17
*Endorsed* by Kerry Hudson
*Rationale*
The unit is mapped as 3w1 and should be 7e1 with High ESC. It appears that a wedge-shaped block is mapped as 3w1 with Low ESC. This is totally incorrect. It contains a mixture of native and pine. The error here is due to some mapping glitch.
Most of the other native forest in Houpoto has been reduced from High to Low.
Viewing the lines over the orthographic image shows no reason for the boundary change of High to Low.




**Legend 06 – Gisborne**

> LUC unit: 7e16 in the Gisborne Legend 06 (Orete forest and East Waiariki)
> **Recommendation:** Change down to High – whole unit

*Advice* from Robin Black email of 10/2/17
*Endorsed* by Kerry Hudson and Malcolm Todd
*Rationale*
Has gone from High to Very High. Indurated Tertiary sandstone (sst) and siltstone (zst).
7e11 has remained as High. Cretaceous thrust fault geology.
In Orete, a large component of the landscape is currently mapped as 7e16.
The erosion varies from High to Very High in reality, due to the variation in Tertiary geology.
Large landslides are not mapped and have some impact on how the steep land erodes.
Planting and harvesting is sustainable on the site but engineering across the site would require end hauling and detailed planning.
The attached photos show the range in sites – comparison of Lagoon Road during harvesting and two years after planting. Mangatoetoe–Te Ranginui Road shows the contrast between 7e16 and the lower 6e5 unit. Remapping would reduce the area of 7e16.

Unit 06 7e16 (GEC Leg) covers Orete and East Waiariki in this northern part of the Gisborne district. Significant areas are still in native regeneration cover east of Orete along the Te Araroa Road, and Hancock Forest Management has the largest plantation unit mapped.

**Legend 07 – Northern Hawke's Bay**

LUC unit: 7e10, 7e15 Northern Hawke's Bay Legend 07
**Recommendation:** Change up to Very High

*Advice* from Peter Manson of Hawke's Bay Regional Council email of 27/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
7e10 (severe occasional earthflow, e.g., would include the Nuhaka slip) – this unit requires replant in woody vegetation to reduce the likelihood of reactivation.
7e15 (Ngatapa area) – this unit needs a cover of woody vegetation, which could be either production forestry or (preferably) native vegetation.

LUC unit: 6e7, 6e10, 6e15, 7e9 and 7e16 Northern Hawke's Bay Legend 07
**Recommendation:** Change up to High

*Advice* from Peter Manson of Hawke's Bay Regional Council email of 27/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
6e7 – this unit is closely associated with 7e4. A potential for increased gully erosion and debris flow post-harvest.
6e10 (earthflow) – an increased potential for earthflow activation and gully formation post-harvest.
6e15 (deep pumice) – a potential for severe gully and rill erosion – needs a permanent ground cover and very good earthworks management.
7e9 (Wharerata) – very steep. A high potential for post-harvest debris flow during storm events. This unit occurs in areas with high frequency, high intensity rain falls.
7e16 (upper Ngaruroro) – move this one to "High". There is a high potential for the creation of new (severe) gullies if runoff is redirected. Terraces with vertical sides, where earthworks need to be well managed.

**Legend 08 – Southern Hawke's Bay Wairarapa**

LUC unit: 7e1 Southern Hawke's Bay Legend 8
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
Earnslaw 1 Franklin Rd
7e1 – high priority land for afforestation.
7e12 – also high priority for afforestation, but some steeper parts of gullies should be unplanted.

LUC unit: 7e2, Southern Hawke's Bay Legend 8
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*

7e2 – steep mudstone with potential for severe slip erosion under pasture. It grows forest quite well and is a priority for afforestation to control erosion. There is very little of it that is too steep for afforestation.

LUC unit: 7e4 Southern Hawke's Bay Legend 8
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
7e4 – steep sandstone. This unit does have some areas that are too hard for radiata roots to penetrate and is therefore not sustainable in forest, but most of it is still recommended for afforestation.

LUC unit: 7e6, 7e7 and 7e8 Southern Hawke's Bay Legend 8
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
7e6 and 7e8 have potential for very severe earthflow erosion under pasture and are a very high priority for afforestation, due to their very high sediment production. Afforestation on these units is encouraged, in order to reduce sediment delivery to rivers.

**Legend 10 – Taranaki Manawatū**

LUC unit: 7e1, 7e2 Taranaki Manawatū Legend 10
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
7e1, 7e2, these are steep slip-prone mudstone.

LUC unit: 7e3, 7e5 Taranaki Manawatū Legend 10
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
These are moderately consolidated sandstone, with potential for severe slip erosion under pasture. It grows forest very well and is a priority for afforestation to control erosion. There is very little of it that is too steep for afforestation. Although these LUC units have the potential for frequent slip erosion (3+) they have good rooting depth of trees in moderately consolidated sandstone. 7e3 is the high rainfall version and 7e5 the low rainfall version.

LUC unit: 7e4, 7e9 Taranaki Manawatū Legend 10

**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
These are moderately consolidated siltstone, with potential for severe slip erosion under pasture. It grows forest very well and is a priority for afforestation to control erosion. There is very little of it that is too steep for afforestation.

LUC unit: 7e6 Taranaki Manawatū Legend 10
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
This is earthflow and slump prone moderately consolidated sandstone, is not that steep, grows forest very well, and is a priority for afforestation, there is little or none of it that is too steep for afforestation.

LUC unit: 7e7 Taranaki Manawatū Legend 10
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
This is banded mudstone, with potential for severe slip erosion under pasture. It grows forest very well and is a priority for afforestation to control erosion. There is very little of it that is too steep for afforestation.

LUC unit: 7e11, 7e13 and 7e23 Taranaki Manawatū Legend 10
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
Only a small proportion of the 7e11 (15% based on ecosat) should not have been afforested. As earthworks is restricted discretionary, it will be possible to define the areas that are too steep in the consent process. To ID the areas that require extra care requires use of LUC unit AND a more precise map of G slope from a nationally available DEM layer, as use of NZLRI slope won't accurately detect the very steep land we want to target. Half is simply mapped as F slope and half as F+G. I have done this using the ecosat slope layer based on 1:50,000 topographic map contour lines and can provide a shapefile to you. This DEM is not supremely accurate at hillslope scale. Some analysis to quantify this inaccuracy has been done (% accuracy). 7e13 is the low rainfall Sm 7e unit (Te Namu west road Hunterville). 7e23 is the same unit in the Taihape uplands, usually is not quite as steep as 7e11 and 7e13. Same recommendations as for the siltstone, banded mudstone.

LUC unit: 7e14 Taranaki Manawatū Legend 10

**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
Although there is potential for deep-seated earthflow only small parts of it should not be afforested. This is top priority land for afforestation. 7e14 mudstone has potential for very severe earthflow erosion under pasture and is a very high priority for afforestation, due to its very high sediment production. Afforestation on these units is encouraged, in order to reduce sediment delivery to rivers.

LUC unit: 7e16 Taranaki Manawatū Legend 10
**Recommendation:** Change down from Very High to High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
Although there is potential for very severe slip and gully erosion in the Whanganui basin unconsolidated sandstone under pasture, it is very suitable land for forestry, because of the unconsolidated sands being so deep rooting. The presence of trees reduces the erosion risk, apart from the "window of risk" period post-harvest. This includes parts of Seddon's forest, Pohangina, Lismore, Te Ara Te Waka. 107e16, this unit has potential for very severe slip erosion under pasture. It is a top priority for afforestation for the same reasons as for 087e6, 8 and 107e14.

LUC unit: 7e17 Taranaki Manawatū Legend 10
**Recommendation:** Very High – remain Very High

*Advice* from Malcolm Todd of Horizons Regional Council email of 29/3/17
*Endorsed* by Kerry Hudson and Robin Black
*Rationale*
This is the steepest sandstone land – hard Tertiary sandstone in the Whanganui basin, Paparangi, Mayo block on Kauarapaoa Road, Rangitatau forestry partnership. The high rainfall massive sandstone (Sm) 7e unit. 7e17 not much forestry on this unit – tends to be natives, appropriately. Waimarino forest, Pipiriki.