Manaaki Whenua
Landcare Research

Update to Highly Erodible Land and Estimated Long-term Soil Erosion data sets for Environmental Reporting

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Update to Highly Erodible Land and Estimated Long-term Soil Erosion data sets for environmental reporting

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Summary

Highly Erodible Land (HEL) and Estimated Long-Term Soil Erosion (ELSE) are national indicators used in the Environment Aotearoa reporting series co-published by the Ministry for the Environment and Stats NZ. The Ministry for the Environment contracted Manaaki Whenua – Landcare Research to update these two indicators with recent land cover information, and provide a report that includes:

(a) A summary of the key differences or limitations each set of HEL and ELSE layers, based on the land cover data used, e.g., temporal coverage, difference in resolution affecting the capture of specific features.

(b) Recommendations for analysing and describing 'trends' or change in state across the time series of different HEL and ELSE layers, including whether it is possible to establish a baseline, e.g., by averaging across the different layers or using appropriate weightings for certain periods.

(c) A detailed description of all the information or data that went into the 'fundamental layer' separate from land cover for both models, i.e., slope and geology/rock type for HEL, and geology/rock type, landform, and rainfall for ELSE.

(d) A section with guidance for regional councils on how to optimise higher resolution spatial layers (LiDAR, remote sensing) to achieve higher resolution mapping of land at high risk of mass movement erosion, as well as features such as space planting.

(e) A glossary of terms with supporting definitions for soil erosion monitoring and soil conservation efforts, including different protective measures (e.g., retirement, adequate protective vegetation).

(f) A description of the pressures and impacts that landform/slope, geology and rainfall have on erosion specifically, and how these should be factored into soil conservation efforts.

(g) Table(s) showing erosion terrains and slope thresholds above which land is at risk to land sliding if there is no protective woody vegetation, for all New Zealand.

Landslide erosion is the sudden failure of soil slopes during storm rainfall. Gully erosion is massive soil erosion that begins at gully heads and expands up hillsides over decadal time scales. Earthflow erosion is the slow downward movement of wet soil slopes towards waterways.

The HEL model identifies five classes of land at risk of erosion.

1 High landslide risk – delivery to stream.

2 High landslide risk – non-delivery to stream.

3 Moderate earthflow risk.

4 Severe earthflow risk.

5 Gully risk.

The different types of mass-movement soil erosion are not ranked in severity, except for earthflow risk, which has extreme and moderate classes of risk. Highly erodible land is defined as 'land at risk of severe mass-movement erosion (landslide, earthflow, or gully)'. When land has protective woody vegetation with reinforcing roots, the risk of mass-movement erosion is significantly reduced and therefore it is not considered at risk.

The HEL model uses a digital elevation model (DEM) to identify slopes, incorporates different erosion terrains and erosion thresholds based on these terrains, and uses land cover mapping from either the Land Cover Database (LCDB) or the Woody layer. The LCDB has five versions at dates 1996, 2001, 2008, 2012, and 2018. Minimum mapping unit of the LCDB is 1 ha. The Woody layer has seven versions, produced from Sentinel-2 satellite imagery, at these dates: 2016, 2017, 2018, 2019, 2020, 2021, and 2022. The minimum mapping unit of the Woody layer is 0.01 ha. This means the Woody layer can be used for annual updates and higher resolution.

The HEL model predicted the location of landslides in cyclone Gabrielle with an accuracy greater than 75% (i.e. the probability of landsliding on HEL land is greater than three times that in non-HEL land).

Estimated Long-Term Soil Erosion (ELSE) is the average mass of soil lost from all erosion processes on land per square kilometre per year (tonnes/km^2/year). It is extrapolated from long-term measurements of sediment load in rivers. Long-term soil erosion is estimated as the product of mean annual rainfall squared with a rock type factor and a land cover factor. The land cover factor may come from either the LCDB, to enable assessment of trends from 1996 through to 2018, or from the Woody layer, to obtain current and annual updates, from 2016 to 2022.

The suitability of HEL and ELSE for different applications is summarised below.

Application	ELSE	HEL
Catchment sediment yield	✓	×
Farm sediment yield	✓	×
Prioritisation of farm (soil conservation) plans	✓	✓
Design of farm (soil conservation) plans	×	×
Prioritisation of catchment soil conservation	×	✓
Prioritisation of regional soil conservation	✓	✓
Prioritisation of soil cons. for reducing sediment yield	✓	×
Regional targets for reduction of erodible land	×	✓
National targets for reduction of erodible land	×	✓

The different dates of HEL using LCDB (1996, 2001, 2008, 2012, and 2018) enable analysis of trends and change over 22 years due to broad-scale land cover change. However, because LCDB does not map individual trees, such as the space-planted poplars used commonly in soil conservation, the impact of some soil conservation actions is not included. We recommend that maps of soil conservation action be included in the HEL model in future. The different dates of HEL using Woody (2016, 2017, 2018, 2019, 2020, 2021, and 2022) enable analysis of recent trends and in greater detail, including shelter belts and small farm forestry lots.

The different dates of ELSE using LCDB (1996, 2001, 2008, 2012, and 2018) enable analysis of trends and change over 22 years due to broad-scale land cover change. However, because LCDB does not map individual trees, such as space-planted poplars used commonly in soil conservation, the impact of some soil conservation actions is not included. We recommend that maps of soil conservation action be included in ELSE in future (as in Monaghan et al. 2021). The different dates of ELSE using Woody layers (2016, 2017, 2018, 2019, 2020, 2021, and 2022) enable analysis of recent trends and change on an annual basis.

1 Introduction

Highly Erodible Land (HEL) and Estimated Long-Term Soil Erosion (ELSE) are national indicators used for Environmental Reporting (see https://www.stats.govt.nz/indicators/estimated-long-term-soil-erosion and https://www.stats.govt.nz/indicators/highly-erodible-land/).

The Ministry for the Environment contracted Manaaki Whenua – Landcare Research to update these two indicators with recent land cover information, and provide a coinciding report which includes:

(a) A summary of the key differences or limitations each set of HEL and ELSE layers, based on the land cover data used, e.g., temporal coverage, difference in resolution affecting the capture of specific features.

(b) Recommendations for analysing and describing 'trends' or change in state across the time series of different HEL and ELSE layers, including whether it is possible to establish a baseline, e.g., by averaging across the different layers or using appropriate weightings for certain periods.

(c) A detailed description of all the information or data that went into the 'fundamental layer' separate from land cover for both models, i.e., slope and geology/rock type for HEL, and geology/rock type, landform, and rainfall for ELSE.

(d) A section with guidance for regional councils on how to optimise higher resolution spatial layers (LiDAR, remote sensing) to achieve higher resolution mapping of land at high risk of mass movement erosion, as well as features such as space planting.

(e) A glossary of terms with supporting definitions for soil erosion monitoring and soil conservation efforts, including different protective measures (e.g., retirement, adequate protective vegetation).

(f) A description of the pressures and impacts that landform/slope, geology and rainfall have on erosion specifically, and how these should be factored into soil conservation efforts.

(g) Table(s) showing erosion terrains and slope thresholds above which land is at risk to land sliding if there is no protective woody vegetation, for all New Zealand.

A glossary of technical terms used in this report is provided in Appendix 1.

2 Highly Erodible Land

2.1 About the data

Landslide soil erosion is the sudden failure of soil slopes during storm rainfall (slope failure from earthquakes is not considered here). Gully erosion is massive soil erosion that begins at gully heads and expands up hillsides over decadal time scales. Earthflow erosion is the slow downward movement of wet soil slopes towards waterways. See Lynn et al. (2009) for a fuller description of soil erosion types in New Zealand.

The Highly Erodible Land model identifies five classes of land at risk of erosion.

1 High landslide risk – delivery to stream (red).

2 High landslide risk – non-delivery to steam (light brown).

3 Moderate earthflow risk (pink).

4 Severe earthflow risk (purple).

5 Gully risk (orange).

The different types of mass-movement soil erosion are not ranked in severity, except for earthflow risk, which has extreme and moderate classes of risk. Highly erodible land is defined as 'land at risk of severe mass-movement erosion (landslide, earthflow, or gully)' (Dymond et al. 2006). When land has protective woody vegetation with reinforcing roots, the risk of mass-movement erosion is significantly reduced and therefore it is not considered at risk in the HEL model.

Some areas of highly erodible land lie above the natural elevation limit for woody vegetation (such as the tree line in alpine areas), which means the risk of erosion cannot be reduced by planting trees.

The model used to identify areas at risk of soil erosion does not consider whether an area has space-planted trees (an erosion mitigation activity) because this information is not available nation-wide. It should be noted that when treating highly erodible land the essential criterion is that vegetation – planted or reverting – has protective woody roots (which usually coincide with woody stems).

While the spatial patterns of highly erodible land generally drive the patterns of soil erosion, the HEL model only identifies where highly erodible land is located, and not the magnitude of soil erosion – it also distinguishes between high landslide risk of delivery or non-delivery to stream. There are some areas in the North Island (particularly Gisborne) where soil erosion rates are excessively high due to very soft rock. Consequently, highly erodible land in Gisborne will be producing an order of magnitude more sediment into rivers in the long term than highly erodible land in other areas, such as Manawatu-Whanganui (Dymond et al. 2010).

Highly erodible land is modelled from three factors:

- slope
- land cover
- erosion terrain.

The HEL model uses a digital elevation model (DEM) to identify slopes, incorporates different erosion terrains (Dymond et al. 2010; see Glossary) and erosion thresholds based on these terrains, and uses land cover mapping from the LCDB. Erosion terrains identify the main soil erosion processes (ie, landslide, earthflow, gully). Both HEL datasets for the North Island and South Island use the same methodology and input data, including LCDB.

The HEL model predicted the location of landslides in Cyclone Gabrielle with an accuracy greater than 75% (McMillan et al. 2023) (i.e. the probability of landsliding on HEL land was greater than three times that on non-HEL land).

For estimating long-term rates of soil erosion (tonnes/km^2/year) and the resulting sediment loads in rivers (tonnes/year), the national indicator Estimated Long-term Soil Erosion (ELSE) should be used.

2.2 Derivation of Highly Erodible Land fundamental layer

The fundamental HEL layer identifies land at risk to soil erosion assuming no protective woody vegetation. For landslide erosion, all steep land over a given slope threshold (from a 10 m pixel DEM), which depends on erosion terrain (see glossary), is considered to have high risk. For earthflow erosion, all land in erosion terrains where earthflow erosion is identified has risk, which is either moderate or severe. For gully erosion, all land in erosion terrains where gully erosion is identified is considered to have risk. The slope thresholds used for identifying high landslide risk are shown in Table 1 (North Island) and Table 2 (South Island). Figure 1 shows a graphic of the North Island fundamental HEL layer and Figure 2 shows a graphic of the South Island fundamental HEL layer. Figures 3 and 4 show clips of the fundamental HEL layer with full detail (10m pixels).

The algorithm used to produce the HEL fundamental layer is described below.

1 A slope threshold was defined for each erosion terrain (Tables 1 and 2). These thresholds were obtained from published field measurements where available, and where not available they were estimated from the most similar erosion terrain with published data (Dymond et al. 2008).

2 All pixels in a 10 m pixel DEM-derived slope above the threshold defined by the pixel's erosion terrain were assigned to 'high landslide risk'. Land with no risk has threshold = 90.

3 The pixel-based map was converted to a hillslope basis by using an aspect-based filter with a 25% risk rule (2 ha minimum mapping unit).

4 All 'high landslide risk' pixels were examined to see whether they could deliver sediment to a water course or not. Land was considered capable of delivering sediment if it was possible to travel down DEM-derived streamlines until a watercourse was reached

without encountering three consecutive pixels of low slope (i.e. < 5 degrees). If 'high landslide risk' can deliver sediment to a watercourse then it is labelled as 'high landslide risk – delivery to stream'. Otherwise, it is labelled as 'high landslide risk – non-delivery to stream'.

5 All pixels in moderate earthflow erosion terrains were assigned to 'moderate earthflow risk'.

6 All pixels in severe earthflow erosion terrains were assigned to 'severe earthflow risk'.

7 All pixels in gully erosion terrains were assigned to 'gully risk'.

Table 1. North Island erosion terrains (from NZLRI, see Glossary) and slope thresholds above which land is at high risk of landsliding if there is no protective woody vegetation. Erosion terrains at risk of gully or earthflow erosion that have no slope thresholds are shaded.

Label	Description	Slope threshold (degrees)
1	**Active flood plains**	
1.1.1	Undifferentiated alluvium from modern overbank depositional events.	90
2	**Sand country**	
2.1.1	Recent fresh dune sand.	90
2.1.2	Mature moderately weathered dune sand.	90
3	**Peatland**	
3.1.1	Organic soils on deep peat.	90
4	**Terraces, low fans, laharic aprons**	
4.1.1	Loess.	90
4.1.2	Young tephra, mostly pumiceous (Waimihia and younger).	90
4.1.3	Basins infilled with Taupo tephra flow deposits—intensely gullied.	90
4.1.4	Mid-aged (late Pleistocene/early Holocene) tephra, older tephra, or tephric loess.	90
4.2.1	Fine grained, weathered, undifferentiated terrace alluvium—above the level of modern Flood plains.	90
4.3.1	Gravelly soils on alluvial terrace gravels or on gravelly laharic aprons—above the level of modern flood plains.	90
5	**Downland**	
5.1.1	Loess.	90
5.1.2	Young tephra (Waimihia and younger), over older tephra.	90
5.1.3	Mid-aged (late Pleistocene/early Holocene) tephra, older tephra, or tephric loess.	90
5.2.1	Young basalt lava fields and low domes (parts are flatter than typical downland).	90
5.3.1	Weathered sedimentary and non-tephric igneous rocks.	90
6	**Hill country**	
6.1.1	Loess.	26
6.1.2	Young tephra (Waimihia or younger), usually over older tephra—shallow (0.3– 1.0 m).	26
6.1.3	Young tephra (Waimihia or younger), usually over older tephra—deep (>1.0 m).	90
6.1.4	Mid-aged (late Pleistocene/early Holocene) tephra, or tephric loess.	26
6.2.1	Relatively young basalt domes and cones.	28
6.3.1	Weak to very weak Tertiary-aged mudstone.	24

Label	Description	Slope threshold (degrees)
6.3.2	Crushed Tertiary-aged mudstone, sandstone; argillite, or ancient volcanic rock (frequently, with tephra covers in the Northern Hawke's Bay–East Coast area)—with moderate earthflow-dominated erosion.	
6.3.3	Crushed mudstone or argillite with severe earthflow-dominated erosion.	
6.3.4	Crushed argillite, sandstone, or greywacke, with severe gully-dominated erosion.	
6.4.1	Cohesive, generally weak to moderately strong Tertiary-aged sandstone.	28
6.4.2	Non-cohesive Tertiary-aged sandstone.	26
6.5.1	Limestone.	90
6.6.1	Unweathered to moderately weathered greywacke/argillite.	28
6.6.2	Unweathered to slightly weathered white argillite.	90
6.7.1	Residual weathered to highly (often deeply) weathered Tertiary-aged sedimentary rocks.	24
6.7.2	Residual weathered to highly weathered ancient basalt and andesite.	24
6.7.3	Residual weathered to highly (often deeply) weathered welded rhyolite.	24
6.7.4	Residual weathered to highly (often deeply) weathered greywacke/argillite.	24
7	**Hilly steeplands.**	
7.1.1	Young tephra (Waimihia or younger), usually over older tephra—shallow (0.3–1.0 m) covers.	26
7.1.2	Young tephra (Waimihia or younger), usually over older tephra—deep (>1.0 m).	26
7.1.3	Mid-aged (late Pleistocene/early Holocene) tephra.	26
7.2.1	Fresh to slightly weathered welded rhyolitic rock, or bouldery, andesitic lahar deposits.	28
7.3.1	Weak to very weak Tertiary-aged mudstone.	24
7.3.2	Crushed argillite with gully-dominated erosion.	
7.4.1	Cohesive, generally weak to moderately strong Tertiary-aged sandstone.	28
7.4.2	Non-cohesive Tertiary-aged sandstone, and younger sandy gravels and gravelly sands.	26
7.5.1	Limestone.	90
7.6.1	Unweathered to moderately weathered greywacke/argillite.	28
7.6.2	Unweathered to slightly weathered white argillite.	26
7.7.1	Residual weathered to highly (often deeply) weathered ancient basalt and andesite.	24
7.7.2	Residual weathered to highly (often deeply) weathered welded rhyolite.	24
7.7.3	Residual weathered to highly (often deeply) weathered greywacke/argillite.	24
8	**Upland plains and plateaux**	
8.1.1	Upland plains and plateaux with tephra covers.	90
9	**Mountain steeplands and upland hills**	
9.1.1	Greywacke/argillite or younger sedimentary rocks of the main ranges prone to landslide erosion.	45
9.1.2	Greywacke/argillite or younger sedimentary rocks of the main ranges prone to sheet/wind/scree erosion.	45
9.2.1	Volcanic rocks in mountain terrains and upland hills.	45
9.2.2	Upper flanks of volcanoes.	90

Table 2. South Island erosion terrains and slope thresholds above which land is at high risk of landsliding if there is no protective woody vegetation. There are no erosion terrains in the South Island where gully erosion or earthflow erosion is the dominant erosion process.

Label	Description	Slope threshold (degrees)
1.1.1	Active floodplains and fans.	90
2.1.1	Sands and gravels.	90
3.1.1	Lowland and upland peats.	90
4.1.1	Alluvium.	90
4.2.1	Loess mantled terraces and fans.	90
5.1.1	Downlands on moraine and dissected alluvium.	90
5.2.1	Downlands on deep >1 m loess.	90
5.3.1	Downlands on soft sedimentary rocks.	90
5.4.1	Downlands on hard sedimentary rocks.	90
5.4.2	Downlands on hard schist rocks.	90
5.4.3	Downlands on hard coarse grained igneous or metamorphic rocks.	90
6.1.1	Hill country on moraine and dissected alluvium.	28
6.2.1	Hill country on deep >1 m loess.	26
6.3.1	Hill country on soft sedimentary mudstone.	24
6.3.2	Hill country on soft sedimentary sandstone.	28
6.3.3	Hill country on soft sedimentary conglomerate.	28
6.3.4	Hill country on soft calcareous sediments and limestone.	90
6.4.1	Hill country on hard sedimentary rocks.	28
6.4.2	Hill country on hard schist rocks.	28
6.4.3	Hill country on hard coarse grained igneous or metamorphic rocks.	28
6.4.4	Hill country on hard grained igneous rocks.	28
7.1.1	Hilly steeplands on soft sedimentary mudstone.	24
7.1.2	Hilly steeplands on soft sedimentary sandstone.	28
7.1.3	Hilly steeplands on soft sedimentary conglomerate.	28
7.2.1	Hilly steeplands on hard sedimentary rocks.	28
7.2.2	Hill steeplands on hard schist rocks.	28
7.2.3	Hilly steeplands on hard coarse grained igneous or metamorphic rocks.	28
7.2.4	Hill steeplands on hard carbonate rocks.	90
7.2.5	Hill steeplands on hard fine grained igneous rocks.	28
7.3.1	Hilly steeplands on weathered hard schist and greywacke rocks.	28
7.3.2	Hill steeplands on weathered coarse grained igneous rocks.	24
8.1.1	Mountain steeplands on hard sedimentary rocks.	45
8.1.2	Mountain steeplands on hard schist rocks.	45
8.1.3	Mountain steeplands on hard coarse grained igneous and metamorphic rocks.	45
8.1.4	Mountain steeplands on hard grained igneous and tuffaceous sedimentary rocks.	45
8.1.5	Mountain steeplands on weathered coarse grained igneous rocks.	45

2.3 Application of land cover information

The HEL layer is derived by applying land cover information to the fundamental HEL layer. Wherever land cover has woody vegetation then it is assumed in the model that erosion risk is significantly reduced through strengthening of soil by woody roots (Phillips et al. 2023; Dymond et al. 2010; Herzig et al. 2011). Figures 5 and 6 show graphics of the North and South Island HEL layers after overlaying woody vegetation derived from the LCDB (see Table 3) to set to no-risk in woody areas. Figures 7 and 8 show clips with full detail. The LCDB has five versions at dates 1996, 2001, 2008, 2012, and 2018, so the Highly Erodible Land layer also has five versions at the same dates as the LCDB. The minimum mapping unit of the LCDB is 1 ha.

Table 3. LCDB woody classes

ID	Description
2	Urban Park
33	Orchard and Vineyard
47	Flaxland
51	Gorse/Broom
52	Manuka/Kanuka
54	Broadleaved Indigenous Hardwoods
55	Subalpine Shrubland
56	Mixed exotic shrubland
58	Grey Scrub
68	Deciduous Hardwood
69	Indigenous Forest
70	Mangrove
71	Exotic Forest

There is another national layer of land cover information that can be used for the HEL model. The Woody layer is an automated annual update of basic land cover produced by applying spectral rules to satellite imagery (Dymond & Shepherd 2004). Table 4 shows the basic land cover classes for the Woody layer. The Woody layer has seven versions, produced from Sentinel-2 satellite imagery, at these dates: 2016, 2017, 2018, 2019, 2020, 2021, and 2022. The minimum mapping unit of the Woody layer is 0.01 ha. This means the Woody layer can be used for annual updates and higher resolution of the HEL model. Figures 9 and 10 show graphics of the North and South Island HEL layers after overlaying woody vegetation derived from the Woody layer, date 2022. Figures 11 and 12 show clips with full detail of HEL produced with the Woody layer, date 2022.

Table 4. Basic land cover classes in the Woody layer

ID	Description
1	Water
2	Bare Ground
3	Woody Vegetation
4	Herbaceous Vegetation
6	Primarily Bare
7	Snow

3 Estimated Long-term Soil Erosion (ELSE)

3.1 Definition and methodology

Long-term soil erosion is the average mass of soil lost per square kilometre per year (tonnes/km^2/year). Long-term soil erosion was modelled as the product of mean annual rainfall squared with an erosion terrain coefficient factor and a land cover factor (Dymond et al. 2010). For ELSE, woody vegetation has a factor 0.1 (one tenth) of that for herbaceous vegetation. The model was calibrated from long-term measurements of sediment load in rivers using a digital map of mean specific sediment yield produced by NIWA (Dymond et al, 2010). Measurements of mean sediment discharge at 220 sites were used to calibrate erosion terrain coefficients for ELSE. The methodology to estimate ELSE is that developed in Dymond et al. (2010). The total sediment in rivers (tonnes/year) for a particular region is the sum of all soil erosion over the entire region (Dymond et al., 2010). Note that the ELSE national indicator is synonymous with the NZeem® erosion model – Smith (2023).

3.2 Application of land cover information

As with the HEL layer, the land cover factor for ELSE can come from either the LCDB, to enable assessment of trends from 1996 through to 2018, or from the Woody layer, to obtain currency and annual updates, from 2016 to 2022. Figure 13 shows ELSE using the Woody2022 layer for the North Island and Figure 14 shows ELSE using the Woody 2022 layer for the South Island.

4 Discussion

4.1 Use of models

The suitability of HEL and ELSE for different applications is shown in Table 5. Assumptions, limitations, and related uncertainties specific to HEL and ELSE are covered in the method description for each indicator.

Table 5. Use of Highly Erodible Land (HEL) and Estimated Long-Term Soil Erosion (ELSE)

Application	ELSE	HEL
Catchment sediment yield	✓	×
Farm sediment yield	×	×
Prioritisation of farm (soil conservation) plans	×	✓
Design of farm (soil conservation) plans	×	×
Prioritisation of catchment soil conservation	×	✓
Prioritisation of regional soil conservation	✓	✓
Prioritisation of soil cons. for reducing sediment yield	✓	×
Regional targets for reduction of erodible land	×	✓
National targets for reduction of erodible land	×	✓

4.2 Recommendations for establishing national and regional baselines using HEL

The fundamental HEL layer can help establish a baseline of land at high risk of mass movement erosion without protective vegetation cover. The impact of some conservation measures cannot be included at every scale, because the HEL model uses LCDB and does not map individual trees, such as space-planted trees for soil conservation.

For a national level baseline, the HEL layer (fundamental and either LCDB based vegetation cover or the Woody layer) can serve as a starting point to establish the area of land at high risk of mass movement erosion without protective vegetation cover. Land that is naturally bare, such as mountain areas above tree-line, could be excluded for example by extracting the LCDB bare natural surfaces, e.g. "gravel or rock", "permanent snow and ice", "Alpine grass/herb field. "

For regional-level baseline, the HEL fundamental layer, LCDB based vegetation cover or the woody layer, and/or regional layers of soil conservation measures can be used to establish the area of land that is at high risk of mass movement erosion without protective vegetation cover. Again, bare natural surfaces should be subtracted.

To establish a baseline, nationally or regionally, with a specific timestamp/year, it is recommended to use the most recent woody layer. Regions with large areas of land in forestry may need to consider forestry rotation cycles to account for large variations in HEL where these are due to areas being felled or maturing in specific years.

4.3 Recommendations for analysing trends and change

The different dates of HEL using LCDB (1996, 2001, 2008, 2012, and 2018) enable analysis of trends and change over 22 years due to broad-scale land cover change. However, because LCDB does not map individual trees, such as the space-planted poplars commonly used in soil conservation, the impact of some soil conservation actions is not included. As conservation action maps are separate layers and vary in time with their maturity, we recommend that maps of soil conservation action be included in the HEL model in future. The different dates of HEL using Woody layers (2016, 2017, 2018, 2019, 2020, 2021, and 2022) enable analysis of recent trends and in greater detail, including shelter belts and small farm forestry lots.

The different dates of ELSE using LCDB (1996, 2001, 2008, 2012, and 2018) enable analysis of trends and change over 22 years due to broad-scale land cover change. However, because the LCDB does not map individual trees, such as space-planted poplars commonly used in soil conservation, the impact of some soil conservation actions is not included. As conservation action maps are separate layers and vary in time with their maturity, we recommend that maps of soil conservation action be included in ELSE in future (as in Monaghan et al. 2021). The different dates of ELSE using Woody layers (2016, 2017, 2018, 2019, 2020, 2021, and 2022) enable analysis of recent trends and change on an annual basis.

4.4 Use of high resolution spatial layers for soil erosion and conservation mapping

Airborne LiDAR information provides an opportunity to improve spatial resolution and distinguish between digital elevation (bare earth) and digital surface models (elevation augmented with natural and human features).

The improvement in spatial resolution from LiDAR could be used to gain spatial resolution for slope information and to create canopy height models. However, whilst regional LiDAR coverage is increasing, it does not have the national coverage necessary for national state of environment indicators. Coverage is currently about 70% of New Zealand and will reach about 80% by 2024 (https://canterburymaps.govt.nz/news/nz-national-elevation-programme-nzs-3d-treasure-trove/). However, for regions that do have LiDAR, which can detect space-planted trees, better operational land management decisions can be made i.e. where to prioritize the targeting of resources to stabilise land at high risk of mass movement erosion through more accurate identification of steep slopes without space-planted trees.

Smith et al. (2021) developed object-based methods for mapping landsides from orthophotography (c. 50 cm) for application over large study areas. The model used machine learning techniques to predict the spatial probability (range 0-1) of landslide occurrence based on geo-environmental data, and was applied in the Hawkes Bay and Gisborne regions. The increased spatial detail of the model enables cost-effective targeting of soil conservation to erodible land at farm scale. The model could be expanded to other regions with LiDAR coverage to increase spatial resolution of the slope factor influencing land susceptibility to erosion, but would require cross-validation using landslide inventories from previous events. It is worth noting that the model still relies on the LCDB and NZLRI, which have mapping scales of 1:50,000, for land cover and rock type data.

Methods for mapping individual trees planted for soil conservation have been recently developed. Spiekermann et al. (2021, 2022) combined regional LiDAR data (1 m) with orthophotography (30 cm) to map individual soil conservation trees. These data have been used to develop models of landslide susceptibility at the scale of individual trees (Spiekermann et al 2023) in response to storm rainfall (Rosser et al. 2017, 2021; Smith et al 2023). They successfully quantified the influence of individual trees on slope stability and incorporated connectivity to streams. This could be used to support the design and implementation of cost-effective and targeted erosion control measures, at a farm scale. Extension of these methods from a study site to the regional and national scale remains, which currently limits application of these advances in national mitigation effectiveness indicators.

List of Figures

Colours for HEL layers

Red: high landslide risk – delivery to stream.

Light brown: landslide risk – non-delivery to steam.

Magenta: moderate earthflow risk.

Purple: severe earthflow risk.

Orange: gully risk

Green: woody vegetation

Grey: non HEL land

Colours for ELSE (tonnes/km2/year)

Dark green: 0-50

Green: 50-200

Light brown: 200-500

Brown: 500–2,000

Dark red: 2,000-5,000

Red: 5000–20,000

Magenta: >20,000

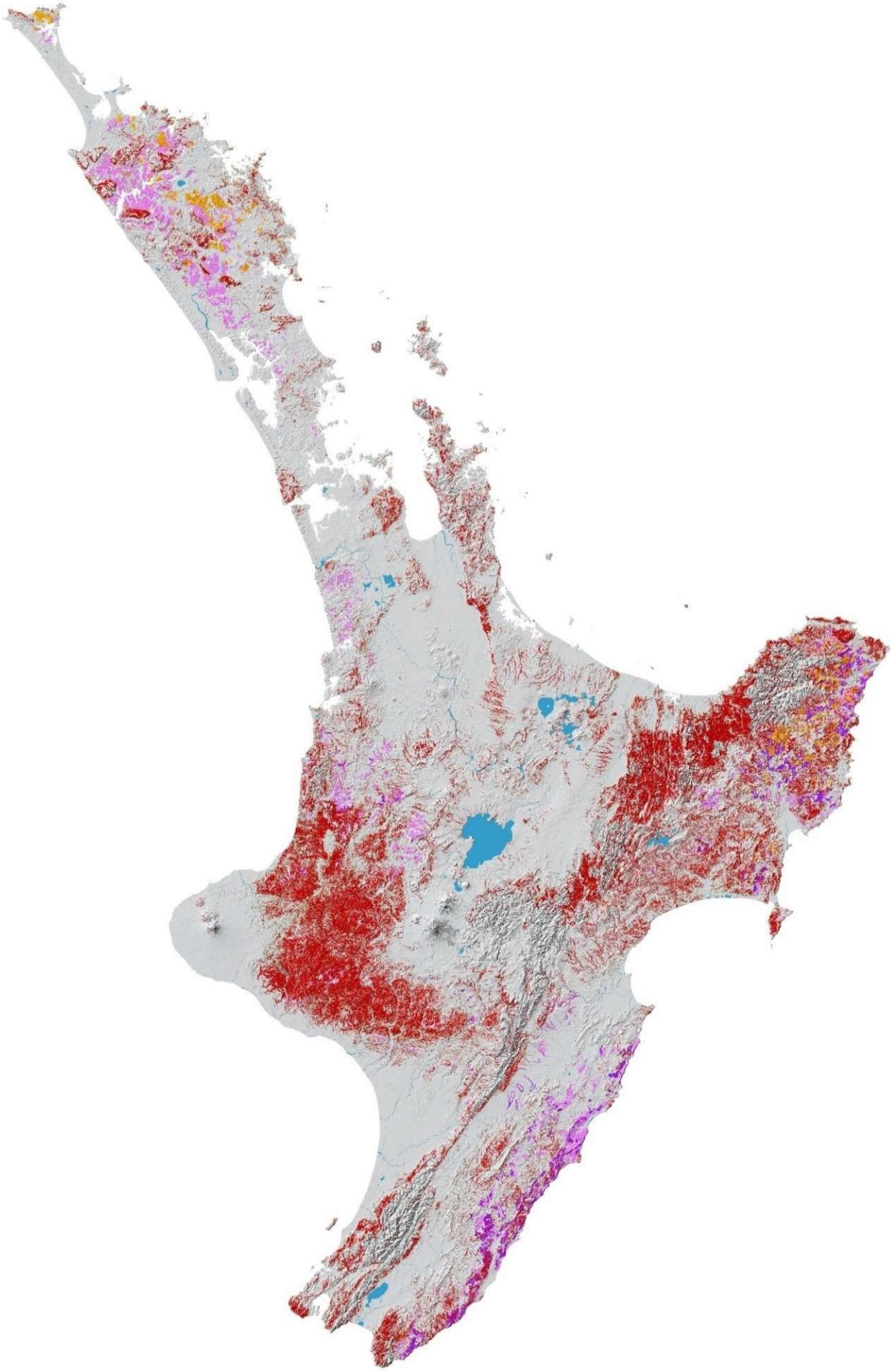

Figure 1. Graphic of fundamental HEL layer of North Island. (Red: high landslide risk – delivery to stream; Light brown: landslide risk – non-delivery to steam; Magenta: moderate earthflow risk; Purple: severe earthflow risk; Orange: gully risk; Green: woody vegetation.)

Figure 2. Graphic of fundamental HEL layer of South Island. (Red: high landslide risk – delivery to stream; Light brown: landslide risk – non-delivery to steam; Magenta: moderate earthflow risk; Purple: severe earthflow risk; Orange: gully risk; Green: woody vegetation.)

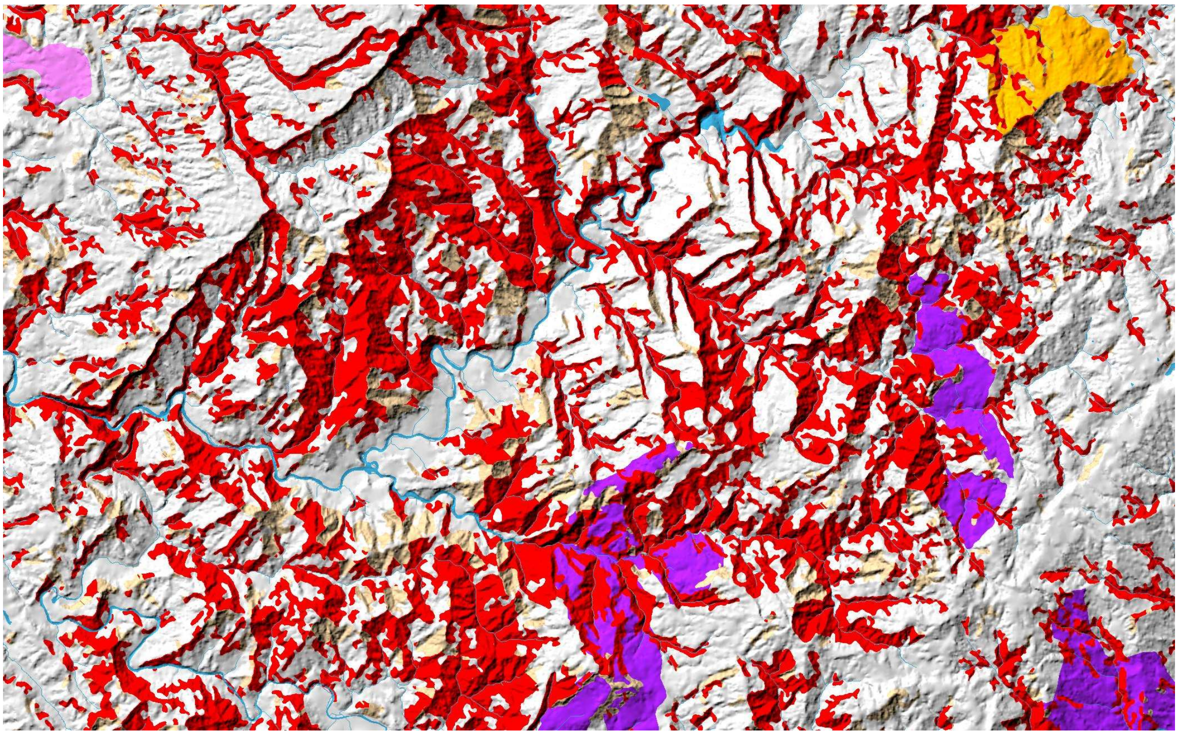

Figure 3. Clip of fundamental HEL layer graphic (from North Island).

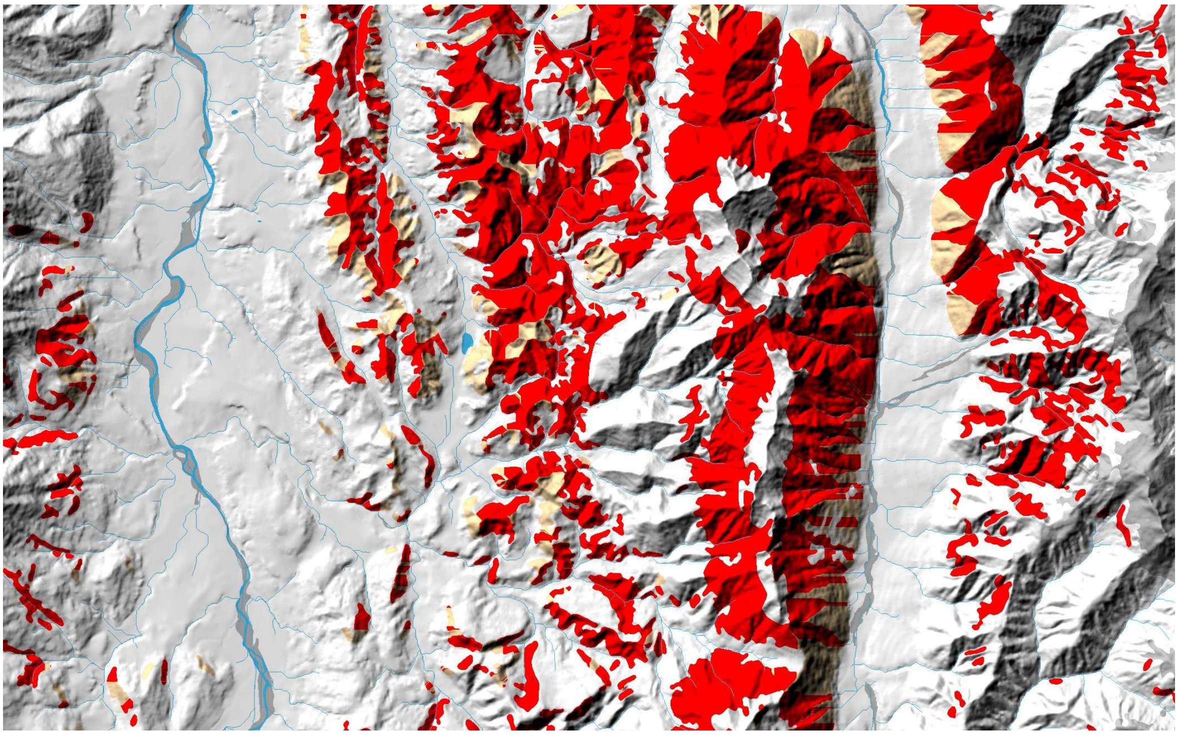

Figure 4. Clip of Fundamental HEL layer graphic (from South Island).

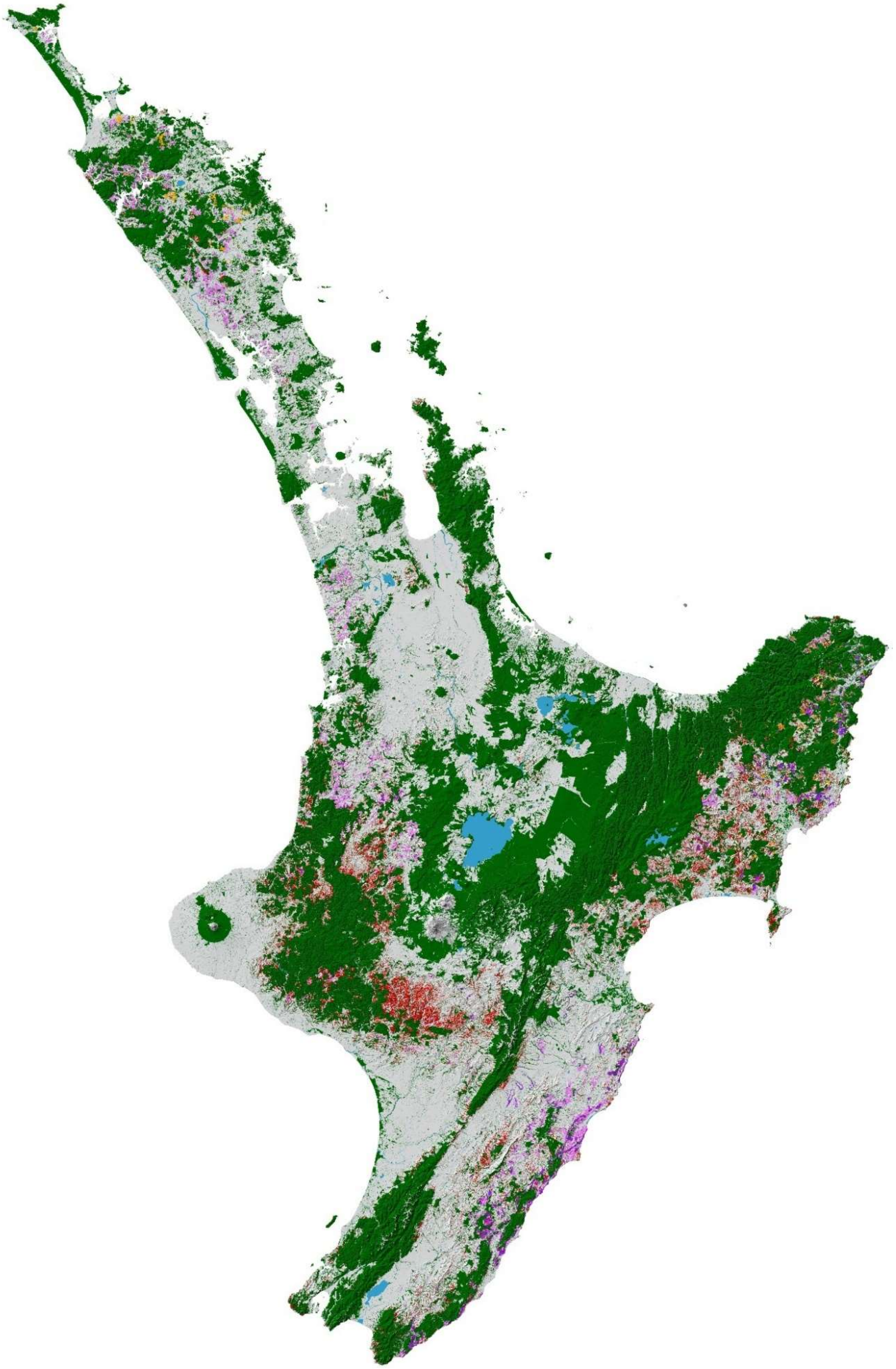

Figure 5. Graphic of HEL layer of North Island (using LCDB5) – date 2018. (Red: high landslide risk – delivery to stream; Light brown: landslide risk – non-delivery to steam; Magenta: moderate earthflow risk; Purple: severe earthflow risk; Orange: gully risk; Green: woody vegetation.)

Figure 6. Graphic of HEL layer of South Island (using LCDB5) – date 2018. (Red: high landslide risk – delivery to stream; Light brown: landslide risk – non-delivery to steam; Magenta: moderate earthflow risk; Purple: severe earthflow risk; Orange: gully risk; Green: woody vegetation.)

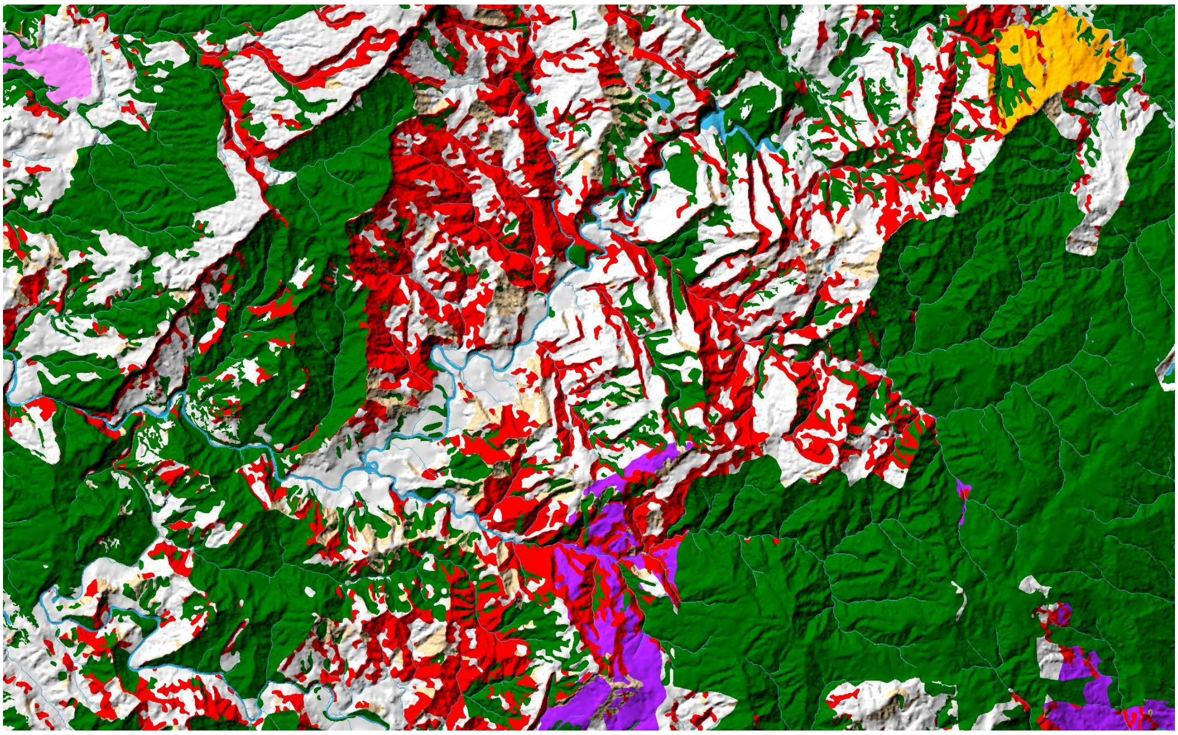

Figure 7. Clip of HEL layer graphic using LCDB5 (from North Island) – date 2018.

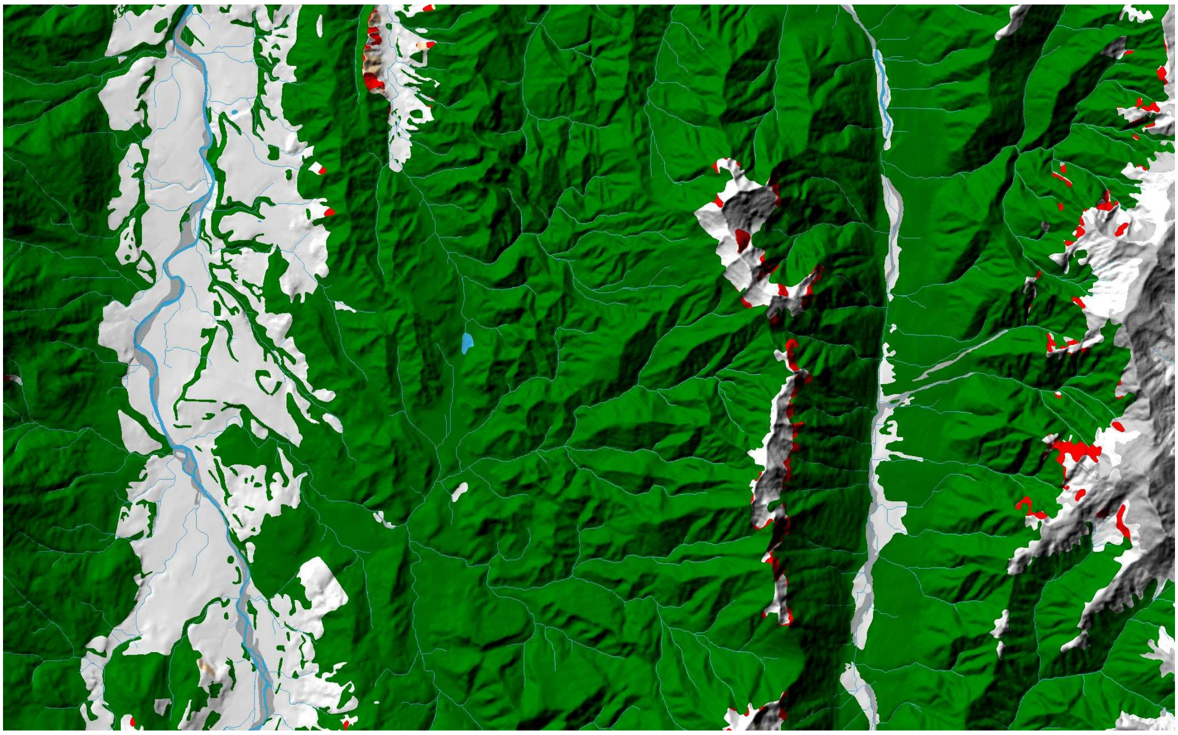

Figure 8. Clip of HEL layer graphic using LCDB5 (from South Island) – date 2018.

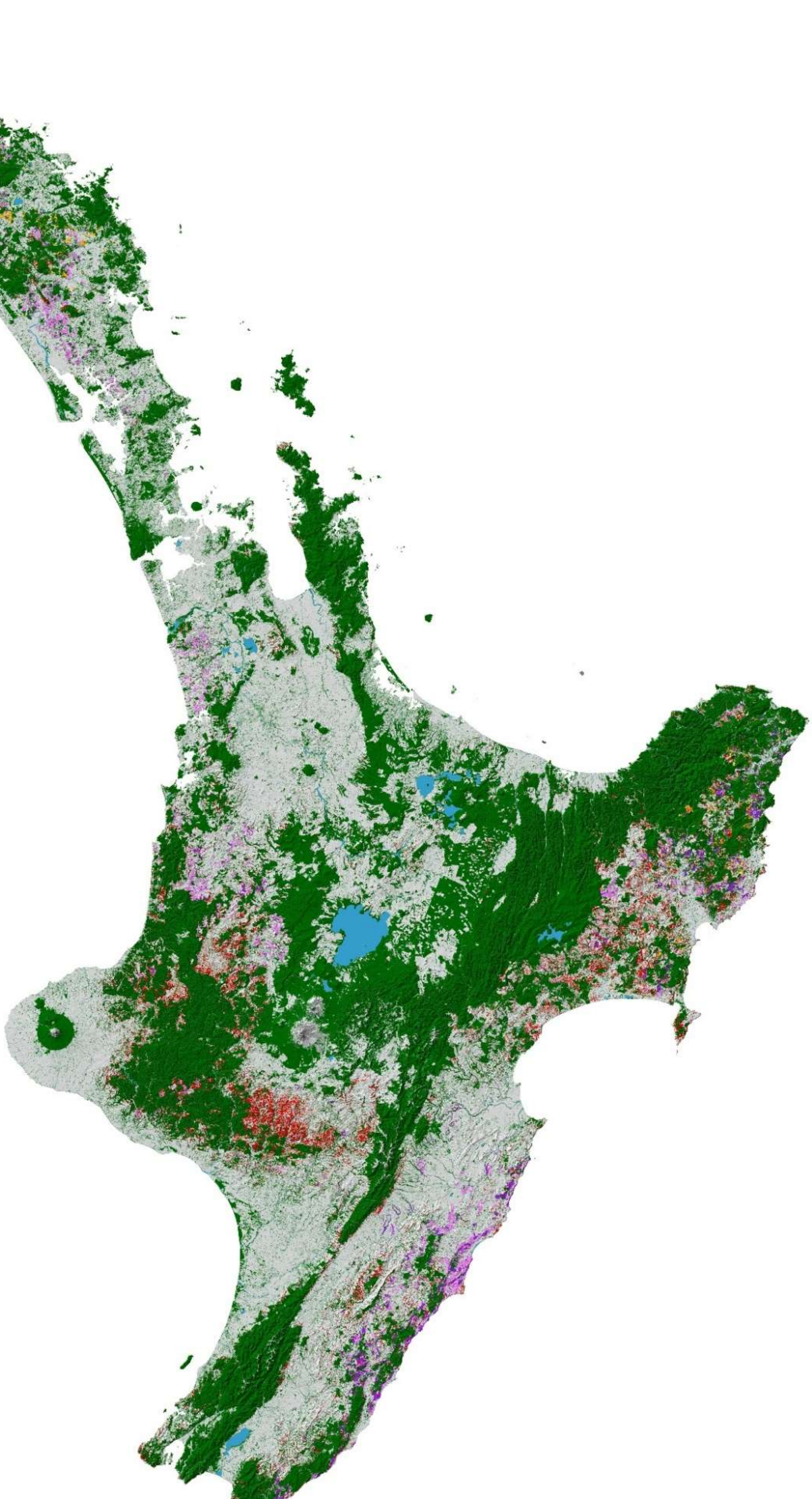

Figure 9. Graphic of HEL layer of North Island (using Woody2022 layer). (Red: high landslide risk – delivery to stream; Light brown: landslide risk – non-delivery to steam; Magenta: moderate earthflow risk; Purple: severe earthflow risk; Orange: gully risk; Green: woody vegetation.)

Figure 10. Graphic of HEL layer of South Island (using Woody 2022 layer). (Red: high landslide risk – delivery to stream; Light brown: landslide risk – non-delivery to steam; Magenta: moderate earthflow risk; Purple: severe earthflow risk; Orange: gully risk; Green: woody vegetation.)

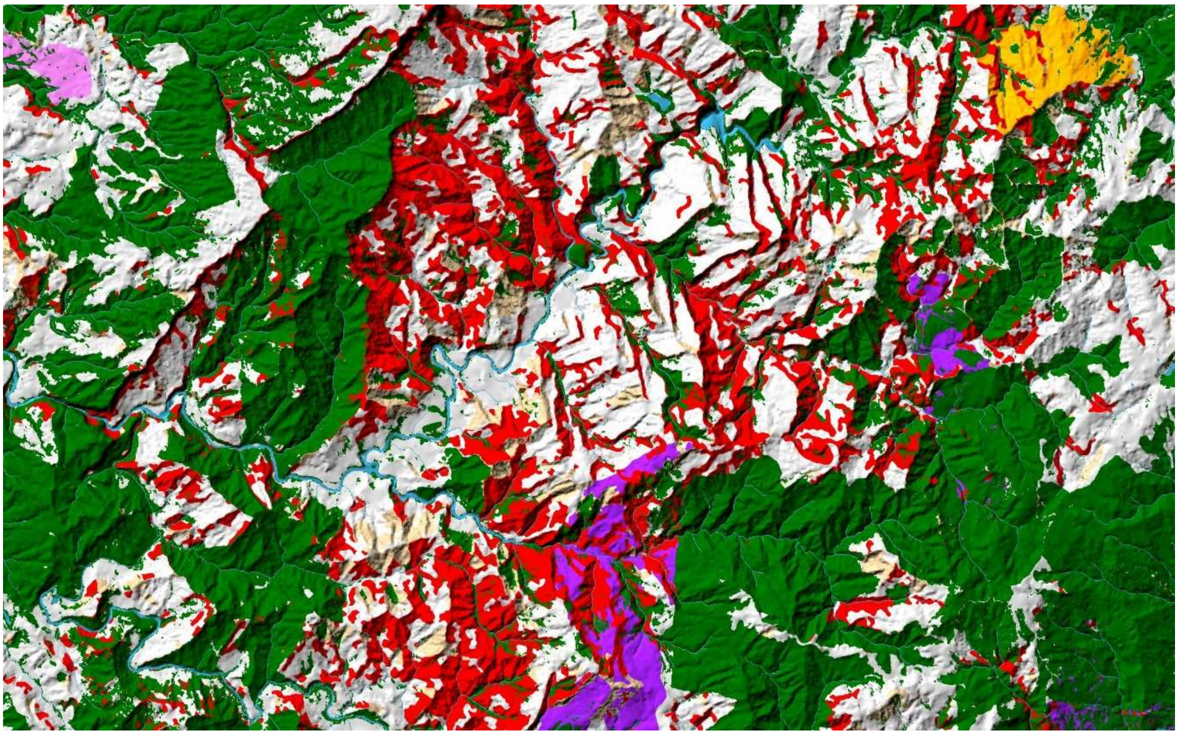

Figure 11. Clip of HEL layer graphic using Woody 2022 layer (from North Island).

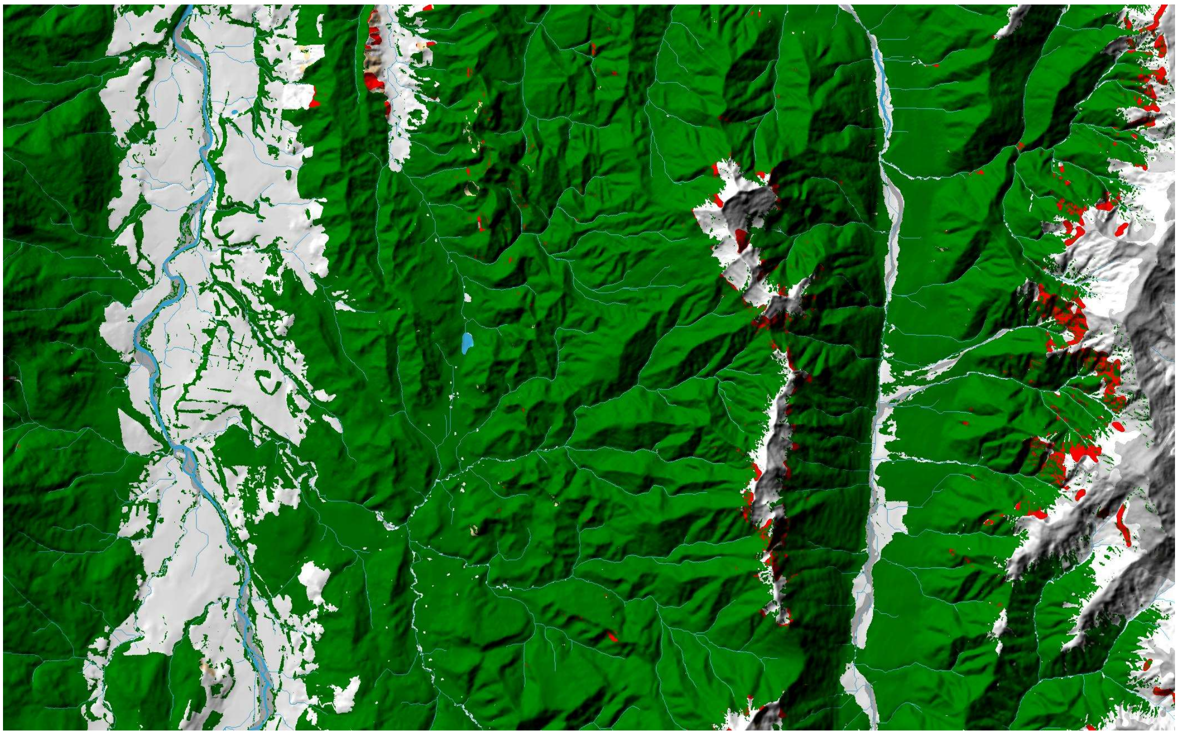

Figure 12. Clip of HEL layer graphic using Woody 2022 layer (from South Island).

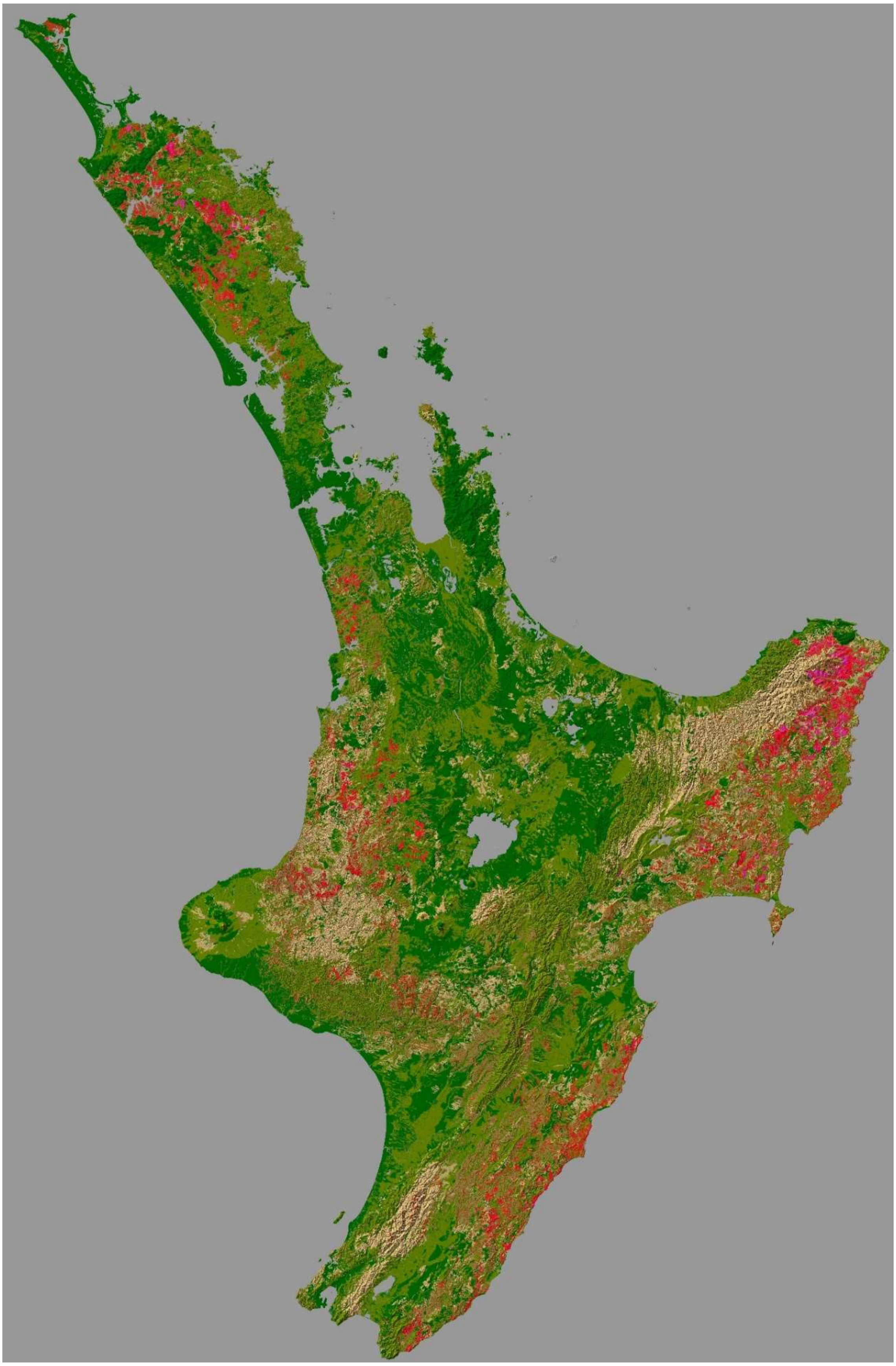

Figure 13. Graphic of Estimated Long-Term Soil Erosion (ELSE) for North Island (using Woody 2022 layer). Units are tonnes/km^2/year and colours as follows: Dark green 0–50; Green 50–200; Light brown 200–500; Brown 500–2,000; Dark red 2,000–5,000; Red 5,000–20,000; Magenta >20,000.

Figure 14. Graphic of Estimated Long-Term Soil Erosion (ELSE) for South Island (using Woody 2022 layer). Units are tonnes/km^2/year and colours as follows: Dark green 0–50; Green 50–200; Light brown 200–500; Brown 500–2,000; Dark red 2,000–5,000; Red 5,000–20,000; Magenta >20,000.

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Appendix 1 – Glossary of terms

Afforestation – the establishment of a forest or stand of trees in an area where there was no tree cover.

Annual rainfall – a list giving the total depth of rain falling in every year (mm/year). Mean annual rainfall is the mean of the list.

DEM – Digital Elevation Model is a raster database of elevations.

Earthflow erosion – slow downward movement of wet soil slopes towards waterways.

Erosion terrain – reclassification of land using the New Zealand Land Resource Inventory into terrains with similar dominant soil erosion processes. A full description of erosion terrains is given by Dymond et al. (2008, 2010).

Farm plan – a spatial plan of soil conservation actions designed to reduce soil erosion on a farm. This commonly involves retirement of very steep slopes, space planting of poplars on steep slopes, afforestation of earthflows and gullies, and/or paired planting of poplars or willows on stream banks. Fully implemented and mature farm plans can reduce soil erosion by 70%.

Gully erosion – massive soil erosion that begins at gully heads and expands up hillsides over decadal time scales.

Highly erodible land – land that is at high risk of mass-movement soil erosion.

Land cover – the type of vegetation covering land (e.g. forest, pasture).

Landslide erosion – sudden failure of soil slopes during storm rainfall.

Landslide susceptibility – the likelihood of a landslide occurring in an area on the basis of local terrain conditions.

LCDB – Land Cover Database (national database of land cover with 1 ha minimum mapping unit).

LiDAR – Light Detection and Ranging is a remote sensing method used to examine the surface of the Earth. From an airplane, pulses of light are sent to the ground, measuring time of return for each. All the returns form a point cloud that can be converted into a detailed elevation model of the earth surface, and also a height model of vegetation if the earth surface is covered by vegetation.

Mass-movement soil erosion – soil erosion processes involving failure at depth (> 0.5 m).

Orthophotography – digital aerial photography projected onto a map projection using a DEM.

Pixel – the smallest element (usually a square) of a raster database.

Protective woody vegetation – vegetation with woody stems and branches usually has woody roots that strengthen soils at the soil/regolith interface.

Retirement of land – pastoral land may be retired from production by fencing to keep stock off. Retired land will progress through weeds to shrubs and eventually to forests.

Reversion – reversion of pasture back to scrub by excluding stock from pasture and allowing weeds to grow.

Sediment load – the mass of soil transported per unit time past a point in a river (tonnes/year).

Soil erosion rate – the mass of soil eroded per unit area per time interval of soil erosion (tonnes/km^2/year).

Slope – the steepness of hillslopes (given in degrees).

Slope threshold – land steeper than 'slope threshold' and without protective woody vegetation has high risk of landsliding.

Space-planted trees – trees (usually poplars) planted at regular intervals to increase the strength of soil.

Streamline – line of steepest descent in a DEM or landscape.