Environment Committee Meeting

20 April 2023

This Report relates to Item 6 in the Agenda

"A Review of Land Use Capability Classification in North Marlborough"

Feasibility of developing 1:10,000 scale land use capability maps from existing land use capability mapping of the Marlborough Sounds

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Disclaimer

This report's assessments of land use capability are not assessments by professional land use capability mappers. They are preliminary assessments of land use capability, using simple methods available to land and resource managers in private and public sectors. Qualified geoscientists should carry out further detailed investigations to assess land use capability at a site level to allow planning of land use operations.

Executive Summary

Background and Objectives

This current work was commissioned following the capture of large areas of LiDAR data in Marlborough as part of a nationwide scheme.

In particular, the new LiDAR data allows the creation of high-resolution (1-metre) digital elevation models (DEMs). These high-resolution DEMs have enabled a more detailed analysis of catchment morphology than was previously possible. One potential application of high-resolution DEMs is the classification of land according to its land use capability (LUC).

Land Use Capability (LUC) classification is a systematic arrangement of different types of land according to those properties that determine its capacity for long-term, sustained production. New Zealand has a nationwide LUC classification based on an interpretation of the physical information in a Land Resource Inventory, rock types, soils, landform and slopes, erosion types and severities, and vegetation cover supplemented with information on climate, flood risk, erosion history and the effects of past land use. This information is held in the New Zealand Land Resource Inventory (NZLRI), a database covering all New Zealand except Stewart Island and outlying islands.

NZLRI mapping occurred in two editions. The initial 1st Ed 1970s national mapping covered North Marlborough at a mapping scale of 1:63,360 (NZLRI Legend 00). For South Marlborough and the Wairau Catchment, LUC was remapped in the early 1990s as part of the 2nd Ed, at a scale of 1:50,000 (NZLRI Legend 11).

The objective of this study is to investigate options for upgrading the 1st Ed LUC mapping for North Marlborough using high-resolution DEMs and other geospatial datasets, to achieve:

1. An equivalent standard of accuracy to the 2nd Ed.
2. A resolution suitable for mapping LUC and erosion susceptibility at an operational scale for modern-day land use planning (1:10,000).

We tested two options for LUC upgrading within a study area in the eastern part of North Marlborough (see Figure 1 in the Introduction).

Methods

Initially, we investigated using disaggregation, a digital soil mapping (DSM) technique. However, many of the Legend 00 map units were not a one-to-one match with the NZLRI 2nd Ed Legend 11 units, and the NZLRI 2nd Ed mapping was at a coarse resolution (~1:50,000 mapping scale). Because of these issues, our attempts to remap LUC using polygon disaggregation techniques for this study area were unsuccessful.

The NZLRI Legend 11 was developed to cover the Marlborough Region, including the Marlborough Sounds. However, Legend 11 mapping was only completed over South Marlborough and the Wairau catchment (pers. com. I Lynn 2022). Legend 11 has the advantage that LUC units are classified according to a systematic key of characteristics (e.g. landform, slope, rock type, rainfall, altitude, soils), which can be readily specified as code with a spatial model.

This study assigned LUC classifications to individual cells in a GIS layer using sequential criteria based on the Legend 11 key. Ten-metre cell size resolution layers for slope and altitude and coarser-resolution rainfall and soil classification layers were inputs to LUC classification.

Results

Details of the geodatabase containing the resulting LUC mapping are in Appendix E-1. There were clear differences between the NZLRI mapping and the LUC classification developed in this study. In the NZLRI, LUC classifications are assigned to relatively large polygons. This study developed a LUC classification using slope and elevation representing the landscape at a 10-m cell size resolution. Although total annual rainfall and soil types were from spatial datasets at coarser spatial resolutions, these data were resampled to the 10-m cell size resolution of the terrain attributes. This results in the following:

- Compound mapping units were refined into single LUC classes, e.g. a Legend 10 LUC 7e9+8e2 unit was refined into Class 7e interfluves with Class 8e in the headwaters and steep-sided gullies.

- Some large coarsely-mapped NZLRI units were refined into three or more LUC classes, e.g. a large Class 8e unit might include a valley floor < 8 degrees slope, and Class 7e interfluves with Class 8e in the headwaters.
- Many NZLRI Class 6e units are remapped as predominantly Class 7e based on slope. Again, even the NZLRI Class 6e units may contain significant areas mapped as Class 8e headwaters.
- Limited areas on ridgetops are separately identified as Class 6e based on slope, provided these occur below 760 m ASL. In the NZLRI, these ridges are not distinguished from the adjoining steep headwaters and are included in larger units.

Discussion

The discussion includes:

- The role of slope and lithology in the identification of LUC units.
- The need to correctly identify Class 8e land with severe physical limitations or hazards that make it unsuitable for arable, pastoral or commercial forestry use. Applying this definition, LUC Class 8 land should not be used for short-rotation commercial plantation forestry. Thus, accurately identifying LUC Class 8 land is critical since it should lead to the decision to withdraw land from pastoral or commercial short-rotation forestry use (Lynn et al. 2009).
- Application of the revised LUC mapping to case studies in the Marlborough Sounds.
- The dependence of slope thresholds on lithology and other geological factors
- The effects of GIS layer resolution on accuracy of LUC and landslide susceptibility prediction.

Conclusions

1. A straightforward classification based on slope, climate, and FSL soil types has been effective in the study area. Since the hill and steepland units in the study area almost invariably have erosion as the dominant limiting factor, a LUC classification using slope can result in an effective classification for planning land use.
2. Existing LUC mapping for North Marlborough is at unsuitable map scales for modern operational planning of forestry and other land uses. Limitations of scale and

consistency between legends meant that existing LUC mapping was not suitable for improved LUC mapping using disaggregation techniques of LUC units.

3. However, the systematic key from the NZLRI Legend 11 LUC mapping was successfully adapted to identify LUC classes down to very fine resolution using a GIS model. This modelling did make a simplifying assumption that LUC classes were completely associated with one NZLRI slope class—LUC 6e with E class slopes, Class 7e with F slopes and Class 8e with G slopes.
4. We have shown that the slope-based LUC classification created by this study is consistent with actual land-use outcomes and landslide occurrence for two case studies in the North Marlborough environment. However, this report's assessments of land use capability are not assessments by professional land use capability mappers. Qualified geoscientists should carry out further detailed investigations to assess land use capability at a site level to allow planning of land use operations. These investigations could include fine-resolution mapping of soils and geology, as well as short-range slope characteristics such as slope length and drainage, which may influence landslide susceptibility at the microsite level.
5. Because the LUC classification method uses a simple, transparent GIS model based on information from widely-available GIS layers, it will be easy to update using any detailed field studies by qualified geoscientists. For example, where field validation suggests that the classification needs to be modified to reflect factors not well-characterised in the GIS model (e.g. variations in lithology or regolith depth), these factors can be included as a GIS layer to provide an improved LUC classification.
6. A key issue is identifying Class 8e land unsuitable for primary production. Our analysis shows that significant housing and commercial forestry areas are on or adjacent to Class 8e land in many parts of the Marlborough Sounds. Improved delineation of Class 8e land is needed, and discussion as to whether a transition to protection/production or conservation-based systems is needed for commercial and/or urban land uses located on or adjacent to such land.
7. LUC classes 1-4 were excluded from this study as a slope-based approach was not applied to LUC classification on slope classes A-D (0-20 degrees). LUC classification for LUC classes 1-4 should be derived from recent intensive soil surveys within the study area.

Recommendations

1. The GIS-based mapping should be field-tested by experienced LUC mappers with knowledge of the Marlborough environment.
2. Detailed field studies of soils and geology will improve the ability of the slope-based LUC classification to predict landslide susceptibility in the Marlborough Sounds.
3. GIS-based LUC mapping should be extended to the western and outer Marlborough Sounds and the Upper Te Hoiere|Pelorus and Wairau Northbank catchments to complete the coverage for North Marlborough.
4. MDC should engage with the forest industry and other land users on the definition of Class 8e land and whether a transition to protection/production or conservation-based systems is needed for commercial land uses located on or adjacent to this land.
5. LUC classification for LUC classes 1-4 within the Marlborough Sounds should be derived from recent intensive soil surveys within the study area.

Introduction

This current work was commissioned following the capture of large areas of LiDAR data in Marlborough as part of a nationwide scheme. In particular, the new LiDAR data allows the creation of high-resolution (1-metre) digital elevation models (DEMs). These high-resolution DEMs have enabled a more detailed analysis of catchment morphology than was previously possible. One potential application of high-resolution DEMs is as a covariate layer in land use capability (LUC) classification, e.g. Barringer et al. (2018).

Lynn et al. (2009) define LUC classification as *"a systematic arrangement of different kinds of land according to those properties that determine its capacity for long term, sustained, production."* New Zealand has a nationwide LUC classification based on an interpretation of the physical information in a Land Resource Inventory (rock types, soils, slopes, erosion types and severities, and vegetation cover) supplemented with information on climate, flood risk, erosion history and the effects of past land use. This information is held in the New Zealand Land Resource Inventory (NZLRI), a database covering all New Zealand except Stewart Island and outlying islands. For North Marlborough, LUC mapping was completed between 1973 and 1979 at 1:63,360 mapping scale (1st Ed NZLRI coverage). For many parts of New Zealand (including South Marlborough and the Wairau Catchment), LUC was remapped as part of the 2nd Ed NZLRI regional upgrade at 1:50,000 scale. However, most of North Marlborough is covered only by the original 1970s LUC mapping.

The objective of this study is to investigate upgrading LUC mapping for North Marlborough using covariates derived from high-resolution DEMs and other databases, to achieve:

1. An equivalent standard of accuracy to the 2nd Ed NZLRI, and
2. A resolution suitable for mapping LUC and erosion susceptibility at an operational scale for land use planning (1:10,000).

We tested options for LUC upgrading within a study area (Figure 1) in the eastern part of the Marlborough Sounds. Note that this report's assessments of land use capability are not assessments by professional land use capability mappers. They are preliminary assessments of land use capability, using simple methods available to land and resource managers in private and public sectors. Qualified geoscientists should carry out further investigations to assess land use capability at a site level to allow planning of land use operations.

Description of the study area

The study area is shown in Figure 1, extending east from the Rai Valley catchment and south from a line extending west-east from Croisilles Peak to Cape Koamaru. The southern boundary is defined by a line extending east-west from Rarangi, through Tuamarina and Okaramio, to just north of Mt Royal in the Richmond Range. The study area encompasses 164,744ha (land area only) and ranges in altitude from sea level to 1365 m ASL (Mt Royal) in the west, with Mt Stokes (1203 m ASL) the highest point east of the Koromiko Valley. Alluvial valleys and terraces are limited in extent, with most of the study area comprising hill country and steeplands. Annual rainfall varies from 1000-1200 mm at lower elevations in the south of the study area to >2200 mm at higher elevations, especially in the west.

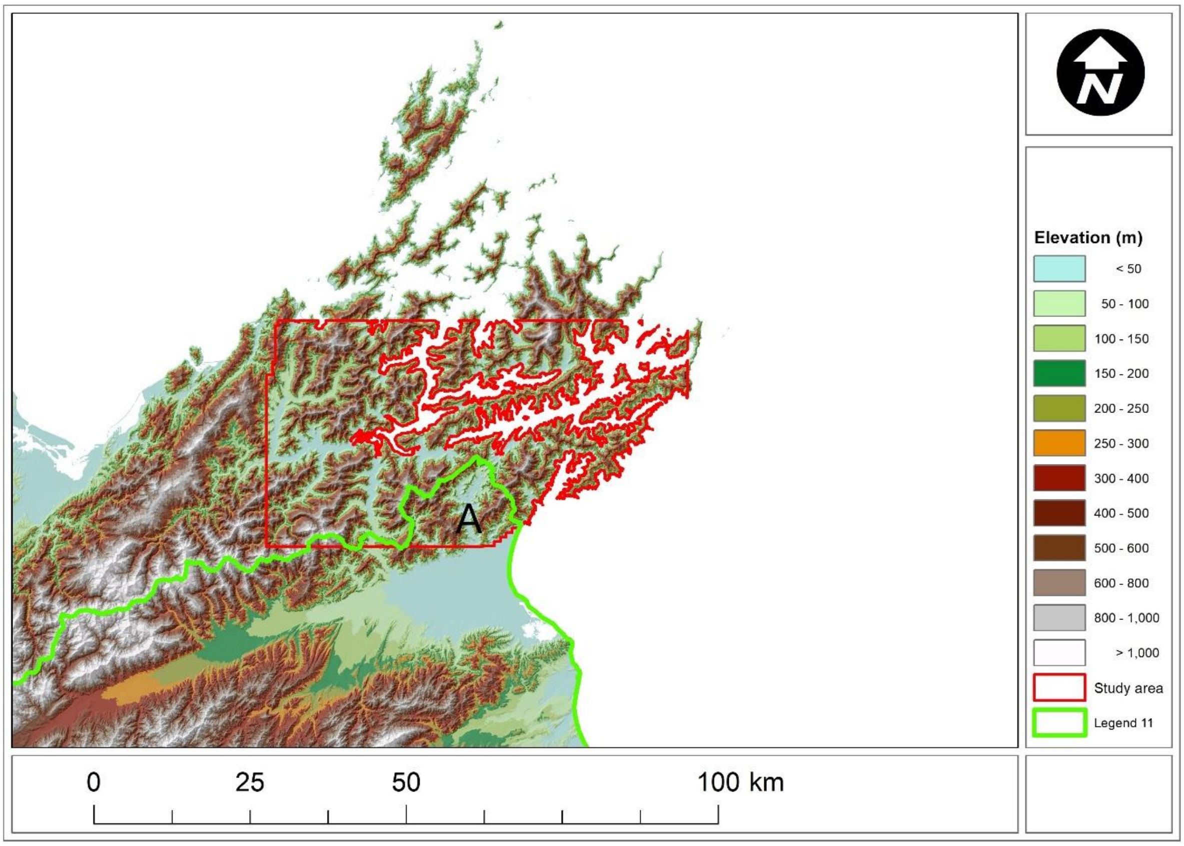

Figure 1. Location and boundaries (shown in red) of the study area. The green line marks the northern boundary of 2nd Ed LUC mapping carried out by Lynn (1996) and colleagues (Legend 11). Areas north of the green line have only been mapped using the original 1970s mapping (Legend 00). The area bounded by the green line to the north and the red line to the south (denoted by "A"), is the only significant part of the study area covered by 2nd Ed LUC mapping

The hill and steepland soils are developed mainly on colluvium and bedrock, with some loess on lower-relief hill country. Lithologies comprise argillites and greywackes, grading eastwards into schistose greywackes and schists (Laffan et al. 1987).

In this study, we used the soil classification in the Fundamental Soil Layer (FSL) (https://lris.scinfo.org.nz/layer/48079-fsl-new-zealand-soil-classification/). The FSL data for the study area are a coarse interpretation of legacy soil survey data (Soils of South Island, New Zealand, Soil Bureau Bulletin 27 with accompanying 1:253,440 scale maps) (NZ Soil Bureau 1968)). The mapping unit in these legacy data is the soil set. The FSL also assigns a nominal New Zealand Soil Classification (Hewitt 2010) to the central concept of each soil set. The FSL should be used with caution at more detailed scales and with acknowledgement of their lack of precision and descriptive detail of inherent soil variability.

FSL soil sets in the study area are typically not differentiated according to their underlying lithology. Ultramafic and basic lithologies, outside and to the north and southwest of the study area boundary, result in a separate suite of Mafic Brown soils (Laffan et al. 1987)[1].

Soils in the study area are predominantly Typic Acidic Brown soils, e.g. Kenepuru Steepland Soils (47a) and Typic Allophanic Brown soils (Patriarch Steepland Soils 57g) at high altitudes with some Pallic soils (Tuamarina Hill Soils 32aH) in the driest parts of the study area. Typic Yellow Ultic soils (Opouri Steepland soils 47b) and Acidic Orthic Brown soils (Pelorus Steepland Soils 65c) occur in the northwestern part of the study area. In these active landscapes, Recent soils, Raw soils, and Orthic, Acid, and Allophanic Brown soils, and even imperfectly drained soils are present on these slopes depending on parent material and weathering status, elevation, aspect, drainage and slope etc., see Laffan et al. (1987 p11-14).

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[1] See also https://soils-maps.landcareresearch.co.nz/?layername=fsl_nzsc&idcolumn=nzsc_order&idvalue=B&mapfile=fsl&srs=EPSG:2193&mode=normal accessed 19th April 2022.

The rationale for this study

Existing LUC mapping for Marlborough includes:

1. Two editions of NZLRI mapping (see https://lris.scinfo.org.nz/layer/48076-nzlri-land-use-capability-2021/):
    a. The 1st Ed NZLRI provides national coverage from mapping between 1973 and 1979 at a scale of 1:63,360. In the South Island, the LUC units are described in Legend 00 (van Berkel 1983).
    b. Ian Lynn and colleagues mapped the 2nd Ed NZLRI at a scale of 1:50,000 for South Marlborough and the Wairau catchment only from 1988-93 (Lynn 1996). North Marlborough was not remapped (see Figure 1) due to the withdrawal of funding while the mapping was in progress (M. Oliver pers. com. 2022). The 2nd Ed mapping is supported by a systematically organised legend (Legend 11) which includes LUC units that also apply to the remaining unmapped area in North Marlborough and the Sounds.
2. Partial mapping of LUC at a scale of 1:25,000 in the Marlborough Sounds by Ron Sutherland in the 1980s was not completed. The legend for this mapping is inconsistent with Ian Lynn and colleagues' NZLRI 2nd Ed mapping.

However, these LUC maps are now at least 30 years old, and in the case of the 1st Ed NZLRI maps for the Marlborough Sounds, they are approaching 50 years old. There is a need to extend the NZLRI 2nd Ed mapping to the rest of Marlborough District. An important driver here is that the NZLRI mapping underpins the erosion susceptibility classification mapping (ESC), used to determine the National Environmental Standards-Plantation Forestry (NES-PF) rules relating to forest establishment, earthworks and harvesting, among other activities (Basher et al. 2017). However, both the 1st and 2nd Ed NZLRI LUC mapping are unsuitable for identifying erosion susceptibility at the 1:10,000 scale required for forestry and other land use operational planning. As previously mentioned, the 1st Ed is outdated. Thus, the ESC interpretation needs to be updated to at least the standard of accuracy of the 2nd Ed NZLRI and preferably to a resolution or map scale suitable for mapping erosion susceptibility at an operational scale. There is scope to update 1st and 2nd Ed NZLRI mapping using digital techniques (see Barringer et al. 2018).

Objectives

In this study, we investigate options for upgrading LRI mapping for North Marlborough to:

1. An equivalent standard of accuracy to the 2nd Ed NZLRI, and
2. A resolution suitable for mapping LRI and erosion susceptibility at an operational scale.

We investigate these options for the study area shown in Figure 1.

Methods

Two methods were utilised to evaluate their potential to update the LUC mapping in the NZLRI. These were LUC map polygon disaggregation, and using a published LUC legend to create a decision key. Both methods rely on geospatial analysis for their implementation.

Disaggregation

Initially, we investigated using polygon disaggregation, a digital soil mapping technique. Digital Soil Mapping (DSM) provides transparent, repeatable, and updateable data-defined methods for producing maps with known predictive accuracy and uncertainty (Lagacherie et al. 2006, McBratney 2003). Soil class maps are often developed using DSM approaches (Kempen et al. 2009; Adhikari et al. 2014; Brungard et al. 2015; Taghizadeh-Mehrjardi et al. 2015; Pahlavan-Rad et al. 2016). Many modelling approaches are available, including C5 Decision Trees (Quinlan 1993, Kuhn *et al.* 2015), Multinomial Log-Linear models (Venables and Ripley 2002, Ripley and Venables 2015), and Random Forest (Breiman 2001, Liaw and Wiener 2002, 2015). Packages within the R statistical environment are frequently used in DSM. For this work, DSMART (Odgers et al. 2014), a map polygon disaggregation technique, was used to attempt disaggregation. DSMART fits classification tree or rule-based models using the Quinlan (1993) C5.0 algorithm. DSMART is designed to disaggregate polygon map units and reassign these polygons to their correct units on a cell-by-cell basis (raster). This means polygons with compound units (2 or more classes occurring in the same polygon) are reassigned independently based on the covariate layers (maps) representing their properties. This approach can realign line work across the landscape using covariates like terrain attributes, climate data, and other geophysical spatial data. The finer the resolution of the covariate inputs used, the greater the detail of disaggregation.

However, polygon disaggregation success depends on the original polygon units being assigned correctly and consistently within the original spatial resolution. Like any modelling approach, it is only as good as the mapping for the property or class you are using to make predictions. In the study area, we used three sources for LUC mapping to attempt disaggregation—NZLRI Ed1 and Ed2 mapping and the 1:25,000 Marlborough Sounds LUC mapping. The NZLRI Ed1 and Ed2 mapping are both at coarse resolutions (~1:50,000 mapping scale). Therefore, outputs from attempted disaggregation may align properties such as slope or soil to the landscape but remain at this coarse resolution. While the 1:25,000 Marlborough Sounds LUC is mapped at a finer scale than the Ed1 and Ed 2 mapping, its legend is inconsistent with the NZLRI Legend 00 (Appendix A-2) and hence Legend 11. The NZLRI Legend 00 units are correlated with the Legend 11 units. However, multiple Legend 11 units may be correlated with a single Legend 00 unit so that a Legend 00 unit cannot be assigned to an equivalent Legend 11 unit on a one-to-one basis.

For these two reasons, our attempts to remap LUC using polygon disaggregation techniques for the study area were unsuccessful.

Using a published decision key

Table 1 shows the NZLRI 2nd Ed Marlborough region (Legend 11) hill and steepland units established for the study area. Although developed to cover the whole Marlborough Region, including the Sounds, the 2nd Ed was only mapped in South Marlborough and the Wairau catchment (Lynn 1996). Legend 11 has the advantage that LUC units are classified according to a systematic key of characteristics (e.g. rock type, slope, rainfall, altitude, soils—see Table 1), which can be readily specified as code with a GIS model.

In this study, Legend 11 LUC classifications were assigned to individual cells in a GIS layer based on the following sequential criteria:

- Altitude: Class 7e18 and 8e 6 were assigned to altitudes > 760 m, the lower altitudinal threshold for Patriarch Soils (NZ Soil Bureau 1968). Class 7e18 units were assigned to slopes ≤35 degrees, and Class 8e6 was assigned to slopes >35 degrees. Class 8e6 is described in Legend 11 as occurring above 1000 m ASL and in the montane-subalpine zone (the altitudes for these zones vary with different sources). However, it is the only 8e unit in the legend with Patriarch (57g) soils, which can occur down to 760m ASL, according to the NZ Soil Bulletin 27 (NZ Soil Bureau 1968). 8e4 is a lowland-montane unit with 47c (Onamalutu Steepland) soils. According to NZ Soil Bulletin 27, these occur up to 760m ASL. Therefore, 760m ASL seems a sensible boundary between 8e4 and 8e6.

All other LUC classes occurred below 760 m, where:

- Class 6e was assigned to C, D and E slopes (8-15, 16-20 and 21-25 degrees, respectively), Class 7e to F slopes (26-35 degrees) and Class 8e to slopes >35 degrees;
- Class units are assigned based on soil types, using the NZ Soil Bureau (1968) soil set codes mapped in the Fundamental Soil Layer. The soil unit mapping could have been refined using climate and altitude as explanatory variables, but this was not undertaken in this study.
- LUC classes 1-4 were excluded from this study as a slope-based approach would not be appropriate for LUC classification on slope classes A (0-3 degrees) and B (4-7 degrees). Here, LUC class is strongly related to soil type. Laffan et al. (1987) did not address LUC on low slopes. However, they identified depositional landforms- beach ridges, alluvial flats and fans, further subdivided according to the age and texture of parent material and drainage to form the basis of a soil/landscape model. This classification could be used to digitally refine soil maps and thus refine the LUC co-variates. LUC classification for LUC classes 1-4 should be derived from recent detailed soil surveys of alluvial valleys within the study area, such as Gray (2012, 2013).

Table 1. Hill and steepland LUC units (Legend 11) recognised within the study area. Adapted from Lynn (1996).

Unit	NZLRI Slope Class[1]			Soil set Code[2]	Rainfall[3]	Altitude[4]
	Dominant	Subdominant	Minor			
6e7	E	D	F	32aH	moderate	lowland
6e9	F	E	-	42, 42a	moderate	lowland
6e10	F	E	-	41	moderate	lowland
6e11	E	F	-	47aH, 47b, 47c	mod-high	low-low montane
6e18	E	F	-	65c	high	low-low montane
7e5	F	E	-	32aH	moderate	low-low montane
7e8	F	-	-	41	moderate	low-low montane
7e9	F	-	-	42, 42a	moderate	low-low montane
7e11	F	E	-	47a, 47b	mod-high	low-low montane
7e12	F	E	G	47c	mod-high	low-low montane
7e18	F	E	-	65c, 57g	high	lowland-montane
8e2	G	F	-	Skeletal (47a, 41, 47c)	mod-high	lowland
8e4	F	G	-	47c, minor 65c	high	lowland-montane
8e5	F	G	-	65c	high	montane-subalpine
8e6	F	G	-	57g, minor 65c	high	montane-subalpine >1000m

[1] D=16-20°, E=20-25°, F=25-35°, G>35°

[2] Soil set codes from NZ Soil Bureau (1968).

[3] Rainfall-low<800 mm, moderate 800-1600 mm, high >1600 mm per annum

[4] Lynn (1996) assigns LUC units to altitudinal classes in terms of the commonly used "lowland-montane-subalpine-alpine" terminology but does not define these in terms of elevation. Using altitudinal ranges in Laffan et al. (1987, p49) we use lowland <550 m ASL, low montane 550-700 m ASL, montane 550-1100 m ASL, subalpine 1100-1300 m ASL. Note that the terminology to describe altitudinal ranges in Laffan et al. (1987) differs from that used by Lynn (1996).

Geospatial analysis

Elevation, slope, mean annual rainfall, and soil class spatial maps were used to model Legend 11 LUC units. A 10-m cell size resolution digital elevation model (DEM) raster was derived from the Marlborough District Council LiDAR point cloud (https://data.linz.govt.nz/layer/105911-marlborough-marlborough-north-lidar-1m-dem-2020/).

A 10-m cell size resolution raster was chosen as a compromise between computational speed and fine-resolution mapping representing the Earth's surface in detail. Finer resolution modelling using terrain attributes is possible but tends to enhance short-range order variability, making modelling trends more difficult to capture. Using the 10-m cell size resolution DEM, we used ArcGIS to develop slope angles (0 to 90 degrees) for each cell. The DEM-derived slope at a 10-m cell size resolution provides a highly detailed representation of the Earth's surface. Resultant map units at some locations are likely to be very complex and often with speckled representation. We decided to average slopes over a 25-m radius using the focal mean tool in ArcGIS to overcome these issues. The averaging effectively smooths much of the high short-range order variability (speckled representation) in slope, providing a better representation of LUC slope classes at a 1:10,000 map scale.

Total annual rainfall (Wratt et al. 2006, https://niwa.co.nz/climate/our-services/virtual-climate-stations) was developed by reclassifying the NIWA 500-m cell size resolution raster to the same extent and resolution as the 10-metre DEM. The Fundamental Soil Layer (FSL) (https://lris.scinfo.org.nz/layer/48079-fsl-new-zealand-soil-classification/) was used to develop a soil map for the LUC modelling. The "GENSOI" shapefile field was used to identify the soil class (Table 1) codes and was converted to a 10-m cell size resolution raster using the ArcGIS polygon to raster conversion tool.

All spatial data sets were given a New Zealand Transverse Mercator projection with identical mapping extent and cell alignment. A purpose-written python script using ArcGIS Python libraries was used to develop the LUC map. Table A-1, Appendix 1 shows the modelling thresholds and their association with LUC units.

Elevations were assigned to above or below 760m, slopes were divided into 0-7, 8-20, 21-25, 26-35, and >35 degrees (the standard slope classes from the NZLRI (Lynn et al. 2009)), and total annual rainfalls classified as greater than or less than 1600mm. Slopes ≤ 8 degrees were not considered in our analysis. Also, note that coastal cliffs adjacent to the open ocean to the east of the Marlborough Sounds were manually identified and overlaid to the final LUC layer. The coastal soil units were not well identified in other spatial data sets, hence manually digitised using slope and Google maps.

In some cases, Table A-1 included soil sets (from the FSL layer) outside their expected rainfall zones (as defined by NZ Soil Bureau Bulletin 27). This was to handle where mapped soil sets occurred outside of their rainfall zones. For example, Pallic soils (Tuamarina Hill soils 32aH, as mapped by the FSL) do occur where the rainfall layer shows mean annual rainfall>1000mm (the upper rainfall limit for Tuamarina Hill soils in the NZSB 27). If this occurred and we had not specified Tuamarina Hill soils in the higher rainfall environment, then the GIS-based classification would have returned N/A. We prioritised the FSL over the rainfall map, noting the lack of accuracy in both layers. This issue could benefit from further geospatial analysis.

Results

The resulting LUC mapping is shown for the study area in Figure 2. Details of the geodatabase containing this mapping are in Appendix E-1.

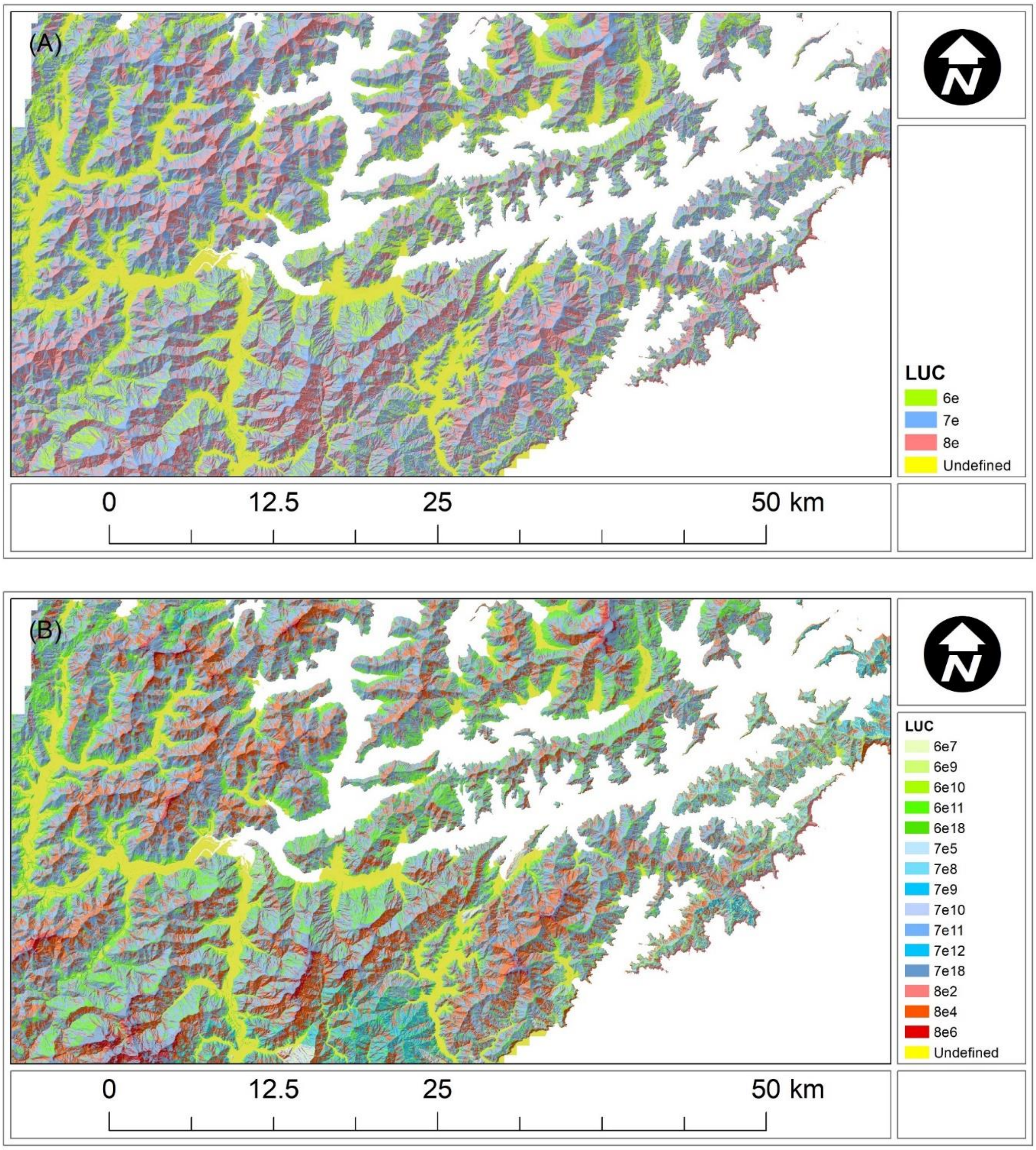

Figure 2. LUC classification assigned to the study area using the GIS classification model. LUC units are Legend 11 units defined in Table 1, modified from Lynn (1996).
A. Shows the three LUC Classes 6e, 7e and 8e coloured green, blue and red, respectively. Valley floor areas not included in the mapping (LUC Classes 1-5) are shown by the bright yellow colour (undefined).
B. LUC unit classification. The LUC units within each subclass are differentiated by increasingly dark shades of colour.

Comparison with the NZLRI

Figure 3 shows the differences between the 1st Ed NZLRI mapping and the GIS-based LUC classification, which assigned LUC to a 10-m cell size resolution raster. This results in:

- Compound units are separated, e.g. 1st Ed NZLRI 7e9+8e2 (red arrow, Figure 3) is segregated into Class 7e interfluves with Class 8e in the headwaters and steep gully sides, Class 6e on ridges and lower slopes, and with the gently sloping valley areas now separated from the Class 7e9+8e 2 unit.
- Steep coastal bluffs are delineated as Class 8e.
- Many NZLRI Class 6e units are remapped as predominantly Class 7e or may even contain significant areas mapped as Class 8e headwaters and steep gully sides.
- Limited areas on ridgetops are identified as Class 6e, provided these occur below 760 m ASL. In the NZLRI, these ridges are not distinguished from the adjoining steep headwaters and are included in larger units.

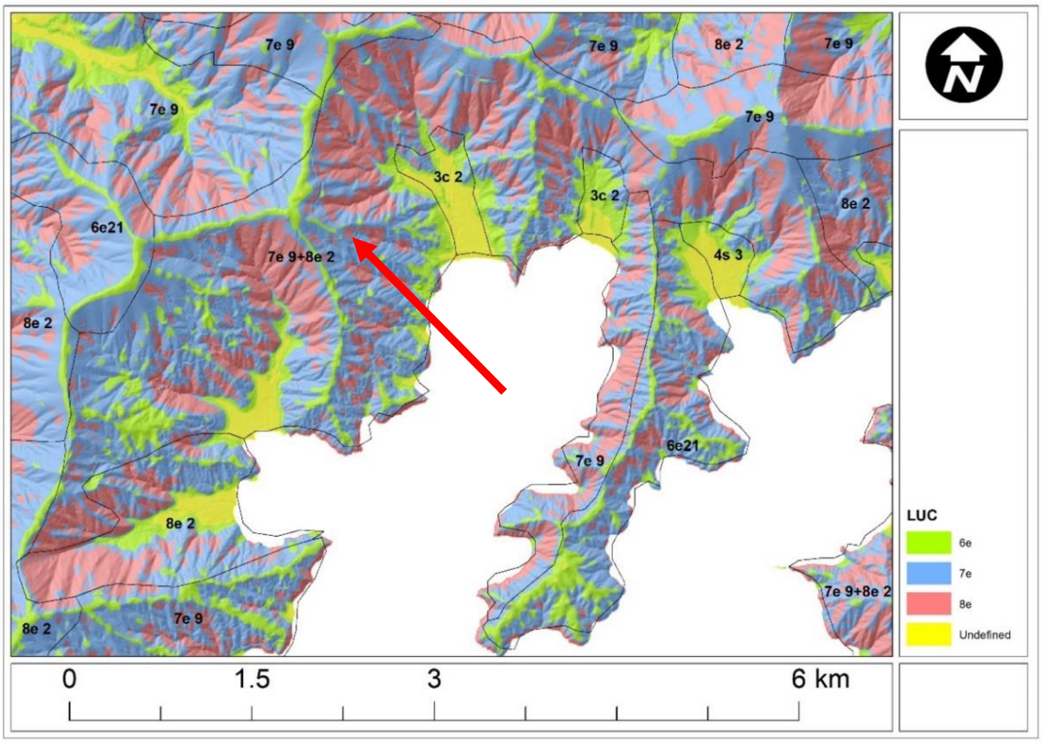

Figure 3. LUC classification was assigned to Port Underwood in the eastern part of the study area. 1st Ed NZLRI LUC units are shown in black. The LUC classifications from this study are shown in the colour legend on the right-hand side of the figure. The red arrow shows a compound NZLRI unit (7e9+8e2) which includes LUC class 8, as well as a valley floor which is likely to be Class 3 or 4 in the GIS-based LUC. Valley areas not included in the mapping (LUC classes 1-4) are shown by the bright yellow colour (undefined).

Figure 4 shows how the study LUC refines large 1st Ed NZLRI units based on slope. The area covered lies between Belvue Bay Road and Moenui Road, on Queen Charlotte Drive, to the east of Havelock Township. This area was entirely mapped as 6e21 (Legend 00), with a low (green) erosion susceptibility classification in the national ESC layer. However, several severe landslides impacted this area in an intense rainfall event in July 2021.

In our revised LUC classification, this area has significant Class 7e and 8e land on steep coastal faces and headwaters. Plotting these Class 7e and 8e polygons over recent Google Earth imagery (Figure 4) shows that they were the main source of the destructive landslides that impacted both the built and marine environments in the July 2021 storm. The remainder of the Legend 00 6e21 unit comprises the equivalent of Legend 11 LUC Class 6e11 on the interfluves and toe slopes.

Figure 4. Using the GIS LUC classification model, the LUC classification was assigned to the area between Belvue Bay Road and Moenui Road on Queen Charlotte Drive. The revised unit boundaries are shown in black. The following colours show LUC classes: Legend 11 6e11 (green), 7e10 (pale) and 8e4 (red).

Agreement with NZLRI

Table 2 is a contingency table showing agreement/disagreement between the LUC classes assigned to cells using the GIS model and the LUC classes assigned by Lynn (1996). This analysis applies to the portion of the study area within the Wairau River catchment that Lynn and colleagues mapped in 1988-93 (Ed 2)- the Waikakaho-Koromiko-Pukaka catchments, shown as area A in Figure 1.

Table 3 shows where cells in the GIS model have been reassigned from their NZLRI classification to another LUC class and suggests reasons for the re-assignment.

Table 2. Agreement of the GIS-classified LUC with NZLRI LUC mapping (Legend 11) for Waikakaho-Koromiko-Pukaka Catchments, shown in terms of the number of randomly-located sample points (n=5355) falling into each classification. Green cells=agreement, red cells =disagreement, yellow cells=some agreement (<50%). ltNA=samples that did not fall within the classification for GIS-classified LUC.

	NZLRI (Legend 11) Units												
GIS LUC class	**6e 7**	**6e11**	**6e12**	**7e 5**	**7e 8**	**7e11**	**7e12**	**7w 1**	**8e 4**	**8e 6**	**8w 3**	**Total**	**% agreement**
6e7	68			6		3		2			1	**80**	85%
6e10					4							**4**	0%
6e11		227	14			287	148		25		1	**702**	32%
6e18									6	7		**13**	0%
7e5	87			12		27						**126**	10%
7e8					10							**10**	100%
7e11		212				1088			112			**1412**	77%
7e12		53				8	569		96			**726**	78%
7e18									48	97		**145**	0%
8e4	20	96		1	25	865	341		426	155		**1929**	22%
8e6									6	61		**67**	91%
ltNA	5	72	6	1		18	2	18	1		18	**141**	-
Total	**180**	**660**	**20**	**20**	**39**	**2296**	**1060**	**20**	**720**	**320**	**20**	**5355**	

Table 3. NZLRI (Legend 11) units where cells in the GIS have been reassigned to another LUC unit, Waikakaho-Koromiko-Pukaka Catchments (Area A, Figure 1).

GIS LUC class*	Unit descriptions	Reassigned from the following NZLRI Legend 11 units
6e7	Lowland, mod. rainfall, Tuamarina Hill Soils	7e5 (steepland equivalent), 7e11 (soil mismatch), 7w3 (adjacent wetland)
6e10	Lowland, mod. rainfall, Arapawa Soils	7e8 (steepland equivalent)
6e11	Lowland, mod. to high rainfall, Kenepuru, Opouri, Onamalutu Soils	7e11, 7e12, and 8e4 are steepland equivalent units to 6e11. Also, one unit was reallocated from a 6e12 unit incorrectly classified (6e12 only applies to South Marlborough since it is a low rainfall unit with Haldon Steepland soils).
6e18	Lowland to low montane, high rainfall, Opouri Soils	8e4 and 8e6 are equivalent steepland units.
7e5	Lowland to low montane, mod. rainfall, Tuamarina Soils	6e7 (hill country equivalent), 7e11 (soil mismatch)
7e8	Lowland to low montane, mod. rainfall, Arapawa Soils	100% agreement with NZLRI
7e11	Lowland-low montane, mod. to high rainfall, Kenepuru, Opouri, Soils	6e11 and 8e4 are equivalent hill country and steepland units, respectively
7e12	Lowland-low montane, mod. to high rainfall, Onamalutu Soils	6e11 and 8e4 are equivalent hill country and steepland units, respectively
7e18	Lowland-montane, high rainfall, dominantly Patriarch soils with some Pelorus Soils	Reallocated from Class 8e4 and 8e6 because slope <35 degrees.
8e4	Lowland-montane high rainfall, Onamalutu soils with some Pelorus Soils	Reallocated from a range of Class 6e and 7e units in NZLRI because slope>35 degrees.
8e6	Montane-subalpine (>760m), high rainfall, Patriarch Soils with some Pelorus Soils	NZLRI allocates some units to 8e4, reallocated to 8e6 by GIS model since above 760 m ASL.

*From GIS analysis using decision criteria described in Methods

Most of the differences in Tables 2 and 3 between the NZLRI (Legend 11) and the GIS-assigned LUC classes arise because the GIS LUC classes are strictly assigned to slope classes, whereas the NZLRI polygons are not. This is shown in Table 4, which compares the nominal slope classes for LUC units in the NZLRI (Legend 00 and Legend 11) within the entire study area, with their mean slopes observed from the DEM. The GIS classification reassigned any

DEM slope that fell outside the assigned slope class for its relevant NZLRI LUC polygon to an appropriate LUC class consistent with its observed slope.

Table 4. Nominal slope classes for LUC units in the NZLRI within the study area, with their mean slopes, observed from the DEM. In compound units, the dominant slope is given first.

NZLRI LUC Units Slope Class			**DEM slope (degrees)**			
Code	**Range (degrees)**	**n**	**Mean**	**Median**	**Maximum**	**Minimum**
D+E	16-20+21-25	7	14.5	10.8	28.7	7.7
D+F	16-20+26-35	1	31	31	31	31
E	21-25	20	24.3	25.8	31.5	13
E+F	21-25+26-35	18	28.6	28.4	33.2	22.2
F	26-35	127	31.4	31.2	38.3	24
F+D	26-35+16-20	1	29.2	29.2	29.2	29.2
F+E	26-35+21-25	35	28.6	29.3	31.9	21.2
F+G	26-35+ >35	69	32.8	32.3	40.2	22.6
G	>35	21	36.1	36	43.7	28.4

The observed DEM slopes are reasonably well correlated with the NZLRI slope classes for the LUC polygons in the study area. However, the results also show that each NZLRI LUC polygon may contain a wide range of slopes, including some well outside the specified range for the polygon’s slope class. This is particularly the case for the compound units, which may contain slopes differing by 20 degrees.

If the mean slope in Table 4 differs markedly from the median, this indicates skewness in the distribution of slopes within a slope class and thus the bias in allocating slope classes in the NZLRI mapping. For most classes, the mean and median are reasonably close, and the distribution of DEM slope values within each slope class appears reasonably symmetric. The main exception is D+E (n=7, mean to median difference=3.7 degrees), although the mean and median for E differ by 1.5 degrees.

Overall, the differences between the NZLRI and the GIS model arise because of the following:

- The strict application of slope class limits to LUC classes in the GIS model, whereas the LUC classification in the NZLRI tolerated a much wider range of actual slopes for each polygon. In some cases, LUC units were reassigned by GIS analysis to steeper equivalent units (similar soils, climate, and lithology but steeper DEM slopes). In other cases, the reverse process was undertaken with steepland LUC units on gentler DEM slopes reassigned to the equivalent unit with a lower slope class.
- Class 8e6 was restricted to altitudes >760m (the reported threshold for Patriarch Soils) in the GIS model, with units below 760m assigned to Class 8e4.
- Some NZLRI LUC classes occurring within the mapped FSL boundaries for soil types assigned to other LUC classes. The GIS model reassigned these to the LUC class appropriate to the soil type.
- Some marginal map boundary issues where wetland classes (7w1, 8w3) in the NZLRI were mapped onto slopes > 8 degrees, according to the DEM.

Discussion

The role of slope in the identification of LUC units

The Marlborough Legend 11 (Lynn, 1996) defines LUC classes using various criteria. However, for Class 6e, 7e and 8e units, slope is a significant criterion, as shown in Table 1, where:

- Class 6e units mostly have E-dominant (20-25 degree) slope classes, although 6e9 and 6e10 have F (26-35 degree) slopes with subdominant E slopes. Presumably, this is because they are “moderate” rainfall units where erosion processes are not as active, so Class 6e is possible on steeper slopes. In contrast, the units with dominant E slopes are in moderate-high or high rainfall (6e11 and 6e18, respectively) or on erodible Pallic soils (6e7).
- Class 7e units all have predominantly F slopes, although 7e5, 7e11,7e12 and 7e18 have subdominant E slopes.
- Most Class 8e units have predominantly F slopes but subdominant G (>35 degree) slopes. Class 8e2 is a coastal cliff and gully unit with predominantly >35 degree slopes.

We contend that it is particularly important to correctly identify Class 8e land in the North Marlborough landscape. LUC Class 8 land has *“very severe to extreme physical limitations or hazards which make it unsuitable for arable, pastoral or commercial forestry use”* (Lynn et al. 2009). Applying this definition, no LUC Class 8 land should be used for production forestry. Thus, accurately identifying LUC Class 8 land is critical since it may lead to the decision to withdraw land from pastoral or commercial forestry use.

The land classified as Class 8e in this study has been identified based on slope. Although Class 8e units may have dominantly F slopes (26-35 degrees), they also have a significant component of G (>35 degree) slopes. In the “Keys to recognising LUC Units” within Lynn (1996, p17 et seq.), almost all Class 8e units are described as having steep to very steep slopes (26 to >35 degrees). Very few Class 7e units have any component with slopes >35 degrees, but see the Class 7e12 unit in Table 1.

Is the identification of Class 8e land, based on slopes >35 degrees, tenable? Eyles (2017) contends that *"The LUC Class 8 unit descriptions, as written in the regional classifications, provide only broad qualitative descriptions of the LUC units as would be expected at that scale. To decide whether or not an area has very severe to extreme limitations a mapper cannot simply apply the inventory criteria of the regional classification and accurately classify these map units. A significant degree of experience is needed to more closely define the units at the farm scale. But once specific inventory criteria are established these can be included in the inventory. Currently, we simply do not have enough defendable, detailed information on most of our landscapes (especially around the LUC Class 8 boundaries), to quantitatively classify areas."*

In addition, Eyles (2017) proposes the following criteria for assigning LUC categories to units:

1. What is the erosion risk of continuing to graze this land or harvesting successive tree crops with no special conservation inputs?
2. Will remedial measures (debris dams, erosion control plantings or closed canopy afforestation plantings) reduce short and long-term erosion susceptibility to an acceptable level? If yes, it is LUC Class 7. If not, it is LUC Class 8.
3. Can rotational harvesting of plantation forests reduce erosion susceptibility from severe/very severe/extreme to moderate? Or will the erosion susceptibility always be severe to extreme? (Note that Lynn (1996) uses present erosion severities of moderate to very severe as a criterion for Class 8e land).

Notwithstanding Eyles' assertion that we do not have enough information on most of our landscapes to classify Class 8e areas quantitatively, experience in the Marlborough Sounds and internationally suggests that a slope threshold of >35 degrees is realistic for identifying Class 8e land.

Application of the revised LUC mapping to case studies in the Marlborough Sounds

During intense rainfall events, debris from slips on steep land can mobilise as debris flows and debris slides, leading to destructive impacts on the built and natural environments. Figures 5 and 6 show examples of landslides on slopes >35 degrees in the aftermath of two major rainfall events in the Marlborough Sounds in 2018 and 2021.

Figure 5. Debris slides were initiated in light regenerating indigenous scrub near Havelock in July 2021. Slides originate at the approximate boundary between upper slopes >35 degrees and lower slopes 26-35 degrees (blue line). This area is part of a large unit currently mapped by the 1st Ed NZLRI as Class 6e21 with E+F slopes (see Figure 4), which does not accurately describe the steep coastal slopes within the unit.

Figure 6. Commercial forest on land in Port Underwood with a significant mid-slope area >35 degrees after Cyclone Gita 2018. Note the debris flows in the gullies and significant “scalping” of topsoil along extraction paths. The two images cover the top of the catchment to the shoreline.

The 1st Ed NZLRI maps the land in Figure 6 as a compound unit (LUC class 7e9+8e2 with F+G slopes). In our revised LUC classification, upper midslopes in this catchment are >35 degrees slope and are classified as 8e4. The “scalping” in Figure 6 indicates that the harvesting system did not provide adequate lift for the extracted logs, resulting in topsoil being gouged and displaced during log extraction. This is often a problem in steep terrain where hauler locations are constrained by topography, making it difficult to achieve good deflection along extraction corridors. This problem can be overcome using logging machinery and techniques that create greater lift. However, a lack of suitable machinery and crews can limit such techniques, especially in the Marlborough Sounds, where logging is generally more difficult and expensive than logging on inland sites.

Similarly, forest harvesting can be feasible on Class 8e land; for example, see Amishev et al. (2014, pp64-66), who describe steepland harvesting in Germany, Switzerland and Italy. For all three countries, forest over 80% (38.6 degrees) slope is predominantly for watershed protection and recreation, with timber harvesting designed for partial or small coupe harvesting with minimum ground disturbance. Harvesting aims primarily to maintain forest health and a windfirm stand structure.

In contrast, the short-rotation clear-fell harvesting currently practised on steep land in North Marlborough may not be sustainable (see Boam 2018, Gray and Spencer 2011, Urlich 2015 for descriptions of significant landslide events on clearfell harvesting sites in North Marlborough). For Class 8e land, harvesting should only occur if needed for the stability of the unit area or to replace the planted forest with more appropriate trees, e.g., a transition to a permanent indigenous forest. Here the purpose of the harvest is to maintain the protective value of the area. The harvest techniques must minimise the erosion risk rather than focus on financial objectives.

Dependence of slope thresholds on lithology and other geological factors

This study has applied uniform slope thresholds based on the NZLRI slope classes. In particular, the 35-degree threshold to identify Class 8e land is consistent with internationally-used thresholds for areas with a high likelihood of landslide initiation following earthworks and harvesting (Amishev et al. 2014, British Columbia Ministry of Forests 1999).

In a recent study, Smith et al. (2021) modelled landslide susceptibility based on observed landslides in six North Island locations. In their review of landslide susceptibility modelling, they stated:

"Slope is the most widely used explanatory variable in landslide susceptibility modelling (Reichenbach et al., 2018). Slope angle exerts a fundamental physical control through its effect on the shear stress acting on a slope and the resulting shear strength required to

maintain stability (Crozier et al., 1980; Crozier, 2010). Several studies in New Zealand have identified variation in slope as the key factor driving spatial patterns in shallow landslide occurrence (Dymond et al., 2006; De Rose, 2013; Betts et al., 2017)."

Smith et al. also stated that other derived topographic variables, such as Topographic Wetness Index (TWI) and aspect, can also be useful predictors of landslide susceptibility.

With respect to the geology and soil type, Smith et al. stated:

"*Rock type may also influence landslide susceptibility. This occurs indirectly through its effect on soil properties (e.g. texture, permeability) and slope angle rather than directly via bedrock strength given that shallow landslides (typically 0.5–1 m deep) in New Zealand generally occur in regolith (Crozier et al., 1980; Reid and Page, 2002; Betts et al., 2017). Notably, Betts et al. (2017) found landslide density to be independent of rock type based on analysis of historic aerial photographs. However, this analysis was limited to weakly and moderately indurated sandstone and mudstone*."

In the study area, most FSL-mapped soil types (sets) can occur on both greywacke and schist (and intergrades between these). Thus, following Smith et al., soil type may be of more importance to landslide susceptibility in the Marlborough Sounds than the underlying geology. In particular, depth and degree of weathering may significantly affect soil strength and landslide susceptibility.

Effect of layer resolution

Smith et al. used topographic, land cover and rock types as explanatory variables for landslide susceptibility. These were obtained from national datasets for elevation (15-m digital elevation model), rock type mapped at 1:63,360 scale with some areas subsequently remapped at 1:50,000 scale (NZ Land Resources Inventory, Newsome et al., 2008), and land cover from the thematic classification of satellite imagery (NZ Land Cover Database, LCDB, from 2012 and 2018). They note that topographic variables derived from the elevation layer were easily the most useful predictors since: "*In comparing models fitted and tested with landslide data from different study areas, a reduction in predictive performance was observed with the inclusion of rock type, irrespective of the model or inventory tested*".

They suggest that this was because “*Rock type is effectively a proxy for potential differences in soil properties such as shear strength and hydraulic conductivity that may directly affect susceptibility to shallow landsliding (Crozier et al., 1980) but which lack spatial representation. Differences in these properties of soils formed on apparently equivalent rock types between study areas may have contributed to the reduced performance, as well as potential errors in the mapping of rock type*.” Thus, mapping geology and soils at a finer resolution may result in a greater contribution of these variables to the prediction of landslide susceptibility. However, it is important to note that usable results were nonetheless obtained by Smith et al. with models where geology was mapped at a coarse resolution.

Conclusions

1. A straightforward classification based on slope, climate, and FSL soil types has been effective in the study area. Since the hill and steepland units in the study area almost invariably have erosion as the dominant limiting factor, a LUC classification using slope can result in an effective classification for planning land use.
2. Existing LUC mapping for North Marlborough is at unsuitable map scales for modern operational planning of forestry and other land uses. Limitations of scale and consistency between legends meant that existing LUC mapping was not suitable for improved LUC mapping using disaggregation techniques of LUC units.
3. However, the systematic key from the NZLRI Legend 11 LUC mapping was successfully adapted to identify LUC classes down to very fine resolution using a GIS model. This modelling did make a simplifying assumption that LUC classes were completely associated with one NZLRI slope class—LUC 6e with E class slopes, Class 7e with F slopes and Class 8e with G slopes.
4. We have shown that the slope-based LUC classification created by this study is consistent with actual land-use outcomes and landslide occurrence for two case studies in the North Marlborough environment. However, this report's assessments of land use capability are not assessments by professional land use capability mappers. Qualified geoscientists should carry out further detailed investigations to assess land use capability at a site level to allow planning of land use operations. These investigations could include fine-resolution mapping of soils and geology, as well as short-range slope characteristics such as slope length and drainage, which may influence landslide susceptibility at the microsite level.
5. Because the LUC classification method uses a simple, transparent GIS model based on information from widely-available GIS layers, it will be easy to update using any detailed field studies by qualified geoscientists. For example, where field validation suggests that the classification needs to be modified to reflect factors not well-characterised in the GIS model (e.g. variations in lithology or regolith depth), these factors can be included as a GIS layer to provide an improved LUC classification.
6. A key issue is identifying Class 8e land unsuitable for primary production. Our analysis shows that significant housing and commercial forestry areas are on or

adjacent to Class 8e land in many parts of the Marlborough Sounds. Improved delineation of Class 8e land is needed, and discussion as to whether a transition to protection/production or conservation-based systems is needed for commercial and/or urban land uses located on or adjacent to such land.

7. LUC classes 1-4 were excluded from this study as a slope-based approach cannot be applied to LUC classification on slope classes A-D (0-20 degrees). LUC classification for LUC classes 1-4 should be derived from recent intensive soil surveys within the study area.

Recommendations

1. The GIS-based mapping should be field-tested by experienced LUC mappers with knowledge of the Marlborough environment.
2. Detailed field studies of soils and geology will improve the ability of the slope-based LUC classification to predict landslide susceptibility in the Marlborough Sounds.
3. GIS-based LUC mapping should be extended to the western and outer Marlborough Sounds and the Upper Te Hoiere|Pelorus and Wairau Northbank catchments to complete the coverage for North Marlborough.
4. MDC should engage with the forest industry and other land users on the definition of Class 8e land and whether a transition to protection/production or conservation-based systems is needed for commercial land uses located on or adjacent to this land.
5. LUC classification for LUC classes 1-4 within the Marlborough Sounds should be derived from recent intensive soil surveys within the study area.

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Appendix 1

Table A-1. Description of elevation, slope, rainfall, and soil class thresholds used to define Land Use Capability classes spatially.

Elev (m)	Slope (deg)	Rainfall (mm)	Soil Classification	LUC
>760	0-7	NA	NA	gtNA
>760	8-20	NA	NA	7e18
>760	21-25	NA	NA	7e18
>760	25-35	NA	NA	7e18
>760	>35	NA	NA	8e6
<760	8-25	<1600	Tuamarina 32aH	6e7
<760			Anakoha 42a	6e9
<760			Ketu 42	6e9
<760			Arapawa 41	6e10
<760			Kenepuru 47a	6e11
<760			Kenepuru Hill 47aH	6e11
<760			Onamalutu 47c	6e11
<760			Opouri 47b	6e11
<760			Patriarch 57g	6e18
<760			Pelorus 65	6e18
<760			Tuamarina 32aH	6e7
<760		>1600	Anakoha 42a	6e9
<760			Ketu 42	6e9
<760			Arapawa 41	6e10
<760			Kenepuru 47a	6e11
<760			Kenepuru Hill 47aH	6e11
<760			Onamalutu 47c	6e11
<760			Opouri 47b	6e11
<760			Patutu 47	6e11
<760			Patriarch 57g	6e18
<760			Pelorus 65	6e18

Table A-1 continued

Elev (m)	**Slope (deg)**	**Rainfall(mm)**	**Soil Classification**	**LUC**
<760	26-35	<1600	Tuamarina 32aH	7e5
<760			Anakoha 42a	7e9
<760			Ketu 42	7e9
<760			Arapawa 41	7e8
<760			Kenepuru 47a	7e11
<760			Kenepuru Hill 47aH	7e11
<760			Onamalutu 47c	7e12
<760			Opouri 47b	7e11
<760			Patutu 47	7e10
<760			Patriarch 57g	7e18
<760			Pelorus 65	7e18
<760		>1600	Tuamarina 32aH	7e5
<760			Anakoha 42a	7e9
<760			Ketu 42	7e9
<760			Arapawa 41	7e8
<760			Kenepuru 47a	7e11
<760			Kenepuru Hill 47aH	7e11
<760			Onamalutu 47c	7e12
<760			Opouri 47b	7e11
<760			Patutu 47	7e10
<760			Patriarch 57g	7e18
<760			Pelorus 65	7e18
<760	>35	<1600	NA	8e4
<760		>1600	NA	8e4
<760		NA	NA	8e2

Table A-2. Summary legend for Class 6e, 7e and 8e units mapped by 1:25,000 Marlborough Sounds Survey (within the study area).

Unit	Unit Description	Slope	Surface Geology	Soils	Legend 00
6e1	Hill and steepland soils, mod. Rainfall	E-F	Gw, St. Some colluvium, deeply weathered	41, 42, 42a	pt. 6e11
6e2	Low-fertility hill soils on harder rock	E-F	Gw, St. Some periglacial	YBE and podsolised YBE	pt. 6e21
6e4	Mod. Steep -steep, deeply weathered schistose greywacke	E-F	Schistose greywacke	41, 42a	
7e2	Higher rainfall, western Sounds?				
7e3	Steep-Very steep on harder rocks, mod. rainfall	F-G	Gw, St	41, 42a, 47a, 47b	-
7e4	Steep-Very steep, coastal locations	F-G	Gw, St, colluvium	42, 42a	-
7e5	Steep-Very steep, coastal with severe potential erosion	F-G	St, Gw, Vo	42, 42a	-
7e7	Steep hill country on harder rocks, low soil fertility	E-G	St, Gw	47a,b,c, 65c	pt. 7e9
7e10	Flat to steep gullies and stream systems	A-F	-	BR	-
8e1	Steep-very steep, mod-high rainfall with rock outcrops	F+G	St, Gw	Steepland YBE	-
8e2	Very steep coastal cliffs	G	Gw, St, Vo	BR, Raw soils	8e2
8e3	Steep to very steep, long slopes, high rainfall	F-G	Gw, St, detritus	Raw, recent soils related to YBE	-
8e5	Montane >1000m to timberline	F-G	Gw, St, colluvium	47b, 65c	-
8e6	Stream heads? High erosion.	-	-	-	-

Appendix E-1. Map deliverables

North Marlborough LUC deliverables were compiled and delivered to MDC at the end of March 2022. The deliverables contain a geodatabase (BaseDataLUC.gdb) with a LUC unit code for each spatial unit.

LUC.mxd is provided with connections to all of the deliverable data. Once the deliverables are downloaded to the MDC system, the data can be viewed in ArcGIS software by double-clicking the LUC.mxd icon.