



# Otago Hill Country Erosion Spatial Prioritisation: Technical Report

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March 2026



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## Recommended citation

Button, E. S. (2026). Otago Hill Country Spatial Prioritisation: Technical Report. Hill Country Erosion Programme. Otago Regional Council, Dunedin.

## Cover image credit

A loessal erosion prone fragic pallic soil that is common in the hill country of North and South Otago exposed along a cutting. Photograph by Erik Button.

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## Executive Summary

The Hill Country Erosion Programme (HCEP) aims to support landowners to plan for, and treat, erosion-prone land to protect vulnerable hill country. To maximise the effectiveness of the Programme by targeting areas that have greater erosion vulnerability a quantitative spatial prioritisation support tool is needed. This report outlines the process and technical development of a hill country erosion prioritisation support tool.

The priority support tool was developed in conjunction with the established HCEP Technical Advisory Group (TAG). This group met regularly and steered the development of the prioritisation including identifying a suitable “hill country” definition, appropriate presentation, and identifying spatial scales of interest (i.e. regional, catchment, property).

Hill country was initially identified spatially based on literature and the consensus of the TAG. This “hill country” was land <1,000 m and between slopes of 15° and 25° with pastoral farming as the dominant land use and cover. A secondary elevation threshold of <500 m was prioritised over higher elevation land due to higher intensity potential (e.g. stocking rates, cropping) and thereby higher erosion reduction potential via mitigation. This delineated 3,761 km<sup>2</sup> of hill country which corresponds to 11.8% of Otago with 3.4% of this being low hill country (1,089 km<sup>2</sup>; <500 m) and 8.4% high hill country (2,672 km<sup>2</sup>; 500 - <1,000 m).

To quantify relative sediment generation and reduction potential, the Otago-adapted SedNetNZ sediment budgeting model was used and summarised into hill country area polygons. SedNetNZ is a process-based sediment model that predicts both generation and transport of sediment through river networks via surficial and streambank erosion processes. It incorporates a relatively simple physical representation of hillslope and channel processes at a small sub-catchment level. In addition to the base sediment yield estimated by the model, the yield reduction due to stock exclusion was simulated and included as a proxy for sediment reduction potential via intervention.

The SedNetNZ modelled sediment yield estimates (i.e. sediment loss rate) under current management practices (sediment generation potential), and the change under the stock exclusion scenario (sediment reduction potential - calculated as the yield difference), were summarised separately within polygons of the two hill country elevation ranges by area-weighted averages. These summaries were then classified by quartiles into a three-class system and merged into a final dataset. Due to the distribution of data being lower in the low elevation hill country, when then combined, the same classes represent lower ranges of values in the low hill country compared to the high hill country, thus artificially enhancing the prioritisation of these areas. Finally, the sediment generation and reduction potential is combined to highlight areas with the highest priority for the HCEP.

The resulting spatial prioritisation identifies three general regions within Otago with the highest priority (medium to high sediment generation and medium to high sediment reduction potential). These are generally the hills southwest of Roxburgh, the hills North of the Silverpeaks mountain range and the hillslopes of the more productive alpine ranges and valleys (Cardrona, Shotover and Matukituki). In addition, many smaller pockets of priority were identified. 7.5% of Otago is identified as highest priority for the HCEP.

This spatial prioritisation is designed to be used at a regional scale as a decision support tool for planning. At a property level, the tool’s uncertainty is high, and value may be limited. User guidance, limitations and assumptions of the prioritisation are discussed.

# 1. Introduction

## 1.1 Background

The Hill Country Erosion Programme (HCEP) is an Otago Regional Council (ORC) led 4-year initiative (2023-2027) funded by the Ministry of Primary Industry (MPI), designed to support landowners to plan for, and treat, erosion prone land to protect vulnerable hill country. The agreed HCEP’s main objectives for Otago are to:

1. Increase ORC’s knowledge of hill slope erosion (risk and actual) including the collation and analysis of existing data to prioritise intervention efforts.
2. Increase capacity for involvement through employing a catchment action planner-land/contractor to advise, engage, and plan erosion control in priority areas.
3. Improve ORC’s engagement with landowners through group workshops, one-on-one landholder meetings, information exchange, and mentoring from other regional councils.
4. Identify and mitigate hill slope erosion in priority areas-through funding and assistance for landowners to plan and undertake erosion control.

## 1.2 Purpose

To provide for the four objectives of the HCEP, this report outlines the process and development of a region-wide hill country erosion spatial prioritisation. The intent of the tool is to enable users to identify areas that are relatively more susceptible to erosion to enable more cost-effective use of funding for implementing erosion mitigation practices in hill country areas. This prioritization builds upon learnings from a previous approach (Appendix 1) including the need for regional coverage, transparency, and collaborative development with the HCEP team to ensure uncertainty is expressed in a useful manner for decision making.

# 2. Design

A Technical Advisory Group (TAG) for the HCEP was established in September 2024 with the intention of supporting the HCEP and aligning its approach with other council work programmes. The TAG was primarily comprised of following members:

<b>Member</b>	<b>Role</b>	<b>ORC Team</b>
Alison Turner	Land Management Advisor, HCEP manager	Environmental Implementation
Murray Harris	Hill Country Erosion Project Advisor	NA; External consultant
Erik Button	Land and Soil Scientist	Science
Mark Crawford	Land and Soil Scientist	Science
Tim van Woerden	Senior Natural Hazards Analyst	Natural Hazards
Simon Whitton	Principal Advisor Rivers	Engineering
Anna Molloy	Principal Advisor Environmental Implementation	Environmental Implementation
Melanie White	Project Delivery Specialist - Jobs for Nature	Environmental Implementation
Sarah Martin	Senior Advisor Iwi Partnerships and Engagement	Partnerships and Engagement

In line with modelling best practice [1], throughout the development of the spatial prioritisation, regular monthly or bi-monthly updates and discussions around the approach to the prioritisation were held within TAG group meetings. This guided the development of the approach ensuring the outputs would be useful in decision making.

## 2.1 Defining hill country

To create a focus on the areas that meet the requirements of the HCEP and enable the prioritization, the first step is to define hill country spatially. Different data sources or approaches can be used to achieve this, but there is no quantitative definition of hill country that has consensus. In addition, the definition used needs to adequately reflect the desired scope of the HCEP including providing a tractable area and generally aligning with the community's conceptualisation of "hill country". Commonly, the New Zealand Land Resource Inventory (NZLRI) Land Use Capability (LUC) classifications, or a combination of slope and altitude thresholds are used to distinguish between lowland, hill country, high country and steep/land/alpine areas. However, the existing classifications do not necessarily align with the requirements of the HCEP as they may conflict with community views of "hill country", work at inappropriate scales (i.e. farm types), and/or identify excessively large areas of Otago hindering effective prioritisation.

### New Zealand Land Resource Inventory

The New Zealand Land Resource Inventory (NZLRI) Land Use Capability (LUC) system [2] has been used in New Zealand since its inception in the 1950s. It is a familiar land classification system designed to identify land use potential and support land production that has been used in regulation, such as in the NPS-HPL<sup>1</sup> and the ESC<sup>2</sup> within the NPS-CF<sup>3</sup>. This use of LUC at property level has been recently critiqued and deemed inappropriate by the Parliamentary Commissioner for the Environment [3] due to its coarse scale and dated nature. LUC has been used to define highly erodible hill country using sub-classes that represent erosion-limited land (6e, 7e and 8e) [4, 5]. This classification is not the best basis for prioritisation as A) the broader discrete categories lack a continuous scale for finer differences in sediment yield potential and prioritisation; B) the mapping dates back to the 1970s–80s with the lower South Island (1:63,360) not receiving the updated second survey at a finer scale; C) the delineation of polygons can be coarse, oversimplifying more complex landscape features.

ORC has an inventory of historic LUC maps of the region from work conducted in the 1960-1990s at finer scales (up to 1:10,000), which offer greater resolution and accuracy of classes and their boundaries [6]. While this scale is sufficient for farm-scale identification of erosion prone areas and spatial prioritisation, this mapping is not entirely digitised and was not done comprehensively in the region.

### Improved New Zealand Land Resource Inventory

A recent report for the Marlborough District Council [7] found that a simple GIS re-classification of LUC using more recent available data (LiDAR-derived slope, climate and soil information from the Fundamental Soil Layer [8, 9]) achieved a spatial scale of 1:10,000 and was consistent with actual land-use outcomes (e.g. erosion from forestry operations) and landslide occurrences. This re-classification resulted in significant change as evidenced by a comparison between original and GIS-based LUC classes 6-8 which agreed an average of 46% ( $n = 5,355$ ). As such, the authors concluded that the use of LUC classes, without re-alignment, was not appropriate for operational planning for forestry and other land uses. The re-alignment of the LUC classes was not a realistic approach for this project considering the scale of the Otago region, the lack of LiDAR data, and time and financial constraints of the HCEP.

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<sup>1</sup> National Policy Statement for Highly Productive Land

<sup>2</sup> Erosion Susceptibility Classification

<sup>3</sup> National Environmental Standards for Commercial Forestry

## Beef and Lamb Livestock Classes

Beef and Lamb NZ use a farm class system to categorise farm types based on factors such as topography, fertility and management, to provide benchmarks for profitability and performance in their economic reports. The classes are developed from weighted averages of individual farm class data to correctly portray a whole region or Aotearoa New Zealand. Although the livestock classes are not a spatial dataset, the class can be predicted by biophysical factors of the landscape. Hill country generally relates to the Beef and Lamb Class 2 (South Island hill country), which is defined as ‘traditionally store stock producers with a proportion sold prime in good seasons. Carrying between two and seven stock units per hectare, they usually have a significant proportion of beef cattle.’

The 2024 Otago region land use map [10] spatialised the Beef and Lamb Classes, using the following slope and elevation thresholds:

- Lowland (<600 m above sea level, slopes < 8 degrees)
- Hill country (<600 m above sea level, slopes between 8 – 21 degrees)
- High country (majority of property above 600 m above sea level, mixed slope)

This spatialised version of the Beef and Lamb Livestock Classes provides a starting point for spatially defining hill country but overrepresent the area the TAG was looking to prioritize limiting the value of this classification in the HCEP.

## Criteria development

As existing classifications were considered unsuitable by the TAG, they were used to guide the development of criteria for use in the prioritisation.

Slope angle is the most common attribute used to define hill country and has been used in conjunction with an elevation threshold or independently. In a national erosion model, hill country was defined as having ‘most slopes 16–25°’, with slopes >25° considered steeplands [11]. Others have defined hill country as having slopes >15° and an elevation <1,000 m [12, 13, 14]. Due to the common use of ca. >15° and <25° slope angles, these were used for slope criteria.

An additional elevation threshold was considered necessary to focus on land that aligns to the HCEP and is used for production of which effects are realistically mitigatable. While different elevations have been used to confine the extent of hill country, a 1,000 m threshold was chosen as an upper limit because it has been used most consistently in New Zealand to define hill country by elevation [12, 13, 14]. A secondary 500 m threshold was used to define lower elevation land within hill country that has greater potential for production due to better access and more favourable climate and topography supporting higher land use intensity and therefore increasing sediment generation reduction potential. This is evidenced by research from Otago that found most crops experienced some to significant limitations above 450 m due to a shorter, cooler growing season [15]. Land >450 m is often steeper with higher rainfall and natural erosion rates, and is managed accordingly with lower intensity, consisting largely of extensive grazing of semi-natural tussock. Hence, there is less mitigation capacity to reduce erosion rates compared to lower elevation hill country. For simplicity, and as the topographic map of New Zealand uses 20 m intervals, a threshold of 500 m was chosen. Within this context, hill country <500 m is considered more effective for erosion mitigation and to be considered priority. Hereafter, hill country at elevations <500 m is termed ‘low hill country’ and at elevations >500-<1,000 m ‘high hill country’.

The criteria that were used for spatially defining hill country in Otago are presented in Table 1, based on the justification presented above and the consensus reached within the TAG.

**Table 1.** Criteria used to define hill country spatially.

Criteria	Definition
Slope	>15° and ≤25°
Elevation	High hill country (500-<1,000 m) Low hill country (<500 m)
Land Cover	Relevant to pastoral production within scope of the HCEP (Appendix 2 for the classes and reasons)
Land Use	Relevant to pastoral production within scope of the HCEP (Appendix 3 for the classes and reasons)

## 2.2 Defining sediment generation

To prioritise areas of hill country that are at greater erosion risk, information is required to compare between different areas within hill country. There are different approaches possible for this.

### Local expert knowledge

Experts bring years of experience and a deep understanding of local landscapes, historical data, and environmental conditions that might not be captured by other quantitative approaches, such as models. Local experts can incorporate a wide range of factors, including socio-economic and practical considerations that may be difficult to quantify and can quickly adapt their assessments based on new information, making them more responsive and dynamic. Also, they often have good relationships and reputations with landowners or community groups. They might be more trusted by rural communities than numerical models. However, local experts are also susceptible to biases and judgement which makes their knowledge contribution more subjective and less repeatable, if it is not properly elicited. Elicitations are resource intensive, can have conflicting opinions/assessments, and it might not be possible to scale the provided information.

### Modelling

The advantage of using a modelling approach is that the results are produced in a consistent and reproducible approach, efficiently integrating data from a wide range of sources. These results are scalable, often providing data at regional to local scales. However, models have the disadvantage of being rigid and not fully able to capture important local context. Many different models developed in or adapted to Aotearoa New Zealand estimate erosion yields, risks or processes [16] (Table 2).

**Table 2.** A selection of models that could be applied in the context of this HCEP and their descriptions, strengths and weaknesses are presented below.

Model	New Zealand empirical erosion model (NZeem®)
Developer	Bioeconomy Science Institute [Manaaki Whenua Landcare Research]
Description	NZeem® is the underlying empirical model used to calculate soil erosion rates at national level for indicators like Estimated Long-Term Soil Erosion (ELSE). It estimates based on mean annual rainfall, terrain type, and land cover, providing estimates of average annual erosion.
Strengths	Robust empirical estimates using multiple land cover datasets.
Weaknesses	Does not differentiate between erosion processes.
Reference	[17, 18]
Model	Highly Erodible Land (HEL)
Developer	Bioeconomy Science Institute [Manaaki Whenua Landcare Research]
Description	The HEL model is a risk-mapping tool that identifies land explicitly susceptible to severe mass-movement erosion (landslide, earthflow, or gully). It uses a digital

	elevation model (DEM) to assign slope thresholds for different erosion terrains and integrates land cover mapping (derived from the LCDB) to classify areas into five risk categories.
Strengths	Detailed risk mapping based on topography and land cover. Sensitive to steep slopes. Integrates and differentiates risk based on 'woody' vegetative cover.
Weaknesses	Focuses on mass-movement erosion processes and "risk" rather than actual sediment loads. Does not simulate downstream sediment transport.
Reference	[19]
Model	Revised Universal Soil Loss Equation (RUSLE)
Developer	USDA; Bioeconomy Science Institute [AgResearch]
Description	RUSLE is an adaptation of the classic Universal Soil Loss Equation that computes soil loss as the product of several empirical factors: rainfall erosivity, soil erodibility, slope length and steepness, cover management, and conservation practices.
Strengths	Straightforward, factor-based approach. Widely used and easy to implement.
Weaknesses	Often underrepresents episodic events and non-linear processes.
Reference	[20]
Model	SedNetNZ
Developer	Bioeconomy Science Institute [Manaaki Whenua Landcare Research]
Description	SedNetNZ is a process-based sediment model originally developed in Australia and applied to Aotearoa New Zealand that predicts both the generation and transport of sediment through river networks. It incorporates a relatively simple physical representation of hillslope and channel processes at a small sub-catchment.
Strengths	Process-based estimation of generation and transport of sediments. Scenario analysis for mitigation. Fine resolution (sub-catchment). Otago-adapted version calibrated to the region.
Weaknesses	Data and calibration intensive. More complex to interpret.
Reference	[21, 22]

After discussions within the TAG, and comparisons of available models that can be used to estimate relative erosion risk (Table 2), the decision was made to use the SedNetNZ model. The reasons SedNetNZ was chosen are as follows:

1. SedNetNZ was recently adapted to the Otago region using visual clarity and mean annual flow data from 116 (34 modelled and 82 monitored) sites and 53 gauging stations with data records >10 years in Otago [22] and was, therefore, available to adapt instead of needing to develop from nothing.
2. 88% of Otago agricultural land is predominantly susceptible to surficial erosion (sheet, rill and wind) [23], which, with stream bank, are the erosion processes modelled by SedNetNZ.
3. Stock exclusion simulations were run as part of the model output which allow for further prioritisation based on mitigation potential [24, 22].
4. Consistency and integration with other ORC work programmes. This model was used to inform the freshwater regulations in the ORC proposed Land and Water Regional Plan.
5. Consistency with other regional councils. It is used by eight other regional councils to estimate sediment loads in rivers and streams [16].

## 2.3 Sediment reduction potential

An advantage of the SedNetNZ adapted for Otago is that mitigation scenarios were run as part of the model output package [22, 24]. These can be integrated as another level of prioritisation. The scenarios are based on stock exclusion from waterways and were informed by an estimation of current fencing extent from the Survey of Rural Decision Makers (SRDM) from 2017. The sediment loads

produced by SedNetNZ for each scenario represent the multidecadal annual average suspended sediment loads expected, if the land cover and spatial extent of riparian fencing were held constant. In the stock exclusion scenario, stream bank erosion is reduced by 80% [6] and surficial erosion is reduced via interception relative to the 3 m buffer using a sediment passing factor [17].

The aspirational scenario is aligned with the Resource Management (National Environmental Standards for Freshwater) Regulations 2020 – whereby all stock must not be on land closer than three metres to the bed of rivers and lakes [22]. This stock exclusion scenario fences off 100% of the mitigatable length of each stream segment relative to the current fenced extent as estimated from the SRDM with a three-meter buffer and applies to all livestock<sup>4</sup>. This was related to low and high producing pasture, cropland, orchards, vineyards, or perennial crops, as classified by LCDB (v5 2018) [4]. While stock exclusion is not the only mitigation tool of the HCEP, which also uses space planting, land retirement and forestry, it is a central land mitigation option implemented by the HCEP. Here, we use it as a proxy for relative sediment reduction potential.

The modelled mitigation area for the aspirational scenarios is based on four LCDB (v5) Name 2018 classes (Appendix 2; low and high producing pasture, cropland, orchards, vineyards, and perennial crops), which does not completely overlap with the LCDB classes chosen for the hill country definition in 2.1. We included additional land cover classes in the definition but also did not include orchards, vineyards. As such, some land covers do not have sediment reduction estimates based on the scenario (Appendix 4). These additional classes are Landslide, Tussock Grassland, Depleted Grassland, Flaxland, Fernland, Gorse & Broom, Sub Alpine Shrubland, Mixed Exotic Shrubland and Matagouri or Grey Scrub. These classes generally correspond to those of low intensity management (no cropping, low stocking rates, limited inputs) where mitigation potential is likely low. Therefore, this is considered acceptable.

## 2.4 SedNetNZ Application

There are several different ways to apply the modelled outputs from the SedNetNZ model to a regional prioritisation. This choice will affect what is prioritised and at what scale the information is most relevant for the outcomes of the HCEP. Table 3 lists the fields used and describes what they represent and how they are applied.

**Table 3.** The modelled SedNetNZ fields that were applied in the development of the spatial prioritisation and a description of what they represent and how they were applied

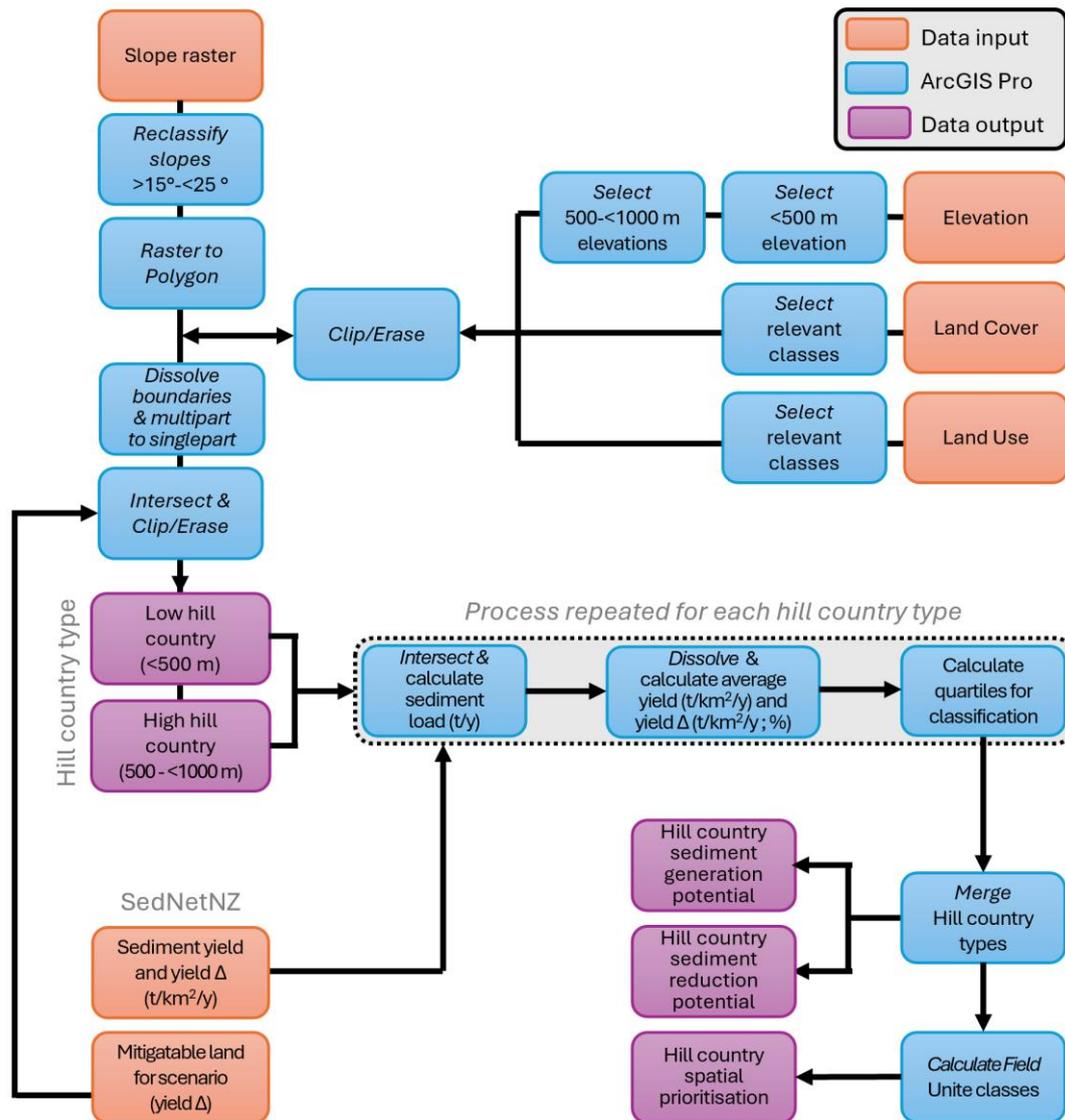
Field	Description	Application
Current management sediment yield (t/km <sup>2</sup> /y)	<i>A</i> Used to quantify sediment generation potential. Provides a sediment loss rate under current management that is a good proxy for susceptibility to erosion.	The relative magnitude between polygons (e.g. $A_1/A_2$ ) identifies which is contributing more sediment. This is relevant at a regional scale.
Mitigation scenario sediment yield (t/km <sup>2</sup> /y)	<i>B</i> Used to derive the difference in sediment yield between current management and the mitigation scenario as a proxy for sediment reduction potential. Provides a sediment loss rate under a mitigation scenario.	The relative magnitude between polygons (e.g. $B_1/B_2$ ) identifies which is contributing more sediment. It does not contain information on how much it differs from the original yield. This is relevant at a regional scale.

Sediment yield differential ( $\Delta$ t/km <sup>2</sup> /y)	$A - B$	Used as one measure of sediment reduction potential. The difference between the sediment yield under the modelled mitigation scenario and the current management. This is the actual reduction in the yield that is estimated from the implementation of the mitigation.	The absolute difference between yields identifies which polygons are reducing more sediment. The relative magnitude between polygons (e.g. $A-B_1/A-B_2$ ) identifies where greater reduction of yields from the original may be possible. This is relevant at a regional scale if the focus is on identifying the maximum absolute sediment reduction.
Sediment yield differential (%)	$\frac{A - B}{A}$	Used as one measure of sediment reduction potential. The relative difference between the sediment yield under the modelled mitigation scenario and the current management. This is the reduction in the yield relative to the original yield estimated from the implementation of the mitigation.	A small absolute sediment yield differential can have a large percent change (and vice versa) which may lead to inefficient sediment reduction at a regional scale. This is relevant at farm to catchment scale if the focus is on identifying the maximum sediment reduction from the original yield.

### 3. Methodology

The methodology can be summarised by the key inputs, processing steps and outputs (Fig. 1). Briefly, the hill country criteria (Table 1) for slope, elevation, land cover and land use information were used to create a hill country extent. This was then split by the elevation threshold (500 m) before intersecting it with SedNetNZ model outputs of sediment yield (used for sediment generation potential) and sediment yield differential (used for sediment reduction potential). Modelled values were then dissolved into the hill country datasets and summarised by their area-adjusted averages and classified by percentiles separately before being merged into a final dataset.

All spatial analyses and processing steps were conducted in ArcGIS Pro (v3.1.1, Advanced License) with the NZGD 2000 New Zealand Transverse Mercator projection. A polygon feature class representing the boundary of the Otago region (hereafter Otago\_Boundary) was used as the extent [25].



**Fig. 1** A simplified overview of the GIS-workflow summarising the steps with the primary inputs, outputs and processing actions in ArcGIS Pro to achieve them. All data inputs and outputs are polygon feature classes unless specified otherwise.

### 3.1 Slope

#### Data source

Land Environments of New Zealand (LENZ) Slope map (1:50,000 scale, derived from a 25 m DEM).

#### Input data

- Raster: LENZ\_Slope\_Otago.tif
- Polygon: Otago\_Boundary.shp

#### Processing steps

1. Add LENZ\_Slope\_Otago.tif to the ArcGIS Pro project.
2. Run *Clip Raster* with:

- Input Raster: LENZ\_Slope\_Otago.tif
  - Clip Features: Otago\_Boundary.shp
  - Check “Use Input Features for Clipping Geometry”
3. Run *Reclassify* on the clipped raster:
    - Reclass Field: Slope angle
    - Class breaks:
      - Class 1:  $\leq 15^\circ$
      - Class 2:  $> 15^\circ$  and  $\leq 25^\circ$
      - Class 3:  $> 25^\circ$
  4. Run *Raster to Polygon* on the reclassified output:
    - Input Raster: reclassified slope
    - Field: Value
    - Check “Simplify Polygons”
  5. Use *Select by Attributes* on the polygon output to isolate Value = 2 to isolate class 2 identified above.
  6. Export the selection to create HC\_Slope\_Polygons.shp.

### Output

A polygon layer (HC\_Slope\_Polygons.shp) representing slope angles  $> 15^\circ$  and  $\leq 25^\circ$  (Fig. 2A).

## 3.2 Elevation

### Data source

Land Information New Zealand (LINZ) 20 m topographic contours (1:50,000 scale).

### Input data

- Polygon: LINZ\_Contours\_Otago.shp
- Polygon: Otago\_Boundary.shp

### Processing steps

1. Add LINZ\_Contours\_Otago.shp to the project.
2. Use *Select by Attributes* to select contour features where Elevation = 1000 m.
3. Run *Merge* to combine:
  - Input Datasets: selected 1000 m contours + Otago\_Boundary.shp
4. Ensure merged lines fully intersect the Otago boundary. If gaps exist, either edit vertices or repeat steps for South Island contours and clip later.
5. Run *Feature to Polygon* on the merged line dataset.
6. Delete the polygon corresponding to the entire Otago boundary, retaining only 1000 m elevation bands.
7. Repeat steps 2–6 for Elevation = 500 m to generate the 500 m polygons.

### Output

Two polygon layers representing land elevation (Fig. 2B).

- HC\_Elev\_1000.shp (land  $> 1000$  m)
- HC\_Elev\_500\_1000.shp (land 500-1,000 m)

## 3.3 Land cover

### Data source

Land Resource Information Systems (LRIS) Land Cover Database v5.0.

**Input data**

- Polygon: LCDB\_v5\_Otago.shp

**Processing steps**

1. Add LCDB\_v5\_Otago.shp to the project.
2. Use *Select by Attributes* to isolate hill-country land-cover classes (see Appendix 2 for class codes).
3. Export the selected features to HC\_LandCover.shp.

**Output**

A polygon layer (HC\_LandCover.shp) containing only land covers aligned with hill-country criteria (Fig. 2C).

## 3.4 Land use

**Data source**

2024 Otago Regional Land Use Map (see [10]).

**Input data**

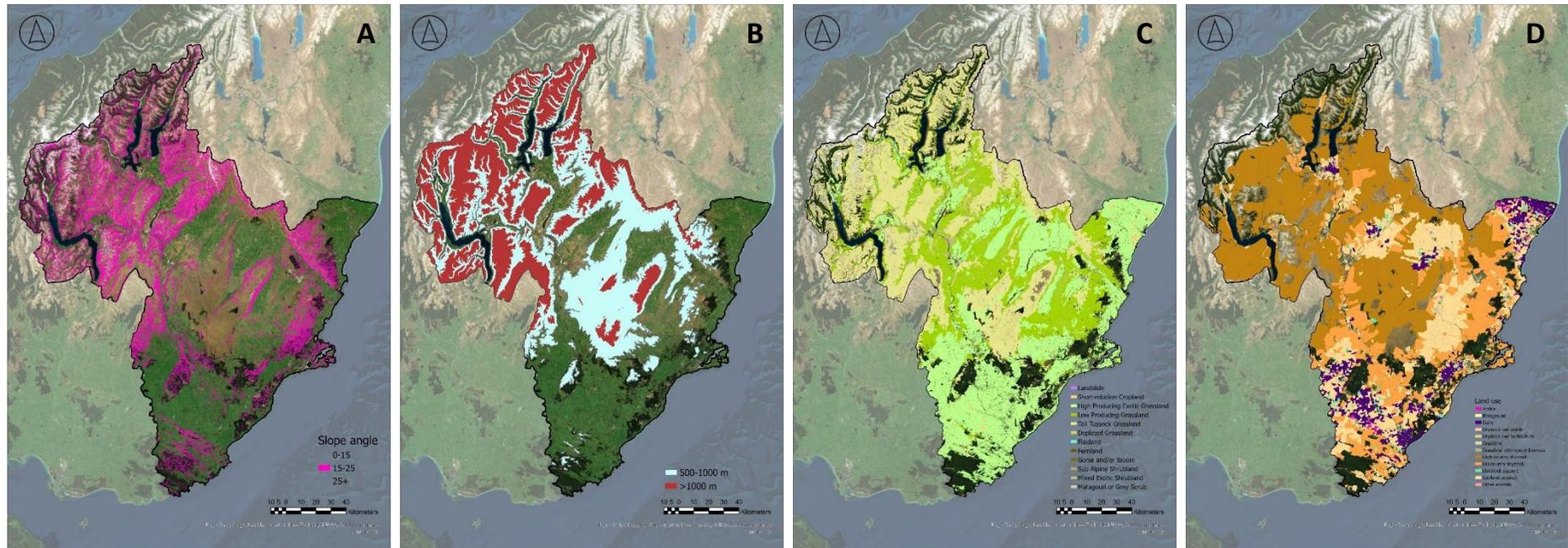
- Polygon: LandUse\_2024\_Otago.shp

**Processing steps**

1. Add LandUse\_2024\_Otago.shp to the project.
2. Use *Select by Attributes* to isolate land-use categories associated with pastoral hill-country farming (see Appendix 3).
3. Export the selection to HC\_LandUse.shp.

**Output**

A polygon layer (HC\_LandUse.shp) containing only relevant hill-country land uses (Fig. 2D).



**Fig. 2** The spatial datasets used to delineate hill country. A) Slope angles between  $>15^\circ$  and  $\leq 25^\circ$ . B) Elevational boundaries of 500-1,000 m and  $>1,000$  m. C) Hill country land covers (LCDB v5.0) that are within the remit of the HCEP aims (see Appendix 2). D) Land uses that are within the remit of the HCEP aims (see Appendix 3).

## 3.5 Hill country area

### Input data

- HC\_Slope\_Polygons.shp
- HC\_Elev\_500.shp and HC\_Elev\_1000.shp
- HC\_LandCover.shp
- HC\_LandUse.shp
- Mitigatable\_land.shp<sup>5</sup> (Appendix 4)

### Processing steps

1. Run *Erase* to remove non-target land covers (HC\_LandCover.shp) and non-target land uses (HC\_LandUse.shp) from HC\_Slope\_Polygons.shp.
2. Run *Multipart to Singlepart* to ensure each polygon is separate.
3. *Dissolve Boundaries* to merge polygons that share a common boundary.
4. Intersect this layer with the Mitigateable\_land.shp to include and clip polygons based on a field that designates whether the mitigation scenario was applied to the polygon.
5. Add a new text field (Mit\_scenario) and populate this with “Yes” or “No” related to whether the polygon was included in the mitigation scenario using the *Field Calculator*.
6. Use *Clip* to split the hill-country polygons by HC\_Elev\_500.shp:
  - Clip A: hill country > 500 m → HC\_High.shp
  - Erase A from original → HC\_Low.shp (< 500 m)
7. Run *Calculate Geometry Attributes* on HC\_High.shp and HC\_Low.shp to recalculate areas (geodesic).

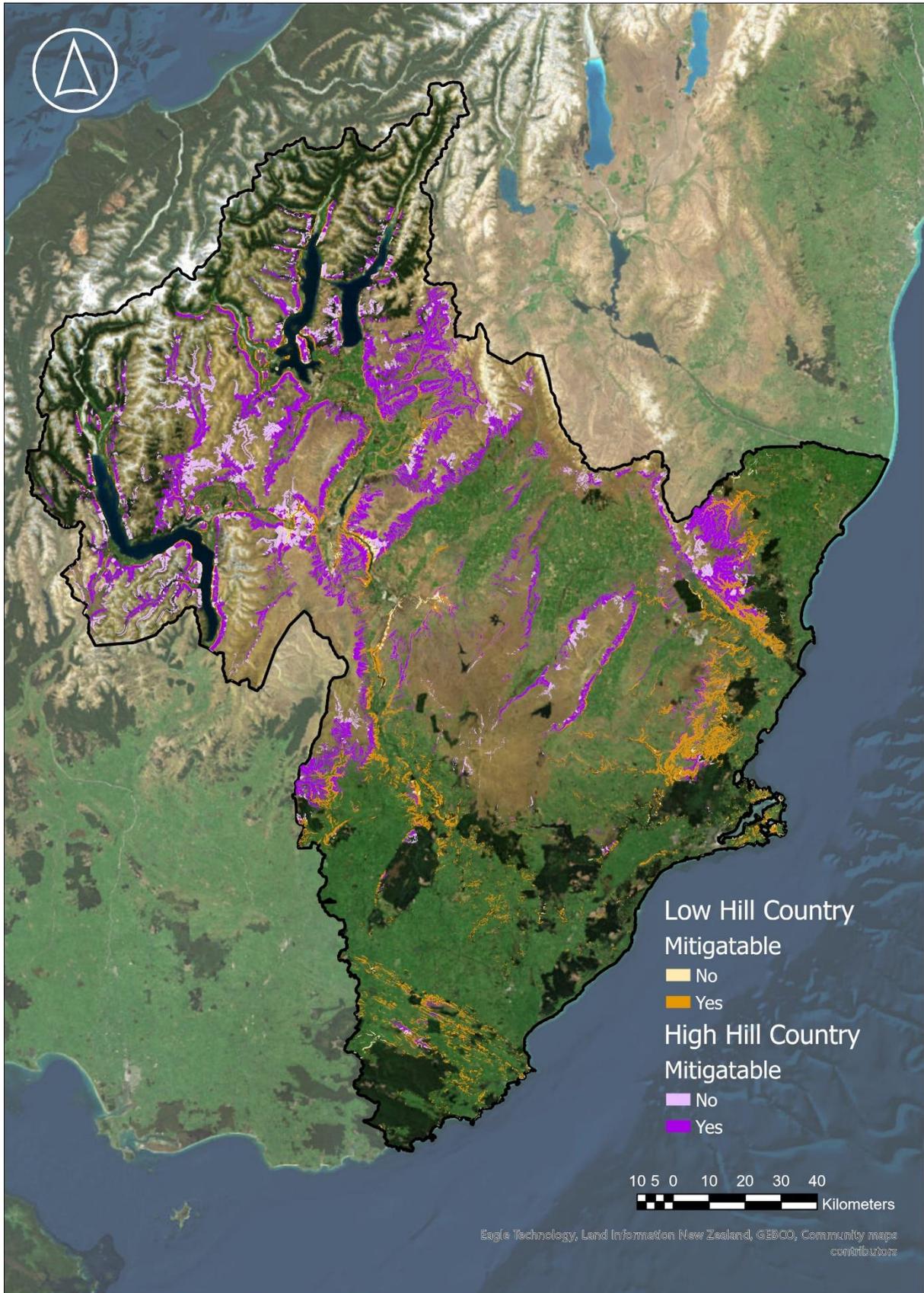
### Output

Two hill country polygon layers of different elevational ranges with differentiation based on whether the mitigation scenario was applied (Fig. 3).

- HC\_Low.shp (< 500 m elevation)
- HC\_High.shp (500–1000 m elevation)

---

<sup>5</sup> This layer represents where the mitigation scenario was or was not applied. Mitigatable land consists of stream segments adjacent to low and high producing pasture, cropland, orchards, vineyards, and perennial crops (LCDB v5) adjacent to major rivers (Appendix 2). This layer can be derived by creating a layer with a column for mitigation scenario (Mit\_scenario) where “No” is applied to areas where the sediment yield differential is equal to 0 and “Yes” where it is >0.



**Fig. 3** Low (<500 m) and High (>500 - <1,000 m) hill country areas in Otago and whether they were considered mitigatable for inclusion in the modelled mitigation scenario.

## 3.6 Sediment data manipulation

### Input data

- Polygon: SedNetNZ modelled sediment yield and yield differential (SedNetNZ.shp)
- Polygon: Low-elevation hill country (HC\_Low.shp)
- Polygon: High-elevation hill country (HC\_High.shp)

### Processing steps

1. *Intersect* the HC\_Low.shp with the SedNetNZ.shp. Ensure that the SedNetNZ.shp polygons are singlepart and that all attributes are selected for the join in the intersection. Where the intersection clips the SedNetNZ polygons, new polygon areas are created.
2. Recalculate the areas of the polygons generated from the *Intersect* using *Calculate Geometry*.
3. Create double-precision fields (Sed\_load and SedDiff\_load) and calculate the sediment load in the *Field Calculator* using the below equation. Repeat this for the sediment yield differential data.

$$\text{Sediment load (t/y)} = \text{Sediment yield (t/km}^2\text{/y)} * \text{Area (km}^2\text{)}$$

4. To calculate the standard deviation of the average sediment yields of the final polygons, to assess the spread of the data summarised in the larger hill country polygons, the area-weighted standard deviation (StDev) of the yield can be derived according to the equation,

$$StDev = \sqrt{\frac{\sum a (y - \bar{y})^2}{\sum a}}$$

where  $\sum a$  is the total area of the summarised polygons,  $y$  is the sediment yield of the original polygons and  $\bar{y}$  is the average sediment yield of the original polygons. As the *Dissolve* step (in 6.) summarises the original polygon data, the derivation needs to be completed in two steps.

The first step is to create double-precision fields (Sed\_yield\_Sq and SedDiff\_yield\_Sq) and calculate the area-weighted sediment squared yield ( $y$ ) in the *Field Calculator* using the below equation. Repeat this for the sediment yield differential data (absolute and relative).

$$y ((t/km^2/y)^2) = (\text{Sediment yield (t/km}^2\text{/y)})^2 * \text{Area (km}^2\text{)}$$

The second step must be completed after the *Dissolve* tool.

5. Summarise the SedNetNZ weighted loads by summing the polygons using *Dissolve* and entering the ID for by the HC\_Low.shp polygons that the SedNetNZ layer will be dissolved into as the dissolve field. Add the area, sediment loads (Sed\_load and SedDiff\_load) and the yield squared (Sed\_yield\_Sq, SedDiff\_yield\_Sq, SedDiff\_Prcn\_Sq) as statistical fields to be summarised as 'Sum'. Add OBJECTID with a 'Count' to get the number of polygons that are summarised from the *Dissolve*, to know how many original polygons the final ones are summarising. This creates new fields adding "SUM\_" to the summarised fields.

6. Create double-precision fields<sup>6</sup> (Sed\_yield\_average; SedDiff\_yield\_average\_per, and SedDiff\_yield\_average) and use *Calculate Field* to calculate the average sediment yield (t/km<sup>2</sup>/y) or  $\bar{y}$  for the new polygon extent using the below equation in the expression box. Repeat this for SUM\_SedDiff\_load.

$$\text{Average sediment yield (t/km}^2\text{/y)} = \frac{\sum \text{Sediment load (t/y)}}{\sum \text{Area (km}^2\text{)}}$$

7. Create a double-precision field (SedDiff\_per) to convert the sediment yield differential ( $\Delta$ ) from absolute (t/km<sup>2</sup>/y) to relative (%) values in the Field Calculator using the below equation.

$$\text{Sediment yield } \Delta \text{ (\%)} = \frac{\text{Sediment yield } \Delta \text{ (t/km}^2\text{/y)}}{\text{Sediment yield (t/km}^2\text{/y)}} * 100$$

8. The second step to calculating the standard deviation of the sediment yield is to create double-precision fields (Sed\_yield\_stdev and SedDiff\_yield\_stdev) and use *Calculate Field* to derive the standard deviation following the second part of the equation

$$\text{Sediment yield standard deviation (t/km}^2\text{/y)} = \sqrt{\frac{\sum y ((\text{t/km}^2\text{/y})^2)}{\sum \text{Area (km}^2\text{)}} - (\bar{y} (\text{t/km}^2\text{/y}))^2}$$

To do this, enter the following expression into the *Field calculator*

`math.sqrt(max((!SUM_Sed_yield_Sq! / !SUM_area!) - (!Sed_yield_average! ** 2), 0))` in the expression. This ensures the calculation executes as the square root of any negative variances, that may exist from floating-point rounding, cannot be derived. This ensures any variance <0 is assigned a '0' standard deviation. Repeat this for the other squared yields.

9. Calculate the quartiles of the three fields (Sed\_yield\_average and SedDiff\_yield\_average\_per and SedDiff\_yield\_average\_per) to be able to classify them in a three-tiered classification. To do this, open the Python window and enter the below, adjusting the file location and field names. Repeat for each of the fields. Note these numbers for the next steps.

```
# import the necessary modules
import arcpy # arcpy helps you access GIS data (e.g., your shapefile).
import numpy as np # numpy provides the percentile() function to compute
percentiles.

# Step 1: Define the path to your shapefile and field name for which the
percentiles are calculated
shapefile_path = r"path_to_file" # change
field_name = "field_name" # change

# Step 2: Extract the field values from the shapefile, filtering out
None values
```

<sup>6</sup> Use the *Add Fields* tool to add all required fields in one step.

```

values = []
with arcpy.da.SearchCursor(shapefile_path, [field_name]) as cursor:
    for row in cursor:
        if row[0] is not None:
            values.append(row[0])

# Step 3: Convert collected values to a NumPy array
data_array = np.array(values)

# Step 4: Calculate the desired percentiles: 25th, 33.3th, 50th, 66.6th,
75th
p25 = np.percentile(data_array, 25) # 25th percentile
p33 = np.percentile(data_array, 33.3333333333) # 33.3th
p50 = np.percentile(data_array, 50) # 50th percentile
p66 = np.percentile(data_array, 66.6666666666) # 66.6th percentile
p75 = np.percentile(data_array, 75) # 75th percentile

# Step 5: Print the results
print("25th percentile:", p25)
print("33.3th percentile:", p33)
print("50th percentile:", p50)
print("66.6th percentile:", p66)
print("75th percentile:", p75)

```

1. Create a double-precision field (Sed\_class, SedDiff\_rel\_class, and SedDiff\_abs\_class) and classify fields based on the quartiles. In *Calculate Field*, set the expression `classify_bin(!Sed_yield_average!)` and in the code block enter the below with the percentiles from the previous step. Repeat this step for SedDiff\_yield\_average\_per and SedDiff\_yield\_average.

```

def classify_bin(value):
    if value is None:
        return None
    if value <= [Enter 33.3rd percentile value]:
        return 1
    elif value <= [Enter 66.6th percentile value]:
        return 2
    else:
        return 3

```

2. Repeat all above steps for HC\_High.shp
3. Add a text field (Hill\_country\_type) and set its value via *Calculate Field*:
  - o For HC\_Low: "Low"
  - o For HC\_High: "High"
4. Merge the two classified layers into HC\_classified\_merged.shp using *Merge*.

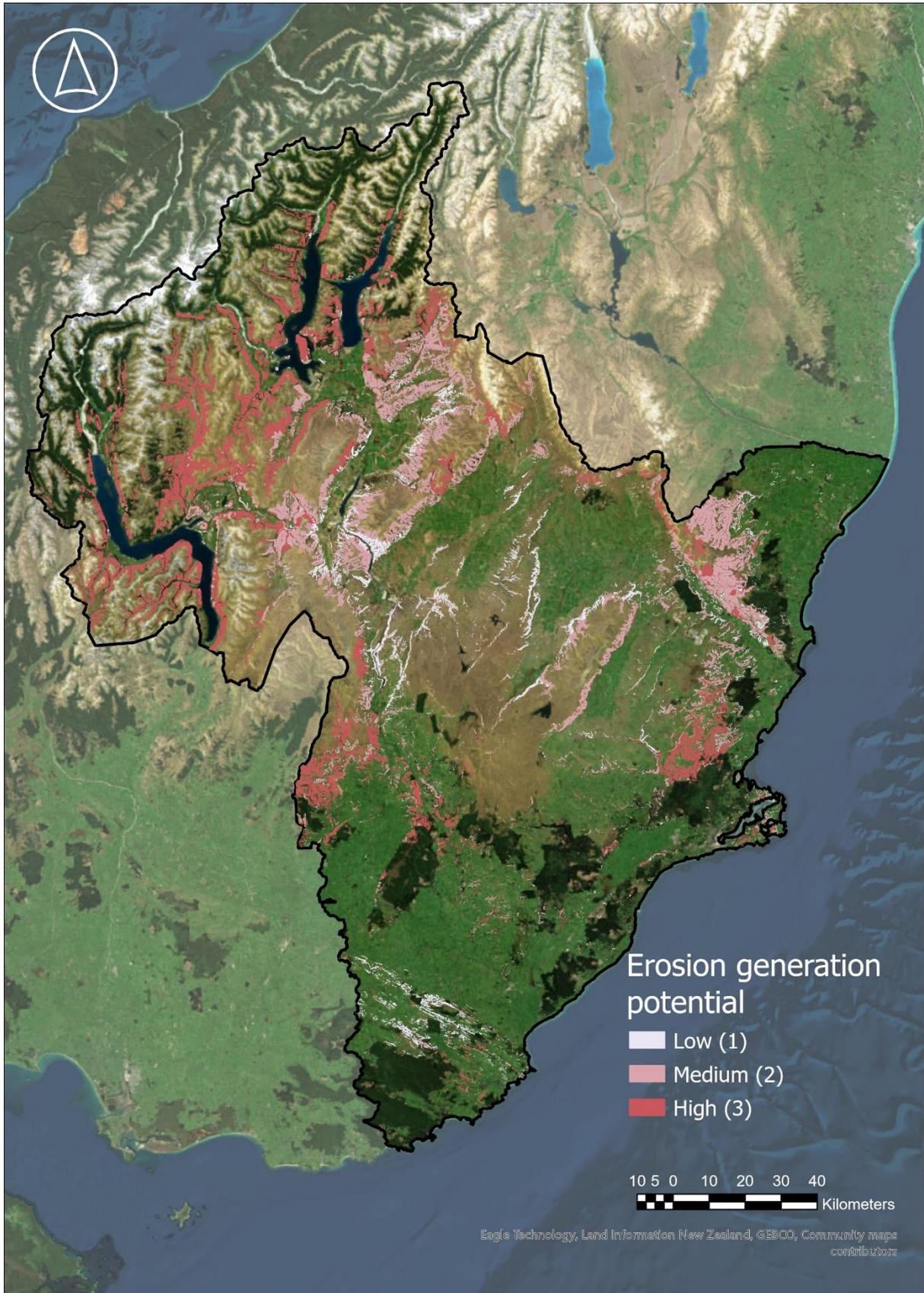
### Output

A single shapefile (HC\_classified\_merged.shp) containing classified average sediment yields (Fig. 4) and relative change in sediment yields with application of the mitigation scenario (Fig. 5) with columns:

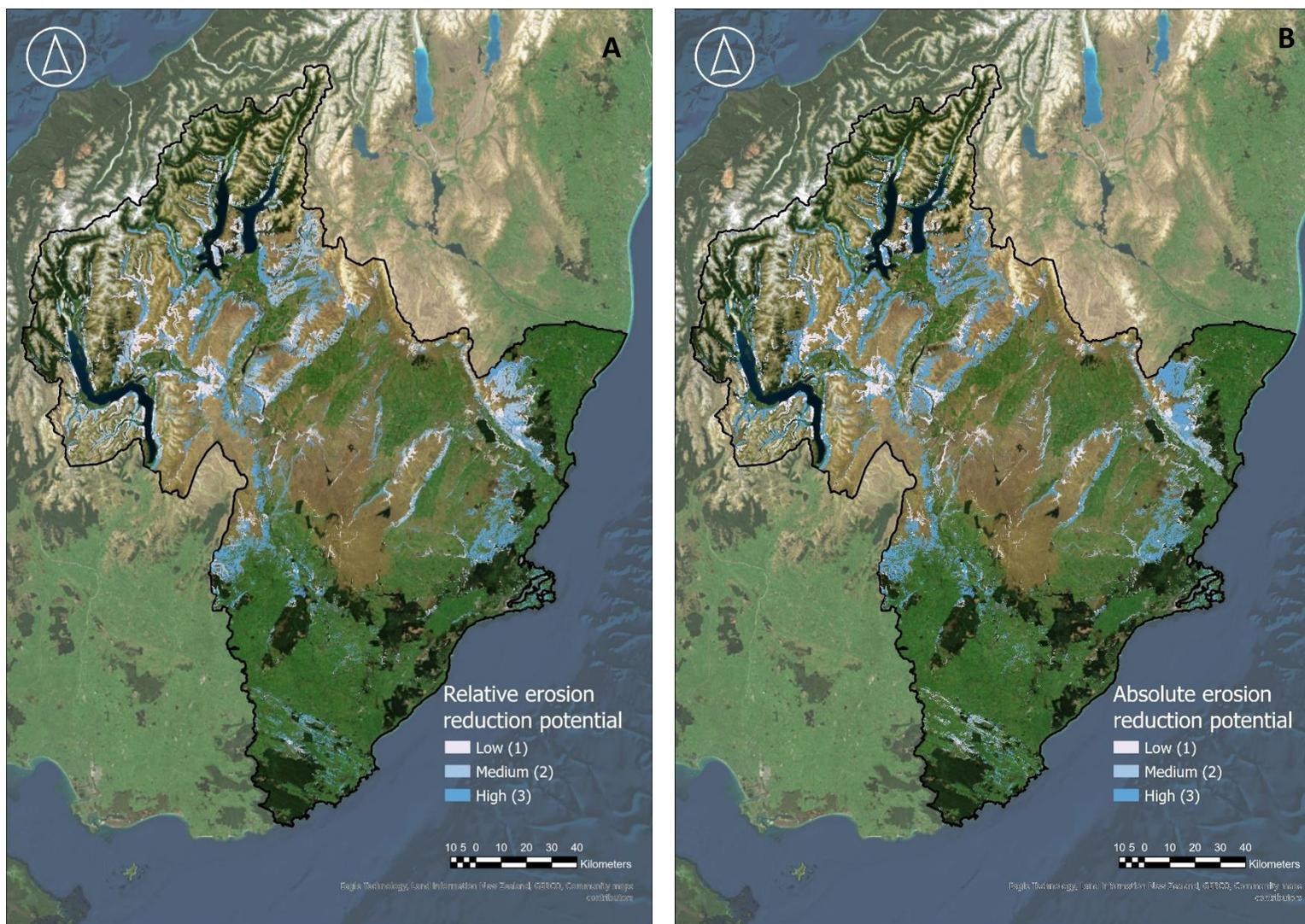
Column name	Units	Description
OBJECTID	NA	Required field to identify individual polygons

Shape	NA	Required field to identify geometry
SUM_Sed_load	$\Sigma t/y$	The sediment load total for the hill country polygons
SUM_SedDiff_load	$\Sigma \Delta t/y$	The sediment differential total for the hill country polygons
SUM_Sed_yield_sqrd	$(t/km^2/y)^2$	Squared sediment yields
SUM_SedDiff_yield_sqrd	$(\Delta t/km^2/y)^2$	Squared absolute sediment yield differentials used for standard deviation derivation
SUM_Sed_yield_per_sqrd	% <sup>2</sup>	Squared relative sediment yield differentials used for standard deviation derivation
Sed_yield_average	$t/km^2/y$	Sediment yields summarised within hill country polygons by average
SedDiff_yield_average	$\Delta t/km^2/y$	Sediment yield differentials summarised within hill country polygons by average
SedDiff_yield_average_per	%	Relative difference between Sed_yield_average and SedDiff_yield_average
Sed_yield_stdev	$t/km^2/y$	Area-weighted variance is the spatial variability of the sediment yield data
SedDiff_yield_stdev	$\Delta t/km^2/y$	Area-weighted variance is the spatial variability of the absolute sediment yield differential data
SedDiff_yield_per_stdev	%	Area-weighted variance is the spatial variability of the relative sediment yield differential data
Sed_class	NA	Quartile classified Sed_yield_average into 3 classes (1–3)
SedDiff_class	NA	Quartile classified SedDiff_yield_average_percentage into 3 classes (1–3)
Count	#	Frequency of polygons summarised within the final polygon
Hill_Country_type	NA	Assigned elevation class of “Low” (0–<500 m) and “High” (500–<1000 m) hill country types
Mit_scenario	NA	Whether the polygon was included in the modelled mitigation scenario (“Yes”) or not (“No”)
Shape_Length	m	Polygon length
Shape_Area	m <sup>2</sup>	Polygon area

See Appendix 5 for figures of standard deviation for the sediment generation (Fig. 6A.A) and reduction potential (Fig. 6A.B; relative, and Fig. 6A.C; absolute).



**Fig. 4** The sediment generation potential classes for Otago hill country based on average estimated sediment yields under current management practices from the SedNetNZ model. The averages were classified separately into three quartile classes for low and high hill country before being combined.



**Fig. 5** The A) relative and B) absolute sediment reduction potential for Otago hill country based on the relative difference between the estimated current management and a stock exclusion scenario sediment yields from the SedNetNZ model. This difference was classified separately into three quartile classes for low and high hill country before being combined.

## 3.7 Spatial Prioritisation

Symbolise the produced dataset to produce a combined erosion risk and mitigation potential bivariate map.

### Input data

- Polygon: HC\_classified\_merged.shp

### Processing steps

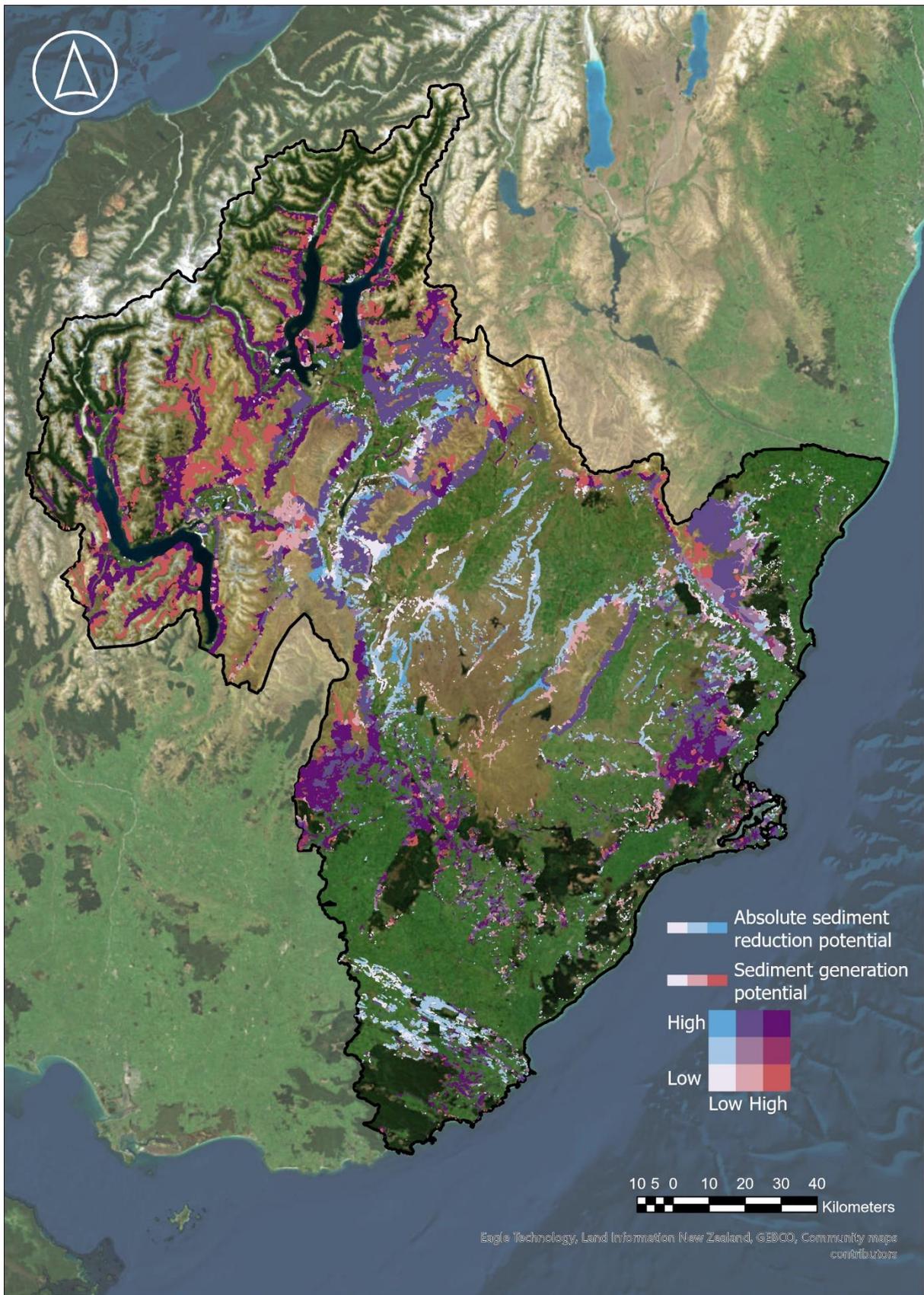
1. Run *Calculate Geometry* to recalculate accurate areas (geodesic).
2. In the map's symbology, choose **Bivariate Colours**:
  - **Field 1:** SedDiff\_class<sup>7</sup>
  - **Field 2:** Sed\_class
  - Change the default classification method to *Manual* and adjust the histogram breaks to align between class boundaries (e.g. 1.5 and 2.5).
3. By default, the sample size limit for a bivariate symbology is 10,000 per field. This can be adjusted in the advanced symbology to include all samples if there are >10,000 in the dataset.
4. Export the final layer to HC\_SpatialPrioritisation.lyrx.

### Output

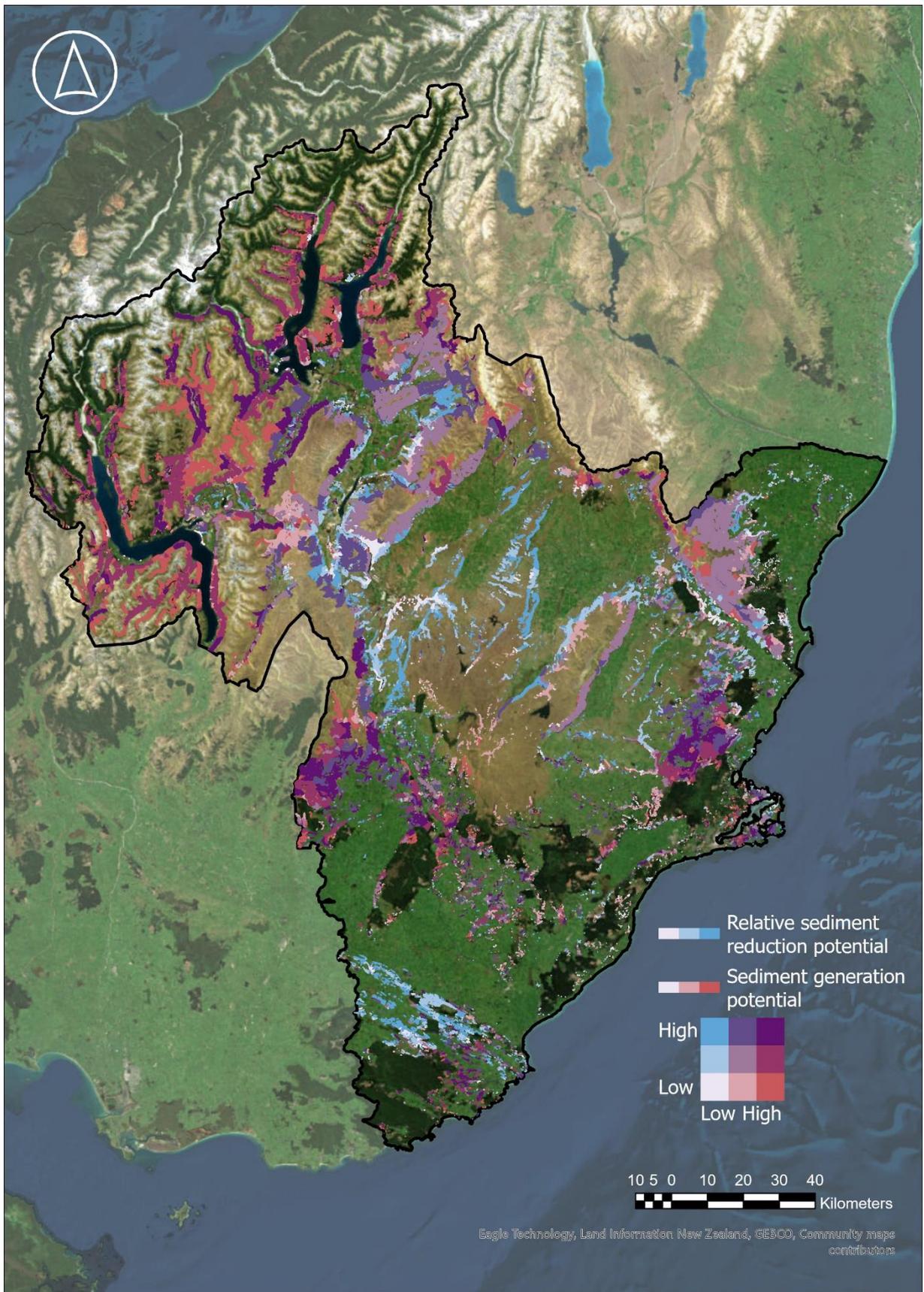
A single layer (HC\_SpatialPrioritisation.lyrx) displaying combined erosion-risk and mitigation-potential classes in a 3×3 bivariate matrix (Fig 6 and 7). The final layer has the same fields as in section 3.6.

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<sup>7</sup> Whether this is the absolute or relative sediment differential yield class depends on the scale that the map is to be applied to. See section 4.2 for more details.



**Fig. 6** Bivariate spatial prioritisation of hill country erosion in Otago. The classes are derived from modelled sediment yield averages, and absolute sediment yield differentials applied to hill country areas defined by spatial criteria.



**Fig. 7** Bivariate spatial prioritisation of hill country erosion in Otago. The classes are derived from modelled sediment yield averages, and relative sediment yield differentials applied to hill country areas defined by spatial criteria.

## 4. Interpretation and Application

### 4.1 Summary of results

A total of 3,761 km<sup>2</sup> was identified as hill country, corresponding to 11.8% of Otago with 3.4% of this low hill country (<500 m) and 8.4% high hill country (500 - <1,000 m; Fig. 3).

The spatial prioritisation produced a nine-level classification, from the interaction of two three-levelled classifications - sediment generation and reduction potential. The resulting spatial prioritisation identifies three general regions within Otago with the highest priority (medium to high sediment generation and medium to high sediment reduction potential). These are, in no particular order, the upper Pomahaka and the hills southwest of Roxburgh, the hills North of the Silverpeaks mountain range and the hillslopes of the more productive alpine ranges and valleys (Cardrona, Shotover and Matukituki). In addition, many smaller pockets of priority were identified. In total, 7.5% of Otago is identified as the highest priority for the HCEP.

For more detailed results and statistics, see Appendix 6.

### 4.2 Application and user guidance

The map and its methodology were designed as a decision support tool primarily for the HCEP management team to prioritise where time and funds are best invested for community and/or landowner support and erosion mitigation efforts. The way the outputs should be interpreted depends strongly on the spatial scale of application.

#### Region

The primary intended use of this tool is at a regional scale. As such, it can be used to screen the region and ensure resources are directed towards areas of greatest potential for generating and reducing sediment. On a regional scale, the impact of model uncertainty on interpretation is reduced. While property spatial scales carry great uncertainty, the overall patterns at a regional scale are robust and representative of the relative magnitude of sediment loss across the region. At this scale, the relativity between the absolute reduction potential values is most meaningful as they highlight where intervention will likely have the greatest impact on sediment yield reduction (Fig. 6), without focussing on the absolute values themselves which are uncertain.

#### Catchment / sub-regional

At a catchment or sub-regional scale, the most appropriate use of the tool depends on the size and heterogeneity of the area of interest. Large catchments (e.g. Clutha/Mata-au, Taieri, Manuherekia) can be treated similarly to the regional scale with sediment generation potential still useful for identifying major contributing areas, but with greater attention to the variability of the averages and the distribution of reduction potential within the catchment. In smaller catchments, the absolute values become more abstract and sensitive to local characteristics, and the relative sediment reduction potential may be more informative than strict ranking by absolute yields (Fig. 7). At this scale, the classing can be used in conjunction with management considerations, and local and expert knowledge to identify sub-areas where sediment generation and reduction potential are likely highest.

#### Property

At an individual property scale, only a small number of polygons will typically intersect a given farm or landholding. This focus on such a small sample carries a greater uncertainty. Model inputs are too coarse to have confidence in absolute values. As such, more care is needed in interpreting the classes and the data within each polygon. The number of polygons summarised, and variability of the averages

are important to understand the effect of the summary. A high variability means that estimates represented by the average span a large range, in which a more targeted approach may be necessary to target the highest risk slopes within the summarised polygon. In addition, the relative sediment generation potential averages are of more meaning than the absolute averages due to the uncertainty and abstract nature of the absolute values at this scale.

Even without using the classes, the polygons provide information that can further be contextualised with local and expert field-based knowledge. The identified hill country polygons represent land that is susceptible to erosion due to its slopes, elevation, and land covers and is at risk to erosion due to the activities upon it. While land at higher slopes (>25) and elevation (>1,000 m) is excluded, it is also less likely to be grazed as frequently or as intensely. Therefore, all identified polygons are likely to represent areas where mitigation could be effective. Prioritising between them and any further investigations need to be conducted in conjunction with local and expert knowledge and/or an approach that uses data inputs more appropriate at this scale (e.g. LiDAR-derived slope).

## 4.3 Limitations

### Methodology

The primary limitations of this methodology are the decisions and assumptions made herein, and the data inputs used. The latter is discussed in more detail in the next section.

Whether the extent of hill country delineated reflects reality depends on the definition. The one used was chosen as it aligns with the TAG and the HCEP. It does not include summit, shoulder, foot, or toe slopes where these are <15° or >25°. However, the rural community may consider these features as part of the hill country landscape and may manage them similarly since they are connected. Also, the lower slopes of the high mountains in central and alpine Otago are prominent (Fig. 3) but may not, traditionally, be considered hill country.

This methodology assumes that the NES-FW 2020 stock exclusion sediment yield reduction is meaningful in the context of this HCEP. While stock exclusion is not the primary mitigation approach of the HCEP, which focusses on space planting, land retirement and forestry, it is used as a proxy for the general potential of mitigation to reduce erosion based on the result rather than the method. The yield reduction result is due to the simulated 80% reduction in stream bank erosion and a relative reduction in surficial erosion based on the 3 m buffer width. As mitigation aims to reduce erosion and the contribution of sediment into waterways, this mitigation potential can be meaningful as an indicator of how much change in sediment yield can be achieved with a modification in management. However, this may not realistically represent the success possible from HCEP intervention.

### SedNetNZ Model

The authors list several assumptions and limitations with the SedNetNZ model [22, 21] that are primarily associated with input data. More specific limitations to the prioritisation are discussed below.

### Surficial erosion

Surficial erosion processes are derived with large influence from factors  $K$ , the soil erodibility factor, and  $C$ , the vegetation cover. For Otago,  $K$  was spatially varied using FSL [8, 9] to represent soil parameters [22]. While this dataset is nationally comprehensive, it is not the most accurate available soil data and lacks certain parameters needed, such as soil structure. However, this already is an improvement over the original SedNetNZ, which assumed a constant soil erodibility factor [21]. S-map

surveys are ongoing but current Otago coverage is around a third and predominantly covers the lowlands.

While surficial erosion has been established as the dominant erosion process in Otago [23], mass movement erosion types such as landslides, debris avalanches, debris flows, earthflows and slumping can contribute significant amounts of sediment to waterways. However, these are not included in the SedNetNZ model. Hence, the focus in this prioritisation is on surficial erosion forms and the contribution of these to waterways.

#### Regional coverage

SedNetNZ does not have 100% regional coverage due to the model design associated with REC river segments and catchment alignment with boundaries. Therefore, those areas that drain out of the region or direct to sea do not have sediment yield estimates. These areas are found in proximity to the land boundary of Otago and total 435 km<sup>2</sup> or 0.01% of the Otago region, with the most extensive of these making up part of the Maitai catchment in South Otago and Waitaki catchment (including Awamoko Stream, King Road Creek, Welcome Creek, Aitchison Road Creek) in North Otago (Appendix 7). There are 1,020 polygons in the hill country spatial prioritisation that occur in these areas and are missing estimates as a result. However, these polygons represent 17 and 2 km<sup>2</sup> of the <500 m and 500-1,000 m hill country areas, respectively, corresponding to 0.4% of Otago hill country. In addition, the missing areas are not the known areas with hill country erosion issues. While it is important to be aware of this limitation, it is unlikely to undermine the results of this work as aligned with the aims of the HCEP.

#### Mitigation potential

The data used to represent 'mitigation potential' is based on the expected sediment yield reductions to streams from riparian fencing and is based on data from the Survey of Rural Decision Makers (SRDM) from the year 2017. This means that 1) the dataset sample size is not spatially consistent as survey respondent numbers vary within the region, and 2) any changes in fencing extents that have occurred since 2017 are not captured. In addition, some districts had a low number of respondents to the SRDM and, therefore, the results may not be representative of the true extent of fencing in the district. Despite fencing likely implemented, the authors used a baseline value of zero fencing extent for the Queenstown-Lakes District due to low respondent numbers. This allows the maximum level of fencing to be implemented between the baseline and scenario, which will artificially inflate the yield reduction possible. In addition, the stock exclusion scenario also assumes that the fencing of all river reaches is equally realistic, even where high slope angle and/or remote location would mean the cost of fencing is prohibitive.

#### Data inputs

The FSL is used in the model for *K* in the surficial erosion estimation and could be improved with S-Map data, the country's most up-to-date and accurate soil dataset. However, current regional coverage is only 32% with mapping ongoing and so this would not be possible until more comprehensive cover is achieved. In addition, the Otago-adapted model uses *C* factor based on version 5 of the Land Cover Database (LCDB) which is from 2018. The LCDB v6 is now available. Of more impact, the use of LiDAR data would support improved representation of slopes and erosion processes which are key inputs both to SedNetNZ estimates and the delineation of hill country herein. The hill country area extent and SedNetNZ could be updated when LiDAR data becomes available for Otago, but this is unlikely to be possible for a few more years.

It is recommended that a new version of this prioritisation is created in five year intervals when it has been used and can be improved with user experience and new data.

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## Appendix 1: Previous approaches

In line with objectives 1 and 4, the HCEP manager commissioned e3Scientific Ltd to produce a prioritisation map [6] as an evidence-based tool to prioritise assignment of time and funding to landowners most susceptible to hill country erosion in the region. The report published in July 2024 failed to meet the requirements of the HCEP. A region wide map was not produced and instead, the prioritisation was focussed on the assessed GNS landslide data which only covers a small area of coastal Dunedin. Based on this, two coastal areas (Kilmog and Saddle/Scroggs Hill) were proposed as priority areas.

The reason for the focus on a limited area rather than the region was due to the decision not to use an available erosion model to inform erosion risk. This was primarily because of a limited linear Pearson correlation coefficient between assessed models. This led instead to a reliance on the GNS landslide dataset. This approach is disputed for the following reasons:

- 67% of the GNS landslide datasets is regionally unverified (landslides have 'no information' or are 'not assessed') which forced the authors to focus on areas where verification had taken place. This biases the focus of the regional prioritisation to a limited extent of the region. This conflicts with the aims of the HCEP.
- Models produce estimates that are generally wrong compared to field-based measurements, however, the numbers are not as important as the spatial relativity of the estimates in the context of generating a regional spatial prioritisation. For example, if one model consistently overestimates it will yield a low Pearson correlation coefficient even if both models rank areas similarly.
- The authors performed Pearson correlations to measure the strength and direction of linear relationships between four models in total, suggesting general agreement between >1 model is needed to choose the most accurate model. However, the relationship between models may not be linear and this logic infers that correlation is equal to accuracy. This is unlikely to be true as the relationship between models is likely driven more by the similarity in the model design. This is supported by the NZeem and NZeem/RUSLE models having the highest correlation ( $r = 0.46$ ) in their analysis, which is based on a similar erosion estimation approach and not evidence of superior model performance or mutual validation.
- Low or high mutual correlation does not establish which model is closer to the true erosion values. Without an independent standard, correlation simply shows divergence, not which divergence is more accurate.

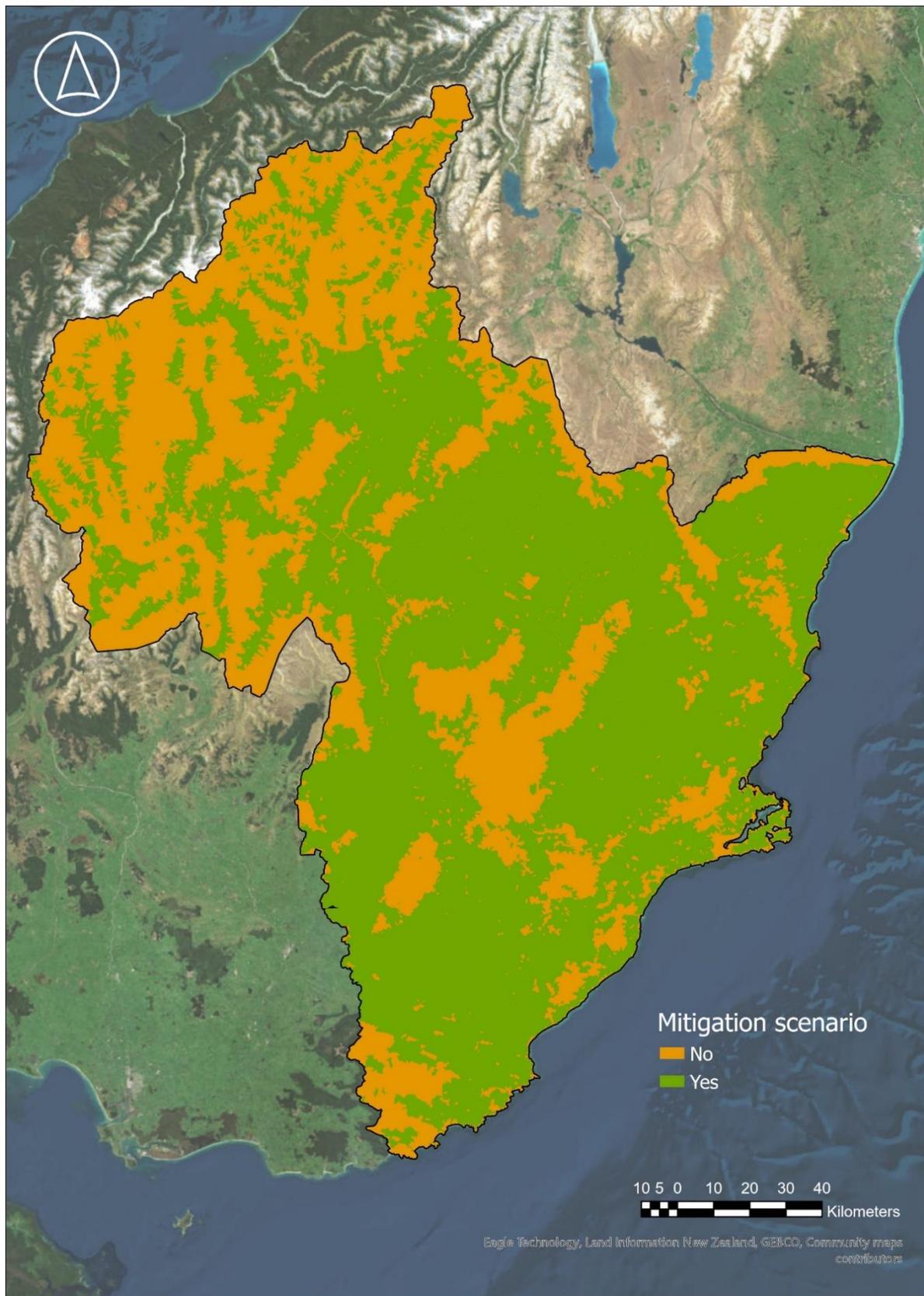
## Appendix 2: LCDB category inclusion list

LCDB5 Land cover names (Name_2018)	Included in hill country definition	Justification	Included in SedNetNZ scenario modelling
Built up	✗	Not pastoral land	✗
Urban Park	✗	Not pastoral land	✗
Transport Inf	✗	Not pastoral land	✗
Mines & Dumps	✗	Not pastoral land	✗
Sand & Gravel	✗	Not pastoral land	✗
Landslide	✓	Could have been/will be productive pastoral land	✗
Snow & Ice	✗	Alpine zone out of remit	✗
Alpine Grass	✗	Alpine zone out of remit	✗
Gravel & Rock	✗	Not pastoral land	✗
Lake & Pond	✗	Not pastoral land	✗
River	✗	Not pastoral land	✗
Estuarine	✗	Not pastoral land	✗
Cropland	✓	Can be part of productive pastoral land	✓
Orchard & Vineyard	✗	Non-pastoral	✓
High Producing Grassland	✓	Productive pastoral land	✓
Low Producing Grassland	✓	Productive pastoral land	✓
Tussock Grassland	✓	Potentially productive pastoral land	✗
Depleted Grassland	✓	Potentially productive pastoral land	✗
Herbaceous Freshwater	✗	Not pastoral land	✗
Herbaceous Saline	✗	Not pastoral land	✗
Flaxland	✓	Potentially within productive land	✗
Fernland	✓	Potentially within productive land	✗
Gorse & Broom	✓	Potentially within productive land	✗
Manuka & Kanuka	✗	Not pastoral land	✗
Broadleaved Indig	✗	Not pastoral land	✗
Sub Alpine Shrubland	✓	Potentially within productive land	✗
Mixed Exotic Shrubland	✓	Potentially within productive land	✗
Matagouri or Grey Scrub	✓	Potentially within productive land	✗
Forest Harvested	✗	Forestry out of remit	✗
Deciduous Hardwood	✗	Not pastoral land	✗
Indigenous Forest	✗	Not pastoral land	✗
Exotic Forest	✗	Forestry out of remit	✗

## Appendix 3: Land use category inclusion list

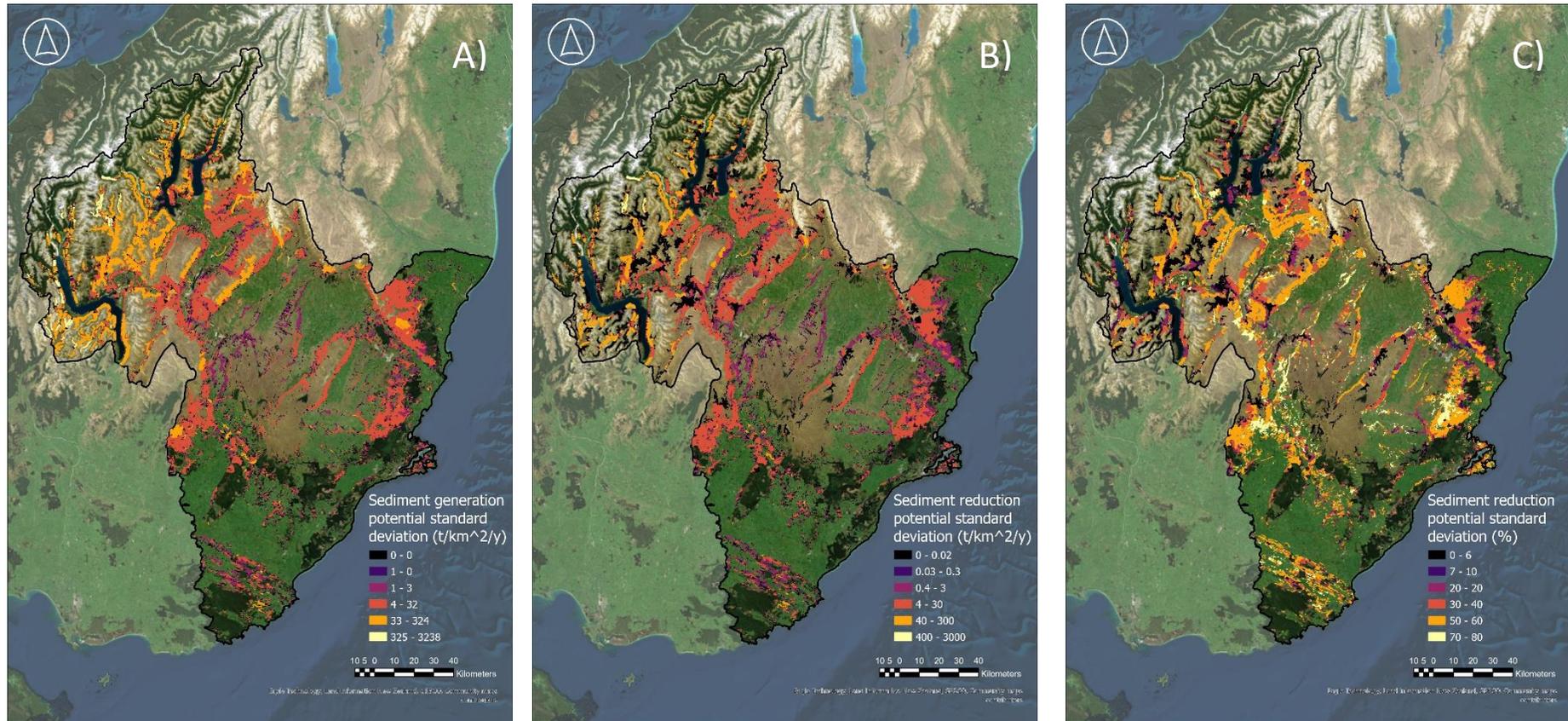
Land Use	Inclusion?	Justification
Arable	✓	May be or become pastoral land
Bareground	✓	Pastoral land
Commercial Forestry	✗	Not pastoral land
Conservation	✗	Non-productive land
Dairy	✓	Pastoral land
Drystock and arable	✓	At least partially pastoral land
Drystock and horticulture	✓	At least partially pastoral land
Exotic forest	✗	Not pastoral land
Grassland	✓	May be or become pastoral land
Grassland with woody biomass	✗	Non-productive land
High country drystock	✓	Potential pastoral land
Hill country drystock	✓	Pastoral land
Horticulture	✓	Pastoral land
Lifestyle	✓	Pastoral land
Livestock support	✓	Pastoral land
Lowland drystock	✓	Pastoral land
Mineral extraction	✗	Not pastoral land
Natural forest and shrubland	✗	Non-productive land
Open water	✗	Not pastoral land
Other animals	✓	Likely pastoral land
Pigs and Poultry	✗	Not pastoral land
Public use	✗	Non-productive land
Railway	✗	Non-productive land
Recreation	✗	Non-productive land
Reserve	✗	Non-productive land
Road	✗	Non-productive land
Rural settlement	✗	Non-productive land
Transport	✗	Non-productive land
Urban	✗	Non-productive land
Utility services	✗	Non-productive land
Wetland	✗	Non-productive land

## Appendix 4: SedNetNZ mitigatable land



**Fig. A5** Areas for which the mitigation scenario was applied. The mitigatable land is based on stream segments adjacent to low and high producing pasture, cropland, orchards, vineyards, and perennial crops, as classified by LCDB version 5 for 2018.

## Appendix 5: Standard deviation



**Fig. A6** The standard deviation for the A) sediment generation potential; B) absolute sediment reduction potential, and C) relative sediment reduction potential.

## Appendix 6: Summary statistics

The delineation of hill country by the criteria used in Table 1 produced a regional area of 3,761 km<sup>2</sup> which corresponds to 11.8% of Otago with 3.4% of this low hill country (1,089 km<sup>2</sup>; <500 m) and 8.4% high hill country (2,672 km<sup>2</sup>; 500 - <1,000 m; Fig. 3).

Hill country sediment yields and the classes that represent them are greater in the high hill country compared to the low hill country (Table A1 and A2). This demonstrates the prioritisation effect that classing the lower elevation hill country separately before combining the dataset has on the final spatial prioritisation – i.e. lower yielding low elevation hill country areas share the same classes as higher yielding high elevation hill country.

**Table A1.** The average ranges, total area-weighted average and area for the classes within low and high hill country for the sediment generation and relative and absolute sediment reduction potentials.

Hill country type	Class	Range	Average	Area (km <sup>2</sup> )
		Average sediment generation (t/km <sup>2</sup> /y)		
Low	1	0.1-12.5	8.3	270.7
	2	12.5-25.0	18.0	352.0
	3	25.0-19,125.5	75.2	466.3
High	1	0.1-17.3	11.5	278.5
	2	17.3-50.1	32.1	1,074.5
	3	50.1-9,189.1	184.9	1,319.1
Average relative sediment reduction (%)				
Low	1	0.0-17.9	5.2	222.3
	2	17.9-45.4	32.0	475.4
	3	45.4-79.9	54.7	391.2
High	1	0.0-0.03	0.0001	691.6
	2	0.0-39.6	26.7	1,133.1
	3	39.6-78.2	47.8	847.4
Average absolute sediment reduction (Δ t/km <sup>2</sup> /y)				
Low	1	0.0-2.2	0.7	202.2
	2	2.2-7.0	4.4	379.3
	3	7.0-3,157.7	25.9	507.5
High	1	0.0-0.0	0.0	691.2
	2	0.0-6.4	3.9	303.1
	3	6.4-3,765.5	34.1	1,677.9

Conversely, this same effect caused a slightly higher classification of the relative sediment reduction potential averages in the high hill country due to their being lower compared to the low hill country dataset (Table A1). This is due to a higher proportion of low hill country included in the modelled scenario resulting in more estimates >0 (Fig. 3). As higher priority, classes 2 and 3 include polygons that would have been in lower classes had they been classed by the same percentiles as in the low hill country. The high hill country overall relative sediment reduction averages in class 2 and 3 are 18.1% and 13.5% lower than in the low hill country, respectively (Table A1). In the absolute sediment reduction values, only the class 3 average is higher in the high hill country dataset (Table A1). However, in both cases, the ranges in the polygon averages have a high degree of overlap. In addition, as the sediment generation estimates are more directly relevant to the prioritisation compared to the proxy used for sediment reduction potential and the reduced focus of the HCEP on high elevation hill

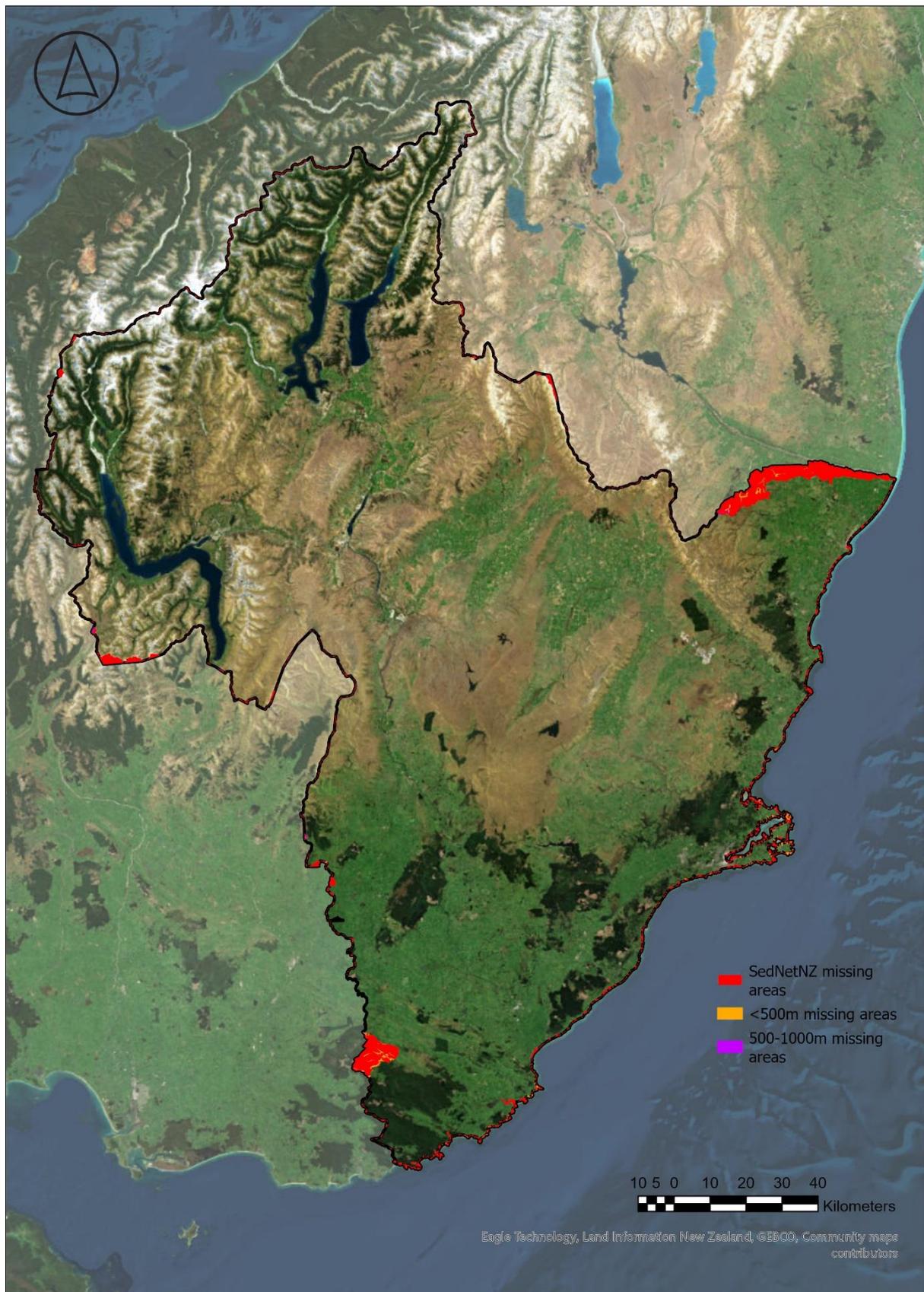
country, this minor prioritisation can be considered to have limited impact on the use of the final output.

Compared to the regional dataset, the extreme end of sediment generation was reduced by the clipping of the dataset to the hill country area. The hill country dataset also displays a greater reduction in sediment yields from the stock exclusion scenario (>50<sup>th</sup> percentile; Table A2).

**Table A2.** Percentiles of the region-wide and hill country sediment generation and reduction potential (relative and absolute) datasets.

Percentiles	Total region	Low hill country (<500 m)	High hill country (500-<1,000 m)	Combined hill country
	Average sediment generation (t/km <sup>2</sup> /y)			
<b>25</b>	9.1	10.2	13.2	11.1
<b>33.3</b>	13.3	12.5	17.3	13.8
<b>50 (median)</b>	27.0	17.6	27.7	20.6
<b>66.6</b>	67.5	25.0	50.1	31.5
<b>75</b>	134.0	31.0	73.8	42.6
Average relative sediment reduction (%)				
<b>25</b>	0.0	9.9	0.0	1.7
<b>33.3</b>	0.0	17.9	0.03	10.6
<b>50 (median)</b>	20.1	32.2	19.0	28.1
<b>66.6</b>	44.5	45.3	39.6	43.5
<b>75</b>	52.3	50.3	46.7	49.2
Average absolute sediment reduction ( $\Delta$ t/km <sup>2</sup> /y)				
<b>25</b>	0.0	1.3	0.0	0.4
<b>33.3</b>	0.0	2.2	0.01	1.6
<b>50 (median)</b>	1.6	4.1	2.9	3.8
<b>66.6</b>	4.9	7.0	6.4	6.9
<b>75</b>	8.4	9.4	9.3	9.3

## Appendix 7: Areas lacking SedNetNZ estimates



**Fig. A4** Areas that lack SedNetNZ sediment estimates with hill country areas overlain.