

A spatial rules-based approach to deriving first-estimate Land Use Capability classes from S-map for New Zealand

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Andrew Manderson, Nathan Odgers, Jing Guo, Ian Lynn, Scott Fraser, Anthony Ward, Kaleb McCollum

Bioeconomy Science Institute Maiangi Taiao

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Reviewed by:

Linda Lilburne
Principal Researcher – Geospatial and Data Science
and Research Priority Area Leader Bioeconomy
Science Institute

Approved for release by:

Sam Carrick
Portfolio Leader – Land Resources & Climate Change
Bioeconomy Science Institute

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Summary

Project and client

The Ministry for the Environment (MfE) contracted the Bioeconomy Science Institute (BSI) to further develop and apply a rules-based model to predict Land Use Capability (LUC) Classes 1–4 from available S-map data.

Objective

The objective was to apply an established spatial rules-based methodology to all available S-map data to produce a nationally consistent, transparent, and repeatable first estimate of LUC Classes 1–4 for New Zealand, and to produce a national estimate of highly productive land (HPL) from resulting LUC classes 1–3.

Methods

- Decision rules and threshold criteria for distinguishing LUC Classes 1–4 from S-map were refined, and separate criteria were developed for modelling organic and mineral soils.
- Input spatial data sets, including S-map, rainfall, LiDAR-dominant Digital Elevation Model (DEM), and calculated slope, were sourced, compiled, standardised, and pre-processed.
- Rules and criteria were coded and implemented within a spatial modelling environment. This involved translating defined rules into a logical decision framework and applying them to input data sets to generate spatially explicit LUC predictions. Outputs also included results for each criterion modelled, to promote transparency and ease of checking.
- Modelling was undertaken using August 2025 S-map data, representing a total modelling area of 11.8 million hectares. This area covers approximately 80% of LUC 1–4 recorded in the NZLRI. Modelled results do not therefore represent an estimate of all potential LUC Class 1–4 land in New Zealand.
- Analyses were performed to identify best data input options for S-map vs. LiDAR-dominant DEM slope, and the best modelling option between modelling the dominant soil sibling, vs. modelling all soil siblings contained within an S-map soil unit.
- Model outputs for Classes 1–4 were evaluated against LUC from the New Zealand Land Resource Inventory (NZLRI), actual high-value land uses from land-cover data, original unpublished 'S-map to LUC' modelling, and expert knowledge. Comparisons were performed in R to test levels of agreement. We discuss if the NZLRI is a suitable comparison dataset.

Results

- The model produced an estimate of 5.07 million hectares of LUC 1–4 land, representing 43% of the total area (Table S1). This is broadly consistent with the 5.18 million hectares (44%) of LUC 1–4 recorded in the NZLRI for the same area footprint.
- Overall model agreement with the NZLRI was moderate, with accuracies of 64.1% by count and 64.8% by area, indicating that approximately two-thirds of compared locations were classified into the same LUC class.
- Model performance improved when LUC 1–3 classes were aggregated as potential HPL. Overall agreement increased to 80.6% (by count) and 82.8% (by area). Total modelled LUC 1–3 area of 3.67 million hectares (31% of total area) is similar to the 3.28 million hectares (28% of total area) of LUC 1–3 recorded in the NZLRI for the same footprint.

Table 1. Modelled and NZLRI LUC 1–4 hectares and percentages for the modelled area.

LUC class	Modelled LUC 1–4		NZLRI LUC 1–4	
	Hectares	% of area	Hectares	% of area**
LUC 1	237,531	2%	146,382	1%
LUC 2	911,242	8%	1,032,991	9%
LUC 3	2,522,752	21%	2,100,343	18%
LUC 4	1,397,454	12%	1,895,699	16%
Other	6,757,439	57%	6,651,003	56%
Total area*	11,826,418		11,826,418	

* Total area is determined by S-map coverage in August 2025 (11.8 million hectares). This area covers approximately 80% of LUC 1–4 recorded in the NZLRI.

** Percentages for each LUC class are calculated using the total area of S-map, and will therefore be different to those that can be calculated using the full NZLRI dataset (which has a total area of 26.6 million hectares).

- Overall agreement within the high value land use footprint was poor at 33.2% by count and 41.9% by area. This comparison was limited to 0.5 million hectares of orchard, vineyards, and cropland identified from national databases.
- DEM-derived slope consistently outperformed S-map slope as a model input, improving overall agreement with the NZLRI by approximately 9% (9.5% by count and 8% by area).
- Model results from both the ‘dominant sibling’ and ‘proportional aggregation of siblings’ methods produced near-identical results.
- New modelling used in this project produced consistently higher agreements with the NZLRI across all metrics when compared with earlier model designs. Overall agreement was improved by 17% and 12% by count and area, respectively.
- Results datasets are available for viewing on Our Environment as [Land Use Capability \(LUC\) Classes 1–4 modelled from S-map](#), or can be downloaded from the [Land Resources Information System \(LRIS\) Portal](#).

Conclusions

- Modelling LUC Classes 1–4 from available S-map has demonstrated that a reproducible, evidence-based approach to land use capability classification is achievable for New Zealand. While agreement can still be improved, the level of agreement achieved for the project is a marked improvement on previous work.
- The modelling produced good to excellent agreement on a tabulated class-area basis, but only moderate agreement in terms of spatial LUC class match. In part this may be explained by differences in scale and the validity of using the NZLRI as a basis for comparison, but equally this project was designed to provide a ‘first estimate’ rather than an NZLRI replacement.
- Project specification relied on a limited set of input data (S-map, elevation, rainfall), largely qualitative criteria from the LUC Survey Handbook, and a rules-based modelling method. There exists a substantial body of new data, technologies, and modelling techniques that collectively have a strong potential to generate improved LUC for New Zealand.
- Results from this project may be satisfactory in a modelling sense, but we are not yet confident that the new data generated are suitable for policy or planning applications without subsequent validation and refinement.

Recommendations

- Regard the model results from this project as a complement to the NZLRI rather than a replacement, with areas of disagreement warranting expert review before application in policy or planning contexts. Further work is recommended, as several opportunities have been identified to improve the framework and the type and quality of input data used. Examples discussed include:
 - Adopting a LiDAR-based DEM derived slope as the default input and investigate methods for more accurately characterising slope within polygons
 - Develop foundational classifications that underpin the conceptual basis of LUC 1-4, especially land use versatility, suitabilities, productivities and vulnerabilities
 - Investigate alternative modelling frameworks
 - Develop a spatially explicit S-map confidence layer
- Understanding what a contemporary LUC classification could and should look like informed by expert practitioners spanning science, land management, policy and planning would help triage priority areas moving forward. Such agreement and clear articulation would help inform a national investment plan for a contemporary LUC classification that meets current and future policy needs.
- Continue to support the modernisation of the Land Use Capability (LUC) system and the highest-value components of the New Zealand Land Resource Inventory (NZLRI), building on the existing framework rather than replacing it. Recent reviews have consistently identified the principal limitation as the age and quality of the underlying NZLRI data, rather than deficiencies in the LUC classification itself. Maintaining a single, nationally consistent classification framework promotes standardisation, supports existing legislative and regulatory processes, and avoids the costs, duplication of effort, and implementation risks associated with alternative or fragmented regional systems.
- This project has demonstrated that a reproducible, transparent, and evidence-based approach to land capability classification is achievable using contemporary data and digital methods. However, New Zealand has yet to fully realise the potential of integrating emerging datasets, technologies, and modelling approaches to improve the accuracy, spatial resolution, versatility, and scope of LUC assessments. Continued support with clear direction will help ensure the LUC system can quickly evolve into the robust and fit-for-purpose decision-support framework that is needed for meeting the increasingly diverse demands of land-use planning, environmental management, and regulation within New Zealand's emerging spatial planning environment.

1 Introduction

The National Policy Statement for Highly Productive Land (NPS-HPL¹) came into effect on 17 October 2022 and establishes national direction to protect highly productive land (HPL), particularly from further loss to urban expansion and rural-residential development. The NPS-HPL seeks to safeguard HPL for land-based primary production, both now and for future generations, by limiting further loss to urban expansion, rural-residential subdivision, and fragmentation (MfE & MPI 2025). This reflects the growing importance of ensuring that New Zealand retains sufficient land capable of supporting domestic food production, supports export-based primary industries, and enhances the long-term resilience of rural communities and regional economies.

A key requirement of the NPS-HPL is that regional councils identify and map HPL, and notify this mapping through proposed regional policy statements. HPL requirements for councils to notify HPL maps in regional policy statements until the end of 2027 were paused or suspended to align with the Plan Stop timeframe. The Plan Stop temporarily pauses most council-led planning work until the end of 2027. This means that councils generally cannot start or continue plan changes unless they obtain an exemption. Mapping of HPL is unlikely to qualify as an exemption.

Until regional mapping is completed and operative, a transitional definition of HPL applies, whereby Land Use Capability (LUC) Classes 1, 2, and 3 from the New Zealand Land Resource Inventory (NZLRI) data set are used to represent baseline HPL.²

The NZLRI is a comprehensive national spatial database that maps physical land resources across New Zealand at a 1:50,000 scale. It was originally developed to provide national standards to support the implementation of central government's financial assistance to farmers for erosion control works. The LUC system has been used in New Zealand to help achieve sustainable land development and management on individual farms, in whole catchments, and at the district, region, and the national level since 1952 (NWASCO 1979). It is still widely used for these purposes, and has been promoted to provide information to support the implementation of legislation and policy by regional and local authorities. Its inclusion in the NPS-HPL, Climate Change Response Act and the basis for the ESC system used in the NES-Commercial Forestry has recently been challenged by New Zealand's Parliamentary Commissioner for the Environment (PCE) regarding concerns about data set fitness-for-purpose in a regulatory context, and unclear alignment with modern national data sets and alternative methods of mapping HPL (PCE 2025).

S-map is New Zealand's national digital soil map, and it is being progressively extended across the country, with priority given to areas containing the nation's most capable land. Compared with the soil information available when the NZLRI was originally compiled, S-map provides more detailed and higher-quality soil data, and therefore has potential as a basis for more refined assessments of land-use capability. Soil is also a key factor influencing the classification of higher capability land. As of August 2025, S-map covers 86% of the land currently identified in the NZLRI as LUC 1–3. This expanding coverage provides a strong foundation for improving the evidence base used in HPL identification and regional planning.

¹ For more on the NPS-HPL, see: <https://environment.govt.nz/assets/publications/nps-hpl-2022-amended-december-2025.pdf>

² In this document, 'LUC Classes 1–3', for example, will be abbreviated to LUC 1–3.

Manaaki Whenua – Landcare Research (now integrated with the Bioeconomy Science Institute) have been investigating and developing new analytical methods for LUC classification from S-map (Lynn & Lilburne 2013), with testing and refinement carried out through application in several regions, including Hawke’s Bay (Manderson 2024), Waikato (Manderson 2025), and Manawātū-Whanganui (Manderson et al. 2026 in prep). These applications demonstrate that the method is sufficiently developed to support broader national application, and there is now a strong case for extending it to all available S-map data across all councils.

Applying the model nationally would make better use of the substantial investment already made in developing the method and in expanding S-map coverage, while providing a more consistent and up-to-date evidence base for informing development and implementation of existing and emerging policy relating to land use. A national application would also help maintain alignment with a single LUC classification standard, reduce the risk of inconsistent regional approaches, and improve integration of mapping across council boundaries. As S-map provides more detailed and improved soil information than that used in much of the original NZLRI, extending the modelling to all S-map-covered areas would strengthen the technical basis for LUC application to inform land use decisions and support councils to meet any statutory responsibilities/obligations to use the best available data.

2 Background

2.1 Highly productive land

Highly productive land generally encompasses 'versatile soils' which includes land that is, but not limited to:

- inherently fertile, flat to gently rolling with few physical or climatic limitations for land-based primary production
- capable of supporting a wide variety of cropping, viticulture, berry fruit, pastoralism, tree crops and forestry.

This is similar to ideas of 'high class soils', 'high class land', 'elite soils', 'prime land', and 'highly versatile land' that have been coined in New Zealand policy and planning over the years, all of which collectively seek to describe an intent to protect New Zealand's finite areas of our most inherently versatile land and soils from loss to urban expansion and land fragmentation (Rutledge et al., 2010; Bloomer, 2011; Andrew & Dymond, 2013; Curran-Cournane et al., 2014; Carrick et al., 2020; Curran-Cournane et al., 2023).

2.1.1 Previous protection mechanisms

Productive land was afforded a high degree of protection under the previous Town and Country Planning Act 1953³ and subsequent Amendment in 1973.⁴ Under this Act, land with a high actual or potential value for food production was protected from subdivision and urban development as a

³ T&CPA 1953: <https://www.legislation.govt.nz/act/public/1953/91/en/latest/#LMS1092862>

⁴ T&CP Amendment Act 1977: https://www.nzlii.org/nz/legis/hist_act/tacpa19771977n121320/

matter of *national importance*, with a requirement that protection be recognised and provided for in regional and district schemes and planning (Molloy 1980).

This national level of protection was not carried through to the Resource Management Act 1991 (RMA),⁵ at least not explicitly. While safeguarding the life-supporting capacity of soil is recognised (section 5), this is a high-level objective subject to interpretation by regional and territorial authorities rather than being a matter of national importance or significance. Having regard to any finite characteristics of natural and physical resources is also a consideration under section 7 which is also subject to interpretation. Consequently, the protection of productive land under the RMA has been limited to regions and districts where the protection of high-class soils and highly capable land has been a historically important consideration.

2.1.2 The National Policy Statement for Highly Productive Land

The National Policy Statement for Highly Productive Land 2022 (NPS-HPL) came into force on 17 October 2022 under the RMA. Its objective is to protect New Zealand's HPL for use in land-based primary production, both now and for future generations. The NPS-HPL responds to long-standing concern about the cumulative loss of versatile and productive rural land to urban expansion, rural-lifestyle subdivision, and associated land fragmentation, particularly in areas surrounding major towns and cities, where development pressures are most intense (MfE & MPI 2022).

Until the Resource Management (Consenting and Other System Changes) Amendment Act (RMAA) 2025 brought in changes to pause councils' work on review and change of their RMA plans, the NPS-HPL required every regional council in NZ to map out their areas of highly productive land that forms large and geographically cohesive areas of predominantly LUC class 1, 2, or 3 located within rural or rural production zones. The NZLRI could be used as the source of LUC status, unless a council accepts more detailed mapping that uses LUC classification method (Lynn et al., 2021). In December 2025 timeframes for mapping HPL were extended to align with the RMAA (Consenting and Other System Changes) 'plan stop' to provide time for new direction on highly productive land to be prepared under the new planning system. The 2025 amendments to the NPS-HPL also made it more flexible for urban development to occur on LUC 3 land.⁶

2.1.3 Progress implementing the NPS-HPL

Criteria for mapping HPL is set out in Clause 3.4 of the NPS-HPL, this is accompanied by an implementation guide. However, there is still a degree of flexibility in how councils map HPL in their respective regions. We are aware that several councils have been investigating detailed methodologies for preparing HPL maps, including Hawke's Bay Regional Council, Waikato Regional Council, and Horizons Regional Council. Other councils, such as Auckland Council and Taranaki Regional Council, have indicated building off their own detailed regional LUC datasets as a basis for mapping. In Marlborough District Council, related work has focused on land versatility mapping.

⁵ RMA 1991: <https://www.legislation.govt.nz/act/public/1991/69/en/latest/#DLM230265>

⁶ <https://environment.govt.nz/publications/national-policy-statement-for-highly-productive-land-2/>

Regionally independent HPL mapping represents a highly decentralised approach, which we believe is likely to result in differences between regions in several important respects:

- how HPL is defined,
- the methods used to identify and map it, and
- the resulting quality, accuracy, and defensibility of HPL outputs.

Under such a decentralised approach, it is plausible that land areas with comparable climate, soil, and land capability characteristics could be classified differently simply because different regional methods, assumptions, or data inputs have been applied. In effect, land with the same intrinsic productive potential may receive different HPL classifications depending on where it is located and how it has been mapped.

This level of discretion adopted for mapping HPL under the NPS-HPL differs markedly from the direction adopted by central government for other nationally significant spatial datasets, particularly in natural hazards management under the National Adaptation Framework⁷ and the National Policy Statement for Natural Hazards.⁸ In both cases, government policy has explicitly shifted away from fragmented, locally developed hazard reporting toward nationally coordinated, risk-based mapping systems and shared datasets—most notably through initiatives such as the New Zealand Flood Map and the New Zealand Landslide Database. This national approach promotes consistency, comparability, and transparency across regions—attributes that may also be desirable for HPL identification and protection.

2.2 The New Zealand Land Resource Inventory and Land Use Capability system

The New Zealand Land Resource Inventory (NZLRI) is a set of land resource data and information, initially produced as the key output of the National Land Resource Survey 1973–79 as a series of 330 maps (referred to as ‘worksheets’), representing a national physical inventory of five land resources (Land Resource Inventory or LRI), together with an LUC classification (NWASCO 1979). The LRI is a physical and factual record of the distribution of rock type, soil unit, slope class, erosion type and degree of severity, and vegetation association. LUC is an interpretation of the LRI and other considerations, represented as an eight-class, general-purpose capability classification divided into three hierarchies:

- class (general suitability for arable, pastoral, and forestry land uses)
- subclass (the most limiting factor for land use)
- unit (groups similar LUC classes according to management requirements).

First edition mapping covered the two main islands relatively quickly. Second edition NZLRI mapping was undertaken for several LUC regions after 1979. This included a scale revision from an original 1:63,360 to a metric 1:50,000 scale, and five new regional update and improvement surveys for Northland, Gisborne – East Cape, Marlborough, Wellington, and part of Waikato.

⁷ <https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/adapting-to-climate-change/national-adaptation-framework/>

⁸ <https://environment.govt.nz/acts-and-regulations/legislation/nps-nh/>

Around this time the NZLRI was migrated into a fully digital format as the NZLRI Database, described as New Zealand's first national spatial database.

The NZLRI includes considerable supporting information, including:

- 12 regional LUC extended legends, providing additional information on LRI factors, along with capability information on production potentials and management requirements
- 8 regional bulletins, detailing LRI factors according to LUC units
- well-developed methodologies and guidelines for classifying erosion, vegetation, rock type, and LUC.

The NZLRI is still New Zealand's main source of spatial land resource data and information, and the only source of a national classification of land capability for multiple uses of land. It is recommended in the NPS-HPL as a default source of LUC 1–3 as a basis for identifying HPL in lieu of better data being available. However, the NZLRI is an old data set and has well-known limitations regarding the scale and quality of first-edition mapping, and the method used to derive the soil unit has been particularly contentious. Of the five LRI factors, soil has the most important influence on differentiating LUC 1–4, as these classes tend to occur on similar, easier-to-cultivate land with similar climatic environments.

Manaaki Whenua – Landcare Research (now part of the BSI) has long served as the custodian of the NZLRI and holds responsibility for its ongoing stewardship as a nationally significant database within the Land Resource Information System (LRIS). As custodian, the BSI maintains extensive supporting resources, including unpublished research, technical documentation, and institutional knowledge that are not generally accessible to the wider public. It also plays a central role in the ongoing governance, maintenance, and evolution of the New Zealand LUC system through its support of the Land Use Capability Classification Governance Group (LUCCGG), which brings together representatives from regional councils, central government, industry, and other key end-users.

2.2.1 The Fundamental Soil Layers as a derivative of the NZLRI

The Fundamental Soil Layers (FSL) are derived directly from the NZLRI, although they are frequently mistaken for a separate dataset. They were developed to "meet future user needs for environmental data" (Barringer et al. 1998) by using the NZLRI polygon framework and soil factor information to generate 16 spatial soil property layers. This involved the production of regional soil legends, which were subsequently correlated using the New Zealand Soil Classification (Hewitt 2010), with reference to the National Soils Database and other relevant soil information sources. In most cases each soil property is represented by a small number of predefined classes (typically five), with the representative value assigned as the midpoint of the corresponding class interval.

FSL data suffer from the same limitations as the NZLRI, but also have limitations for contemporary modelling applications due to the class-based nature of the soil information and the limited set of available soil properties (Lilburne & Webb 2022). Consequently, the FSLs are gradually being depreciated as better soil map data become available through greater S-map coverage.

2.2.2 Parliamentary Commissioner for the Environment review

The Parliamentary Commissioner for the Environment (PCE) recently critiqued the use of the NZLRI and LUC in a regulatory context (PCE 2025). They concluded that the current LUC system is no longer sufficiently robust to support modern regulatory decision-making in New Zealand. The LUC system has been widely used since the 1950s and remains a valuable framework for assessing long-term productive potential, but it was originally developed for soil conservation and agricultural land management rather than contemporary environmental regulation. The report notes that the LUC is now embedded within several regulatory instruments, including the NPS-HPL, the Climate Change Response Act, and the Erosion Susceptibility Classification used in forestry regulation, despite never being designed for these purposes.

A key finding was that the NZLRI as the underlying national LUC dataset, is too coarse and outdated for many regulatory applications, particularly at the property scale, where regulatory decisions are often made. The report highlights limitations arising from the age of the data, inconsistencies in mapping quality, and the inability of the NZLRI to reflect contemporary understanding of land resources. Of particular relevance to HPL identification, the Commissioner found poor alignment between the NZLRI-derived LUC classifications and alternative approaches based on S-map digital soil information. In some areas there are substantial differences between the two methods, creating uncertainty about which areas should be regulated as HPL. The report argues that relying solely on the NZLRI-based LUC system where such discrepancies exist is difficult to justify without further validation.

There is a general acceptance that the NZLRI in its current form is outdated, and that we need to examine options for moving towards contemporary, fit-for-purpose data sets and models. The PCE identified S-map as an example of a modern, high-resolution soil information system that offers substantially improved soil data compared with the historical NZLRI. However, the report stopped short of recommending S-map as a complete replacement data input for LUC, noting that further validation and development are required.

2.3 S-map

S-map is New Zealand's national digital soil spatial information system, developed and maintained by Manaaki Whenua – Landcare Research (now BSI), with funding support from central and regional government agencies. It was established to provide a nationally consistent, scientifically robust, modern replacement for legacy soil information systems, particularly the soil component of the NZLRI and related derivative soil datasets such as the Fundamental Soils Layers (Lilburne et al. 2004; Ford 2019; Lilburne & Ross 2025).

S-map is based on the hierarchical New Zealand Soil Classification (NZSC) down to the fifth level. The full system comprises order, suborder (or group), subgroup, family, and sibling (Webb & Lilburne 2011; Hewitt et al. 2010). The top three levels define the profile's characteristics, while individual soil families are defined by unique combinations of NZSC, parent material, rock type, dominant texture, and permeability class. Siblings within families are distinguished as unique combinations of depth-to-rock class, stoniness, land type, drainage, texture (more detailed), functional horizons, and miscellaneous variant information.

Each sibling in the S-map database is populated with field-collected data from observation and measurement (base properties), including depth, depth to slowly permeable layer, rooting depth, rooting barrier, horizon thickness, stoniness, and clay and sand content. Additional soil properties are estimated from modelling, including available water, macroporosity, water retention, bulk

density, pH, and phosphorus retention. S-map also generates soil qualities and classifications such as dairy effluent risk, nitrogen and phosphorus leaching vulnerability, and risk of soil structural damage associated with pugging.

S-map is a geospatial vector database (digital map) at a nominal minimum 1:50,000 scale, which uses polygons as base units to represent and group similar soils and their distribution. Each polygon is tagged with a unique soil map unit (SMU) that can represent single or multi-part polygons (i.e. can represent several polygons that share the same SMU). SMUs are classed as having one or more siblings, with up to a maximum of five siblings per individual SMU.

S-map is currently available for 11.8 million ha of the country (43% of New Zealand's total land area), with a high representation for LUC 1–4 land. For the 6.6 million ha (or 25%) of land classified as LUC 1–4 in the NZLRI, almost 80% (or 5.2 million ha) is currently covered by existing S-map (Figure 1). This only leaves 1.5 million ha of NZLRI LUC 1–4 land not covered by S-map, but this will further decrease with the next upload of S-map data in August 2026.

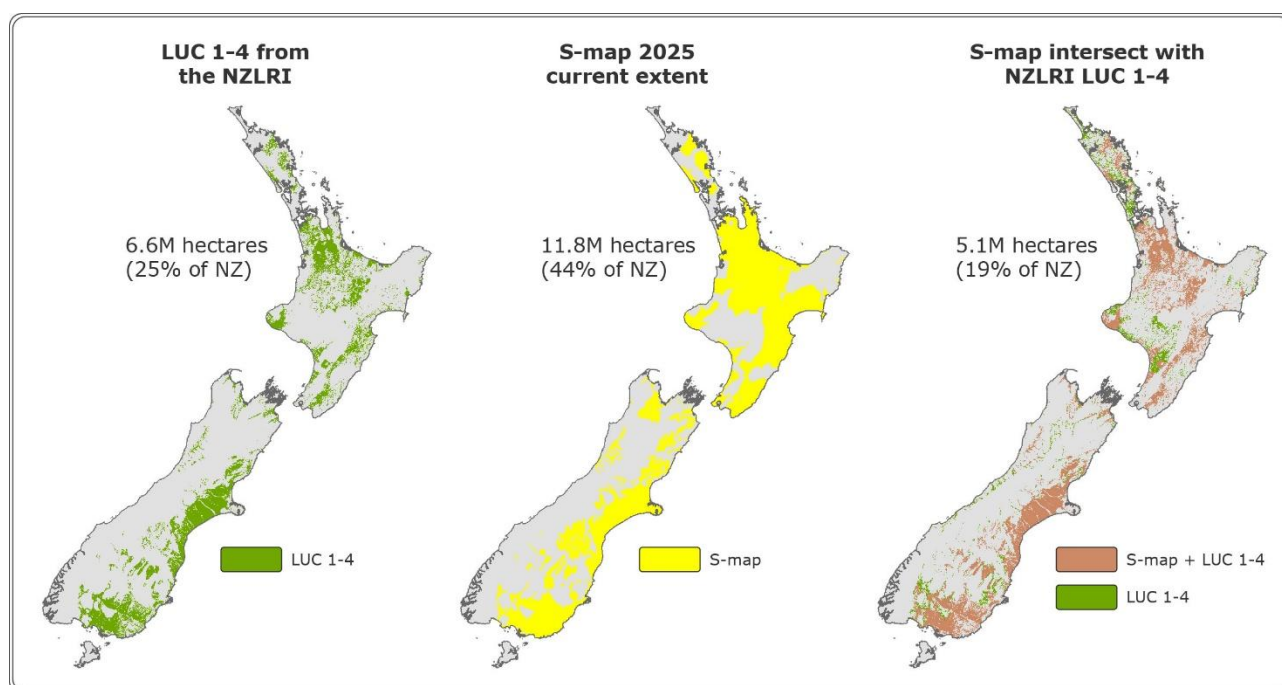


Figure 1. Area of NZLRI LUC 1–4 relative to August 2025 S-map coverage.

Note: S-map data are available for approximately 80% of the NZLRI LUC 1–4 area.

S-map has strong potential for improving New Zealand's LUC classification. Firstly, it represents a much-improved source of soil information relative to what was available to the NZLRI. Much of the historical NZLRI was compiled using soil data and information sourced from previously published surveys (Figure 2). In many areas soil surveys of comparable or finer scale were unavailable, requiring broad interpretations from much coarser-scale work, such as the 1:253,440 scale general soil survey (Soil Bureau 1954, 1968). Consequently, only approximately 18% of the NZLRI is derived from soil surveys undertaken at comparable scales (1:63,360 or finer), while the remaining 82% was based on substantially more generalised information (Manderson et al. 2015).

In contrast, S-map provides finer resolution, spatially explicit soil data that directly describe the physical and functional properties that underpin productive potential, including rooting depth,

drainage, stoniness, texture, and profile-available water. It uses a standardised methodology to ensure soils are classified consistently across regions, reducing variability in interpretation and improving equity in planning decisions. S-map also incorporates explicit measures of uncertainty, and links mapped soil classes to quantitative fundamental and derived soil property layers, allowing LUC to be assessed using a standard and breadth of soil data and qualities that weren't available to the original NZLRI surveyors.

Secondly, soil strongly influences the classification and use of our most productive and capable land (MPI & MfE 2019), and soil characteristics and properties have a strong deciding influence on the classification of LUC 1–4 (Manderson 2025). This is partly because one or more soils with different productive capacities can occur on the same landform, often with the same slope, and cannot be reliably delineated using traditional LRI mapping methods, or even modern digital extraction methods that rely heavily on identifying surface changes. Further, for a given area with the same climate and relief (which represents extensive areas of arable plains across New Zealand), it is the inherent differences in soil characteristics and qualities that will have the greatest influence on differences in land capabilities and productivities, all other variables being equal (i.e. excluding land development, irrigation, fertiliser, etc.).

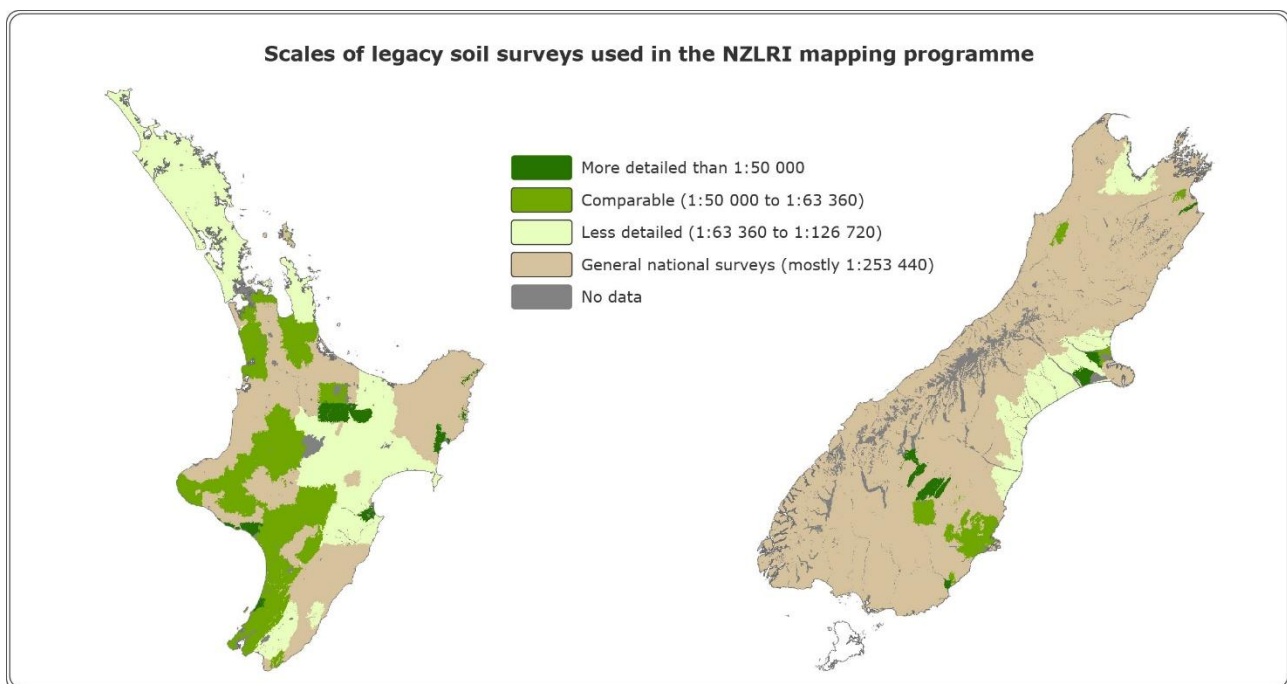


Figure 2. Scales of historical soil surveys used to identify the soil factor used in the NZLRI data set. (Source: adapted from Manderson et al. 2015)

2.4 Previous work

2.4.1 Rules-based classification of LUC Classes 1–4 from S-map soil attributes

Lynn and Lilburne (2013) undertook a scoping study to investigate whether LUC could be derived from S-map data, using the Canterbury Region as a case study. This work was undertaken to support future nutrient management policy development, particularly evaluation of the 'natural capital' approach for setting nitrogen discharge limits. A secondary objective was to modernise Canterbury's outdated LUC mapping using nationally consistent digital soil data.

The method developed used a rules-based modelling approach to translate key soil attributes from S-map into LUC classes. Existing LUC criteria from the LUC handbook (Lynn et al. 2009) were compared with available S-map attributes (discussed further in Section 4.2), and a series of decision rules was developed to assign LUC classes based on factors such as slope, soil depth, texture, drainage, permeability, salinity, and profile-available water. These rules were applied sequentially to Canterbury S-map data, then repeatedly refined through expert review and manual validation to ensure consistent and credible classifications. The approach was designed primarily for flat to rolling land ($<20^\circ$ slope), where S-map data could reliably support class assignment. Non-soil criteria such as elevation and rainfall were not included in the rules.

S-map results for LUC 1 and 2 were later compared against NZLRI LUC 1 and 2 (Lilburne et al. 2020). The differences were significant, which the authors attributed to improvements in S-map data and data collection, and improved knowledge of soil behaviour.

2.4.2 Modelling LUC Classes 1, 2, and 3 from S-map for the Hawke's Bay Region

Manderson (2024) undertook a desktop project to produce a layer of LUC 1–3 and base HPL polygons from the existing S-map coverage of the Hawke's Bay Region. The unpublished method of Lynn and Lilburn (2013) was adapted to accept additional non-soil criteria used in LUC classification, including rainfall and LiDAR-determined elevation and slope. The modelling framework was redesigned to produce individual outputs for each variable to promote quick interrogation and checking.

The results compared favourably with the total area of modelled HPL (186,272 ha or 13.3%) compared with total NZLRI HPL area (175,240 ha or 12.5%), but substantial differences were apparent for individual LUC classes, and the spatial match of modelled HPL compared with NZLRI HPL was only moderate at 42%. The discussion presented reasons why comparison with the NZLRI may not be a robust way of validating S-map model outputs. Results were later combined with high value land use data to produce classes of potential HPL by GIS likelihood to improve the final estimate of HPL. This project also highlighted that LUC and HPL are difficult concepts to validate. Field validation was recommended as the next step.

2.4.3 Modelling LUC Classes 1–3 from S-map for mapping HPL in Waikato

Manderson (2025) refined the approach further to produce a regionally updated LUC map in GIS form for LUC 1–3 to support the regional mapping of Waikato HPL. The method was further refined to model Organic Soils and peaty soils, Gley Soils associated with artificial drainage in Waikato, and new classification criteria specific to Granular Soils. Validation was undertaken by comparison against five alternative data sources.

Strong agreement was observed between modelled S-map LUC and NZLRI LUC, regional definition of high-class soils, and high value land uses. Agreements in the range of 69–89% were achieved for S-map LUC 1 and 2, and 92–95% when LUC was included. Moderate to low agreement was observed for LUC estimated from traditional soil names and expert classification, but there were control problems with this comparison method. In all cases modelled, LUC 3 produced a significantly larger area than was otherwise expected from the other data sources. Stratified field validation was recommended as a possible next step in the development of a regional HPL map.

2.4.4 Upgrading the NZLRI for arable land in the Horizons Region

S-map to LUC modelling has also been applied as a first step in remapping LUC 1–4 in a special upgrade to the NZLRI data set for the Horizons Region to support HPL mapping (Manderson et al. 2026). In this project, S-map data were used to replace dated NZLRI polygons for LUC 1–4, along with additional refinements to map or refine new features, including coastlines, lakes, rivers, quarries, and towns, and boundary remapping from LiDAR for all other LUC 1–4 polygons not replaced with S-map. In total 367,000 ha of new polygons were added or redigitised, and 486,740 ha of additional polygon area was modified, representing NZLRI data improvements for 38% of the region (Figure 3).

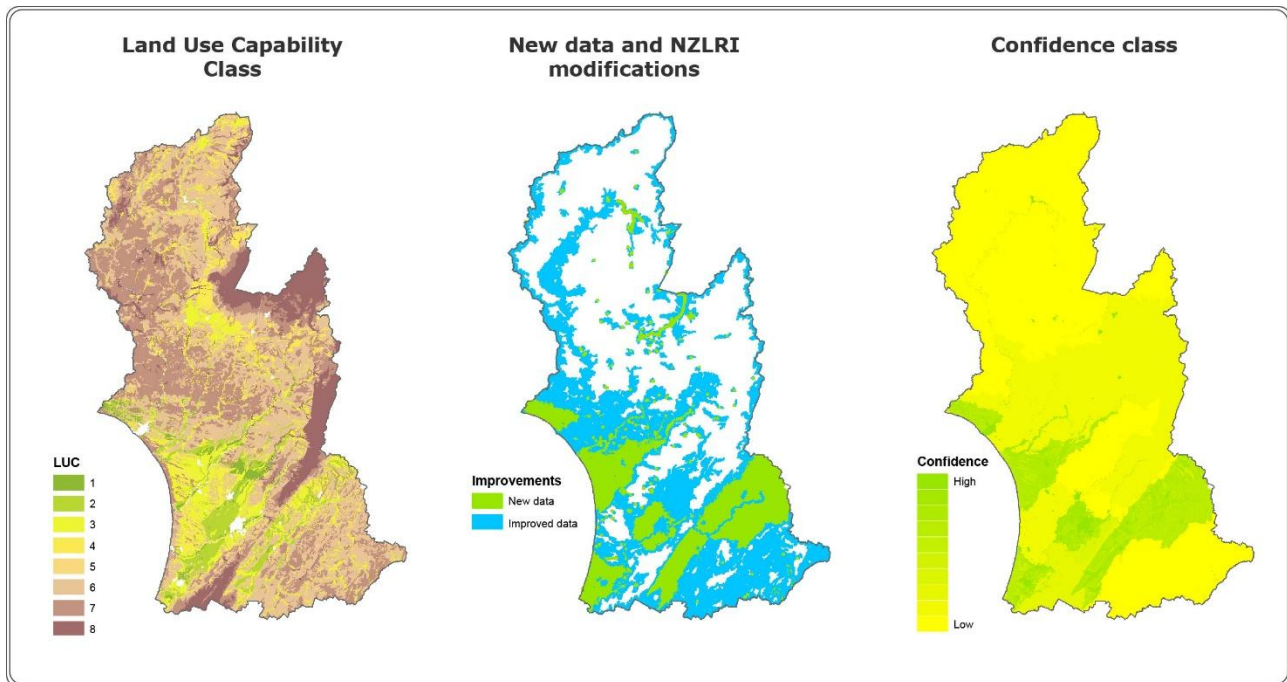


Figure 3. Upgraded LUC for the Horizons Region (left map), new data and improvements to the regional NZLRI layer (middle map), and author confidence (map on the right).

While the model was not subject to further development, and no attempts were made at regional tuning or fitting, the project is notable in that modelling was used as a first step in classifying LUC 1–4, to be followed by refinement using conventional LUC classification methods of S-map, according to Lynn et al. (2021). Also, this method generated two results from the same data, thereby providing a basis for comparison.

For the comparison data set, modelling overestimated HPL area (LUC 1–3) by 18% when compared with the conventional mapping method. LUC 1 was over-predicted by 100% (twice the area) and LUC 2 by 24%, while the difference between modelled and mapped LUC 3 was negligible. When compared with NZLRI LUC 1–3, modelling generated an HPL area 23% higher, while conventional mapping produced an area 4% greater. However, with all methods there were notable differences between individual LUC classes. This is not an uncommon observation when comparing data sets that have different scales: often the total is similar but the component tallies are substantially different (Manderson 2025).

3 Objective

The objective of this project was to apply S-map to LUC spatial-rules methodology across all S-map data available at August 2025 to deliver a nationally consistent, transparent, and repeatable first estimate of LUC Classes 1–4 for New Zealand. This work will implement and build on the methods developed for previous BSI projects to model LUC Classes 1, 2, 3, and 4 using S-map soil attributes and associated spatial rules.

4 Methods

The methods used to model LUC 1–4 from S-map data are largely based on the approach developed by Lynn and Lilburne (2013), and later refined by Manderson (2024, 2025) and Manderson et al. (2026) for regional case studies. The method involves four steps.

- 1 **Development of classification criteria:** Define the decision rules and threshold criteria used to distinguish LUC 1–4, based on the key soil and site attributes available from S-map and their interpretation within the LUC framework. This includes identifying the relevant land-use limitations (e.g. soil stoniness), selecting appropriate input variables, and formalising how combinations of attributes correspond to different LUC classes. Organic Soils have different criteria compared with mineral soils.
- 2 **Data preparation:** Compile, standardise, and pre-process the required spatial data sets for modelling, including S-map soil attributes and any supporting environmental layers. This step includes checking data quality, resolving inconsistencies, deriving additional variables where needed, and structuring the data to ensure compatibility with the rules-based modelling framework.
- 3 **Model development and application:** Implement the classification criteria within a spatial modelling environment to generate predicted LUC 1–4 across available S-map data. This involves translating the defined rules into a logical decision framework, applying them to the input data sets, and producing a spatially explicit model output.
- 4 **Testing and refinement:** Evaluate model outputs against existing LUC information, expert knowledge, and any available validation data to assess their accuracy, consistency, and practical usefulness. Refine the rules, thresholds, and input handling as required to improve model performance and to ensure the outputs are robust and fit for purpose.

4.1 Model development (iterations)

Model development has been performed over two iterations. For the first iteration the model is reconstructed to mirror the original unpublished design of Lynn and Lilburne (2013) as far as possible: this will never be 100% reproducible because the original was developed for implementation alongside the S-map database itself, whereas the work described in this report is undertaken in Geographical Information Systems (GIS) and Python coding environments (Python is a high-level, general-purpose programming language). First-iteration modelling also excludes any regionalisation undertaken by Manderson (2024, 2025, 2026), because tuning for one region may have resulted in distorted results for other regions.

First-iteration modelling was focused on developing a model that can run across all S-map data, with its primary purpose being to provide a confirmed base for second-iteration modelling. Consequently, we do not separately report the criteria and assumptions of first-iteration modelling, expert feedback, or the relatively limited testing undertaken for development purposes. However, first-iteration output layers are available if required.

Second-iteration modelling has accommodated several new developments, drawing from both select regional changes from previous work (carefully applied) and new changes arising from first-iteration modelling. These are discussed in the following sections.

4.2 LUC classification criteria

New Zealand's LUC classification was adapted from the American Land Capability Classification (LCC; Soil Conservation Service 1961) in the early 1950s, and has undergone continued adaptation and development over the decades, initially as a tool for farm planning and catchment control, but later as a basis for the national assessment survey that led to the production of the NZLRI national data set. Guidelines and standards for classifying LUC have been captured and refined over time within the various editions of the LUC survey handbook (Soil Conservation and Rivers Control Council 1969, 1974; Lynn et al. 2009, 2021).

The first step was to extract and review guideline criteria for the target LUC classes from the most recent edition of the LUC handbook (Lynn et al. 2021) and then match these criteria to the closest equivalent S-map attributes. This was a straightforward translation where criteria and data were both quantitative, such as slope. However, many of the handbook's LUC criteria are more qualitative,⁹ and require a degree of interpretation before they can be used with S-map and other modern data sets.

4.2.1 LUC 1 criteria

LUC 1 is the most versatile, high-quality, multiple-use land with negligible physical limitations. It is highly suitable for continuous arable cropping, horticulture, viticulture, pastoral grazing, and forestry without causing soil degradation. Stand-alone criteria are summarised in Table 2.

⁹ LUC handbook criteria are oriented towards traditional methods of field-based observation and mapping, and are thus qualitative. While qualitative mapping frameworks do have strengths (and they still feature prominently in contemporary methods of collecting land, soil, and geology data), in rules-based modelling the preference is for clearly defined criteria with defensible thresholds that can be applied to modern quantitative data sets.

Table 2. Guideline criteria for LUC Class 1 mineral soils

Attribute	Guideline criteria
Slope	Flat to undulating 0 to $\leq 7^\circ$ (NZLRI slope categories A & B)
Soil depth	Deep soils ≥ 100 cm
Soil texture	Fine-textured, notably silt loams and fine sandy loams
Soil drainage	Well drained
Salinity	Nil
Soil erosion risk	Minimal erosion risk (negligible under cultivation)
Stoniness	Not specified
Droughtiness	Not seriously affected by drought
Landform and parent material	Flood plains (larger rivers), tephric and recent loess soils on terraces, some inland frost-free localities with favourable climate
Soil cultivability and resilience	Easily worked and resilient
Soil fertility	Well supplied with plant nutrients and responsive to fertilisers
Climate	Favourable for many crops, incl. pasture and forestry. Climate is non-limiting for yields.
Elevation	South Island: <200 m North Island: <350 m
Rainfall	South Island: 650–1,500 mm North Island: 650–1,500 mm

Seven LUC criteria are readily applicable to Boolean rule development¹⁰ and can be used immediately with existing data sets (Table 3). Slope is available within S-map as classes from two slope classification systems, or it can be calculated from elevation data, while soil depth, texture, salinity, and drainage class are all available from S-map. Rainfall and elevation are available as spatial data surfaces (section 4.3.2).

Other criteria require interpretation or proxies, while a small number would require the development of models that don't yet exist (e.g. soil resilience from S-map). For example, S-map has no data for rock type in the way it is defined in the handbook. To partially accommodate this, we use S-map's profile material class to represent a mix of soil form and soil-forming parent material. Another example is using profile-available water (PAW) as a proxy for droughtiness, while recognising that new and separate modelling would be required to generate a better measure of droughtiness. Rooting depth and permeability are introduced because both can influence limitations in an LUC classification sense, and both contribute to how either families or siblings are defined. Classes from the NZSC are included as a catch-all in cases where the NZSC captures a quality or capability that cannot otherwise be calculated in a modelling approach.

¹⁰ Boolean logic is an approach to modelling where all result values are strictly either true or false. This is discussed more fully in Section 4.4.1.

Table 3. LUC Class 1 attributes and values for modelling mineral soils

S-map attribute*	Source	Value and range
Slope	S-map or slope data	A or B (<7°)
Profile material class	S-map	Stoneless soils, Soils with stones, Tephric soils (Md or Ms or Mt)
Soil depth	S-map	d (>100 cm)
Rooting depth	S-map	≥100 cm
Permeability	S-map	Medium, rapid, medium over rapid, rapid over medium (m or r or m/r or r/m)
Primary texture**	S-map	Loamy or silty (l or z).
Secondary texture**	S-map	Loamy or silty (l or z)
Drainage	S-map	Well or moderately well drained
Topsoil stones	S-map	1 or 2 (<5%)
Salinity	S-map	N (not saline)
Profile available water	S-map	>145 mm
NZSC	S-map	Not M*W or M**W or MO* or MO** or MPT. Not W** and W*** other than WF* and WG
Rainfall	Mean rainfall data	South Island 650–1500 mm, North Island 650–1500 mm
Elevation	Elevation data	South Island < 200 m, North Island < 350 m

* S-map symbology descriptions are included as Appendix 1

** There are exceptions for soils with different functional textures (section 4.2.6).

Definitions and values for S-map attributes are included as Appendix 1. For LUC 1 we have included ‘moderately well drained’, which is outside the Lynn et al. (2021) LUC 1 classification criteria; this is modified because early testing demonstrated this particular criterion to be too restrictive and resulted in far less LUC 1 being predicted. In practice, the presence of minor hydromorphic features that define ‘moderately well drained’ are unlikely to be significantly limiting during the main seasons for growing most crops. The NZSC criteria are used to disqualify certain types of Pumice Soils with known impeded layers, Orthic Pumice Soils with low reserves of nutrients and a droughtiness risk, and some Perch-gley Pumice Soils.

4.2.2 LUC 2 criteria

LUC 2 is very good land with slight physical limitations to arable use that are readily controlled by management and soil conservation practices. It is suitable for many cultivated crops, vineyards, and berry production, along with pasture, tree crops, and production forestry. Criteria for LUC 2 are presented in Tables 4 and 5.

Table 4. Guideline criteria for LUC Class 2 mineral soils

Attribute	Guideline criteria
Slope	Flat to undulating 0 to $\leq 7^\circ$ (NZLRI slope categories A & B)
Soil depth	Deep and moderately deep soils >45–100 cm
Soil texture	Wide range. Loamy and clay textures are less favourable.
Soil drainage	Well, moderately well, and imperfectly drained. Slight wetness after drainage.
Salinity	Nil, very weak to weak salinity
Soil erosion risk	Slight susceptibility to erosion under cultivation
Stoniness	Not specified
Droughtiness	Not specified
Landform and parent material	Mainly alluvium and recent loess, and some fine-textured andesitic and basaltic ash
Soil cultivability and resilience	Slightly difficult to work
Soil fertility	Not specified
Climate	Slight climatic limitations
Elevation	South Island: <400 m; North Island: <500 m
Rainfall	South Island: <1,500 mm; North Island: 800–2,000 mm

Table 5. LUC Class 2 attributes and values for modelling mineral soils

S-map attribute	Source	Value and range*
Slope	S-map or slope data	A or B ($< 7^\circ$)
Profile material class	S-map	Md, Ms, Mt, Mg or Mm
Soil depth	S-map	md or d (>45 cm)
Rooting depth	S-map	>45 cm
Permeability	S-map	m, r, r/m, m/r, m/s
Primary texture**	S-map	l or z or c
Secondary texture**	S-map	l or z or s or c
Drainage**	S-map	w or mw or i
Topsoil stones	S-map	1 or 2 (<5%)
Salinity	S-map	N or W (not saline to weakly saline)
Profile available water	S-map	>120 mm
NZSC	S-map	Not M*W or M**W or MO* or MO** or MPT. Not W** and W*** other than WF* and WG
Rainfall	Mean rainfall data	South Island <1500 mm, North Island 800–2000 mm
Elevation	Elevation data	South Island < 400 m, North Island < 500 m

* S-map symbology descriptions are included as Appendix 1.

** There are exceptions for soils with different functional textures (section 4.2.6) or with artificial drainage potential (section 4.2.7).

4.2.3 LUC 3 criteria

LUC Class 3 has moderate physical limitations to arable use that restrict the choice of crops and the intensity of cultivation and/or necessitate special mitigation practices. Land is suitable for cultivated crops, vineyards, berry fields, pasture, tree crops, and production forestry. Criteria for LUC 3 are presented as Tables 6 and 7.

Table 6. Guideline criteria for LUC Class 3 mineral soils

Attribute	Guideline criteria
Slope	Flat to rolling slopes 0–≤15° (NZLRI slope categories A, B, C)
Soil depth	Deep, moderately deep, and shallow (20–45 cm)
Soil texture	Wide range, clay loam and sandy loam textures are less favourable
Soil drainage	Well, moderately well, and imperfectly drained. Moderate wetness after drainage.
Salinity	Nil, very weak, and weak salinity
Soil erosion risk	Slight to moderate erosion potential under cultivation
Stoniness	Non stony to stony (5–35% in upper 20 cm)
Droughtiness	Low moisture holding capacity
Landform and parent material	Occurs on rolling country, flat pumice country, areas of slow-draining soils, and extensive areas of shallow and stony plains
Soil cultivability and resilience	Often difficult to work
Soil fertility	Low natural fertility
Climate	Moderate climatic limitations
Elevation	South Island < 650 m, North Island < 750 m
Rainfall	South Island <2,400 mm, North Island 800–2,500 mm

Table 7. LUC Class 3 attributes and values for modelling mineral soils

S-map attribute	Source	Value and range*
Slope	S-map or slope data	A, B or C (0–≤15°)
Profile material class	S-map	Md, Ms, Mt, Mg, Mm, MI, Mp, Mr, Ma
Soil depth	S-map	S, md, d (>20 cm)
Rooting depth	S-map	>20 cm
Permeability	S-map	m, r, r/m, m/r, m/s, r/s
Primary texture**	S-map	l, z, c, s
Secondary texture**	S-map	l, z, c, s
Drainage**	S-map	w, mw, i
Topsoil stones	S-map	1 or 2 or 3 (<35%)
Salinity	S-map	N or W (not saline to weakly saline)
Profile available water	S-map	>90 mm
NZSC	S-map	Not MPT, not W** and W*** other than WF* and WG
Rainfall	Mean rainfall data	South Island <2,400 mm, North Island 800–2,500 mm
Elevation	Elevation data	South Island < 650 m, North Island < 750 m

* S-map symbology descriptions are included as Appendix 1.

** There are exceptions for soils with different functional textures (Section 4.2.6) or with artificial drainage potential (section 4.2.7).

4.2.4 LUC 4 criteria

LUC 4 land is suitable for arable, but overall is the least suitable because of severe limitations that reduce the range of crops and/or make intensive mitigations necessary. This land is suitable for occasional cropping, with higher suitability for pasture, tree crops, and forestry. Some LUC 4 land is used for berry fields and vineyards. Criteria for LUC 4 are presented in Tables 8 and 9.

Table 8. Guideline criteria for LUC Class 4 mineral soils

Attribute	Guideline criteria
Slope	Flat to strongly rolling slopes 0 to $\leq 20^\circ$ (NZLRI slope categories A, B, & C)
Soil depth	Deep, moderately deep, shallow, and very shallow (<20 cm)
Soil texture	Wide range, with clay, loamy sand, and sand being least favourable.
Soil drainage	Well, moderately well, imperfectly, poorly drained.
Salinity	Nil, very weak, weak, moderate salinity
Soil erosion risk	Severe erosion risk under cultivation
Stoniness	Non stony to very stony (30–70% in upper 20 cm)
Droughtiness	Very low moisture-holding capacity
Landform and parent material	Occurs on strongly rolling country, and very shallow and/or stony or very stony flats and terraces, shallower stony soils of the river terraces and outwash surfaces where cultivation is marginal, and on flat and rolling land in Central Otago where cropping is limited by low rainfall.
Soil cultivability and resilience	Often difficult to work. Severe structural impediments to cultivation.
Soil fertility	Low fertility difficult to correct (e.g. aluminium toxicity).
Climate	Severe climatic limitations
Elevation	South Island: <800 m; North Island: <1,000 m
Rainfall	South Island: <3,000 mm; North Island: 800–3,000 mm

Table 9. LUC Class 4 attributes and values for modelling mineral soils

S-map attribute	Source	Value and range*
Slope	S-map or slope data	A, B, C, or D (0 to $\leq 20^\circ$)
Profile material class	S-map	Md, Ms, Mt, Mg, Mm, MI, Mp, Mr, Ma
Soil depth	S-map	S, md, d (>20 cm)
Rooting depth	S-map	≥ 15 cm
Permeability	S-map	m, r, r/m, m/r, m/s, r/s, s/m, s/r or s
Primary texture**	S-map	l, z, c, s
Secondary texture**	S-map	l, z, c, s
Drainage**	S-map	w, mw, l, p
Topsoil stones	S-map	1 or 2 or 3 or 4 (>35%)
Salinity	S-map	N or W or M (not saline to moderately saline)
Profile-available water	S-map	>60 mm
Rainfall	Mean rainfall data	South Island: <1,500 mm; North Island: 800–2,000 mm
Elevation	Elevation data	South Island: <400 m; North Island: <500 m

* S-map symbology descriptions are included as Appendix 1.

** There are exceptions for soils with different functional textures (section 4.2.6) or with artificial drainage potential (section 4.2.7).

4.2.5 Organic Soils and soils with peaty topsoil

Organic Soils and soils with a peaty topsoil are treated separately. In the original rule development, the merit of including these soils as actual or potential 'highly productive land' was debated from a social responsibility perspective. From one perspective these soils are either current wetland that was never developed/drained, or former wetlands that have been drained and could perhaps be restored for ecological values. The main question is whether land with high actual or potential ecological value be included as land for high production uses. The debate was not resolved, so a conservative approach was adopted, where Organic Soils were assigned to LUC 5, and peaty Gley Soils were classed as either LUC 3 or 4 according to drainage status.

However, Organic Soils and peaty soils are included in LUC 1 and 2 classifications in the NZLRI (Table 10), and the NPS-HPL definition does not exclude these soils from qualifying as higher capability LUC and HPL. For these reasons, Manderson (2025) reframed the criteria to align better with that used for mineral soils, but with the following changes.

- No criteria for profile material class are used, because Organic Soils and soils with a peaty topsoil include both mineral and organic soil-forming parent materials.
- Peaty texture classes are added to the texture criteria, including clayey peat (Tc), loamy peat (Tl), sandy peat (Ts), and silty peat (Tp).
- It is assumed that the presence of artificial drainage is implied by the depth to an anoxic rooting barrier for Organic Soils. Organic Soils are formed under anoxic conditions associated with a high water-table. Artificial drainage that lowers the regional water-table will thus increase the depth to the anoxic rooting barrier (all things remaining equal). In principle, S-map mapping and field observation will be recording depth to an anoxic root barrier, which will be deeper than it would have been under natural, undrained conditions.
- Drainage class is not used, because all Organic Soils will be very poorly drained (by definition), irrespective of the effects of artificial drainage and lowered water-tables.
- The qualities of a peaty soil will not be too dissimilar from those of mineral soils. The key difference from mineral soils is a peaty topsoil >10 cm thick, or a buried topsoil within 60 cm of the surface (Hewitt 2010). In the final classification, the results for soils with peaty topsoils will take precedence if these soils are also modelled as mineral soils.

Known wetlands are excluded from the analysis on the basis that existing natural wetlands are protected from development under freshwater legislation, although some legislation is subject to review. The method involved calculating the area of Land Cover Database version 6.0 'wetland' (MWLR 2025) that is currently not under production land covers¹¹ and that occurs within S-map polygons. Where non-production cover wetland was >50% of the sibling polygon by area, and the soil qualified as Organic or peaty Gley Soil, the sibling polygon was classed 'Non Ag wetland'. This class over-rides any LUC class classification for Organic Soils and peaty soils in the production of the final layers.

¹¹ Production land covers used include LCDB 6 High Producing Exotic Grassland, Low Producing Grassland, Orchard, Vineyard or Other Perennial Crop, and Short-rotation Cropland.

Table 10. Hectares of NZLRI Organic Soils and soils with peaty topsoils, by LUC class

NZSC	LUC 1	LUC 2	LUC 3	LUC 4	Other LUC
BAO					557,809
ERO					710
GAO		1,995	3,747	977	1,202
GOO		11,042	8,534	6,490	4,742
GRO		2,560	2,533		367
GSO		389	192	587	
NPO			175	6,860	12,254
OFA		19,986	145	2,014	2,403
OFS		7,216	772	1,732	15,204
OHA		5,136	6,143	384	351
OHM	82	9,951	10,687	2,783	18,808
OMA		11,180	15,259	26,003	35,566
OMM		34,135	3,310	1,511	1,153
O?		3,393	3,058	1,589	4,533

Notes: NZ Soil Classification codes with an 'O' prefix are Organic Soils. NZSC codes with an 'O' suffix are soils with a peaty topsoil. Several NZSC codes in the NZLRI include a '?', symbol suggesting an unconfirmed or provisional classification.

4.2.6 Soils with different texture properties

LUC classification uses soil texture as a criterion where loamy and silty textures tend to be associated with higher-capability LUC, and clayey and sandy textures with lower-capability LUC. However, some Allophanic and Granular Soils can be dominated by clay types that influence functional texture and aggregate behaviour and can convey properties that are more commonly encountered in higher-capability soils. An example is Granular Patumahoe clay loam soils, whereby clay-rich texture disqualifies them as being higher-capability soils (according to LUC classification criteria), yet these soils represent some of the most capable vegetable-growing soils in northern Waikato. To accommodate soils with differing functional textures, exception criteria are applied to all Allophanic Soils, Allophanic Orthic Granular Soils (NOL), and Typic Orthic Granular Soils (NOT).

4.2.7 Land development criteria

The LUC classification system recognises that some physical land limitations, such as wetness, stoniness, droughtiness, and flooding risk, can be remedied or mitigated through land development, depending on economic feasibility, the availability of appropriate technology, and relative to the severity of physical limitations or difficulty of modification (Lynn et al. 2021). For example, land can be assessed as having less of a limitation (and thus, a higher capability) where:

- permanent drainage has been installed or is part of an approved drainage scheme
- permanent irrigation has been installed, especially as part of an irrigation scheme
- major community-based flood control schemes for 50–100 years or greater return periods are present
- stone removal by stone picking has removed a significant stoniness limitation.

In this project our ability to include land development is constrained by the type and availability of national data that can be used to evaluate land development implications. We have not yet included flood protection because these data – as far as we are aware – are held by regional and local authorities, and compilation into a national data set would be a large exercise. In time, however, we may be able to access actual or proxy data from the New Zealand Flood Map project, to be published in early 2027 (MfE 2026). Likewise, we have yet to include irrigation, despite the availability of a national irrigated land spatial data set (Dark 2020), because further work is required to establish the longevity of irrigation instalments. We envisage that irrigation within large irrigation schemes and irrigation with long consent periods, particularly in locations where irrigation water is still readily obtainable, will probably qualify as having the necessary degree of permanence. We are not aware of any data set that describes if stone picking has been undertaken.

There are some national data that describe artificial drainage extent, mostly as surface drain networks and some localised subsurface drainage (Manderson & Belliss 2016; Manderson 2018, 2019). Further, the likelihood that land has been artificially drained in New Zealand has been assessed (Manderson 2018), so some insight and national data are available. In particular, we examined where observed drainage networks that are managed as part of drainage schemes coincide with poorly and very poorly drained NZSC soils that are known to respond well to drainage, using both S-map and the NZLRI (Figure 4). From this we identified soils by NZSC that have a high likelihood of being drained. These NZSC soils were then considered against NZLRI LUC 1–4 to develop rule exceptions for soils likely to be artificially drained (Table 11).

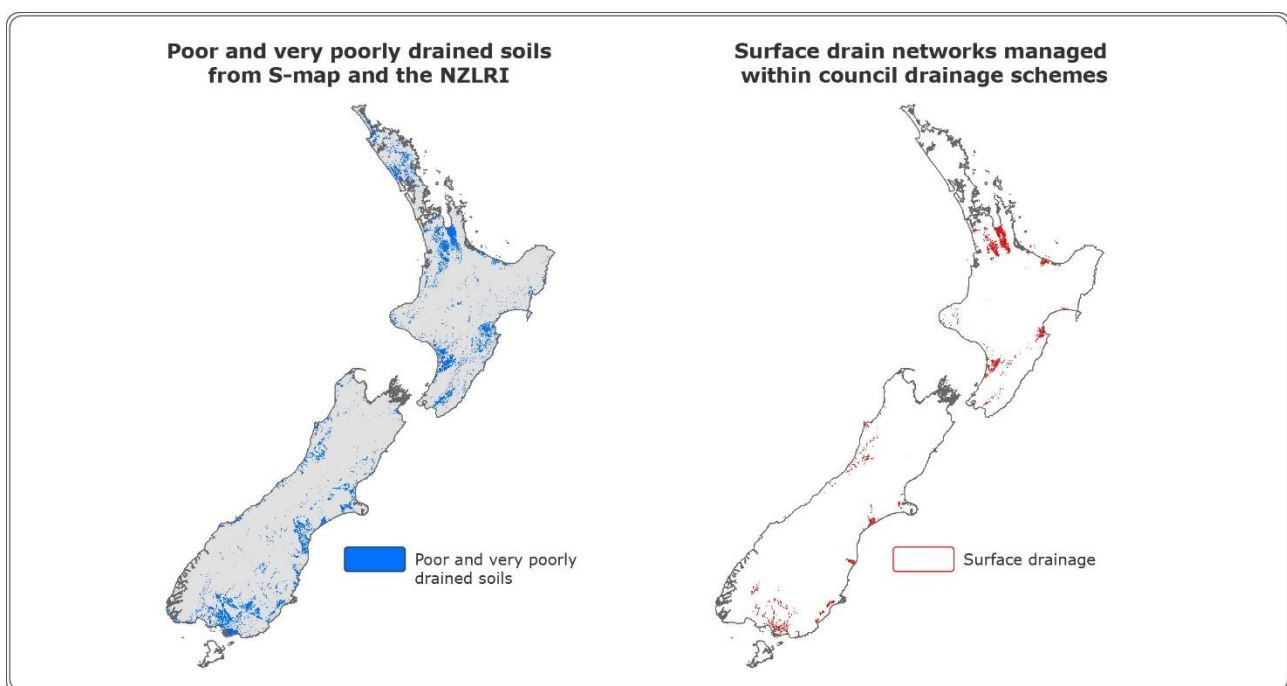


Figure 4. Poor and very poorly drained soils, and the network of surface drains managed within council drainage schemes.

Table 11. Criteria exceptions for LUC Classes 1 and 2 according to likelihood of artificial drainage, by NZSC

Order	Poor and very poorly drained* NZSC that intersect with surface drain networks managed by councils	Criteria exceptions
Gley	GAH, GAO, GAT, GOA, GOE, GOI, GOJ, GOM, GOO, GOT, GRA, GRC, GRF, GRO, GRQ, GRT, GSA, GSC, GSO, GSQ, GST, GTA, GTO, GTT	All poorly drained Gley Soils can be considered for LUC 2,3,& 4.
Allophanic	LGT, LPT	Poorly drained LGT and LPT can be considered for LUC 3 & 4 but not 1 & 2.
Pallic	PJM, PJT, PPF, PPJ, PPJX, PPT, PPU, PPX, PUJ, PXJM, PXM	Poorly drained Pallic Soils can be considered for LUC 2,3, & 4.
Ultic	UDM, UEP	Poorly drained UDM and UEP can be considered for LUC 3 & 4 but not 1 & 2.
Podzol	ZOH, ZPOZ, ZPH, ZPHP, ZPP, ZPT, ZPU, ZPZ	Poorly drained ZOH can be considered for LUC 2,3, & 4. Other poorly drained Z can be considered for LUC 3 & 4 but not 1 & 2.
Organic	OFA, OFS, OHA, OHM, OMA, OMM	Organic Soils are modelled separately. We note that no OL soils were implicated.
Raw	WGF, WGQ, WGT, WW	Poorly drained WG soils can be considered for LUC 4 but not 1, 2, & 3.

* Imperfectly drained soils already qualify for LUC 2, 3, and 4.

There are several assumptions and considerations regarding this method. Firstly, surface drains do not necessarily indicate that the land has been drained: a drain removing excess water from poorly drained soils can pass through land with soils that do not have drainage limitations. Further, while we can assume that surface drains in porous soils with high water-tables will lower the regional water-table, thus improving the drainage status of a large area of land, we cannot assume the same for fine-textured soils, where secondary subsurface drainage would be necessary to achieve similar results. Other than for Southland, we have no data for subsurface drainage, and the Southland data set is recent and does not include historical drainage. Lastly, our surface drainage data sets are limited to drainage schemes managed by local councils and will not contain private land drainage systems. Accordingly, the interpretation of results for modelled LUC for artificially drained land should be tempered with a recognition that this method may under-estimate LUC influenced by artificial drainage.

4.2.8 Land-use suitability criteria

The LUC classification is inherently a combined land-use suitability and versatility classification, with a primary focus on the relative suitability of arable, pastoral, forestry, and conservation land uses (Figure 5). Of particular interest to this project, arable land-use criteria are expressed in terms of cropping suitability and versatility for LUC 1–4:

- LUC 1 land is suitable for a wide range of crops (i.e. high cropping versatility)
- LUC 2 is suitable for many crops
- LUC 3 has a restricted range of crop types
- LUC 4 is suitable for occasional cropping for a small range of crop types.

The handbook details what ‘suitable for cropping’ means, including examples and some criteria. Also, LUC 1–4 land is considered ‘multiple use’ land, which is synonymous with ideas of land-use versatility, with less-capable land described as having a decreasing versatility of use.

Increasing limitations to use	LUC Class	Arable cropping suitability†	Pastoral grazing suitability	Production forestry suitability	General suitability	Decreasing versatility of use
	1	High ↓ Low	High ↓ Low	High ↓ Low	Multiple use land	
	2					
	3					
	4					
	5	Unsuitable	Low ↓ Unsuitable	Low ↓ Unsuitable	Pastoral or forestry land	
	6					
	7					
	8					
		Unsuitable	Unsuitable	Conservation land		

Figure 5. Land-use suitability and versatility within the Land Use Capability system. (Source: Lynn et al. 2021)

However, we do not yet have an appropriate land-use suitability/versatility classification available to use in this project. We are seeking to develop such a classification that aligns with LUC criteria, but at this time affordable access to climate data is a significantly constraining factor and the classification cannot be developed without access to these data. However, the BSI are currently in negotiations with data suppliers, and new working relationships within the BSI offer the potential for the collaborative development of a land-use suitability/versatility classification that accommodates both traditional LUC land uses and new land uses, such as viticulture.

4.3 Data preparation

Data preparation is a significant step that includes data extraction, preparation for modelling, and reconfiguring spatial surfaces for rainfall, elevation, and slope into attribute values that can be used with S-map data within the modelling framework.

4.3.1 S-map data and analysis fields

S-map describes up to five different siblings within each S-map ‘soil map unit’, with the first sibling being the most dominant sibling by area. Each sibling has the potential to be classified as a different LUC class, and the aggregate result of up to five proportional LUC classes may be different from that modelled for the dominant sibling alone (see section 4.4.1). We examine the implications of multiple LUC classes within a single map. To do this, five separate layers are extracted from the S-map database, with each layer representing a single sibling and its proportion within a map unit (Figure 6).

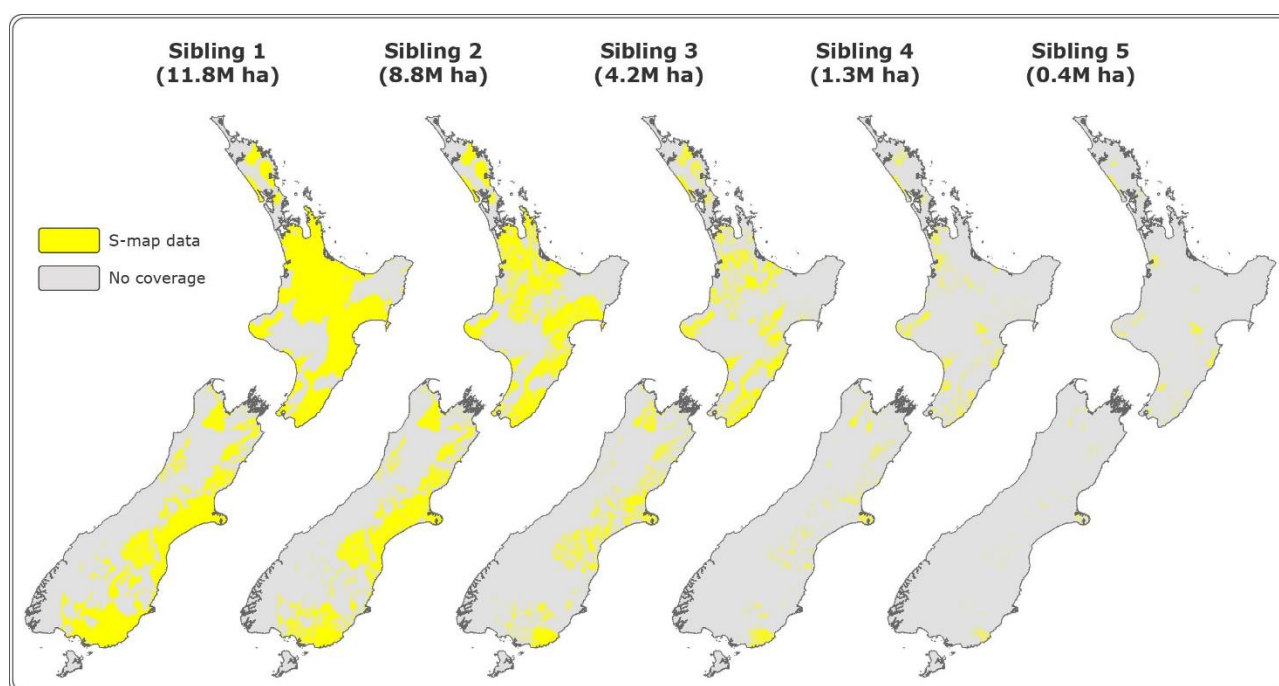


Figure 6. Map extents of S-map siblings from soil map unit codes extracted as single layers for modelling (up to five siblings can occur within a single S-map soil map unit).

A Structured Query Language (SQL) query was developed and implemented across the S-map database to extract each sibling layer with a set of attributes that match the modelling criteria from section 4.2 (Table 12). Minor modifications were performed to standardise the data. S-map slope class codes with a '-' or '+' qualifier were simplified to their primary slope classes (e.g. 'C-' and 'C+' were simplified to 'C'). Soil depth and rooting depth fields that had mixed numerical and ordinal data were converted to numerical data only. Generalised S-map slope classes of W (wheelable slopes), H (hilly), and S (steep) were reclassified from DEM-derived slope into NZLRI slope classes.

Non-soil S-map polygons (urban, water, bare rock) were later added, and approximately 1,000 polygons with 'bare rock' as the first sibling were manually extracted from the S-map database and added to the sibling 1 layer (bare rock is a non-soil and is managed differently in the S-map database). In cases where bare rock is the first sibling in a compound code, the polygon is not extracted into the sibling 1 layer, but subsequent siblings are extracted with polygons for the other sibling layers. (If not amended this would create an inconsistency in the modelling.)

Table 12. List of S-map attributes used in this project

S-map attribute
SOILMAPUC, GISLAYER, SMU, SiblingList, S-mapSib1, sib1_prop, SlopeCode, sib1_conf, NZSC, NZSCOrder, nzscGroup, nzscSubGroup, SoilProfileMaterial, ParentMaterialOrigin, TextureGroupCode, PermeabilityCode, SiblingDepthCode, SiblingTopsoilStonesCode, SiblingDrainageCode, SiblingTexture, UpperTexture, LowerTexture, RootBarrierCode, RootBarrier, FH1, FH2, FH3, FH4, FH5, FH6, Depth, DepthRange, RootDepth, rootDepthRange, SlowDepth, slowdepthRange, PAWmm, SVI, Salinity, LocalSeriesName

Note: A short description of each attribute is provided in Appendix 2.

Analysis fields were added to each of the five feature layers (Table 13). Non-S-map fields were added for polygon rainfall, elevation, and slope, and populated but calculating the mean value for rainfall, elevation and slope for each S-map polygon (section 4.3.2).

Table 13. List of modelling fields added to each of the five S-map sibling layers

Fields added for modelling
luc1_slp_ldr, luc1_PM, luc1_depth, luc1_rooting, luc1_perm, luc1_TXT1, luc1_TXT2, luc1_drain, luc1_Tsstones, luc1_Salt, luc1_DSLO, luc1_PAW, luc1_NZSC, luc1_ELEV, luc1_RAIN, luc1_Out2, luc2_slp_ldr, luc2_PM, luc2_depth, luc2_rooting, luc2_perm, luc2_TXT1, luc2_TXT2, luc2_drain, luc2_Tsstones, luc2_Salt, luc2_DSLO, luc2_PAW, luc2_NZSC, luc2_ELEV, luc2_RAIN, luc2_Out2, luc3_slp_smap, luc3_slp_ldr, luc3_PM, luc3_depth, luc3_rooting, luc3_perm, luc3_TXT1, luc3_TXT2, luc3_drain, luc3_Tsstones, luc3_Salt, luc3_DSLO, luc3_PAW, luc3_NZSC, luc3_ELEV, luc3_RAIN, luc3_Out2, luc4_slp_ldr, luc4_PM, luc4_depth, luc4_rooting, luc4_perm, luc4_TXT1, luc4_TXT2, luc4_drain, luc4_Tsstones, luc4_Salt, luc4_DSLO, luc4_PAW, luc4_NZSC, luc4_ELEV, luc4_RAIN, luc4_Out2, Final_1b_1, Depth2, RootDepth2, Sib1_domLUC_1b

Note: A short description of each field is provided in Appendix 2.

4.3.2 Non-S-map data (elevation, calculated slope, rainfall)

Non-S-map data used in this project include elevation, calculated slope, and rainfall. For elevation and slope, a new 5 m resolution DEM for New Zealand was generated using the best available data sources (Figure 7). The DEM incorporates elevation data from two sources: Toitū Te Whenua Land Information New Zealand's (LINZ's) 1 m resolution mosaic of regional LiDAR DEMs (LINZ 2026), and BSI's national 15 m DEM, which was interpolated from LINZ Topo50 20m contour lines and spot heights, originally created for correcting topography distortions in satellite imagery (Dymond & Shepherd 2004) and then used subsequently for many national applications, including the creation of a stock exclusion low-slope map (MfE 2022). The 15m DEM was used where LiDAR is not yet available.

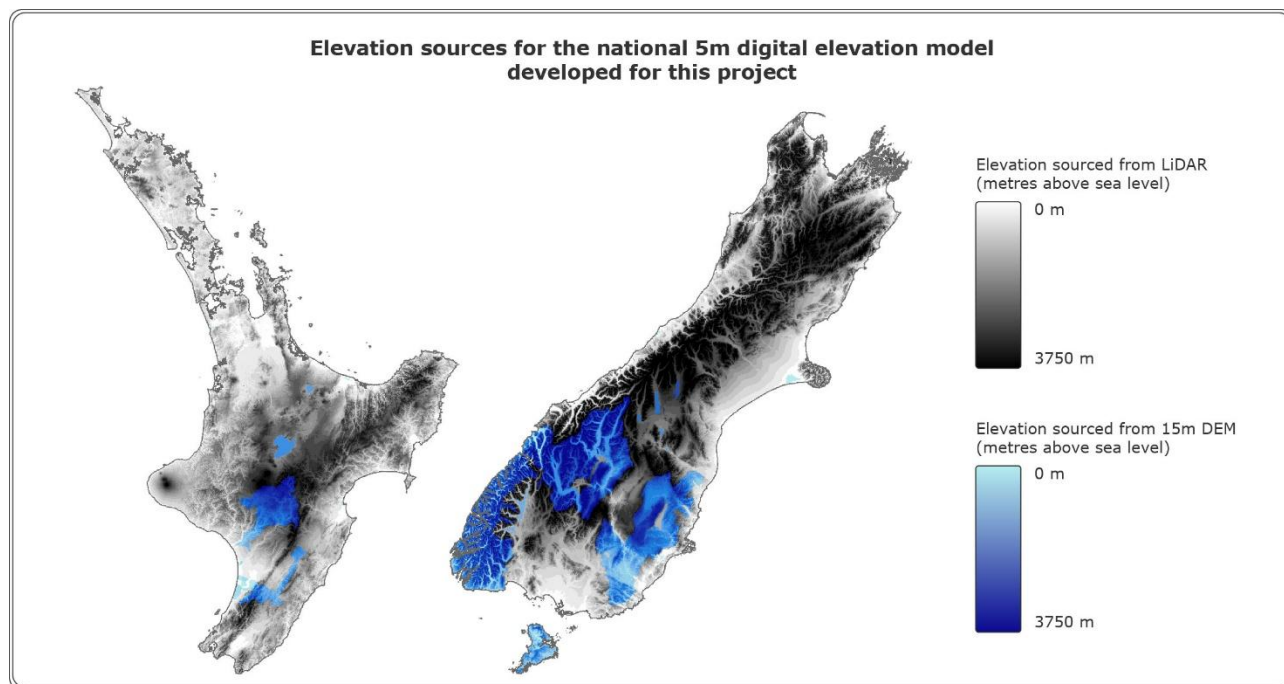


Figure 7. Data source for the 5 m resolution LiDAR-dominant DEM developed for this project.

Both the 15 m and LiDAR DEMs were resampled using bilinear interpolation to 5 m resolution and mosaicked to generate a complete data set. Resampling the 15 m DEM to 5 m does not improve the data in any way, and is undertaken only to produce a single consistent raster surface for extracting data to polygons. An extra layer for slope was then calculated from the 5 m DEM.

Rainfall was sourced as mean annual rainfall for the period 1991–2020 at 500 m resolution from Earth Sciences NZ (ESNZ 2026).

Rainfall, slope, and elevation data from raster services are summarised into S-map polygons using summary statistics to generate a mean value for each polygon. In some cases, S-map polygons were too small or complicated in shape, so mean values were generated by generating 100 randomly located points per polygon, which were subsequently used to sample each of the three raster layers, and then the mean for each polygon was calculated from the average values for rainfall, slope, and elevation from each polygon set of 100 points.

4.4 Model framework and application

S-map attributes and qualifying criteria for LUC 1–4 soils were used to build a Boolean rules model, whereby each criterion for each LUC class (from section 4.2) was assessed in absolute terms of either ‘does meet the criteria’ or ‘does not meet the criteria’.

4.4.1 Boolean classification logic

Boolean classification logic is a rules-based, decision-making framework in which conditions are evaluated as either true or false, and outcomes are determined by the logical combination of those conditions (MacMillan & Shary 2009). In the context of LUC classification, each input variable is assessed against a defined threshold or condition, returning a binary result that is then combined with other conditions to determine class membership. For example, a rule might state that an S-map unit qualifies for a particular LUC class only if the slope is A OR B, AND soil depth exceeds a minimum threshold, AND the NZSC is NOT a particular soil class. If all conditions are satisfied, the unit is assigned to that class; if any condition fails, it is not.

Boolean logic is used as a basis for modelling in this project for two key reasons. The first is a very practical reason: Boolean modelling has been the basis for previous S-map-to-LUC projects, and this project aims to apply that modelling to all available S-map data (i.e. it is the objective of this project). Secondly, Boolean logic is well suited to modelling LUC classes because the LUC system is itself founded on a structured, criteria-based framework in which land is assigned to a class based on defined physical limitations and classification criteria.

The LUC handbook (Lynn et al. 2021) sets out explicit thresholds and criteria for slope, soil depth, drainage, texture, permeability, stoniness, and other attributes that determine class membership – a structure that maps directly onto Boolean decision rules. While the handbook is vague on some inputs and criteria, in a general sense the LUC classification system, through the handbook, can be applied in a consistent and repeatable manner. For modelling, this means that much of the method can be translated into logical conditions without requiring statistical inference or model training from observed outcomes. This makes Boolean logic a transparent and auditable approach, in which every classification decision can be traced back to specific input values and the rules applied to them (see section 4.4.2). It is also reproducible and consistent across large spatial data sets, which is important for a national-scale application where the uniform application of criteria is essential.

Furthermore, because the LUC framework is fundamentally concerned with whether land meets or fails defined capability thresholds rather than expressing a continuous gradient of suitability, the binary nature of Boolean logic aligns well with the discrete class structure of the LUC system.

4.4.2 Model development and application

Boolean rules were used as a basis for building an ArcGIS model, initially as rules coded as nested Python. These rules were later migrated from the ArcGIS environment into stand-alone Python code to improve modelling efficiency and performance. However, because this project has a strong development and testing component, most of the development and refinement have continued to be undertaken in the ArcGIS modelling environment, so the most recent versions of the model are only available as ArcGIS models. The full framework of the model is included in Appendix 3 as Python code, including classification criteria, thresholds, and logic used for iteration 1 modelling.

A key feature of the method is that each criterion is assessed, and the result is recorded in the output layers as Boolean 1 or 0 values (yes or no). While this requires many output fields for each sibling layer (see previous Table 12), it has the advantage of providing full interrogative transparency for each criterion result (Figure 8), which is important for the testing and evaluation component of the project (section 4.5).

Individual sub-models were constructed for each LUC class and implemented in sequence across all five sibling feature layers. Boolean results (i.e. values of 1 or 0) were then summed for each target LUC class to determine if they qualify. For example, if the total number of individual criteria evaluated for LUC 1 is 15, and if the sum of the Boolean outputs is also 15, then all conditions are met and the resulting classification is LUC 1. It should be noted that we have not weighted any criteria: each criterion has equal influence on the result.

A second suite of LUC 1–4 models based on the same logic and framework were implemented separately across all Organic Soils and soils with peaty topsoils, across all five sibling layers. The key difference is that these models use slightly fewer criteria, as discussed in section 4.2.5. Results for Organic and peaty soils were combined with those for mineral soils to produce the final classification.

4.4.3 Comparing two sources of slope data

Slope is one of the major influencing criteria in LUC classification, and we have available two sources of slope data that can be used to model LUC in this project. Sources of data include S-map slope for each sibling, and slope calculated from LiDAR-dominant DEM data as a single polygon value. Both sources differ in terms of what they represent and how they have been determined. The implications, if any, of using one source of slope data over the other are tested by generating two separate LUC model outputs for comparison.

4.4.4 LUC from the dominant sibling

Using only the first or dominant soil from a soil data set is both simple and a common approach used in spatial modelling. The key reason is that it is quick and uncomplicated, but relies on the assumption that the dominant soil will fairly represent the overall character of the spatial unit being modelled.

Classifying LUC from the dominant sibling is one of two methods tested in this project. LUC is modelled for the dominant sibling as a separate output. This is achieved simply by applying the models only to the sibling 1 layer (meaning the other four sibling layers are not used in this method).

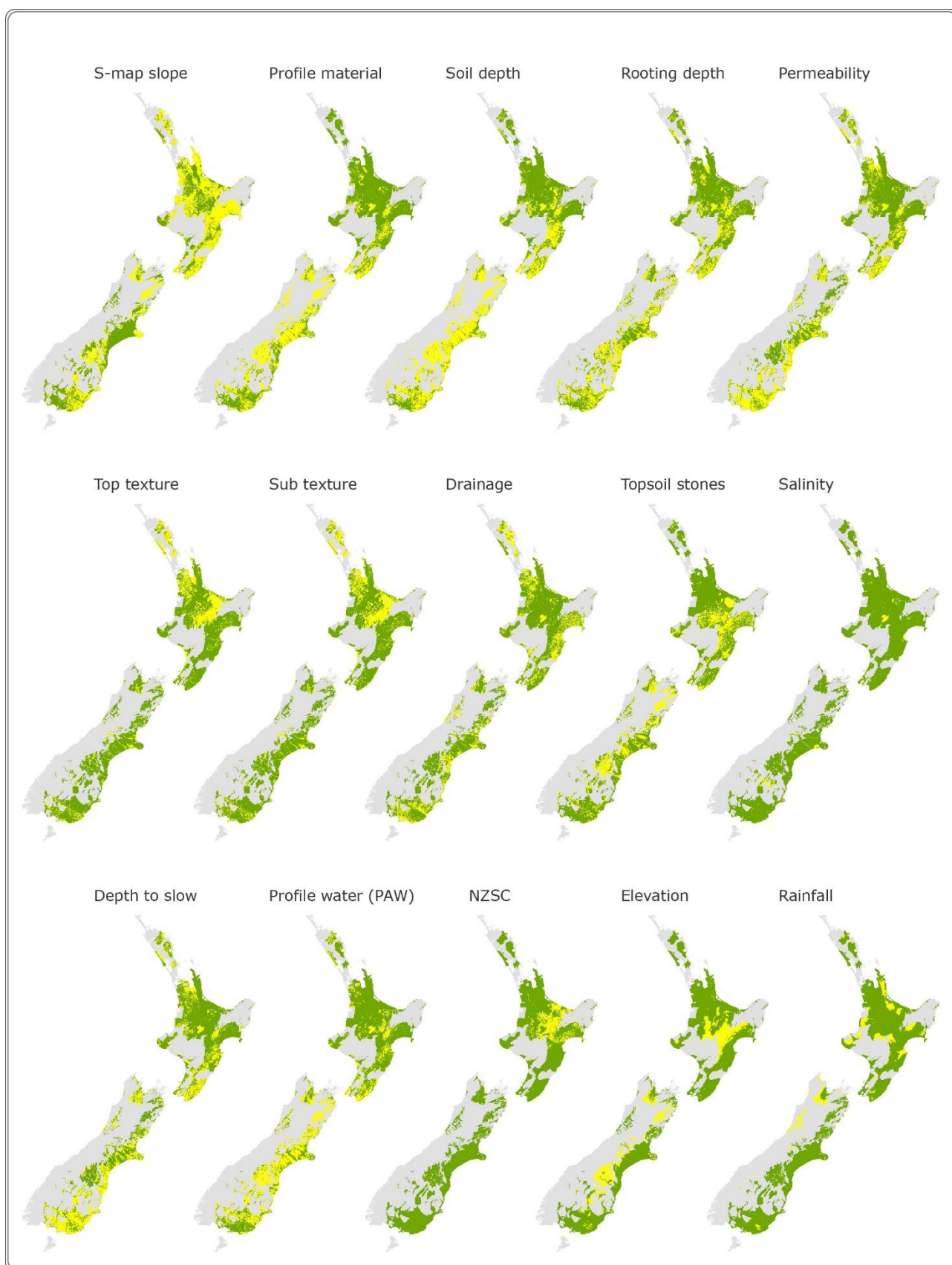


Figure 8. Boolean output maps for each of the 15 variables for LUC Class 1 as an example. Colour indicates if the variable qualifies according to LUC Class 1 criteria: yellow = does not qualify, green = qualifies, grey = areas that do not yet have S-map coverage.

4.4.5 LUC from multiple siblings in a soil map unit

S-map describes up to five different siblings within each S-map map unit, with the first sibling the most dominant sibling by area. Each of the (up to) five siblings can be considered as spatially inexplicit: they have been observed by the soil surveyor to occur within a large 'soil map unit' (one polygon or several joined polygons that share the same soils and proportions) in the field, but their exact extent and location as individual soils within the soil map unit is not spatially explicit.

The aggregate total of up to five different LUC classes from five siblings could produce a net overall LUC for the soil map unit that is different from the capability drawn from the dominant sibling alone. For example, a unit that encompasses soils on a flat terrace dissected with gullies may produce two LUC classes of, for example, LUC 2 and LUC 7, but it may be the lower capability classification that determines how the land can be used in a practical sense (e.g. the gullies may be a significant limitation to crop harvesting). Consequently, the soil map unit may need to be classified differently from than what using the dominant sibling may otherwise produce (in practice there is probably a recognised LUC unit that accommodates this scenario).

4.5 Testing

Model outputs were compared against other sources of HPL representation, including the NZLRI, 'high value land use' data (Section 4.5.1), and evaluated by expert review. The purpose was to assess accuracy, consistency, and practical usefulness, and, as far as time permits, to use the findings to improve model performance. We also examined the implications of using different sources of slope data (S-map slope vs. DEM-calculated slope), and LUC classification using the proportional area of up to five map unit siblings vs. the dominant sibling.

Each layer of interest was intersected with modelled data, with resulting paired data sets for comparison exported as comma-separated values (csv). All analyses were undertaken in R Studio.¹² The following metrics were generated for each comparison: confusion matrices (ha, %), overall agreement by polygon count (%), area-weighted overall agreement (%), unweighted and weighted Cohen's kappa statistic (equal linear and quadratic), and class-specific producer's and user's accuracies. Cohen's kappa is a statistical measure of agreement between two classifications that accounts for the agreement expected to occur by chance, while producer's and user's accuracies are measures of agreement derived from a confusion matrix (which in turn, is a table that compares modelled classes with reference classes).

4.5.1 Comparison with high value land uses

If land has supported – or is currently supporting – a highly productive land use or cover, such as horticulture or cropping, it follows that the land has a fair chance of being highly productive land (HPL). We incorporated this comparison by generating a 'high value land use' layer from LINZ Topo50¹³ data for orchards and vineyards (including kiwifruit), together with LCDB6 classifications for 'Orchard, Vineyard or Other Perennial Crop', and 'Short-rotation Cropland' (Figure 9). We included these categories for any of the six LCDB time stamps (1996–2023) on the basis that if a high-value land use had been present in the past, then this is still indicative of high-value land.

¹² <https://www.r-project.org/>

¹³ <https://data.nationalmap.co.nz/layer/87334-vegetation-topo50/>

Although this produces a small data set for comparison (about 0.5 million ha or 4% of S-map total area), we rate the data as having a high value for comparison, because they are data from remote sensing methods. This was further supported when the NZLRI was intersected with the 'high value land use' layer, resulting in a 95% agreement between the two data layers.

However, some 'high value' land uses will encompass a percentage of lower capability land, especially land growing grapes for wine. For example, in Hawke's Bay the Gimblett Gravels (LUC 7 land) are famous for wine production. These exceptions, however, do not discourage us from using the vineyard classification, because the majority of vineyard footprint (91%) matches LUC 1–4 from the NZLRI.

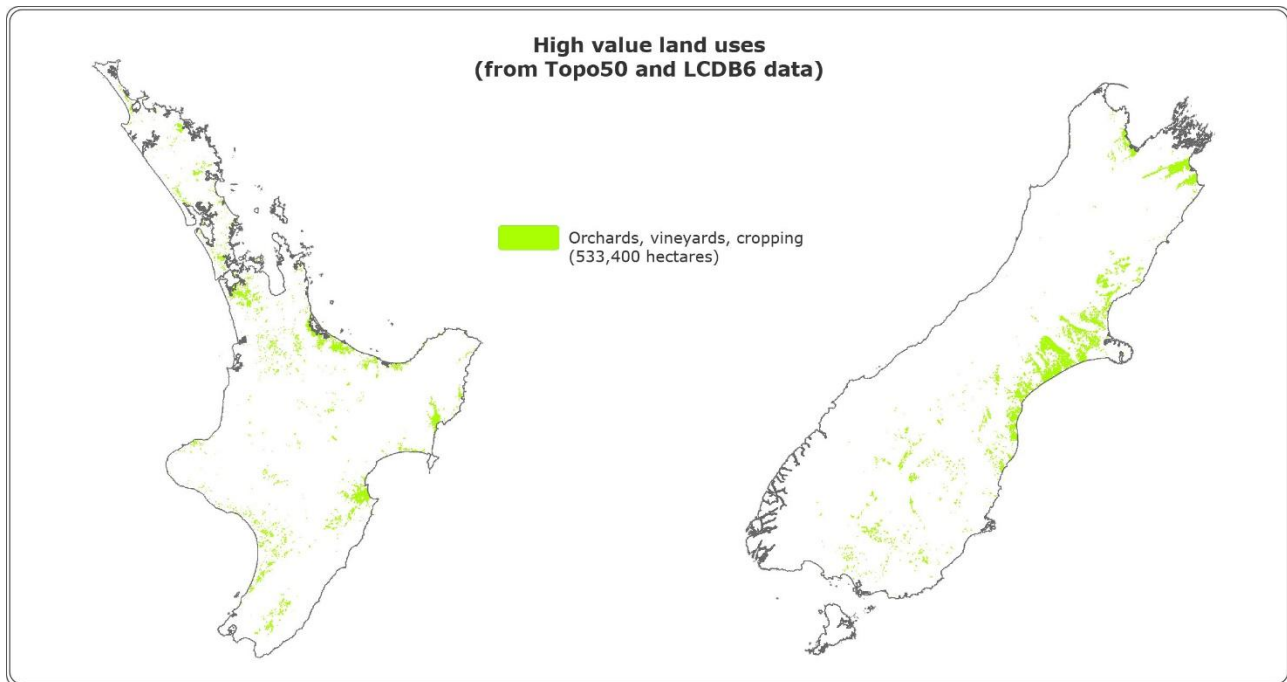


Figure 9. High-value land-use layer, which includes vineyards, orchards, and cropping land. (Source: Topo50 and LCDB6 data).

4.5.2 Expert review

Inhouse experts in LUC mapping and the LUC classification system reviewed the first iteration of modelling. They were supplied with output layers and asked to assess areas of familiarity by comparing results against both the NZLRI, local knowledge, and their LUC expertise. This included reviewing the individual Boolean outputs for each criterion to help identify discrepancies. The review was undertaken with a negative focus, in that the experts were asked to look for misclassifications and errors. Experts included Scott Fraser, Anthony Ward, and Kaleb McCollum. Their feedback is collated and discussed in the results section, with full feedback included as Appendix 4.

4.5.3 Comparison with previous modelling

We have access to an early model output from the 2013–2017 period. While S-map from this time has less coverage and now-outdated predictions of some soil properties, we have compared this historical result to the NZLRI and the new S-map to LUC modelling. The primary purpose of this modelling was to evaluate if there has been any change or improvement.

5 Results

5.1 Key model outputs

Modelling LUC 1–4 from S-map has produced an estimate of 5.07 million hectares, representing 43% of the total area modelled (11.8 million hectares). This total agrees well with the NZLRI for the same area, with NZLRI LUC 1–4 accounting for 5.18 million hectares representing 44% of the area modelled (Table 14 and Figure 11). Regional summaries are provided in Appendix 5.

Table 14. Modelled and NZLRI LUC 1–4 hectares and percentages for the modelled area

LUC class	Modelled LUC 1–4		NZLRI LUC 1–4	
	Hectares	% of area	Hectares	% of area**
LUC 1	237,531	2%	146,382	1%
LUC 2	911,242	8%	1,032,991	9%
LUC 3	2,522,752	21%	2,100,343	18%
LUC 4	1,397,454	12%	1,895,699	16%
Other	6,757,439	57%	6,651,003	56%
Total area modelled*	11,826,418		11,826,418	

* Total area is determined by S-map coverage in August 2025 (11.8 million hectares). This area covers approximately 80% of LUC 1–4 recorded in the NZLRI.

** Percentages for each LUC class are calculated using the total area of S-map, and will therefore be different to those that can be calculated using the full NZLRI dataset (which has a total area of 26.6 million hectares).

5.2 Comparisons

5.2.1 Slope comparison

S-map uses two slope classifications (Figure 10). One is based on the classification used in the NZLRI and so is directly applicable to the modelling, while the other is a generalised classification that is not suitable for LUC classification. Approximately 35% of S-map by area has the generalised classification. For this project we replaced the generalised classes with NZLRI equivalents calculated from LiDAR-dominant DEM data.

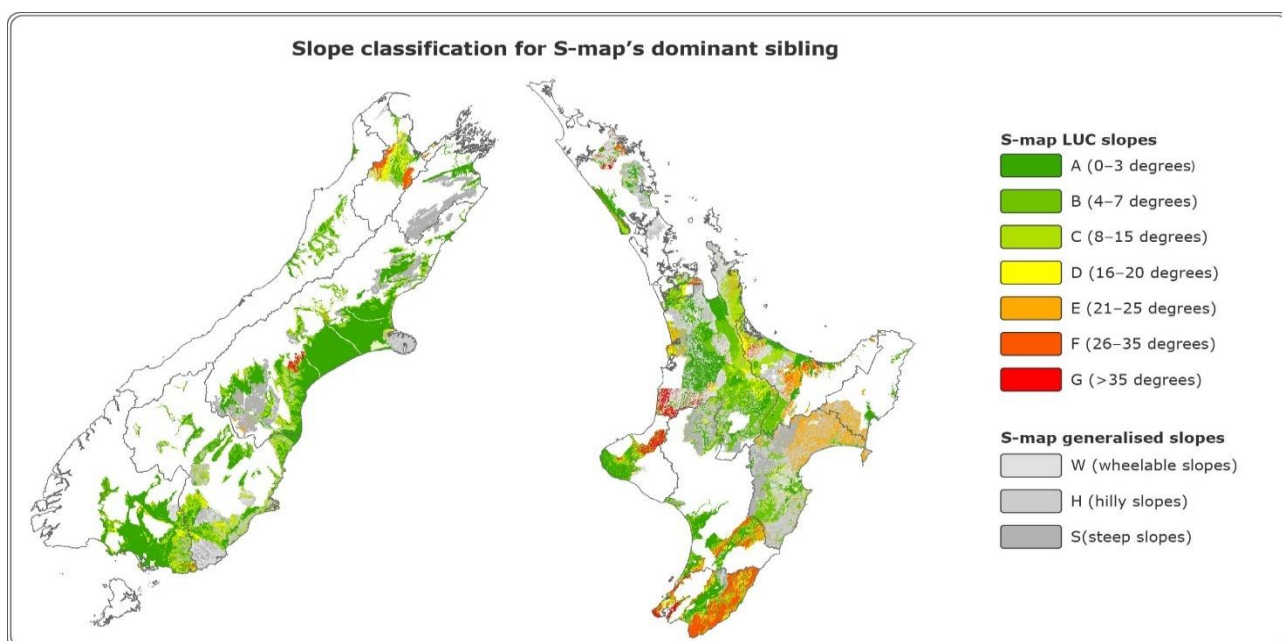


Figure 10. Slope classes and classifications used in S-map.

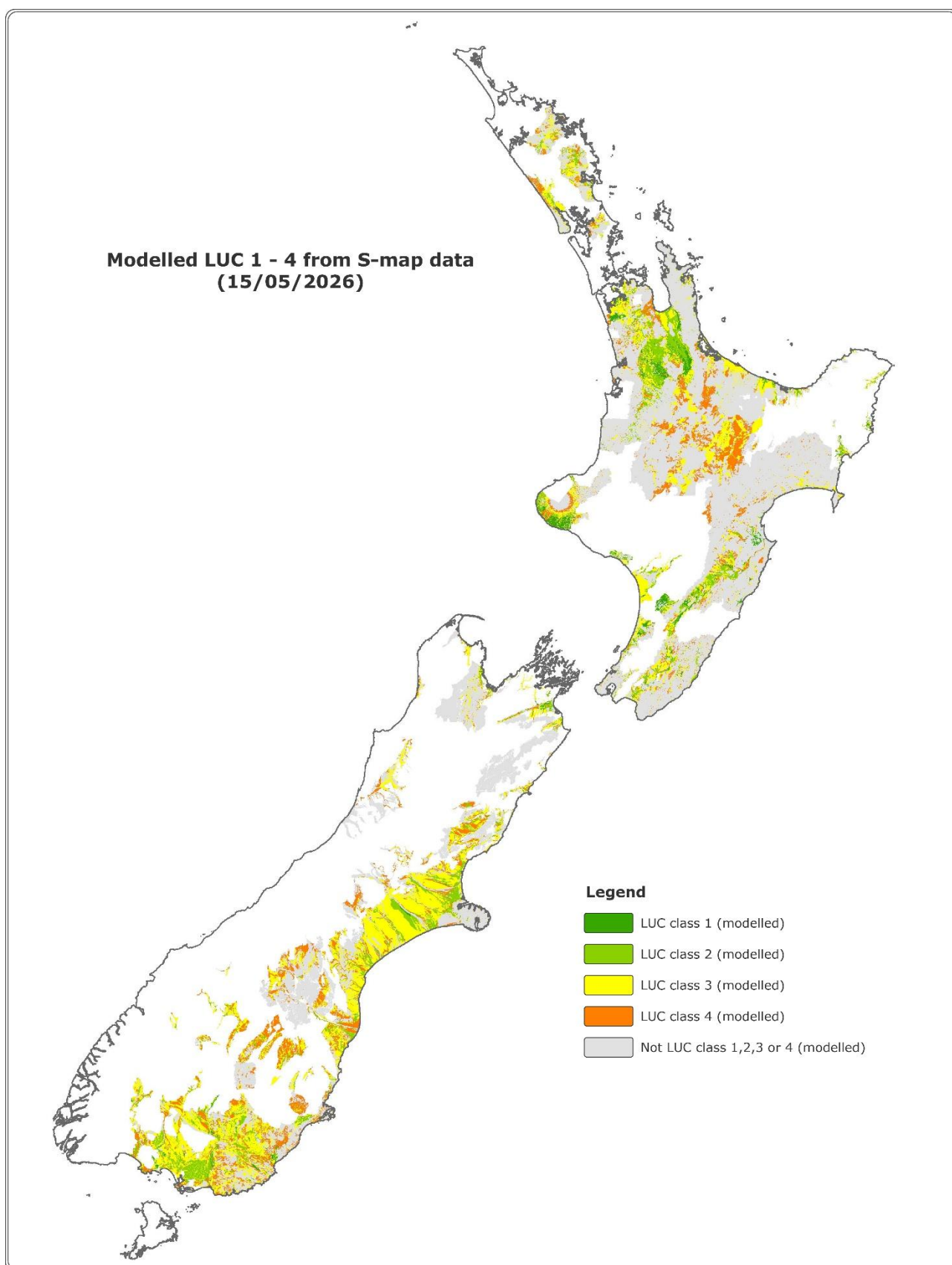


Figure 11. Key model output of LUC classes 1, 2, 3 and 4 from S-map and other data.

Comparison of the actual *slope classes* showed moderate overall agreement, with exact class matches occurring for 59% of observations and 56% of the mapped area. An unweighted kappa statistic of 0.489 indicates moderate agreement when only exact class correspondence is considered. However, agreement increased substantially when the ordered nature of slope classes was considered, with linear- and quadratic-weighted kappa values of 0.650 and 0.749, respectively. This indicates that many of the discrepancies occur between adjacent slope classes rather than between classes representing markedly different terrain.

Class-level accuracies reveal considerable variation in agreement across the slope classes. Producer's accuracies were highest for slope classes G (99.8%) and F (69.9%), indicating these classes were consistently identified between data sets, while classes B (31.0%), E (35.0%), and C (40.3%) showed lower levels of correspondence. User's accuracies followed a similar pattern, with class A exhibiting very high reliability (90.3%), whereas classes B, C, D, and E all achieved less than 45% agreement. These results suggest that the data sets are generally consistent in distinguishing the steepest and most distinct slope classes, but show greater uncertainty and overlap among intermediate slope classes, where differences in classification thresholds and boundary placement are likely to have the greatest influence.

For LUC 1–4 classification, the high level of agreement for slope class A ($0-3^{\circ}$) is reassuring, but less so for the B, C, and D classes ($4-7^{\circ}$, $8-15^{\circ}$, and $16-20^{\circ}$) at less than 45% agreement. It is therefore not surprising that different sources of slope classification produced differences in LUC classification (Figure 12). For the area analysed, 75% produced the same class, 17% produced a higher capability result, and 8% produced a lower capability classification result.

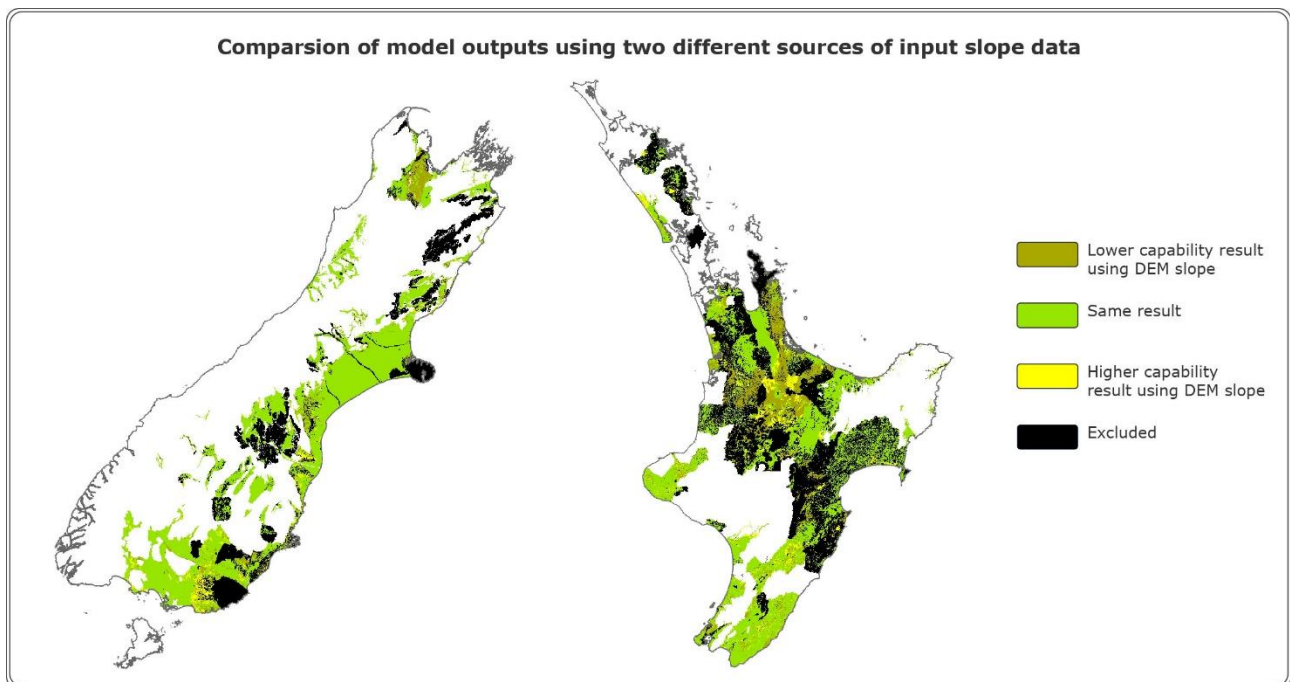


Figure 12. Differences in model output from using two sources of input slope data. The ‘Excluded’ class represents S-map’s generalised slope classification, which is not used in this comparison. Note that this analysis also includes the ‘not LUC 1, 2, 3 or 4’ category.

5.2.2 LUC calculated from the dominant sibling vs. proportional method

We classified 'whole polygon LUC' using two methods. The first classification was based on results for the dominant sibling alone, and the second was based on proportional area, where the LUC results for up to five siblings within a polygon were aggregated, with the final all-of-polygon LUC assigned according to which LUC class was proportionally dominant.

The differences between the two methods were minor, with only a small percentage of LUC 1–4 area that was not in absolute agreement (Table 15). Overall agreement was 98.6% by count and 98.3% weighted by area, indicating that nearly all observations and mapped extent were classified identically. An unweighted kappa statistic of 0.977 indicates almost perfect agreement beyond that expected by chance, and the linear- and quadratic-weighted kappa values of 0.986 and 0.991, respectively, further demonstrate that any discrepancies are both infrequent and minor in magnitude. Collectively, these results indicate that the two methods are effectively equivalent for practical purposes.

Table 15. Confusion matrix (percentage of total area) for dominant sibling LUC (columns) compared to proportional area LUC (rows)

	LUC 1	LUC 2	LUC 3	LUC 4	Row totals
pLUC 1	6%	0%	0%	0%	6%
pLUC 2	0%	19%	0%	0%	19%
pLUC 3	0%	1%	51%	0%	52%
pLUC 4	0%	0%	1%	21%	22%
Column totals	6%	20%	52%	21%	

5.2.3 Comparison with NZLRI LUC 1–4

Comparison using LUC from S-map slope

Modelled LUC results for the dominant sibling and S-map slope were compared with NZLRI LUC. The comparison indicated a low level of correspondence between mapped classes. Only limited areas produced identical spatial agreement (Table 16). Overall agreement was 54.6% on a count basis and 56.8% when weighted by area, suggesting that just over half the observations and mapped extent were assigned to the same class in both data sets. The unweighted kappa statistic of 0.247 indicates only fair agreement beyond that expected by chance, demonstrating considerable differences in the exact allocation of LUC classes between the two classifications.

Agreement improved when the ranked nature of the classes was considered, with linear- and quadratic-weighted kappa values of 0.359 and 0.446, respectively. Although these values remain within the fair to moderate range, the increase relative to the unweighted statistic indicates that many of the disagreements occur between adjacent LUC classes rather than between fundamentally different land capability groupings. This suggests that the two data sets broadly identify similar patterns of land capability but differ in the placement of class boundaries and the assignment of marginal areas.

Producer's accuracies show that agreement is particularly low for the HPL classes. LUC 1 exhibited very poor correspondence, with only 14.5% of areas identified in one data set also being classified as LUC 1 in the other. Producer's accuracies for LUC 2, LUC 3, and LUC 4 were similarly low, ranging from 31.8% to 34.6%. User's accuracies present a similar pattern.

The reliability of mapped LUC 1, 2, and 4 areas was relatively poor, with user accuracies of 40.1%, 41.0%, and 23.7%, respectively, while LUC 3 performed somewhat better at 50.5%. Collectively, these results indicate substantial uncertainty in the allocation of individual LUC classes.

Table 16. Area-weighted confusion matrix (hectares) comparing LUC class results from S-map modelling (rows) to NZLRI LUC (columns)

	nzLUC 1	nzLUC 2	nzLUC 3	nzLUC 4	Other	Total S-map
LUC 1	58,619	106,352	103,924	49,225	85,530	403,649
LUC 2	48,986	423,025	406,309	137,560	207,164	1,223,044
LUC 3	25,936	398,586	1,060,155	808,212	984,581	3,277,470
LUC 4	3,546	49,630	259,929	448,691	651,578	1,413,374
Other	9,295	55,398	270,027	452,012	4,722,150	5,508,881
Total NZLRI	146,382	1,032,991	2,100,343	1,895,699	6,651,003	11,826,417

Comparison using LUC modelled from S-Map and LiDAR-dominant DEM slope

Using slope calculated from the LiDAR-dominant DEM improved agreement to a moderate level of correspondence between the mapped classes. Overall agreement was 64.1% by count and 64.8% by weighted area, showing that approximately two-thirds of observations and mapped extent were assigned to the same class in both data sets. An unweighted kappa statistic of 0.324 indicates fair agreement beyond chance when only exact class matches are considered.

Agreement improved when the ordinal nature of the classes was taken into account, with linear- and quadratic-weighted kappa values of 0.462 and 0.567, respectively. This increase suggests that many disagreements occur between adjacent classes rather than between fundamentally different capability classes. Producer's accuracies for the individual HPL classes remained relatively low, ranging from 22.7% for LUC 1 to 43.5% for LUC 2, indicating considerable inconsistency in the allocation of individual classes. User's accuracies showed a similar pattern, with moderate reliability for LUC 2 and LUC 3 (38.4% and 49.8%, respectively) and lower reliability for LUC 1 and LUC 4 (36.8% and 27.6%, respectively).

Compared with the results from using S-map slope, this comparison demonstrates a modest but meaningful improvement in agreement. Overall agreement increased by approximately 9%, while all kappa statistics improved, with the quadratic-weighted kappa increasing from 0.446 to 0.567 and the unweighted kappa from 0.247 to 0.324. Producer's and user's accuracies also generally improved across the individual LUC classes, particularly for LUC 2 and LUC 3.

These improvements suggest that the use of LiDAR-dominant DEM-determined slope provides a greater level of agreement with the NZLRI on a total area basis, but uncertainty remains regarding the spatial match of individual LUC classes.

5.2.4 Comparison with high value land uses

New Zealand has approximately 0.5 million ha of land under high value land uses according to the LCDB 6 and Topo50 data sets. When compared with LUC from the NZLRI, and from modelling results using both S-map slope and LiDAR-dominant DEM slope, we observe high levels of agreement (Table 17). For LUC 1-4 combined, the total percentage agreement is 95%, 90%, and 89% for the NZLRI, S-map LUC using S-map slope, and S-map LUC using LiDAR-dominant DEM slope, respectively.

The differences are minor, (falsely) suggesting that modelling produces an overall result that has similar quantities of LUC 1-4 to NZLRI relative to land that is actually used for high value purposes.

Table 17. Relative areas (ha) and proportions (%) of LUC from three sources (NZLRI, S-map LUC modelled using S-map slope, S-map LUC modelled using DEM slope) under high value land uses

	NZLRI (ha)	S-map LUC using S-map slope (ha)	S-map LUC using DEM slope (ha)	NZLRI (%)	S-map LUC using S-map slope (%)	S-map LUC using DEM slope (%)
LUC 1	38,282	30,496	28,038	8%	6%	6%
LUC 2	177,824	130,069	120,409	35%	26%	24%
LUC 3	206,098	252,411	252,909	41%	50%	50%
LUC 4	57,629	39,700	44,588	11%	8%	9%
Not 1,2,3,4	22,676	49,832	56,564	5%	10%	11%
Total	502,508	502,508	502,508	100	100	100

However, when the modelled results are compared at the individual class matching level, the degree of agreement is low. Using S-map LUC from DEM slope as an example, the overall agreement was only 33.2% by count, increasing to 41.9% when weighted by area, suggesting that less than half of the mapped extent was classified consistently with the exact same class. The linear- and quadratic-weighted kappa statistics of 0.220 and 0.297, respectively, indicate only fair agreement beyond that expected by chance. The higher quadratic-weighted kappa value suggests that there are some disagreements between adjacent classes rather than entirely different classes; however, the generally low agreement statistics indicate substantial differences in class allocation and spatial representation.

5.2.5 Results if LUC 1, 2, and 3 are aggregated and compared as HPL

The preceding results suggest that the aggregation of LUC to HPL may produce higher agreement. To test this, LUC 1, 2, and 3 were reclassified as HPL for both the modelled S-map to LUC method (using LiDAR-dominant DEM slope) and the NZLRI.

When compared, the two classifications of HPL exhibited high overall agreement, with 80.57% agreement based on polygon counts and 82.75% when weighted by area (Figure 13). However, a medium Cohen's kappa statistic of 0.4703 (equal, linear, quadratic, and unweighted) indicates only moderate agreement beyond that expected by chance. This type of result is not uncommon (high overall agreement and modest kappa statistic), because kappa is sensitive to class prevalence and can underestimate agreement in binary, imbalanced classifications, which is apparent with HPL versus non-HPL in this comparison.

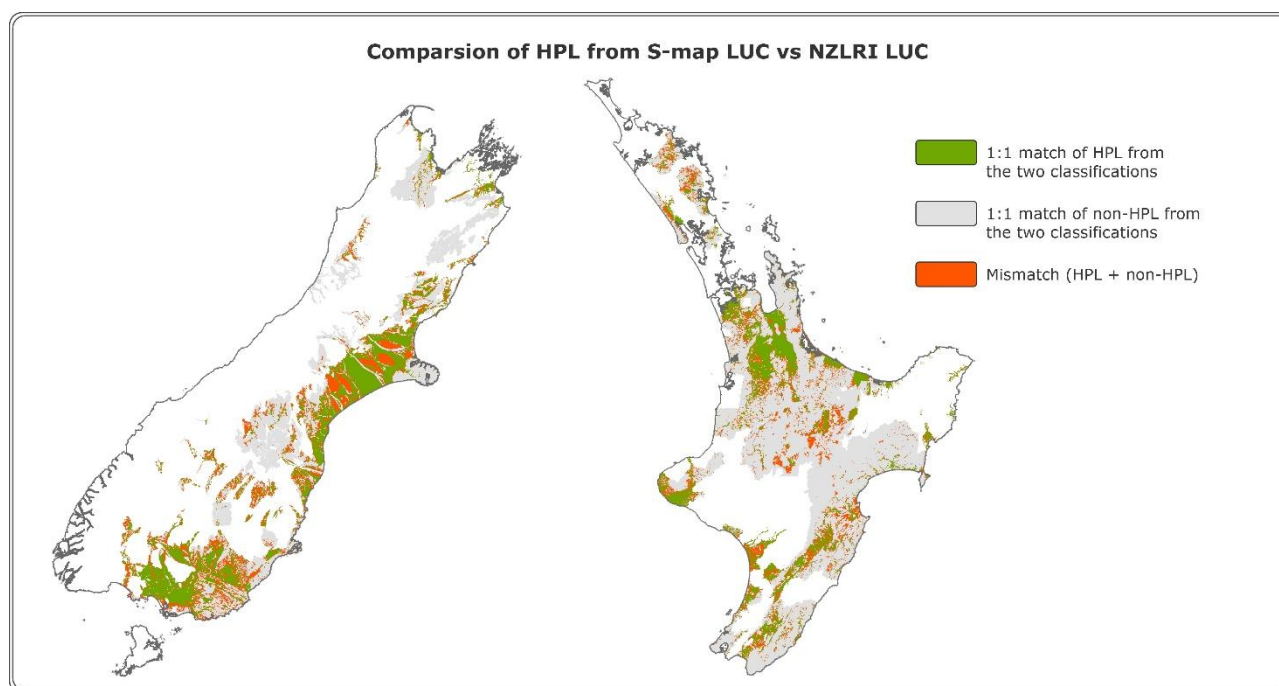


Figure 13. Visualisation of the spatial differences between S-map LUC as HPL and NZLRI LUC as HPL.

5.2.6 Comparison with previous modelling

An early classification of S-map to LUC 1-4 was produced during the initial development of the spatial rules-based approach. This is an unvalidated and unpublished draft that was applied to a smaller area of S-map available circa 2017. However, it represents a snapshot of model design and output for the time.

The historical output has been compared to NZLRI LUC. This early work achieved a moderate level of correspondence between the two data sets. Overall agreement was 51.7% and 52.9% by record count and weighted by area, respectively. This indicates that just over half the observations and mapped extent were assigned to the same class. Linear- and quadratic-weighted kappa results of 0.312 and 0.403 indicate fair to moderate agreement beyond that expected by chance.

New modelling using the latest S-map data and refined rules has produced a higher level of agreement. Overall agreement with NZLRI LUC is increased to 68.8% on a count basis and 64.9% when weighted by area, indicating that approximately two-thirds of observations and mapped extent were classified consistently. The linear- and quadratic-weighted kappa statistics of 0.545 and 0.658 indicate moderate to substantial agreement beyond chance, with the increase in weighted kappa values suggesting that most disagreements are relatively minor and occur between neighbouring classes rather than fundamentally different categories.

Overall, the results in the most recent modelling (this project) demonstrate a substantial improvement. Agreements are consistently higher, with improvements of approximately 17% in count-based agreement and 12% in area-weighted agreement, accompanied by substantial increases in both weighted kappa statistics. These improvements indicate that the new modelling produces a closer correspondence with the NZLRI data set, with fewer classification discrepancies and a greater proportion of disagreements being limited to adjacent classes.

5.2.7 Expert review

Three LUC experts were supplied iteration 2 results in GIS form and asked to evaluate how well they considered the modelling performed for locations they were familiar with. It should be noted that they were asked to find faults and problems, so understandably the feedback does not emphasise where agreement was high and the model performed well. Further, the feedback is expert based and may carry a level of subjectivity or even bias. Full feedback is provided as Appendix 4, while commonly recurring themes were isolated by AI (Claude AI, Sonnet 4.6 model) for discussion below.

1. The most pervasive theme across all feedback was an apparent tendency of the model to assign land to higher-capability LUC classes than would be expected based on expert knowledge and the NZLRI. This manifested as:
 - some soils being classified as LUC 1–2 where LUC 3–4 would be expected
 - examples of hill soils being assigned to LUC 2–3 where LUC 4–6 would be appropriate
 - some poorly drained soils qualifying as LUC 1 where drainage limitations alone would disqualify LUC 1.
2. There are examples of slope discrepancies resulting in the wrong LUC being classified. This is a common theme across multiple survey areas, including Tararua, Waikato, and Bay of Plenty. Key issues reported included:
 - slope categories in the data that do not adequately differentiate between flat, rolling, and hill terrain (see next)
 - large map units that are mapped or calculated as having one slope class, when the size of the unit covers land with many different slope categories – soil representation may be correct, but in such cases a single soil can be found on multiple slope categories
 - cases of S-map slope classes being different from slope classes calculated from the DEM.
3. There are factors that influence LUC classification that are currently out of modelling scope. It was noted that several important risk and hazard data are consistently absent from the model's classification criteria, resulting in the misclassification of LUC in some cases. Missing factors noted in the feedback include:
 - flood risk and floodability – river flat and low-lying soils have cases that should be classed as having lower capability because of the hazard
 - wind and water erosion susceptibility – particularly relevant for sand country and coastal areas
 - climate limitations – relevant to elevated or exposed areas.
4. S-map data inconsistencies were encountered in some examples. The experts are all qualified and experienced soil mappers with a deep familiarity with the S-map system. Feedback highlighted that some discrepancies appear to originate not from the model itself but from inconsistencies in how soils have been entered into S-map. This was observed across areas in Manawatu, Wairarapa, Marlborough/Nelson, and the Heretaunga Plains, and includes:
 - examples of incorrect or inconsistent rooting barrier depths and types
 - examples questioning the assignment of slow or low-penetration horizons
 - known challenges in converting some legacy soil surveys into S-map, especially regarding how legacy soils are represented (series) and described (see next).

5. Legacy soil survey conversion challenges: the conversion of legacy soil series maps into S-map siblings was noted as problematic, and was noted for Marlborough/Nelson, the Heretaunga Plains, and Wairarapa, and as implicitly relevant to other legacy surveys. Key concerns included:
 - different practitioners can interpret legacy surveys and concepts in different ways
 - soil series with wide or generalised soil property ranges can be difficult to represent as discrete siblings (and ideally require further field work, although this is not always possible with legacy map conversions).
6. There were cases of poorly drained soils being assigned to more capable LUC classes than drainage characteristics alone would justify. This feedback was specific to five S-map areas of the Kairanga plains, lower Hauraki Plains, Hikurangi swamp area, and Poutu peninsula, and for some river flat systems in the lower North Island.
7. Sand country and Organic Soils are two soil landscape types that were noted as having LUC classification problems. Some sandy and dune soils where wind erosion and low fertility were not considered have been misclassified across parts of the Rangitikei, Horowhenua, Wairarapa, and Northland. Some Organic Soils and peaty soils have been misclassified in Waikato, Northland, and Bay of Plenty, with LUC classes frequently misassigned relative to drainage and agricultural utility.
8. S-map can contain large map units that cover wide differences in slope, drainage, and other soil properties. This may be related to variable scales (especially legacy surveys) or the methods used by some practitioners to delineate and represent soil extent and boundaries. Large units were noted for the following locations:
 - Waikato, where single allophanic map units associated with tephra mantling, can encompass hundreds of hectares and include many slope categories
 - Tararua, where examples of large polygons have been mapped in areas of challenging access with relatively low productive potential – these units can integrate ridges, lower slopes, and valley floors.
9. Rooting barrier was noted as having a negative influence on some LUC classifications in the lower North Island. Examples were given for the following soils:
 - Marton silt loam in the Rangitikei
 - Kairanga silt loam in the Manawatu
 - Ashhurst soils in the Horowhenua
 - Multiple soils in the Wairarapa.

6 Discussion

6.1 How well did the model perform?

The S-map-to-LUC model produced estimates of 238,200 ha, 911,900 ha, 2,525,900 ha, and 1,398,300 ha for LUC Classes 1, 2, 3, and 4 respectively for the total area modelled (11.8 million hectares), representing approximately 3.68 million hectares of highly productive land (HPL) from available S-map coverage, which compares favourably with the 3.83 million hectares of HPL from the NZLRI for the same area.

At the aggregate level these totals are broadly consistent with expectations and with the NZLRI, providing us with confidence that the model is capturing the overall distribution of land capability at a national scale. However, aggregate 'net' agreement of this type can mask spatial disagreements between individual classes of LUC, with the results of some of our more detailed comparisons and the expert feedback indicating limitations that must be considered before the outputs are applied in policy or planning contexts.

Comparison with the NZLRI produced overall agreement of approximately 65% when DEM-derived slope was used, with moderate weighted kappa statistics. This represents a meaningful improvement over earlier modelling iterations, which achieved overall agreement of approximately 52–53% and considerably lower kappa values. While this trajectory is encouraging, a 65% agreement also means that approximately one-third of mapped area is classified differently between the two data sets, a level of disagreement that warrants careful interpretation, particularly for individual LUC class boundaries relevant to HPL identification.

Notably, when LUC 1, 2, and 3 are aggregated into a single HPL category and compared with the equivalent NZLRI classification, overall agreement increases to approximately 83%, with a moderate kappa statistic of 0.47. This improvement under aggregation is a consistent finding across all comparisons performed and carries practical significance: it suggests to us that the model reliably distinguishes HPL from non-HPL land at a broad level, even where individual class boundaries are less certain. The relatively high aggregate or 'net' agreement – combined with comparably high correspondence under actual high value land uses – is therefore a meaningful indicator of model usefulness, provided the limitations of individual class precision are clearly communicated and understood.

6.2 How robust is the NZLRI as a reference data set?

A fundamental question underpinning all comparisons in this project is whether the NZLRI constitutes an appropriate and reliable reference against which modelled outputs can be compared. Our main reason for using the NZLRI is that it provides an extensive set of LUC data, and is widely regarded as our best source of truth in the absence of having anything better available. (This is also an argument that has been used by policy and regulation developers, and others who continually rely on the NZLRI for their applications.)

The NZLRI was compiled over several decades using qualitative, expert-based methods at a nominal scale of 1:50,000, with considerable variation in survey methods, data quality, and the period of mapping across regions. As a result, it is not a spatially or thematically uniform data set, and in many areas it reflects the knowledge, conventions, and data limitations of the era in which it was produced.

Expert review of the modelled outputs in this project have highlighted cases where NZLRI classifications appeared inconsistent with current soil knowledge, particularly in areas where S-map has been resurveyed with modern methods and finer spatial resolution. In some instances the model's outputs were considered by reviewers to be more accurate than the NZLRI rather than simply different from it. This raises an important conceptual issue: disagreement between the model and the NZLRI does not necessarily indicate that the modelling is wrong. In some areas, particularly where new S-map data represent a genuine improvement in soil knowledge, the approach to modelling LUC may in fact be a better representation of land capability than the legacy classification it is being compared with (Lynn & Lilburne 2017; Manderson 2025).

At the same time, the NZLRI embeds a substantial body of local and regional expert knowledge – including factors such as flood risk, erosion susceptibility, and practical land-use experience – that is not always fully captured in soil attribute data alone. The NZLRI therefore remains a valuable reference but should be treated as one input into model evaluation rather than an unambiguous ground truth. In analytical terms, comparison against the NZLRI is best understood as an assessment of consistency between two ‘imperfect data sets’, each with distinct strengths and limitations.

6.3 How important is slope?

Slope is an influential determinant of LUC classification, particularly for LUC 1–4, and in this project the source and quality of slope data have had a demonstrable effect on model outputs. As part of the model application we compared two sources of slope classification: slope classes recorded in S-map (cleaned) and slope classes derived from a 5 m DEM developed from New Zealand's almost national coverage of LiDAR data. The comparison revealed only moderate agreement between the two sources, with exact class matches occurring for 59% of observations and a moderate unweighted kappa of 0.489. Agreement was substantially lower for intermediate slope classes (B, C, D, and E), which are precisely the threshold classes most critical to distinguishing HPL from non-HPL land. Using DEM-derived slope improved overall agreement with the NZLRI by approximately 9% and produced consistently higher kappa statistics across all metrics.

Despite this improvement, both slope sources have their limitations. S-map slope classes are recorded at the sibling level and reflect the characteristic slope of the soil type rather than the specific terrain within a mapped polygon. In this way, each sibling within a map unit is assigned its own slope class. However, for large polygons – particularly those found in some legacy surveys or digital soil mapping, or in remote terrains – a single slope class from the dominant sibling may be assigned to a unit that in reality encompasses a wide range of terrain conditions and slope classes. In such cases the recorded slope class may reflect the central tendency of the soil's typical landscape position rather than the actual slope distribution within the polygon boundary. Expert reviewers identified specific examples of this problem in the Tararua and Waikato regions, where large map units were assigned low slope classes despite containing substantial variation in terrain and slope.

DEM-derived slope, calculated as an average over the polygon, produced improved modelling results, but this technique is subject to an analogous limitation: averaging slope across a large, topographically heterogeneous polygon can produce a calculated slope value that does not represent any particular part of the landscape. A polygon that encompasses both flat valley floor and steep hillside because of mapping scale may yield an average slope value in an intermediate class that reflects neither land type accurately.

This presents a genuine methodological dilemma. We do not consider either slope method as unambiguously superior for all situations, and the choice between them involves trade-offs that are not easily resolved within the current framework. At a minimum, the results support a recommendation to use DEM-derived slope as the default input, given its demonstrably better agreement with the NZLRI.

However, the more fundamental issue – how slope should be determined for the ‘crisp’ polygon model of representing natural bodies such as soils and LUC – is unlikely to be resolved without either mapping LUC and soil polygons at scales more detailed than current, or by applying or developing new methods of calculating correctly representative slope from high-quality data such as LiDAR. Alternative methods to test could include the use of different summary statistics (e.g. median vs. mean), advanced statistical slope categorisation (e.g. via clustering, variance, tendency), aggregation of finer-scale slope polygons (based on the soil mapping idea that accuracy is improved by mapping at half the final publication scale), and sampling or transect-based techniques that are guided by secondary DEM products.

6.4 Is it better to classify LUC from the dominant sibling or the proportional aggregate of sibling LUC?

The comparison between LUC classification based on the dominant sibling alone and that based on proportional aggregation of up to five siblings produced near-identical results, with overall agreement of 98.6% by count and a kappa statistic of 0.977. This finding has practical implications for model design: the additional computational complexity of proportional aggregation provides negligible benefit over the simpler, dominant-sibling approach, at least within the current modelling framework. The dominant-sibling method is therefore considered adequate for further iterations and is the recommended approach going forward for this type of modelling.

6.5 Expert feedback: key findings and implications

Expert review of model outputs across multiple regions provided valuable qualitative insights that complement the quantitative comparisons. Reviewers were specifically asked to identify problems and inconsistencies, so the feedback necessarily emphasises areas of poor performance. Nevertheless, the themes that emerged consistently across reviewers and geographically distinct regions are informative and useful for any future development.

The most pervasive concern was a tendency for the model to assign land to higher-capability LUC classes than expert knowledge would support. Poorly drained soils were classified as LUC 1 or 2 in cases where drainage limitations alone would preclude such classification; hill soils were assigned to LUC 2–3 where LUC 4–6 would be expected; and river flat soils subject to regular flooding were classified as LUC 2 or 3 rather than LUC 4. These patterns suggest that while the model's soil attribute thresholds are broadly appropriate, they may not be sufficiently conservative in cases where multiple moderate limitations interact, or where hazard factors not represented in S-map have a strong or overriding determination on LUC classification (e.g. unmitigated flood risk can change LUC by two or more classes. Conversely, permanent irrigation to overcome a soil moisture deficit limitation will improve LUC by at least one class, potentially more).

Several reviewers identified S-map data quality as a potential source of model discrepancies, independent of the model rules themselves. Concerns were raised regarding rooting barrier depths, horizon classifications, and the challenges of converting legacy soil series into S-map siblings, all of which were cited as contributing to misclassification in specific areas.

Manderson (2025) has also noted that salinity class data for a small area of soils in Hawke's Bay were identified as a cause of erroneous LUC classification.

Some degree of variation in input data quality is an expected and unavoidable condition of large-scale spatial modelling, particularly where data sets are compiled from a combination of structured qualitative and quantitative field survey methods. This applies to many of New Zealand's foundational mapping data sets – including geology, soils, and land resources – as well as the NZLRI itself. S-map is no exception. While it represents a highly structured and standardised system, and is a significant advance on previous approaches to soil data collection and storage both nationally and internationally, it nonetheless relies on field survey as its principal method of data collection. As with all comparable data sets, this means that data quality is inevitably variable: some parts of the database reflect more recent survey methods, greater site density, or more experienced practitioners than others.

Identifying where quality differences exist is, in our view, an important consideration for any modelling that draws on S-map as a primary input. A spatially explicit confidence layer – one that communicates the relative reliability of S-map data across the country – would substantially improve the interpretability of model outputs and help direct future investment in survey and data review towards areas where it would have the greatest impact on classification accuracy.

6.6 Factors and data outside of model scope

A recurring theme in expert feedback was the absence from the model of several land-use limitation factors that have traditionally informed LUC classification. These include flood risk and floodability, wind and water erosion susceptibility, and climate limitations such as growing season length, frost frequency, and exposure at elevation. The current model is necessarily soil-attribute-focused, reflecting both the scope of the project and the data available through S-map. However, the systematic under-representation of these factors means that in certain landscape contexts (particularly river flats, coastal sand country, and elevated or exposed terrain), modelled LUC outputs should be interpreted with caution.

The absence of floodability as a classification criterion is particularly consequential for lowland river systems, where many soils that would traditionally be assigned to LUC 3 or 4 on the basis of flood frequency are being modelled as LUC 1 or 2 on the strength of their soil attributes alone. Similarly, the omission of wind erosion susceptibility leads to systematic over-classification of coastal and inland sand country in several regions. These are not insurmountable limitations – relevant spatial data sets for flood risk and erosion susceptibility exist or are in development – but their integration into a future modelling framework would require both methodological development and agreement on appropriate classification thresholds.

Feedback was not provided on challenges regarding the inclusion or omission of land developments, especially with regard to permanent irrigation to overcome soil water deficit limitations, and artificial drainage to overcome wetness limitations. However, both have major implications for LUC classification and modelling, but we have only endeavoured to account for artificial drainage in this project. While this has had a positive effect on overall model performance, there were instances of some undrainable soils in Waikato being classified as more capable than either the experts or NZLRI were reporting. Data are available for integrating the removal of moisture deficit limitations (i.e. spatial irrigation data sets), but there are conceptual challenges that need to be addressed and tested.

The LUC handbook also contains several broad criteria that were too vague or challenging to use within this project's scope. One of these is the idea of cultivability, where LUC 1 is regarded as being easier to cultivate and can be cultivated more frequently than lower-capability arable land such as LUC class 4. While we started the development of a New Zealand cultivability layer, and made good progress, it is the type of work that requires its own separate testing before we would have confidence to include it as an LUC classification modelling criterion.

The most significant omission from modelling, however, has been input data that represent crop suitability, crop versatility, and, by implication, land-use suitability and land-use versatility. The omission is made partly because the handbook criteria on the topic are vague, but mostly because we do not have ready access to these data layers because many do not yet exist or haven't been developed in a way that can be used to inform LUC classification. Also, we do not have the same affordable access to necessary climate data layers as in the past. We see these types of suitability, versatility, capability etc. as a key pathway forward to not only provide essential information to land users and others, such as those involved in spatial planning, but also an opportunity to vastly improve on the work started here for LUC and NZLRI development.

It is also worth noting that our modelling has been developed based almost solely on the guidelines and criteria in the handbook. Many of these criteria are dated, especially regarding the types of limitations built into the classification. Of note are the omission of contemporary limitations such as nitrate leaching, phosphorus run-off, and the effects of permanent contamination from heavy metals and chemicals.

6.7 Modelling considerations: is it the best approach to modelling LUC?

The current model operates on a Boolean, rules-based logic in which each criterion is evaluated against a fixed threshold, and land either qualifies or does not qualify for a given LUC class. This approach has the advantage of transparency and reproducibility, and it aligns closely with the structure of the original LUC classification system. However, the results of this project raise the question of whether a strictly Boolean framework is well suited to the inherent continuity and overlap in soil and terrain properties that determine land-use capability.

Many of the classification errors identified – particularly those involving adjacent LUC classes – appear to reflect cases where soil or terrain attributes fall close to a threshold boundary, and where the binary nature of the rules results in a classification that is sensitive to small differences in input data. In such cases, a fuzzy logic or probabilistic approach could provide a more nuanced and arguably more accurate representation of LUC, by assigning degree-of-membership to multiple classes rather than forcing a binary outcome. Such approaches have been applied successfully in related New Zealand contexts (e.g. Manderson 2018; Manderson et al. 2019) and may warrant investigation in future model development.

The removal of regional parameterisation in this iteration of the model – a deliberate design decision aimed at producing a nationally consistent and reproducible output – is believed to have contributed to reduced performance in some regions, where local soil and terrain relationships were previously accommodated through region-specific thresholds. While de-regionalisation is appropriate for a national-scale model, the results suggest that some mechanism for accommodating known regional soil behaviour, perhaps through soil order or family-level rules rather than geographical boundaries, may be necessary to maintain classification accuracy across the full range of New Zealand's soil landscapes.

Original extraction and interpretation of LUC classification criteria were undertaken using appropriate expertise. However, a degree of expert interpretation was required for some criteria, and we suspect that some of the hard thresholds (e.g. for elevation and rainfall) are subjective in origin. Because of this, we have already instigated data mining and AI-driven reanalysis of the decision criteria and thresholds that go into making a given LUC classification. While the investigation is tentative at this stage, the aim is to improve this component of modelling with more defensible and objective criteria and thresholds.

There are also several alternative and technically more sophisticated modelling approaches that are being explored. Of greatest interest is a new focus on machine-learning frameworks such as random forest and gradient boosting, because these methods have consistently performed well for similar applications, including digital soil mapping, and we have available suitable data sets for training. Other moderately suitable frameworks include Bayesian and multi-criteria analysis types of approach, which fit well with the traditional decision-tree structure of LUC classification. In practice, however, the best approach may eventually be a hybrid or ensemble approach that takes the best results to produce the best overall LUC classification result.

6.8 Is the model an improvement on the NZLRI?

At this stage it is difficult to make a definitive claim that the modelled S-map-to-LUC outputs represent an improvement on NZLRI LUC 1–4 in all respects. We believe the theoretical basis for such a claim is sound: S-map provides a more consistent, attribute-rich, and spatially resolute representation of soils than the legacy survey data underlying the NZLRI, and the model applies classification criteria in a transparent and reproducible manner. In areas where S-map has been resurveyed with modern methods, there is evidence that the modelled outputs better reflect current soil knowledge than the NZLRI.

However, the comparison results indicate that in many areas the two classifications diverge substantially, and it is not always possible without detailed local knowledge to determine which is more accurate. The NZLRI captures a range of non-soil factors, including erosion risk, flooding, and practical land-use experience, that the current model does not. It also embeds decades of expert knowledge that, while qualitative, represent a significant evidence base. In order to confidently conclude that the model is superior to the NZLRI, more extensive independent validation than has been possible in this project, would be required, including field-based checking of areas of significant disagreement.

What can be said with confidence is that the model represents a meaningful and systematic improvement over previous modelling iterations, that it performs best when LUC classes are aggregated to the HPL/non-HPL level, and that it provides a reproducible, evidence-based platform that can be progressively refined as input data quality improves. It should be regarded as a complement to the NZLRI rather than a replacement, and the two data sets are best used together, with areas of significant disagreement flagged for expert review.

6.9 Towards a contemporary LUC classification and updated, fit-for-purpose NZLRI

The limitations identified in this project are not solely attributable to the model or method. They also reflect the inherent constraints of the LUC classification system itself, which was developed in an era when the available data, computational tools, and policy demands were fundamentally different from those of today. The LUC system was designed as a qualitative, expert-driven framework, and while it has served New Zealand well, it was not designed to be reproduced algorithmically from soil attribute databases or to meet the evidentiary standards increasingly demanded by contemporary resource management and spatial planning policy.

If the goal is a truly contemporary, evidence-based LUC classification that meets New Zealand's current and future needs, a more fundamental development of the system may ultimately be required. This would involve developing robust spatial layers for traditional land limitations, including wetness, moisture deficit, stoniness, flood risk, and erosion risk, and emerging considerations such as nitrogen leaching risk and soil degradation risk. These should be developed alongside land-use suitability and versatility classifications for key land uses, including pastoral farming, arable cropping, horticulture, forestry, and, to be truly contemporary, the ecologically important land uses such as wetlands that have historically been overlooked because of their relatively low agricultural value. These component layers could then be combined into an overall LUC classification that is transparent, reproducible, and updatable as new data become available.

Such a programme of work would represent a significant national investment. The NZLRI and its component data sets are among New Zealand's most valuable spatial information assets, yet we believe they have been chronically under-resourced relative to their policy significance. The contrast with national investment in flood hazard mapping or erosion hazard modelling is instructive: where a clear policy mandate and funding commitment exist, spatially explicit, evidence-based national data sets can be developed and maintained. A similar commitment to the renewal of LUC information – underpinned by S-map, high-resolution terrain data, and modern analytical methods – would substantially strengthen New Zealand's ability to make and defend decisions about its most productive soils.

The current project demonstrates both the promise and the current limitations of a model-based approach to LUC classification. It confirms that meaningful progress is achievable with existing data and methods, and that the theoretical foundation for a more rigorous, data-driven LUC is sound. What is now required is a clearer articulation of what a contemporary New Zealand LUC classification should look like, what data and methods would be needed to produce it, and what national investment would be required to develop and sustain it. This is ultimately a question of policy as much as science, but the scientific case for taking it seriously has never been stronger.

7 Conclusions

Modelling LUC Classes 1–4 from S-map and DEM-derived terrain data has demonstrated that a reproducible, evidence-based approach to national-scale land capability classification is achievable. The model produced an aggregate estimate of approximately 5.07 million ha of LUC Classes 1–4 (43% of the modelling area), broadly consistent with the NZLRI (5.18 million hectares and 44% of total area), and achieved overall agreement of 64.1% (by count) and 64.8% (by area) with the NZLRI at the individual class level, which is a meaningful improvement over previous modelling iterations. Agreement increased to approximately 80.6% and 82.8% (by count and area, respectively) when LUC 1–3 were aggregated into a single HPL category, indicating that the model reliably distinguishes HPL from non-HPL land, even where individual class boundaries remain uncertain. These outputs should be regarded as a complement to the NZLRI rather than a replacement, with areas of significant disagreement warranting expert review before application in policy or planning contexts.

DEM-derived slope consistently outperformed S-map slope as a model input, improving overall agreement with the NZLRI by approximately 9%. However, both slope sources are subject to limitations for large, topographically heterogeneous polygons, and how slope should best be characterised within the current polygon-based soil mapping framework remains an unresolved methodological challenge requiring further investigation. Classification based on the dominant sibling and proportional aggregation of siblings produced near-identical results, confirming that the simpler dominant-sibling approach is adequate for this type of modelling.

Expert review identified a consistent tendency for the model to assign land to higher-capability classes than local knowledge supports, particularly for poorly drained soils, hill country, and flood-prone river flats. This reflects the systematic absence from the model of several important classification factors – including flood risk, erosion susceptibility, and climate limitations – as well as variability in S-map data quality, particularly in areas where legacy soil surveys have been converted to the sibling framework by different practitioners. A spatially explicit S-map confidence layer is recommended to improve model interpretability and guide future investment in data quality.

The Boolean, rules-based modelling framework, while transparent and reproducible, is sensitive to threshold placement and does not handle multiple interacting moderate limitations well. Fuzzy logic, machine-learning approaches such as random forest and gradient boosting, and hybrid ensemble methods are identified as priority areas for future methodological investigation. The removal of regional parameterisation is also believed to have reduced performance in some cases, suggesting that soil-order or family-level rule adjustments may be an option to maintain classification accuracy nationally.

The most significant omissions from the current model are land-use suitability and versatility criteria, which are central to the LUC framework, and the effects of land development factors such as permanent irrigation and artificial drainage. Access to affordable climate data remains the primary constraint on developing a land-use suitability classification, and progress on this front is considered essential for any future iteration that seeks to fully implement the LUC system as originally conceived.

More broadly, the limitations identified in this project reflect not only the constraints of current data and methods, but also the age of the LUC classification system itself. A truly contemporary, fit-for-purpose national land capability classification would require sustained investment in spatial data infrastructure, including limitation and hazard layers, land-use suitability classifications, and high-resolution soil survey, and comparable to that directed at flood and erosion hazard mapping. The

scientific and policy case for this investment is strong, and the work presented provides a sound foundation on which to build it, because it provides the underlying evidence for the following recommendations.

8 Recommendations

- Adopt DEM-derived slope as the default input. DEM-derived slope consistently outperformed S-map slope in model comparisons and should be used as the default slope input in all future modelling iterations. We also recommend that methods for more accurately characterising slope within polygons be investigated.
- Prioritise the integration of unused classification factors. Flood risk, erosion susceptibility, and climate limitations are consistently absent from the current model and are contributing to systematic over-classification of lowland, coastal, and elevated terrain. Integration of these factors – drawing on the New Zealand Flood Map project (anticipated 2027), existing erosion susceptibility data sets, and climate data under negotiation – should be treated as a priority for any further development work.
- Develop the necessary classifications and layers for the various suitabilities, vulnerabilities, and versatilities mentioned in this report. This is the most significant gap relative to the full intent of the LUC framework for the arable LUC classes. Securing affordable access to climate data and developing this classification, encompassing both traditional LUC land uses and emerging uses such as viticulture, should be pursued as a matter of priority, building on collaborative relationships currently being established within BSI.
- Investigate alternative and hybrid modelling frameworks. The current Boolean rules-based approach has known limitations in handling threshold sensitivity and interacting moderate limitations. Fuzzy logic, random forest, gradient boosting, and hybrid ensemble approaches should be formally evaluated as candidate frameworks for future model development, alongside AI-assisted reanalysis of classification criteria and thresholds to improve their objectivity and defensibility.
- Develop a spatially explicit S-map confidence layer. Variability in S-map data quality – particularly in areas where legacy surveys have been converted to the sibling framework – is a material source of model uncertainty. A national confidence layer communicating the relative reliability of S-map data would improve model interpretability, support end-user decision-making, and help direct future investment in survey and data review toward areas of greatest need.
- Commit to a nationally funded programme to ensure policy and legislation are underpinned by fit-for-purpose soil and land data and information. The limitations identified in this project ultimately reflect chronic under-investment in New Zealand's LUC and NZLRI infrastructure. A sustained, nationally funded programme – encompassing improvements in soil data, spatial limitation and hazard layers, land-use suitability classifications, and modern modelling methods – is required to produce a contemporary LUC classification that meets current and future policy needs.

9 Acknowledgements

We would like to acknowledge Fiona Curran-Cournane as a supporting and driving force behind much of the new work, including this project, which is seeking to ensure New Zealand's most important productive land – a finite natural resource – is protected for future generations. We would also like to acknowledge the LUC Governance Group, who continue to support and advance correct LUC application and improvement at the many scales and different ways it is used in New Zealand. We also gratefully acknowledge the Ministry for the Environment, who provided the funding that allows the BSI to provide our technical and scientific rigour to help inform the development of policy and legislation and ensure the best science is being used.

Declaration of the use of generative AI / AI-assisted technologies

This research work included the use of Claude AI (Sonnet 4.6 model) to help check and refine the template R code used to compare model outputs with the NZLRI and high value land use data. It was also used to isolate key recurring themes from expert feedback, and to summarise preceding work by the author to help identify key conclusions and recommendations. In all cases where AI has been used to assist, the content was reviewed and heavily edited (and in many cases completely replaced).

10 References

- Andrew R, Dymond J 2012. Expansion of lifestyle blocks and urban areas onto high-class land. *Journal of the Royal Society of New Zealand* 43: 128–140.
- Barringer J, Wilde H, Willoughby J, Burgham S, Hewitt A, Gibb R, Newsome P, Rijkse W 1998. Restructuring the New Zealand Land Resource Inventory to meet the changing needs for spatial information in environmental research and management. 10th Colloquium of the Spatial Information Research Centre, University of Otago, New Zealand, 16–19 November 1998. Pp. 25–33. <https://www.researchgate.net/publication/228892268>.
- Bloomer D 2011. Versatile soils – productive land. Page Bloomer Associates Ltd. Report prepared for Hawke's Bay Regional Council, New Zealand.
- Carrick S, Drewry J, Barnes M, et al. 2020. Land fragmentation environmental reporting indicator – technical methods for analysis from 2002 to 2019. Manaaki Whenua – Landcare Research Contract Report LC3846.
- Curran-Cournane F, Carrick S, Barnes MG, et al. 2023. Cumulative effects of fragmentation and development on highly productive land in New Zealand. *New Zealand Journal of Agricultural Research* 66: 1–24.
- Curran-Cournane F, Vaughan M, Memon A, Fredrickson C 2014. Trade-offs between high class land and development: recent and future pressures on Auckland's valuable soil resources. *Land Use Policy* 39: 146–154.
- Dark A 2020. National irrigated land spatial dataset: 2020 update. Ministry for the Environment. <https://environment.govt.nz/assets/Publications/national-irrigated-land-spatial-dataset.pdf>
- Dymond JR, Shepherd JD 2004. The spatial distribution of indigenous forest and its composition in the Wellington region, New Zealand, from ETM+ satellite imagery. *Remote Sensing of Environment* 90: 116–125.

- ESNZ (Earth Sciences New Zealand) 2026. Climatology grid total rainfall (1991–2020): regional climatology gridded data. NIWA. <https://data.niwa.co.nz/products/climatology-grids>
- Ford R 2019. Implementing a nationally funded S-map programme: S-map briefing paper report. <https://silverstripe-prod-smap.s3.ap-southeast-2.amazonaws.com/public/Uploads/S-map-briefing-paper-report-Oct2019.pdf>
- Griffiths E 2001. Soils of the Heretaunga Plains: A Guide to Their Management. Napier, New Zealand: Grifftech and Hawke's Bay Regional Council. 102 p.
- Harmsworth, G.R. 1996. Land Use Capability Classification of the Northland Region: A Report to Accompany the Second Edition (1:50,000) New Zealand Land Resource Inventory Worksheets. Landcare Research Science Series No. 9. Lincoln, New Zealand: Manaaki Whenua Press. 269 p.
- Hewitt AE 2010. New Zealand soil classification (3rd edn). Manaaki Whenua Press.
- Lilburne L, Guo J, Barringer J, et al. 2020. Comparison of S-map soil information with the older fundamental soil layers: implications for modelling. In: CL Christensen, DJ Horne, R Singh eds. Nutrient management in farmed landscapes. Occasional Report No. 33. Farmed Landscapes Research Centre, Massey University. <http://flrc.massey.ac.nz/publications.html>
- Lilburne L, Hewitt A, Webb TH, et al. 2004. S-map: a new soil database for New Zealand. In SuperSoil 2004: 3rd Australian New Zealand Soils Conference. University of Sydney.
- Lilburne L, Ross J 2025. Expanding our horizons: further coverage for S-map. Soil Horizons 34.
- Lilburn L, Webb T 2022. S-map correlation of soils in the Fundamental Soil Layer. Manaaki Whenua – Landcare Research Contract Report LC4226. <https://environment.govt.nz/assets/publications/Freshwater/smap-correlation-of-soils-report.pdf?v=f91466bbf257b486b73d8ac92b04af9c5e74d4d1>
- LINZ (Land Information New Zealand) 2026. National elevation programme. <https://www.linz.govt.nz/products-services/data/types-linz-data/elevation-data>
- Lynn IH, Lilburne LR 2013. Deriving land use capability classes from the S-map database. Landcare Research. Unpublished report.
- Lynn IH, Manderson AK, Page MJ, et al. 2009. Land use capability survey handbook: a New Zealand handbook for the classification of land. (3rd edn). AgResearch Ltd.
- Lynn IH, Manderson AK, Page MJ, et al. 2021. Land use capability survey handbook: a New Zealand handbook for the classification of land (3rd edn, revised and reprinted). AgResearch Ltd.
- MacMillan RA, Shary PA 2009. Landforms and landform elements in geomorphometry. In: T. Hengl, HJ Reuter eds. Geomorphometry: concepts, software, applications. Elsevier. Pp. 227–254.
- Manderson A, Lilburne L, Hewitt A, Pollacco J, Carrick S 2015. Recommendations and interim soils data to support the development of a national freshwater reporting model. Manaaki Whenua – Landcare Research Contract Report LC2380.
- Manderson A 2018. Mapping the extent of artificial drainage in New Zealand. Manaaki Whenua – Landcare Research Contract Report LC3325.
- Manderson A 2024. Developing a method of mapping Land Use Capability (LUC) classes 1, 2, & 3 from S-Map data for the Hawkes Bay Region. Manaaki Whenua - Landcare Research contract report LC4461 for Hawkes Bay Regional Council.

- Manderson A 2025. Modelling Land Use Capability classes 1-3 from S-map for Waikato Highly Productive Land mapping. MWLR contract report LC4612 for Waikato Regional Council.
- Manderson A, Belliss S 2016. Proposal for estimating artificial drainage extent in New Zealand. Landcare Research Contract Report LC2690.
- Manderson A, Hoogendoorn C, Newsome P 2019. Grassland improvement mapping using Innovative Data Analysis (IDA) techniques. Manaaki Whenua – Landcare Research Contract Report LC3373, prepared for the Ministry for the Environment.
- Manderson A, Ward A, McCollum K 2026. Mapping of highly productive land in the Horizons region (in preparation). Manaaki Whenua – Landcare Research.
- MfE (Ministry for the Environment) 2022. Method for deriving the stock exclusion low slope land map for the Resource Management (Stock Exclusion) Regulations 2020 (December 2022 update). <https://environment.govt.nz/assets/publications/Method-for-deriving-the-stock-exclusion-low-slope-land-map.pdf>
- MfE (Ministry for the Environment) 2024. Highly productive land. <https://environment.govt.nz/facts-and-science/land/highly-productive-land/>
- MfE (Ministry for the Environment) 2025. National Policy Statement for Highly Productive Land 2022. Amended December 2025. <https://environment.govt.nz/publications/national-policy-statement-for-highly-productive-land-2/>
- MfE (Ministry for the Environment) 2026. New Zealand flood map: developing the first map to provide flood risk information for the whole of New Zealand. <https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/adapting-to-climate-change/national-adaptation-framework/new-zealand-flood-map/> (accessed 30 May 2026).
- MfE, MPI (Ministry for the Environment, Ministry for Primary Industries) 2022. National policy statement for highly productive land (amended December 2025). Ministry for the Environment. <https://environment.govt.nz/assets/publications/npsmpl-2022-amended-december-2025.pdf>
- Molloy LF (ed.). 1980. Land alone endures: land use and the role of research. Discussion Paper No. 3. New Zealand Department of Scientific and Industrial Research.
- MPI, MfE (Ministry for Primary Industries, Ministry for the Environment) 2019. Valuing highly productive land: a discussion document on a proposed national policy statement for highly productive land. MPI Discussion Paper 2019/05. New Zealand Government.
- MWLR (Manaaki Whenua – Landcare Research) 2025. LCDB v6.0 – Land Cover Database version 6.0, mainland New Zealand.
- National Water and Soil Conservation Organisation (NWASCO) 1979. Our Land Resources. Wellington, New Zealand: National Water and Soil Conservation Organisation. 79 p.
- Parliamentary Commissioner for the Environment (PCE) 2025. Reviewing the Use of the Land Use Capability (LUC) System in a Regulatory Context. Wellington, New Zealand: Parliamentary Commissioner for the Environment.
- Rutledge DT, Price R, Ross C, et al. 2010. Thought for food: impacts of urbanisation trends on soil resource availability in New Zealand. Proceedings of the New Zealand Grassland Association 72: 241–246.
- Soil Bureau 1954. General survey of the soils of North Island, New Zealand. Bulletin No. 5. New Zealand Soil Bureau.

- Soil Bureau 1968. General survey of the soils of South Island, New Zealand. Bulletin No. 27. New Zealand Soil Bureau.
- Soil Conservation and Rivers Control Council 1969. Land use capability handbook. Water and Soil Division, Ministry of Works.
- Soil Conservation and Rivers Control Council 1974. Land use capability survey handbook: as New Zealand handbook for the classification of land. Soil Conservation and Rivers Control Council.
- Soil Conservation Service 1961. Land-capability classification. USDA handbook No. 210. US Government Printing Office. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052290.pdf
- Webb TH, Lilburne LR 2011. Criteria for defining the soil family and soil sibling: the fourth and fifth categories of the New Zealand soil classification. Landcare Research Science Series No. 3 (2nd edn). Manaaki Whenua Press.

Appendix 1 – Definitions and values for S-map attributes

The following tables list the S-map attribute symbols and their descriptions from the S-map data definitions manual.

Table A1. S-map slope classes

Code	Degrees	Description
A	0–3°	Flat to gently undulating slopes
B	4–7°	Undulating slopes
C-	8–11°	Easy rolling slopes
C+	12–15°	Moderately rolling slopes
C	8–15°	Rolling slopes
D	16–20°	Strongly rolling slopes
E	21–25°	Moderately steep slopes
F	26–35°	Steep slopes
G	>35°	Very steep slopes
W	0–15°	Wheel-able slopes (wheeled-tractor territory: A–C slopes)
H	16–25°	Hilly (D and E slopes)
S	>26°	Steep and very steep (F and G slopes)

Table A2. Soil-profile-material classes of mineral soils

Code	Name	Description
Mf	Fragmental soils	Soils in which gravels and/or boulders, with insufficient fine earth to fill interstices, begin within 20 cm of the mineral soil surface and extend to more than 60 cm
MI	Lithic soils	Other soils that have coherent-lithic or shattered-lithic contact at less than 45 cm from the mineral soil surface
Mp	Paralithic soils	Other soils that have a paralithic contact less than 45 cm from the mineral soil surface
Mt	Tephric soils	Other soils with at least 30 cm of tephric soil material, with or without the properties of allophanic or vitric soil material, within 100 cm of the mineral soil surface. Tephra may be significantly weathered such as in Granular Soils (Hamilton Ash) or reworked by fluvial/colluvial processes (Hinuera Formation).
Mr	Rounded-stony soils	Other soils with 35% or more rounded or subrounded gravel or boulders by volume extending from within 45 cm of the mineral soil surface to a depth of more than 100 cm
Ma	Angular-stony soils	Other soils with 35% or more angular or subangular gravel or boulders by volume extending from within 45 cm of the mineral soil surface to a depth of more than 100 cm
Mm	Moderately deep soils on rock	Other soils that have lithic or paralithic contact at less than 100 cm from the mineral soil surface
Mg	Moderately deep soils on gravel	Other soils with 35% or more rounded or subrounded gravel or boulders by volume occurring within 45 cm to 90 cm from the mineral soil surface and extending continuously to 100 cm depth and having a cumulative thickness of 50 cm or greater (unless overlying rock)
Md	Stoneless soils	Other soils that have less than 3% (weighted average) gravel by volume in the upper 100 cm of mineral soil
Ms	Soils with stones	Other soils

Table A3. Definition of soil depth and rooting depth classes

Code	Name	Soil depth (cm)
d	Deep	≥100
md	Moderately deep	≥45, <100
s	Shallow	≥20, <45
vs	Very shallow	<20

Table A4. Definition of topsoil stoniness classes

Code	Name	Percent of stones by volume in top 20 cm
1	Stoneless	<1
2	Slightly stony	≥1, <5
3	Moderately stony	≥5, <35
4	Very stony	≥35

Table A5. S-map salinity classes

Code	Name	Description
S	Strongly saline	Saline above 20 cm depth (electrical conductivity ≥0.8 mS/cm)
M	Moderately saline	Saline subsoil at 20–60 cm depth (electrical conductivity ≥0.8 mS/cm)
W	Weakly saline	Electrical conductivity < 0.79 mS/cm (shallower than 60 cm) or saline subsoil (deeper than 60 cm)
N	Not saline	

Table A6. S-map permeability classes

Code	Name	Permeability (mm/h)
s	Slow	<4
m	Moderate	≥4, <72
r	Rapid	≥72

Table A7. Drainage classes

Code	Name	Classification criteria (uses standard horizon notation)
vp	Very poorly drained	Peaty topsoil OR Bg, Br, Cg, Cr, Eg, Er < 10 cm from surface
p	Poorly drained	Bg, Br, Cg, Cr, Eg, Er < 30 cm from surface OR Bg, Br, Cg, Cr, Eg, Er < 15 cm below topsoil
i	Imperfectly drained	Bg, Br, Cg, Cr, Eg, Er within 30 to < 60 cm OR Bw(g), C(g), Ew(g) < 30 cm from surface OR Bw(g), C(g), Ew(g) < 15 cm below topsoil
mw	Moderately well drained	Bw(f), C(f) < 90 cm from surface OR Bg, Br, Cg, Cr, Eg, Er within 60 to < 90 cm OR Bw(g), C(g), Ew(g) within 30 to < 90 cm
w	Well drained	Other

Table A8. S-map texture groups

Code	Name	Carbon (%)	Silt (%)	Clay (%)
c	Clayey	<18		≥35
s	Sandy	<18	<40	<8
l	Loamy	<18	<40	≥8, <35
z	Silty	<18	≥40	<35
p	Peaty	≥18		

Appendix 2 – Description of model fields

Description of fields, with example data.

Table A9. List of S-map attributes used in this project

Field	Example data	Description
SOILMAPUC	cgl_WRC_100004	S-map reference
GISLAYER	Waikato	S-map GIS layer
SMU	Waikato\ cgl_WRC_100004	S-map map unit code
SiblingList	Bushc_47 (100%)	Sibling name & proportion
SmapSib1	Bushc_47a.1	Sibling name
sib1_prop	100	Sibling proportion (%)
SlopeCode	C	S-map slope code for sibling
sib1_conf	M	S-map map unit confidence
NZSC	BOM	NZ Soil Classification
NZSCOrder	B	NZ Soil Classification order
nzscGroup	O	NZ Soil Classification group
nzscSubGroup	M	NZ Soil Classification subgroup
SoilProfileMaterial	Mg	Soil profile material
ParentMaterialOrigin	Lo/FI	Parent material origin
TextureGroupCode	z	S-map texture group
PermeabilityCode	m	S-map permeability
SiblingDepthCode	md	S-map sibling depth
SiblingTopsoilStonesCode	3	S-map sibling topsoil stones
SiblingDrainageCode	i	S-map sibling drainage
SiblingTexture	z/l	S-map sibling texture 1
UpperTexture	z	S-map sibling texture 2
LowerTexture	z	S-map sibling texture 3
RootBarrierCode	L	Rooting barrier
RootBarrier	Low penetration soil material	Type of root barrier
FH1	tSLw	Functional Horizon 1
FH2	SLw	Functional Horizon 2
FH3	VLc	Functional Horizon 3
FH4	<Null>	Functional Horizon 4
FH5	<Null>	Functional Horizon 5
FH6	<Null>	Functional Horizon 6
Depth	45	Soil depth cm
DepthRange	35–55 cm	Soil depth range cm
RootDepth	45	Rooting depth cm
rootDepthRange	35–55 cm	Rooting depth range cm
SlowDepth	100	Depth to a slowly permeable layer cm
slowdepthRange	No slowly permeable horizon	Depth to a slowly permeable layer range cm
PAWmm	79	Profile available water mm
SVI	0.64	Structural Vulnerability Index
Salinity	N	Salinity code
LocalSeriesName		Local name of soil series if known

Table A10. Field names, descriptions, and example data for model processing

Field	Example data	Description
OBJECTID *	1	Unique ID
Shape *	Polygon	Feature type
SmapSib1	Taup_85a.1	Sibling name
sib1_prop	100	Sibling proportion (%)
Sib1_unique	ID_1	Unique ID for each sibling – unique only to this feature layer
RAIN	1,434	Mean rainfall of map unit (NIWA data via zonal stats)
ELEV	890	Mean elevation of map unit (LiDAR data via zonal stats)
SLOPE	10	Mean slope of map unit (LiDAR data via zonal stats)
luc1_slp_ldr	0	LUC 1 result for slope criteria (LiDAR slope)
luc1_PM	1	LUC 1 result for parent material criteria
luc1_depth	1	LUC 1 result for soil depth criteria
luc1_rooting	1	LUC 1 result for rooting depth criteria
luc1_perm	1	LUC 1 result for permeability criteria
luc1_TXT1	0	LUC 1 result for texture 1 criteria
luc1_TXT2	0	LUC 1 result for texture 2 criteria
luc1_drain	1	LUC 1 result for drainage class criteria
luc1_Tsstones	0	LUC 1 result for stoniness criteria
luc1_Salt	1	LUC 1 result for salinity criteria
luc1_DSLO	1	LUC 1 result for depth to a slow horizon criteria
luc1_PAW	1	LUC 1 result for profile available water criteria
luc1_NZSC	0	LUC 1 result for NZ Soil Classification criteria
luc1_ELEV	0	LUC 1 result for elevation criteria
luc1_RAIN	1	LUC 1 result for rainfall criteria
luc1_Out1	9	LUC 1 sum of criteria results (S-map input data only)
luc2_slp_ldr	0	LUC 2 result for slope criteria (LiDAR slope)
luc2_PM	1	LUC 2 result for parent material criteria
luc2_depth	1	LUC 2 result for soil depth criteria
luc2_rooting	1	LUC 2 result for rooting depth criteria
luc2_perm	1	LUC 2 result for permeability criteria
luc2_TXT1	0	LUC 2 result for texture 1 criteria
luc2_TXT2	1	LUC 2 result for texture 2 criteria
luc2_drain	1	LUC 2 result for drainage class criteria
luc2_Tsstones	0	LUC 2 result for stoniness criteria
luc2_Salt	1	LUC 2 result for salinity criteria
luc2_DSLO	1	LUC 2 result for depth to a slow horizon criteria
luc2_PAW	1	LUC 2 result for profile available water criteria
luc2_NZSC	0	LUC 2 result for NZ Soil Classification criteria
luc2_ELEV	0	LUC 2 result for elevation criteria
luc2_RAIN	1	LUC 2 result for rainfall criteria
luc2_Out2	10	LUC 2 sum of criteria results (S-map + external data inputs)
luc3_slp_ldr	1	LUC 3 result for slope criteria (LiDAR slope)

Field	Example data	Description
luc3_PM	1	LUC 3 result for parent material criteria
luc3_depth	1	LUC 3 result for soil depth criteria
luc3_rooting	1	LUC 3 result for rooting depth criteria
luc3_perm	1	LUC 3 result for permeability criteria
luc3_TXT1	1	LUC 3 result for texture 1 criteria
luc3_TXT2	1	LUC 3 result for texture 2 criteria
luc3_drain	1	LUC 3 result for drainage class criteria
luc3_Tsstones	0	LUC 3 result for stoniness criteria
luc3_Salt	1	LUC 3 result for salinity criteria
luc3_DSLO	1	LUC 3 result for depth to a slow horizon criteria
luc3_PAW	1	LUC 3 result for profile available water criteria
luc3_NZSC	1	LUC 3 result for NZ Soil Classification criteria
luc3_ELEV	0	LUC 3 result for elevation criteria
luc3_RAIN	1	LUC 3 result for rainfall criteria
luc3_Out2	13	LUC 3 sum of criteria results (S-map + external data inputs)
luc4_slp_ldr	1	LUC 4 result for slope criteria (LiDAR slope)
luc4_PM	1	LUC 4 result for parent material criteria
luc4_depth	1	LUC 4 result for soil depth criteria
luc4_rooting	1	LUC 4 result for rooting depth criteria
luc4_perm	1	LUC 4 result for permeability criteria
luc4_TXT1	1	LUC 4 result for texture 1 criteria
luc4_TXT2	1	LUC 4 result for texture 2 criteria
luc4_drain	1	LUC 4 result for drainage class criteria
luc4_Tsstones	1	LUC 4 result for stoniness criteria
luc4_Salt	1	LUC 4 result for salinity criteria
luc4_DSLO	1	LUC 4 result for depth to a slow horizon criteria
luc4_PAW	1	LUC 4 result for profile available water criteria
luc4_NZSC	1	LUC 4 result for NZ Soil Classification criteria
luc4_ELEV	1	LUC 4 result for elevation criteria
luc4_RAIN	1	LUC 4 result for rainfall criteria
luc4_Out2	15	LUC 4 sum of criteria results (S-map + external data inputs)
Island	North	North or South Island for elevation and rainfall criteria
Depth2	100	Soil depth reformatted as a number
RootDepth2	100	Root depth reformatted as a number
SlopeCode2	A	NZLRI slope classes from Lidar
SlopeCode3	B	Amended S-map slope classes to correct to NZLRI classes and infill any null values
Sib1_domLUC_1a	LUC 1	
Sib1_domLUC_1b	LUC 1	
Hectares	6.404755	Hectares
Sib1_LUC_min_slp1	LUC 1	LUC class result for dominant sibling using S-map slope classes
Sib1_LUC_min_slp2	LUC 1	LUC class result for dominant sibling using LiDAR slope statistics.

Appendix 3 – Model code (mineral soils)

The following PYTHON3 code is designed to be run as ArcPy script, so it must be run in an ArcGIS Python environment under ArcGIS Pro.

```
# -*- coding: utf-8 -*-
# -----
# combined_luc_model_pro.py
#
# Combined and modernized from:
#   1_LUC1.py
#   2_LUC2.py
#   3_LUC3.py
#   4_LUC4.py
#   5_final.py
#
# Description:
#   Runs LUC1 -> LUC2 -> LUC3 -> LUC4 -> Final classification sequentially
#   on a single input feature class/table.
#
# Features:
#   - ArcGIS Pro / PYTHON3-friendly CalculateField usage
#   - Adds missing fields automatically
#   - Logs progress
#   - Can run as standalone script or script tool
#
# Usage:
#   python combined_luc_model_pro.py <input_feature_class>
#
# Or as ArcGIS script tool:
#   Parameter 0 = input feature class/table
# -----

import sys
import traceback
import arcpy

# -----
# Logging helpers
# -----

def log(message):
```

```

    try:
        arcpy.AddMessage(message)
    except Exception:
        pass
    print(message)

def warn(message):
    try:
        arcpy.AddWarning(message)
    except Exception:
        pass
    print(f"WARNING: {message}")

def err(message):
    try:
        arcpy.AddError(message)
    except Exception:
        pass
    print(f"ERROR: {message}")

# -----
# Field management helpers
# -----

def list_field_names(table):
    return {f.name.lower(): f for f in arcpy.ListFields(table)}

def field_exists(table, field_name):
    return field_name.lower() in list_field_names(table)

def ensure_field(table, field_name, field_type="LONG", field_length=None):
    """
    Add a field if it does not already exist.
    """
    if field_exists(table, field_name):

```

```

    return

    log(f"Adding field: {field_name} ({field_type})")
    if field_type.upper() == "TEXT":
        if field_length is None:
            field_length = 50

        arcpy.management.AddField(table, field_name, field_type,
field_length=field_length)
    else:
        arcpy.management.AddField(table, field_name, field_type)

def calc_field(table, field_name, expression, code_block=None, field_type="LONG",
field_length=None):
    """
    Ensure the field exists, then calculate it using PYTHON3.
    """
    ensure_field(table, field_name, field_type=field_type, field_length=field_length)
    log(f"Calculating field: {field_name}")
    arcpy.management.CalculateField(
        in_table=table,
        field=field_name,
        expression=expression,
        expression_type="PYTHON3",
        code_block=code_block
    )

# -----
# Validation helpers
# -----

def require_fields(table, required_fields):
    existing = list_field_names(table)
    missing = [f for f in required_fields if f.lower() not in existing]
    if missing:
        raise ValueError(
            "The following required input fields are missing from {}: \n{}".format(
                table, ", ".join(missing)
            )
        )

```

```

    )

# -----
# LUC1
# -----

def run_luc1(table):
    log("=== Running LUC1 ===")

    calc_field(
        table, "luc1_slp_smap", "eval_slopecode(!SlopeCode2!)",
        """
def eval_slopecode(SlopeCode2):
    if SlopeCode2 in ("A", "B"):
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc1_slp_ldr", "eval_slope(!SLOPE!)",
        """
def eval_slope(SLOPE):
    if SLOPE is not None and SLOPE <= 7:
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc1_PM", "eval_pm(!SoilProfileMaterial!)",
        """
def eval_pm(SoilProfileMaterial):
    if SoilProfileMaterial in ("Md", "Ms", "Mt"):
        return 1
    return 0
"""
    )

```

```

    calc_field(
        table, "luc1_depth", "eval_depth(!Depth2!)",
        """
def eval_depth(Depth2):
    if Depth2 is not None and Depth2 >= 100:
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc1_rooting", "eval_rooting(!RootDepth2!)",
        """
def eval_rooting(RootDepth2):
    if RootDepth2 is not None and RootDepth2 >= 100:
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc1_perm", "eval_perm(!PermeabilityCode!)",
        """
def eval_perm(PermeabilityCode):
    if PermeabilityCode in ("m", "r", "m/r", "r/m"):
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc1_TXT1", "eval_txt1(!UpperTexture!, !NZSC!, !NZSCOrder!)",
        """
def eval_txt1(UpperTexture, NZSC, NZSCOrder):
    if NZSC in ("NOL", "NOT"):
        return 1
    elif NZSCOrder == "L":
        return 1
    elif UpperTexture in ("l", "z"):
        return 1

```

```

    return 0
"""
)

    calc_field(
        table, "luc1_TXT2", "eval_txt2(!LowerTexture!, !NZSC!, !NZSCOrder!)",
        """
def eval_txt2(LowerTexture, NZSC, NZSCOrder):
    if NZSC in ("NOL", "NOT"):
        return 1
    elif NZSCOrder == "L":
        return 1
    elif LowerTexture in ("l", "z"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc1_drain", "eval_drain(!SiblingDrainageCode!, !NZSC!, !NZSCOrder!,
!NZSCGroup!)",
        """
def eval_drain(SiblingDrainageCode, NZSC, NZSCOrder, NZSCGroup):
    if SiblingDrainageCode in ("w", "mw"):
        return 1
    elif SiblingDrainageCode == "i" and NZSCOrder == "P" and NZSCGroup == "I":
        return 1
    elif SiblingDrainageCode == "p" and NZSC in ("GRT", "GOT", "GOA"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc1_Tsstones", "eval_tsstones(!SiblingTopsoilStonesCode!)",
        """
def eval_tsstones(SiblingTopsoilStonesCode):
    if SiblingTopsoilStonesCode in ("1", "2"):
        return 1
    return 0
"""
)

```

```

"""
)

    calc_field(
        table, "luc1_Salt", "eval_salt(!Salinity!)",
        """
def eval_salt(Salinity):
    if Salinity == "N":
        return 1
    return 0
"""
)

    calc_field(
        table, "luc1_DSLO", "eval_dslo(!SlowDepth!)",
        """
def eval_dslo(SlowDepth):
    if SlowDepth is not None and SlowDepth >= 100:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc1_PAW", "eval_paw(!PAWmm!)",
        """
def eval_paw(PAWmm):
    if PAWmm is not None and PAWmm >= 145:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc1_NZSC", "eval_nzsc(!NZSC!, !NZSCOrder!, !NZSCGroup!,
!NZSCSubGroup!)",
        """
def eval_nzsc(NZSC, NZSCOrder, nzscGroup, nzscSubGroup):
    if NZSC in ("MPT", "MIMW"):
        return 0

```

```

elif NZSCOrder == "M" and nzscSubGroup == "W":
    return 0
elif NZSCOrder == "M" and nzscGroup == "O":
    return 0
return 1
"""
)

calc_field(
    table, "luc1_ELEV", "eval_elev(!ISLAND!, !ELEV!)",
    """
def eval_elev(ISLAND, ELEV):
    if ISLAND == "N" and ELEV is not None and ELEV <= 350:
        return 1
    elif ISLAND == "S" and ELEV is not None and ELEV <= 200:
        return 1
    return 0
"""
)

calc_field(
    table, "luc1_RAIN", "eval_rain(!ISLAND!, !RAIN!)",
    """
def eval_rain(ISLAND, RAIN):
    if RAIN is None:
        return 0
    if ISLAND == "N" and 650 <= RAIN <= 1500:
        return 1
    elif ISLAND == "S" and 650 <= RAIN <= 1500:
        return 1
    return 0
"""
)

calc_field(
    table,
    "luc1_Out2",
    "!luc1_slp_ldr! + !luc1_PM! + !luc1_depth! + !luc1_rooting! + !luc1_perm! +
!luc1_TXT1! + !luc1_TXT2! + !luc1_drain! + !luc1_Tsstones! + !luc1_Salt! + !luc1_DSL0!
+ !luc1_PAW! + !luc1_NZSC! + !luc1_ELEV! + !luc1_RAIN!"
)

```

```

    calc_field(
        table,
        "luc1_Out1",
        "!luc1_slp_smap! + !luc1_PM! + !luc1_depth! + !luc1_rooting! + !luc1_perm! +
!luc1_TXT1! + !luc1_TXT2! + !luc1_drain! + !luc1_Tsstones! + !luc1_Salt! + !luc1_DSL0!
+ !luc1_PAW! + !luc1_NZSC! + !luc1_ELEV! + !luc1_RAIN!"
    )

# -----
# LUC2
# -----

def run_luc2(table):
    log("=== Running LUC2 ===")

    calc_field(
        table, "luc2_slp_ldr", "eval_slope(!SLOPE!)",
        """
def eval_slope(SLOPE):
    if SLOPE is not None and SLOPE <= 7:
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc2_slp_smap", "eval_smap(!SlopeCode2!)",
        """
def eval_smap(SlopeCode2):
    if SlopeCode2 in ("A", "B"):
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc2_PM", "eval_pm(!SoilProfileMaterial!)",
        """
def eval_pm(SoilProfileMaterial):

```

```

    if SoilProfileMaterial in ("Md", "Ms", "Mt", "Mg", "Mm"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_depth", "eval_depth(!Depth2!)",
        """
def eval_depth(Depth2):
    if Depth2 is not None and Depth2 >= 45:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_rooting", "eval_rooting(!RootDepth2!)",
        """
def eval_rooting(RootDepth2):
    if RootDepth2 is not None and RootDepth2 >= 45:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_perm", "eval_perm(!PermeabilityCode!)",
        """
def eval_perm(PermeabilityCode):
    if PermeabilityCode in ("m", "r", "m/r", "r/m", "m/s"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_TXT1", "eval_txt1(!UpperTexture!)",
        """
def eval_txt1(UpperTexture):

```

```

    if UpperTexture in ("l", "z", "c"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_TXT2", "eval_txt2(!LowerTexture!)",
        """
def eval_txt2(LowerTexture):
    if LowerTexture in ("l", "z", "c", "s"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_drain", "eval_drain(!SiblingDrainageCode!, !NZSC!, !NZSCOrder!)",
        """
def eval_drain(SiblingDrainageCode, NZSC, NZSCOrder):
    if SiblingDrainageCode in ("w", "mw", "i"):
        return 1
    elif SiblingDrainageCode == "p" and NZSCOrder == "P":
        return 1
    elif SiblingDrainageCode == "p" and NZSC in ("GRT", "GAT", "GOT", "GOA"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_Tsstones", "eval_tsstones(!SiblingTopsoilStonesCode!)",
        """
def eval_tsstones(SiblingTopsoilStonesCode):
    if SiblingTopsoilStonesCode in ("1", "2"):
        return 1
    return 0
"""
)

```

```

    calc_field(
        table, "luc2_Salt", "eval_salt(!Salinity!)",
        """
def eval_salt(Salinity):
    if Salinity in ("N", "W"):
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc2_DSLO", "eval_dslo(!SlowDepth!)",
        """
def eval_dslo(SlowDepth):
    if SlowDepth is not None and SlowDepth >= 45:
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc2_PAW", "eval_paw(!PAWmm!)",
        """
def eval_paw(PAWmm):
    if PAWmm is not None and PAWmm >= 120:
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc2_NZSC", "eval_nzsc(!NZSC!, !NZSCOrder!, !NZSCGroup!,
!NZSCSubGroup!)",
        """
def eval_nzsc(NZSC, NZSCOrder, nzscGroup, nzscSubGroup):
    if NZSC in ("MPT", "MIMW"):
        return 0
    elif NZSCOrder == "M" and nzscSubGroup == "W":
        return 0
    elif NZSCOrder == "M" and nzscGroup == "O":

```

```

        return 0
    return 1
"""
)

    calc_field(
        table, "luc2_ELEV", "eval_elev(!ISLAND!, !ELEV!)",
        """
def eval_elev(ISLAND, ELEV):
    if ISLAND == "N" and ELEV is not None and ELEV <= 500:
        return 1
    elif ISLAND == "S" and ELEV is not None and ELEV <= 400:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc2_RAIN", "eval_rain(!ISLAND!, !RAIN!)",
        """
def eval_rain(ISLAND, RAIN):
    if RAIN is None:
        return 0
    if ISLAND == "N" and 800 <= RAIN <= 2000:
        return 1
    elif ISLAND == "S" and RAIN <= 1500:
        return 1
    return 0
"""
)

    calc_field(
        table,
        "luc2_Out2",
        "!luc2_slp_ldr! + !luc2_PM! + !luc2_depth! + !luc2_rooting! + !luc2_perm! +
!luc2_TXT1! + !luc2_TXT2! + !luc2_drain! + !luc2_Tsstones! + !luc2_Salt! + !luc2_DSL0!
+ !luc2_PAW! + !luc2_NZSC! + !luc2_ELEV! + !luc2_RAIN!"
    )

    calc_field(
        table,

```

```

        "luc2_Out1",
        "!luc2_slp_smap! + !luc2_PM! + !luc2_depth! + !luc2_rooting! + !luc2_perm! +
!luc2_TXT1! + !luc2_TXT2! + !luc2_drain! + !luc2_Tsstones! + !luc2_Salt! + !luc2_DSL0!
+ !luc2_PAW! + !luc2_NZSC! + !luc2_ELEV! + !luc2_RAIN!"
    )

# -----
# LUC3
# -----

def run_luc3(table):
    log("=== Running LUC3 ===")

    calc_field(
        table, "luc3_slp_ldr", "eval_slope(!SLOPE!)",
        """
def eval_slope(SLOPE):
    if SLOPE is not None and SLOPE <= 15:
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc3_slp_smap", "eval_smap(!SlopeCode2!)",
        """
def eval_smap(SlopeCode2):
    if SlopeCode2 in ("A", "B", "C"):
        return 1
    return 0
"""
    )

    calc_field(
        table, "luc3_PM", "eval_pm(!SoilProfileMaterial!)",
        """
def eval_pm(SoilProfileMaterial):
    if SoilProfileMaterial in ("Md", "Ms", "Mt", "Mg", "Mm", "Ml", "Mp", "Mr", "Ma"):
        return 1
    return 0
"""
    )

```

```

"""
)

    calc_field(
        table, "luc3_depth", "eval_depth(!Depth2!)",
        """
def eval_depth(Depth2):
    if Depth2 is not None and Depth2 >= 20:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_rooting", "eval_rooting(!RootDepth2!)",
        """
def eval_rooting(RootDepth2):
    if RootDepth2 is not None and RootDepth2 >= 20:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_perm", "eval_perm(!PermeabilityCode!)",
        """
def eval_perm(PermeabilityCode):
    if PermeabilityCode in ("m", "r", "r/m", "m/r", "m/s", "r/s"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_TXT1", "eval_txt1(!UpperTexture!)",
        """
def eval_txt1(UpperTexture):
    if UpperTexture in ("l", "z", "c", "s"):
        return 1
    return 0
"""
)

```

```

"""
)

    calc_field(
        table, "luc3_TXT2", "eval_txt2(!LowerTexture!)",
        """
def eval_txt2(LowerTexture):
    if LowerTexture in ("l", "z", "s", "c"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_drain", "eval_drain(!SiblingDrainageCode!, !NZSC!, !NZSCOrder!,
!NZSCGroup!)",
        """
def eval_drain(SiblingDrainageCode, NZSC, NZSCOrder, NZSCGroup):
    if SiblingDrainageCode in ("w", "mw", "i"):
        return 1
    elif SiblingDrainageCode == "p" and NZSCOrder in ("P", "G", "R", "N", "E"):
        return 1
    elif SiblingDrainageCode == "p" and NZSCOrder == "Z" and NZSCGroup == "E":
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_Tsstones", "eval_tsstones(!SiblingTopsoilStonesCode!)",
        """
def eval_tsstones(SiblingTopsoilStonesCode):
    if SiblingTopsoilStonesCode in ("1", "2", "3"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_Salt", "eval_salt(!Salinity!)",

```

```

    """
def eval_salt(Salinity):
    if Salinity in ("N", "W", "M"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_DSLO", "eval_dslo(!SlowDepth!)",
        """
def eval_dslo(SlowDepth):
    if SlowDepth is not None and SlowDepth >= 20:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_PAW", "eval_paw(!PAWmm!)",
        """
def eval_paw(PAWmm):
    if PAWmm is not None and PAWmm >= 90:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc3_NZSC", "eval_nzsc(!NZSC!)",
        """
def eval_nzsc(NZSC):
    if NZSC == "MPT":
        return 0
    return 1
"""
)

    calc_field(
        table, "luc3_ELEV", "eval_elev(!ISLAND!, !ELEV!)",

```

```

"""
def eval_elev(ISLAND, ELEV):
    if ISLAND == "N" and ELEV is not None and ELEV <= 750:
        return 1
    elif ISLAND == "S" and ELEV is not None and ELEV <= 650:
        return 1
    return 0
"""

)

calc_field(
    table, "luc3_RAIN", "eval_rain(!ISLAND!, !RAIN!)",
    """
def eval_rain(ISLAND, RAIN):
    if RAIN is None:
        return 0
    if ISLAND == "N" and 800 <= RAIN <= 2500:
        return 1
    elif ISLAND == "S" and RAIN <= 2400:
        return 1
    return 0
"""

)

calc_field(
    table,
    "luc3_Out2",
    "!luc3_slp_ldr! + !luc3_PM! + !luc3_depth! + !luc3_rooting! + !luc3_perm! +
!luc3_TXT1! + !luc3_TXT2! + !luc3_drain! + !luc3_Tsstones! + !luc3_Salt! + !luc3_DSLO!
+ !luc3_PAW! + !luc3_NZSC! + !luc3_ELEV! + !luc3_RAIN!"

)

calc_field(
    table,
    "luc3_Out1",
    "!luc3_slp_smap! + !luc3_PM! + !luc3_depth! + !luc3_rooting! + !luc3_perm! +
!luc3_TXT1! + !luc3_TXT2! + !luc3_drain! + !luc3_Tsstones! + !luc3_Salt! + !luc3_DSLO!
+ !luc3_PAW! + !luc3_NZSC! + !luc3_ELEV! + !luc3_RAIN!"

)

```

```

# -----
# LUC4
# -----

def run_luc4(table):
    log("=== Running LUC4 ===")

    calc_field(
        table, "luc4_slp_ldr", "eval_slope(!SLOPE!)",
        """
def eval_slope(SLOPE):
    if SLOPE is not None and SLOPE <= 20:
        return 1
    return 0
    """
    )

    calc_field(
        table, "luc4_slp_smap", "eval_smap(!SlopeCode2!)",
        """
def eval_smap(SlopeCode2):
    if SlopeCode2 in ("A", "B", "C", "D"):
        return 1
    return 0
    """
    )

    calc_field(
        table, "luc4_PM", "eval_pm(!SoilProfileMaterial!)",
        """
def eval_pm(SoilProfileMaterial):
    if SoilProfileMaterial in ("Md", "Ms", "Mt", "Mg", "Mm", "Ml", "Mp", "Mr", "Ma"):
        return 1
    return 0
    """
    )

    calc_field(
        table, "luc4_depth", "eval_depth(!Depth2!)",
        """

```

```

def eval_depth(Depth2):
    if Depth2 is not None and Depth2 >= 5:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_rooting", "eval_rooting(!RootDepth2!)",
        """
def eval_rooting(RootDepth2):
    if RootDepth2 is not None and RootDepth2 >= 5:
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_perm", "eval_perm(!PermeabilityCode!)",
        """
def eval_perm(PermeabilityCode):
    if PermeabilityCode in ("m", "r", "r/m", "m/r", "m/s", "r/s", "s/m", "s/r", "s"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_TXT1", "eval_txt1(!UpperTexture!)",
        """
def eval_txt1(UpperTexture):
    if UpperTexture in ("l", "z", "c", "s"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_TXT2", "eval_txt2(!LowerTexture!)",
        """

```

```

def eval_txt2(LowerTexture):
    if LowerTexture in ("l", "z", "s", "c"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_drain", "eval_drain(!SiblingDrainageCode!, !NZSC!)",
        """
def eval_drain(SiblingDrainageCode, NZSC):
    if SiblingDrainageCode in ("w", "mw", "i", "p"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_Tsstones", "eval_tsstones(!SiblingTopsoilStonesCode!)",
        """
def eval_tsstones(SiblingTopsoilStonesCode):
    if SiblingTopsoilStonesCode in ("1", "2", "3", "4"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_Salt", "eval_salt(!Salinity!)",
        """
def eval_salt(Salinity):
    if Salinity in ("N", "W", "M"):
        return 1
    return 0
"""
)

    calc_field(
        table, "luc4_DSLO", "eval_dslo(!SlowDepth!)",
        """

```

```

def eval_dslo(SlowDepth):
    if SlowDepth is not None and SlowDepth >= 5:
        return 1
    return 0
    """
)

    calc_field(
        table, "luc4_PAW", "eval_paw(!PAWmm!)",
        """
def eval_paw(PAWmm):
    if PAWmm is not None and PAWmm >= 60:
        return 1
    return 0
    """
)

    calc_field(
        table, "luc4_NZSC", "eval_nzsc(!NZSC!)",
        """
def eval_nzsc(NZSC):
    return 1
    """
)

    calc_field(
        table, "luc4_ELEV", "eval_elev(!ISLAND!, !ELEV!)",
        """
def eval_elev(ISLAND, ELEV):
    if ISLAND == "N" and ELEV is not None and ELEV <= 1000:
        return 1
    elif ISLAND == "S" and ELEV is not None and ELEV <= 800:
        return 1
    return 0
    """
)

    calc_field(
        table, "luc4_RAIN", "eval_rain(!ISLAND!, !RAIN!)",
        """

```

```

def eval_rain(ISLAND, RAIN):
    if RAIN is None:
        return 0
    if ISLAND == "N" and 800 <= RAIN <= 3000:
        return 1
    elif ISLAND == "S" and RAIN <= 3000:
        return 1
    return 0
"""
)

calc_field(
    table,
    "luc4_Out2",
    "!luc4_slp_ldr! + !luc4_PM! + !luc4_depth! + !luc4_rooting! + !luc4_perm! +
!luc4_TXT1! + !luc4_TXT2! + !luc4_drain! + !luc4_Tsstones! + !luc4_Salt! + !luc4_DSLO!
+ !luc4_PAW! + !luc4_NZSC! + !luc4_ELEV! + !luc4_RAIN!"
)

calc_field(
    table,
    "luc4_Out1",
    "!luc4_slp_smap! + !luc4_PM! + !luc4_depth! + !luc4_rooting! + !luc4_perm! +
!luc4_TXT1! + !luc4_TXT2! + !luc4_drain! + !luc4_Tsstones! + !luc4_Salt! + !luc4_DSLO!
+ !luc4_PAW! + !luc4_NZSC! + !luc4_ELEV! + !luc4_RAIN!"
)

# -----
# Final model
# -----

def run_final(table):
    log("=== Running Final Classification ===")

    calc_field(
        table, "Final_1b", "eval_final(!luc1_Out2!, !luc2_Out2!, !luc3_Out2!,
!luc4_Out2!)",
        """
def eval_final(luc1_Out2, luc2_Out2, luc3_Out2, luc4_Out2):
    if luc1_Out2 == 15:
        return "LUC 1"

```

```

    elif luc2_Out2 == 15:
        return "LUC 2"
    elif luc3_Out2 == 15:
        return "LUC 3"
    elif luc4_Out2 == 15:
        return "LUC 4"
    else:
        return "Not 1,2,3,4"
"""
    field_type="TEXT",
    field_length=20
)

calc_field(
    table, "Sib1_domLUC_1b", "!Final_1b!",
    field_type="TEXT",
    field_length=20
)

calc_field(
    table, "Final_1a", "eval_final(!luc1_Out1!, !luc2_Out1!, !luc3_Out1!,
!luc4_Out1!)",
    """
def eval_final(luc1_Out1, luc2_Out1, luc3_Out1, luc4_Out1):
    if luc1_Out1 == 15:
        return "LUC 1"
    elif luc2_Out1 == 15:
        return "LUC 2"
    elif luc3_Out1 == 15:
        return "LUC 3"
    elif luc4_Out1 == 15:
        return "LUC 4"
    else:
        return "Not 1,2,3,4"
"""
    field_type="TEXT",
    field_length=20
)

calc_field(

```

```

        table, "Sib1_domLUC_1a", "!Final_1a!",
        field_type="TEXT",
        field_length=20
    )

# -----
# Main
# -----

def get_input_table():
    if len(sys.argv) > 1:
        return sys.argv[1]
    try:
        return arcpy.GetParameterAsText(0)
    except Exception:
        return None

def main():
    table = get_input_table()

    if not table or table == "#":
        raise ValueError("Input feature class/table is required.")

    log("Starting combined LUC model...")
    log(f"Input dataset: {table}")

    required_fields = [
        "SlopeCode2", "SLOPE", "SoilProfileMaterial", "Depth2", "RootDepth2",
        "PermeabilityCode", "UpperTexture", "LowerTexture", "SiblingDrainageCode",
        "SiblingTopsoilStonesCode", "Salinity", "SlowDepth", "PAWmm", "NZSC",
        "NZSCOrder", "NZSCGroup", "NZSCSubGroup", "ISLAND", "ELEV", "RAIN"
    ]
    require_fields(table, required_fields)

    run_luc1(table)
    run_luc2(table)
    run_luc3(table)
    run_luc4(table)

```

```
run_final(table)
```

```
log("Combined LUC model completed successfully.")
```

```
if __name__ == "__main__":
```

```
    try:
```

```
        main()
```

```
    except Exception as ex:
```

```
        tb = traceback.format_exc()
```

```
        err(str(ex))
```

```
        err(tb)
```

```
    raise
```

Appendix 4 – Expert review summaries, by S-map survey area

Lower North Island – Tararua

The model identifies extensive areas within the Woodville and Kumeroa Valley districts as LUC Class 1, including Dannevirke silt loam, Ohakea, and Manawatu soils. Given recognised limitations relating to climate, drainage, and flood susceptibility, these soils would generally be expected to fall within LUC Classes 2–3 rather than Class 1.

Similarly, Te Arakura silt loam, Kairanga silt loam, Raumati silt loam, and Ohakea soils would not generally qualify as LUC Class 1 on the basis of drainage characteristics alone.

The slope thresholds also appear to require further refinement. Matamau soils should predominantly classify as LUC Classes 4 or 6; however, the model frequently assigns them to Class 2. This suggests the model may not adequately account for the way in which larger map units integrate ridges, lower slopes, and valley floors, potentially reducing the average slope class assigned to a given polygon.

For example, one polygon mapped as LUC 2 contained the primary sibling 'Matamau silt loam, hill soil' with an assigned slope code of E, while the calculated slope value was only 6.8 degrees. This discrepancy suggests the slope interpretation may not be functioning as intended. During the original mapping process using LiDAR-derived average slope values, some adjustment of slope thresholds was required – for example, aligning slope class C more closely with approximately 7–11 degrees rather than the standard 8–15 degrees – although the overall fit was considered reasonably consistent at the time.

In more extreme cases, the model has classified these soils as LUC Classes 2 or 3 in areas previously mapped as LUC Class 6 under the NZLRI framework.

Overall, many LUC units within the Upper Manawatu likely require reclassification to a higher-severity class. While it is acknowledged that the model may not fully capture factors such as flood susceptibility or erosion risk, the slope and drainage thresholds likely require refinement to ensure that poorly drained and hilly soils are assigned to appropriately higher-severity LUC classes.

As observed in the Upper Manawatu, many river flat soils in the Mangatainoka catchment have been classified as LUC Classes 1 or 2 where they were previously mapped as Classes 3 or 4. Likewise, hill soils such as Matamau have been assigned to LUC Class 4 where they were previously classified as Class 6 under the NZLRI framework.

Lower North Island – Manawatu

The most notable discrepancy is the widespread reclassification of the Kairanga Plains from LUC Class 2 to Class 1. Soils in this area would not generally qualify as LUC Class 1 on the basis of drainage characteristics alone. Affected soils include Kairanga fine sandy loam and Te Arakura silt loam.

While not necessarily attributable to a modelling error, the results also highlight potential data entry issues within S-map. In particular, Kairanga silt loam appears to have been recorded with a low-penetration soil material as a rooting barrier. As a result, more than 3,000 hectares of floodplain previously classified as LUC Classes 2–3 have been modelled as not qualifying for Classes 1–4.

On the higher terraces, Marton silt loam has similarly been modelled as not qualifying for LUC Classes 1–4, apparently due to the presence of low-penetration soil material. It appears these soils may have been entered into S-map with a clayey coarse horizon. It may be worth reviewing rooting barrier depth thresholds or establishing exceptions for YC (Clayey Coarse) horizons.

River flats along the Manawatū and Oroua rivers have generally been modelled as LUC Classes 2 or 3, which is broadly reasonable, although many of these flats were previously mapped as Class 4 primarily on the basis of flood susceptibility.

Lower North Island – Rangitikei

Two areas exhibit particularly significant classification differences: the sand country and the high terraces.

The sand country, previously mapped as a mosaic of LUC Classes 3 through 7 owing to wind erodibility and the relatively low natural fertility of some sand soils, has been largely reclassified as LUC Class 3. While erosion susceptibility may fall outside the current scope of the model, it may be worth considering lower slope thresholds for sandy recent and sandy raw soils in order to assign rolling terrain units to higher-severity LUC classes.

The second notable contrast occurs on the high terraces, where Marton silt loam has been modelled as not qualifying for LUC Classes 1–4, apparently due to anoxic conditions. This outcome is more likely attributable to a data entry issue in S-map than to a modelling error; however, it does highlight the sensitivity of the model to rooting barrier inputs.

A further observation from a reviewer notes that LUC modelling of sand dunes is variable, and that results appear to have been more consistent for the Horowhenua and Whanganui surveys, likely due to the low plant-available water (PAW) values associated with those soils. Some Marton soils have been assigned to lower-capability classes; upon investigation, this appears to occur because the second functional horizon in the Rangitikei survey has been recorded as YC and classified as a slow horizon. In practice, these soils are more likely to be LUC Class 3, or possibly Class 2.

Lower North Island – Horowhenua

The model appears to have performed comparatively well across the Horowhenua sand country. However, there remain areas classified as LUC Class 3 extending directly to the coastline.

On closer inspection, soils recorded with a shallow clean sand barrier generally do not qualify for LUC Classes 1–4, whereas soils with an anoxic barrier continue to qualify as Class 3 in areas that were previously classified as not meeting the LUC 1–4 threshold, primarily due to erosion severity and low to moderate nutrient status.

As observed in the Upper Manawatu, several map units along the foothills have been classified as LUC Classes 3 or 4 despite clearly representing hill soils that would not traditionally qualify for Classes 1–4.

There is also a 280-hectare map unit north of Manakau and a further 1,400-hectare unit on the southeastern margins of Levin where Ashhurst soils do not qualify for LUC Classes 1–4. These areas fail to meet topsoil stoniness and depth thresholds. A review of these thresholds may be warranted, although the outcome may ultimately reflect the manner in which these soils were entered into S-map.

Lower North Island – Wairarapa East Coast

Overall, the increased spatial resolution appears to have improved classification accuracy along the coast and within valley systems.

There remain notable areas of rolling hill country that have been modelled as LUC Class 4 but would not traditionally qualify as such on the basis of erosion susceptibility. However, this limitation may fall outside the intended scope of the model.

Classifications for Homewood and Riversdale generally appear reasonable. Flat Point also appears broadly acceptable, although there is a recurring issue whereby young sand dunes are modelled as LUC Class 3 despite traditionally being classified closer to Class 6.

A second reviewer identified four additional issues in this region:

- Shallow coastal soil (Rang_93a.1 – Turakirae gravel): This soil is shallow for the Wairarapa region, with a recorded depth of less than 15 cm. The current classification is considered incorrect; however, reclassification may be possible if parent material origin is taken into account.
- Sand dunes near Flat Point and Homewood: These areas are incorrectly classified due to wind erosion not being incorporated into the model criteria. Consideration of parent material origin may assist in improving LUC classification for these areas.
- Pallic soils near Homewood: These soils have been classified as LUC Class 2 where Class 3 or higher would be more appropriate, given the wind erosion limitation.
- Raw Fluvial soil: One instance of a Raw Fluvial soil classified as LUC Class 3 was identified in an area subject to high flood risk and erosion susceptibility. This highlights the need for additional external criteria – such as flood risk and erosion risk – to be incorporated into the model to improve LUC classification accuracy.

Lower North Island – Wairarapa

A significant number of map units surrounding Martinborough have been modelled as not qualifying for LUC Classes 1–4. Affected soils include Wharekaka, Pukeo, Ahikouka, and Tauherenikau.

Comparison between the NZLRI and modelled S-map-to-LUC outputs indicates that extensive areas throughout the Wairarapa survey region have been classified as not meeting the LUC 1–4 threshold, well beyond the Martinborough area.

This issue spans multiple siblings and may relate more to the manner in which these soils have been entered into S-map than to any inherent limitation of the model itself.

Lower North Island – Summary

Overall, the model demonstrates improved spatial resolution and performs adequately in some areas. However, several consistent trends indicate that the current LUC outputs are generally underestimating land-use limitations across multiple regions. The most prevalent issue is the over-assignment of soils to lower-severity LUC classes – particularly Classes 1–3 – for soils and landscapes that would not traditionally qualify for such classifications.

Waikato

Pirongia and Te Kuiti: The S-map-to-LUC model has classified areas of flat to rolling terrain (map units 3e1/4e1) as not qualifying for LUC Classes 1–4, despite the terrain exhibiting predominantly 3–15 degree slopes. For the same area, farm-scale modelling using a 5 m DEM predicts predominantly LUC Classes 2 and 3 for flat to rolling land. The affected area falls within the Waikato DSM/Wp9b map unit – an Allophanic unit with a single sibling extending across tens of thousands of hectares, encompassing slopes ranging from 0 to more than 35 degrees. This is considered to reflect an inherent feature of how soils have been modelled in the Waikato, where a single map unit may span a wide range of slope categories. While this approach is technically valid – a single soil type can occur across multiple slope classes – it differs substantially from conventional slope-based LUC assessment practice.

Ōtorohanga: Differences between S-map-derived and modelled LUC Classes 2 and 3 were observed on the Ōtorohanga plains, particularly for imperfectly drained and well-drained Pumice Soils adjacent to Rangiatea Road. Gley and Organic Soils south of Otewa Road have been LUC classifications that correspond with the NZLRI. Rolling hills to the south of Otorohanga have been misclassified generally match the NZLRI, but expert review would place them as LUC 3 and 2, and are considered more appropriately LUC 4.

Māhoenui: River terraces at Māhoenui have been modelled as LUC Class 3 when they should predominantly be classified as Class 2.

Cambridge: The Moanatuatua Peat Dome has been correctly predicted as LUC Class 2. Hinuera Formation Allophanic and Gley soils have been predicted as Classes 1 and 2 respectively; however, both should be Class 2. Waikato Pumice Soils have been predicted as Class 4 when they should be Class 3.

Lower Hauraki Plains: The NZLRI classifies clayey marine clays situated near sea level, with limited capacity to mitigate wetness limitations, as LUC Class 3. The model predicts Classes 2 and 3, with Class 2 assigned to slightly lower-lying areas closer to rivers and along the coastal strip, and Class 3 to inland areas. It is considered unlikely that any of this area should qualify as Class 2, given that the landscape is characteristically wet during winter, lies less than 3 m above sea level, and has clay textures with slow permeability at depth.

Peatland around Torehape, classified in the NZLRI as LUC 2, 4, and 7, has been modelled entirely as LUC 3 based on Organic and peaty soil characteristics. This is broadly realistic, except for LUC 7 land (non-ag wetland) on the eastern and western margins of the Kapuatai Peat Dome. With modelled LUC 2 organic and peaty soils, the larger units are generally in agreement with expert review, but some of the smaller LUC 2 units could be more appropriately classed as LUC 3.

Northland

Poutu Peninsula: The S-map-to-LUC model has not performed well for the Poutu Peninsula; however, some NZLRI units also appear inconsistent with S-map soil classifications. For example, Harmsworth (1996) documented the relationship between soils and LUC in the coastal sand country, assigning Te Kopuru Pan Podzols to LUC Classes 4 and 6, and Redhill soils (predominantly deep Allophanic) to Classes 3–6. The NZLRI, however, records Te Kopuru as predominantly Class 4 and Redhill as predominantly Classes 6 and 4, with very little Class 3. Based on detailed S-map survey work, Redhill soils should be classified as LUC Classes 2–3 where slopes are less than 15 degrees. The model has predicted Redhill soils as predominantly

Class 4, while Te Kopuru soils are largely predicted as Class 3 – though for reasons that are unclear, these change to Class 4 north of Dargaville.

In the expert assessment presented here, Te Kopuru soils should be no better than LUC Class 5, except where the pan horizon occurs at depth and drainage is moderate to well drained, in which case Class 4 may be appropriate. The flat areas are also problematic: the Kaipara side of the Poutu Peninsula has been predominantly modelled as LUC Class 2, while the Ruawai Flats have been modelled as Class 3 – despite both areas supporting broadly similar Gley and high-clay alluvial or estuarine soils. The NZLRI records both areas predominantly as Class 2, which is inconsistent with similar soils on the lower Hauraki Plains and lower Waikato River, which are largely classified as Class 3. Peat and Peaty-gley Soils in small valleys on the Poutu Peninsula present additional complexity, as some are adequately drained and used for maize production (LUC Class 2), while others are poorly drained (Classes 3–6). The model has predicted LUC Class 2 for these areas.

Kerikeri: A considerable area of highly productive horticultural land around Kerikeri has been predicted as LUC Class 3, with a substantial proportion classified as lower-capability land (Classes 5–7). The NZLRI records this area as LUC Classes 2 and 3, comprising Oxidic Soils on predominantly A and B slope classes. Based on local mapping experience, a greater proportion of Class 2 and 3 land would be expected.

Ohaeawai: Ohaeawai and Kiripaka soils are characteristically stony, including the presence of basalt boulders, which renders much of the area unsuitable for arable use. These soils are recorded in S-map as a complex; some components may qualify as arable due to low stone content, but the stoniness in practice refers to large boulder-sized material that significantly limits arable suitability. These are complex landscapes. The NZLRI classification of LUC Classes 4 and 6 is considered more realistic, although some stoneless soils within the area may qualify as Classes 1 or 2. The model predicts predominantly LUC Class 3, with some Class 2.

Kaikohe: The area is characterised predominantly by stoneless soils. Oxidic Soils have been predicted as LUC Class 3, while Brown and Allophanic Soils have been predicted as Class 2. The NZLRI records these as Class 2; however, in the expert assessment presented here, classification should reflect slope, with appropriate allocation across Classes 1, 2, or 3.

Lake Ōmapere: The wet lake margin, characterised by high groundwater levels, should appropriately be classified as LUC Classes 5–7. The NZLRI records Classes 4 and 6, while the model predicts Class 2 for these areas. Oxidic Soils to the west of the lake have been predicted predominantly as lower-capability land (not qualifying for Classes 1–4), whereas the NZLRI records them as Class 3.

Hikurangi Swamp: The NZLRI records predominantly LUC Classes 4, 3, and 7 along the river corridor. The model predicts predominantly Class 2, with the remainder as Class 3. These soils are mostly poorly drained, of clayey texture, and subject to flooding every few years. LUC Class 3 is considered realistic, with Class 4 appropriate for more flood-prone areas. This appears to be an instance where the model fails to capture the subtle field-level distinctions necessary for accurate classification.

Bay of Plenty

Katikati: Large areas of deep Allophanic Soils with sandy loam to silt loam textures, predominantly on 0–7 degree slopes with few areas at 8–15 degrees, have been predicted as LUC Classes 2 and 4. The NZLRI records these predominantly as Classes 3, 2, and 4. Areas classified as LUC Class 4 in the NZLRI are slightly more dissected by terraces and shallow gullies; however, slopes remain predominantly 0–7 degrees and may more appropriately qualify as Class 3.

Te Puke: The area comprises predominantly buried-allophanic Pumice and Allophanic Soils, all deep, with loamy sand to sandy loam textures and up to 5% lapilli (with occasional stony to very stony lapilli layers within 45 cm depth). Slopes are predominantly 0–7 degrees. The NZLRI records LUC Class 2, while the model predicts Classes 3 and 4. Intensive kiwifruit production areas should be classified as LUC Class 2.

Maketu: Pumice Soils on low hills around Maketu, on predominantly 0–7 degree slopes with sandy loam textures and no lapilli, have been recorded as predominantly LUC Class 3 by the NZLRI, while the model predicts Class 4. Based on soil characteristics and slope, a classification of Classes 2 and 3 is considered more appropriate. For Pumice Soils on fluvial fans – slightly elevated above the fluvial or estuarine plain, imperfectly to well drained, with sandy loam textures and predominantly 0–3 degree slopes – the NZLRI records LUC Class 2, the model predicts Class 3, but Class 2 is considered most appropriate. For Gley Soils on the low coastal plain (predominantly less than 3 m above sea level), the NZLRI records Classes 2 and 3, while the model predicts Class 3. Given the moderate wetness limitation characteristic of these soils, the model prediction is considered more accurate than the NZLRI in this instance.

Mamaku: Deep Allophanic and Podzol Soils on the predominantly flat to undulating Mamaku Plateau (up to 600 m elevation), with loamy sand over sandy loam and clay loam textures, mostly well drained with some imperfect drainage in low-lying areas, have been classified as LUC Classes 4 and 3 by the NZLRI. The model predicts predominantly Class 4, with some lower-lying areas interestingly predicted as Class 3. In the expert assessment presented here, Class 3 best represents these soils, given broadly equivalent constraints from erosion, soil properties, and climate.

Waiotapu: This area includes deep, well-drained Tephric Recent Soils (Rotomahana mud) with silt loam texture, 3–6% stones, and an elevation of approximately 400 m. Slopes are predominantly 0–7 degrees, with few areas at 8–15 degrees. The NZLRI records predominantly LUC Classes 3 and 4, while the model predicts lower-capability land (not qualifying for Classes 1–4). Where slopes are less than 16 degrees, a classification of LUC Class 3 is considered appropriate.

Canterbury

Large areas of the Canterbury Plains classified as LUC Class 4 under the NZLRI are characterised by shallow (20–45 cm) and/or stony silt loam soils. The model has predicted these as LUC Class 3. In S-map, these are recorded as shallow soils; however, the LUC handbook provides limited definitional clarity regarding soil depth criteria for Classes 3 and 4. This ambiguity complicates classification of Lismore soils, which have a mean soil depth of approximately 30 cm. A practical interpretation would suggest that soils with a depth of 20–45 cm over gravels are best assigned to Class 3, while soils less than 20 cm over gravels are more appropriately assigned to Class 4. Under this interpretation, the model's prediction of Class 3 for areas previously mapped as Class 4 in the NZLRI may in fact be more accurate.

Methven: Two apparently identical map units have been modelled differently, as LUC Classes 1 and 2. The differentiation appears to be based on elevation, with Class 2 assigned to the higher-elevation unit.

Flock Hill Station: The NZLRI records LUC Class 4 for Q2 glacial till on flat to undulating terraces at 600–700 m elevation, with shallow silty Acid Brown Soils. The model predicts Classes 3 and 4. While evidence of cultivation is visible, confirming arable land use, the predictions of Classes 3 and 4 appear inconsistent with the sibling data (Balm_26a.1 and Glad_53a.1) and the landscape context, with the discrepancy appearing to reflect minor differences in elevation between the two units.

Marlborough/Nelson

Lower Wairau: Following entry of Iain Campbell's updated soil map into S-map by Ian Lynn, there is a very strong correspondence between modelled LUC and the NZLRI in many areas – a match so close as to suggest the legacy soil map and the NZLRI may have been based on the same polygon boundaries. Ian Lynn subsequently updated the map with revised siblings; in most cases this has not materially affected LUC predictions, with a few exceptions. For example, some areas previously classified as LUC Class 2 north of Blenheim have been reclassified to Class 4 following a change from Recent Soil to Gley, with a slow horizon at 20 cm depth.

Richmond/Waimea (legacy): This area is based on a separate soil map compiled by Iain Campbell; however, the data were entered into S-map by a different surveyor from Ian Lynn. The correspondence between modelled LUC and the NZLRI is poor for this area. This is noteworthy given that both areas are situated in similar soil landscapes and were compiled by the same field surveyor using broadly consistent methods based on well-developed soil–landscape conceptual models. The divergence appears to stem from the conversion of soil series data to siblings by different practitioners. Challenges arose in interpreting classic soil series into the sibling framework due to wide ranges in soil properties, including drainage, texture and stoniness, depth to firm or slow horizons, and NZSC subgroup classification. This may be a case in which the legacy map would have benefited from redigitisation with revised boundaries. Caution should be exercised in interpreting differences in LUC predictions across these three areas, as the underlying issue relates to the quality and consistency of the S-map input data rather than the model itself. This has broader implications for national-scale LUC prediction from S-map, given the considerable variation in authorship, methodology, and data quality across the S-map data set.

The relationship between survey quality and agreement between predicted and NZLRI LUC is not, however, universally consistent. The Upper Wairau S-map exhibits limited agreement between the two data sets, despite representing new S-map data with new linework and fresh field observations rather than legacy data.

Heretaunga Plains

The Heretaunga Plains warrant specific discussion, given the considerable time recently invested in understanding soil and LUC relationships in this area, particularly around Hastings. The NZLRI for this region was informed by a legacy soil map from the 1930s; a subsequent survey by Elwin Griffiths (2001) was digitised and entered into S-map by a different practitioner. For reasons analogous to those described for the Marlborough/Nelson plains, S-map data quality for this area appears unreliable, owing to the inherent difficulties in interpreting soil series data within the sibling framework. Examination of areas where the model predicts LUC Class 1 alongside lower-capability

land (not qualifying for Classes 1–4) around Hastings reveals that a wide range of LUC classes is present at the property scale, with erosion, soil, and wetness limitations all playing important roles.

These areas – which are likely disproportionately represented in S-map by legacy series-to-sibling conversions are also among those most subject to pressure for plan changes. The entire Heretaunga Plains is mapped as highly productive (versatile) land, and considerable caution is warranted before relying on S-map-derived predictions to distinguish between HPL and non-HPL, particularly given the scale at which these decisions are being made. In the view expressed here, mapping at 1:10,000 scale should be a mandatory requirement for any plan change affecting these highly productive plains.

Appendix 5 – Result summaries by region

Table A11. Results for modelled LUC 1-4 from S-Map (hectares)

Row Labels	LUC 1	LUC 2	LUC 3	LUC 4	Not 1,2,3,4	Total
01 Northland Region	1,315	37,359	90,645	49,778	220,486	399,582
02 Auckland	3,617	12,910	48,393	12,968	74,596	152,483
03 Waikato Region	71,767	230,505	330,144	239,680	1,405,974	2,278,071
04 Bay of Plenty Region	5,368	12,972	140,105	117,182	470,592	746,218
05 Gisborne Region	5,700	10,030	11,668	6,312	161,242	194,952
06 Hawke's Bay Region	18,341	30,064	79,982	73,456	1,214,473	1,416,315
07 Taranaki Region	35,529	23,196	45,335	33,015	126,888	263,962
08 Horizons Region	44,914	55,530	124,242	44,845	438,372	707,904
09 Wellington Region	9,603	34,245	76,272	38,062	474,290	632,471
12 West Coast Region			33,080	21,552	111,960	166,592
13 Canterbury Region	5,117	198,024	783,164	303,757	983,331	2,273,393
14 Otago Region	11,525	96,759	353,584	298,194	389,084	1,149,146
15 Southland Region	17,162	150,684	344,877	137,728	176,325	826,776
16 Tasman Region	1,920	5,183	29,883	10,266	265,978	313,230
17 Nelson Region	11	370	644	580	6,509	8,114
18 Marlborough Region	5,642	13,413	30,734	10,079	237,340	297,207
Total	237,531	911,242	2,522,752	1,397,454	6,757,439	11,826,418

Table A12. Results for modelled LUC 1-4 from S-Map (regional percentages)

Row Labels	LUC 1	LUC 2	LUC 3	LUC 4	Not 1,2,3,4
01 Northland Region	0.3%	9%	23%	12%	55%
02 Auckland	2%	8%	32%	9%	49%
03 Waikato Region	3%	10%	14%	11%	62%
04 Bay of Plenty Region	1%	2%	19%	16%	63%
05 Gisborne Region	3%	5%	6%	3%	83%
06 Hawke's Bay Region	1%	2%	6%	5%	86%
07 Taranaki Region	13%	9%	17%	13%	48%
08 Horizons Region	6%	8%	18%	6%	62%
09 Wellington Region	2%	5%	12%	6%	75%
12 West Coast Region			20%	13%	67%
13 Canterbury Region	0%	9%	34%	13%	43%
14 Otago Region	1%	8%	31%	26%	34%
15 Southland Region	2%	18%	42%	17%	21%
16 Tasman Region	1%	2%	10%	3%	85%
17 Nelson Region	0.1%	5%	8%	7%	80%
18 Marlborough Region	2%	5%	10%	3%	80%

Table A13. NZLRI LUC 1-4 within the S-map footprint (for comparison) (hectares)

Row Labels	LUC 1	LUC 2	LUC 3	LUC 4	Not 1,2,3,4	Total
01 Northland Region		25,681	49,543	117,100	207,258	399,582
02 Auckland	4,379	33,349	25,111	23,680	65,965	152,483
03 Waikato Region	46,332	252,388	275,156	331,555	1,372,640	2,278,071
04 Bay of Plenty Region	2,840	52,836	72,343	178,130	440,070	746,218
05 Gisborne Region	5,334	8,997	20,500	7,801	152,319	194,952
06 Hawke's Bay Region	17,518	26,417	137,765	100,455	1,134,160	1,416,315
07 Taranaki Region	12,823	35,927	54,613	34,732	125,867	263,962
08 Horizons Region	17,967	67,858	111,098	68,263	442,718	707,904
09 Wellington Region	5,138	29,604	87,171	39,565	470,993	632,471
12 West Coast Region			9,954	55,861	100,777	166,592
13 Canterbury Region	23,104	268,547	527,428	440,523	1,013,791	2,273,393
14 Otago Region	3,030	46,553	328,947	297,315	473,302	1,149,146
15 Southland Region	1,097	169,161	329,646	167,673	159,200	826,776
16 Tasman Region	4,370	4,457	34,494	20,313	249,596	313,230
17 Nelson Region		312	1,017	183	6,602	8,114
18 Marlborough Region	2,449	10,905	35,557	12,552	235,744	297,207
Total	146,382	1,032,991	2,100,343	1,895,699	6,651,003	11,826,418

Table A14. NZLRI LUC 1-4 within the S-map footprint (for comparison) (regional percentages)

Row Labels	LUC 1	LUC 2	LUC 3	LUC 4	Not 1,2,3,4
01 Northland Region		6%	12%	29%	52%
02 Auckland	3%	22%	16%	16%	43%
03 Waikato Region	2%	11%	12%	15%	60%
04 Bay of Plenty Region	0.4%	7%	10%	24%	59%
05 Gisborne Region	3%	5%	11%	4%	78%
06 Hawke's Bay Region	1%	2%	10%	7%	80%
07 Taranaki Region	5%	14%	21%	13%	48%
08 Horizons Region	3%	10%	16%	10%	63%
09 Wellington Region	1%	5%	14%	6%	74%
12 West Coast Region			6%	34%	60%
13 Canterbury Region	1%	12%	23%	19%	45%
14 Otago Region	0.3%	4%	29%	26%	41%
15 Southland Region	0.1%	20%	40%	20%	19%
16 Tasman Region	1%	1%	11%	6%	80%
17 Nelson Region		4%	13%	2%	81%
18 Marlborough Region	1%	4%	12%	4%	79%

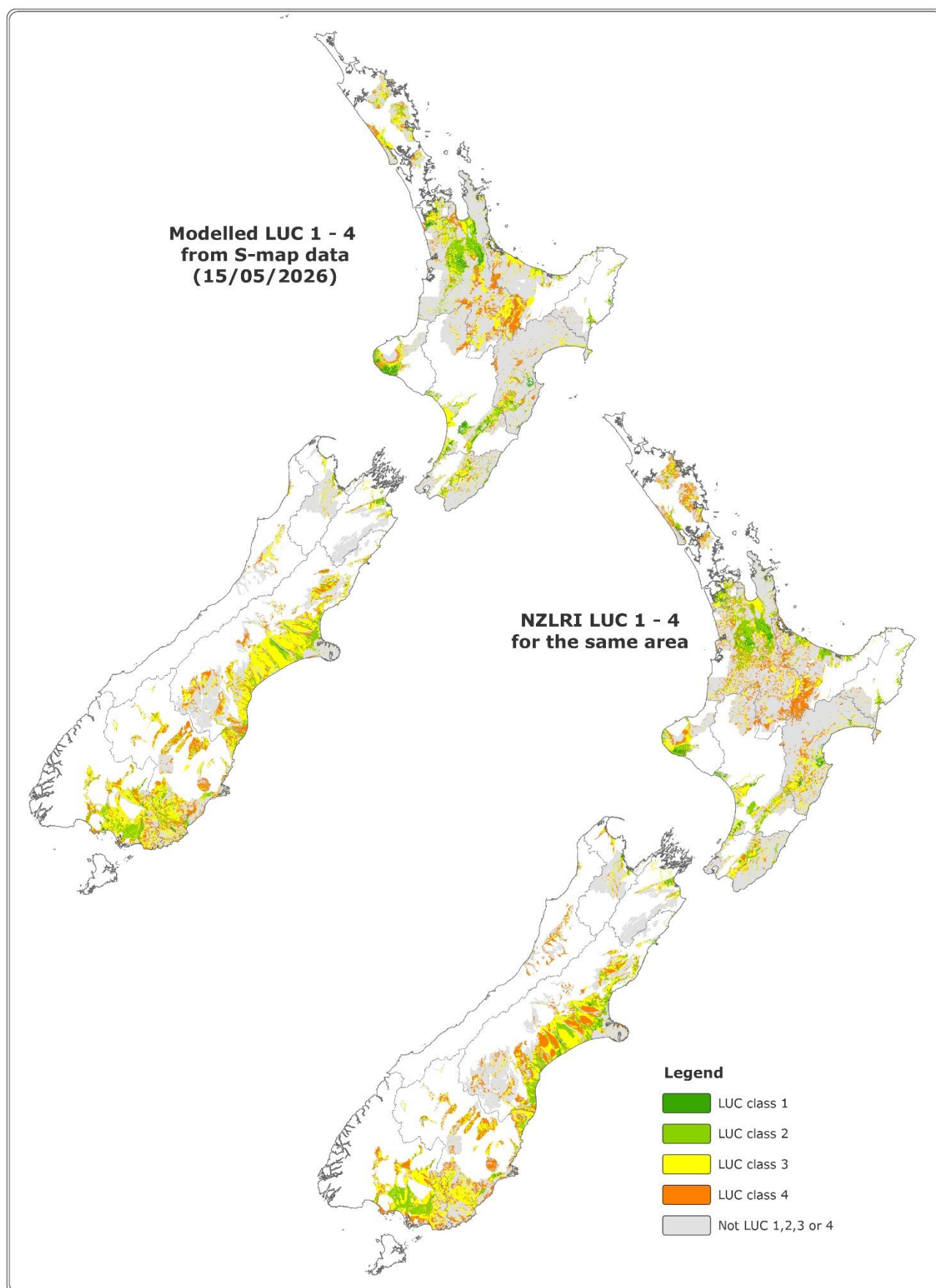


Figure A1. Visualisation of modelled LUC 1-4 and NZLRI LUC 1-4 with region boundaries.