Manaaki Whenua
Landcare Research

Enabling flexibility and connectivity in land-use classification for state of the environment soil quality monitoring

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Enabling flexibility and connectivity in land-use classification for state of the environment soil quality monitoring

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Summary

Project and client

- Land use is recognised as a critical driver of environmental change, and regional council state of the environment (SOE) soil quality monitoring underpins national reporting on land use.
- However, there are several recognised inconsistencies in land-use classification, both across councils and over time. This project was undertaken to facilitate consistent land-use classification for SOE monitoring to use regionally and nationally.
- The project was undertaken for the Regional Council Land Monitoring Forum under Envirolink Tools grant C09X2205.

Objective

- To develop a prototype model for inter-operable land-use classifications using detailed information about land-use classes. This includes:
  - confirming and refining attributes and land-use categories for SOE soil quality monitoring developed by Cavanagh and Whitehead (2022)
  - developing guidance for the use of the prototype model.

The process

- Workshops were held with the Land Monitoring Forum (LMF) to:
  a confirm and refine, via expert elicitation, the attributes and land-use categories developed by Cavanagh and Whitehead (2022)
  b test and validate the semantic model against the information captured in (a)
  c test the prototype model against (a) and (b) and incorporate any associated feedback from LMF.
- The finalised attributes and land-use classes, and the development and description of the model, are provided in the main report, along with mapping of the developed categories with other existing land-use / land-cover schema.
- The model is stored in a dedicated version control repository within Manaaki Whenua – Landcare Research's institutional GitHub account.[1] As part of the model development, and given the high current use of Excel to capture site information (Cavanagh & Whitehead 2022), an Excel template that outlines the attribute and value information required to develop robust land-use categorisations was developed as an additional output.

[1] The repository is currently only accessible by invitation, which is a result of the project still being in progress. The repository will eventually be made openly available. In the interim, please email Brandon Whitehead (whiteheadb@landcareresearch.co.nz) to request access permission.

Results

- The proposed land-use categories are shown in Table S1. They are broadly similar to those used in the National Environmental Monitoring Standard for Soil Quality and Trace Element Monitoring (NEMS-SQ).

Table S1. Proposed land-use categories for regional council soil quality monitoring. The relevant NEMS-SQ category is provided in brackets where this differs. Italics indicates sub-groups that were discussed but are currently not incorporated into the model.

Category	Sub-groups	Description
Conservation and natural environment (indigenous vegetation)	Forest, scrub and shrubs, grassland	Native forest, tussock, shrubland, and scrub dominated by indigenous species. Undisturbed or unfertilised in recent decades.
Plantation forestry	Exotic forestry	Plantations of exotic tree species grown for pulp and timber production, generally radiata pine, but can include other exotic species (e.g. redwood, Douglas fir). Usually harvested using clear-felling methods.
Perennial horticulture	Tree crops, vine crops, berry fruit	Permanent tree, vine or berry crops
Short-rotation cropping	Arable	Predominantly grain, seed or fodder crops; over time may include short-term (c. 1–3 years) pasture and livestock rotations and/or vegetable rotations. Pasture and livestock rotations may occur up to 50% of the time. Includes maize, barley, wheat, peas, other grain and seed crops, and fodder crops. May be used for dairy support.
	Vegetable	Predominantly vegetable rotation; may include livestock rotation, but less likely.
Dairy	Bovine/*non-bovine*	Dairy is the area on which milking cows are grazed during the milking season, which may include rotations of grazed forage crops and maize for silage, and dry-stock grazing. Where the land is permanently used for dry-stock grazing it should be classified under dry stock land use.
Dry stock	Flat–rolling, hill country	All other (non-dairy platform) pasture, including dry-stock farms for sheep, beef, deer, goats, horses, dairy support (defined by the absence of a dairy platform) and cut and carry; flat–rolling includes slope<15°, and typically low altitude; hill country includes slopes ≥15°.
Production from relatively natural environments (subset of dry stock)	High-country farming (where there are minimal anthropogenic inputs)	This captures high-country farming with domestic stock grazing on native vegetation where there has been limited or no deliberate attempt at pasture modification. Some change in species composition may have occurred.
Rural residential	*With agriculture* *Without agriculture*	Residential properties with low-intensity (non-commercial) land management practices (e.g. hobby farm, on land in rural or peri-urban areas).
Recreation and culture (urban open space)	Grassland	Open areas of grass in urban areas, including parks, school grounds, and playgrounds

Conclusions and next steps

- This project has demonstrated a process to develop, and the development of, a prototype model using controlled vocabulary to enable robust land-use classification for state of the environment soil quality monitoring.
- An Excel spreadsheet template that can help councils to collect the required land-use data in a standardised way was developed and can be used to run though the land-use classification model or provide land-use information that can be incorporated directly into council databases.
- A critical change in the way councils currently collect land-use information is required to ensure consistency in land-use classification: a consistent set of information (the key attributes) needs to be collected and captured in a systematic way.
- In the longer term it would be preferable to use field applications (e.g. Survey 123) for the collection of site information. The development of a specific soil quality monitoring interface that captures the required information *in situ*, using the controlled vocabulary developed from this project, could be scoped by Manaaki Whenua – Landcare Research (MWLR).
- Given the clearer identification of attributes and land-use categories outlined by this project, it would be useful for councils to review the land-use information they currently hold from previous sampling to ascertain the robustness and consistency of historical determinations of land use.
- Finally, although the semantic model is currently considered stable, we hope the community of practice (most likely LMF) can continue to develop the resource as needed, perhaps with releases conceptually similar to other more traditional software projects. Developing a richer semantics (i.e. more specific definitions and relationship types), and further fleshing out the mapping between the concepts captured in this project with other relevant classification schemes, would provide an inter-operability between schema that is currently lacking.

1 Introduction

Regional authorities and the Land Monitoring Forum (LMF) have been monitoring soil quality (including trace elements) since the Landcare Research '500 Soils' programme finished in 2000. A subsequent review by Hill et al. (2003) resulted in improvements and the publication of soil quality guidelines in 2009 (Hill & Sparling (2009). The programme was initially designed to give regions flexibility in reporting on those soil quality issues most relevant to their region. However, the Environmental Reporting Act 2015 requires a more uniform approach for national-level reporting.

Land use is recognised as a critical driver of environmental change, and regional council state of the environment (SOE) soil quality monitoring underpins national reporting on land use (e.g. *Our Land 2021*, MfE 2021). However, there are a number of recognised inconsistencies in land-use classification between councils (see Cavanagh et al. 2017; Cavanagh et al. 2020; Stevenson et al. 2020).

Greater consistency in land-use categorisation was recognised as a high priority to inform improvements in soil quality monitoring at the LMF meeting in March 2021, and it was a recommendation for further work stemming from the development of the Soil Quality & Trace Element Monitoring NEMS by the National Environmental Monitoring Standards (NEMS) Steering Group. This project also fits within the Environmental Monitoring and Reporting land project for improving regional and national reporting of soil quality and trace element data (via the Land, Air, Water Aotearoa[2] and national Environmental Domain reports), which is supported by all 16 regional authorities.

Cavanagh and Whitehead (2022) present a detailed review of different land-use categorisations and previous efforts to develop land-use classifications in New Zealand. This information provided the basis for working with the Regional Council Land Monitoring Forum to develop more clearly defined land-use categories that enable consistent classification regionally and nationally for SOE soil quality monitoring and reporting. This included the identification of the key attributes that determine land use, and those that are relevant to interpreting soil quality.

This project further refines the attributes, values, and land-use descriptions identified in Cavanagh & Whitehead 2022 and encodes those relationships in a semantic model (a machine-readable model of concepts and relations) that supports automated land-use classification for use with regional council SOE soil quality monitoring. This report provides the refined attributes, values, and land-use descriptions, outlines the development of the ontology, and illustrates the use of a spreadsheet-based process to apply the ontology modules in council workflows.

[2] https://www.lawa.org.nz/

2 Background

2.1 Definitions

'Land use', 'land cover', and 'land management' are often (erroneously) used interchangeably in discussions about land use. This erroneous use seems to stem from a lack of awareness of the distinct meaning of each of these terms. The following definitions, which have been drawn from the Australian Department of Agriculture, Water and the Environment,[3] help to make explicit the differences.

- **Land use** means the purpose to which the land is committed, including the production of goods (such as crops, timber, and manufactures) and services (such as defence, recreation, biodiversity, and natural resources protection).
- **Land management practice** means the approach taken to achieve a land-use outcome – the 'how' of land use (e.g. cultivation practices such as minimum tillage, direct drilling, and choices around stocking rate density).
- **Land cover** refers to the physical surface of the earth, including various combinations of vegetation types, natural bare surfaces (e.g. exposed rock or gravel, permanent snow and ice, etc.), and water bodies, as well as anthropogenic elements, such as agriculture, transport infrastructure, and built environments. Land-cover classes can usually be distinguished by characteristic patterns using remote sensing.
- **Land-use classification** provides general information on land cover, and the types of human activity involved in land management.

2.2 National Environmental Monitoring Standard for Soil Quality and Trace Elements (NEMS-SQ)

Under the National Environmental Monitoring Standard for Soil Quality and Trace Elements (NEMS-SQ), defining land-use type and soil order are critical requirements to ensure soil quality indicator and trace element data can be interpreted correctly for reporting. The standard requires that a site have a land-use type classification to allow for national collation of regional data by land-use type, and a current land-use type at the time of sampling. The land-use types are provided in Table 1.

The land-use ***type*** classification allows for different land use activities (e.g. maize crop, livestock grazing on pasture) to occur over time within a given land-use type (e.g. livestock farming) at a sampling site. The intent is to avoid erroneous classification of a site as having undergone a land use change when in fact it is simply a different rotation within the same land use type.

[3] https://www.awe.gov.au/abares/aclump/definitions

Table 1. Description of land-use categories to be assigned to sampling sites under the Soil Quality and Trace Element Monitoring NEMS

Land-use type	Definition
Horticulture	Permanent-row orchards and vines.
Cropping	Annual crops, usually grown on a rotational system that can include a short-term (c. 1–3 years) pasture rotation. Includes maize, barley, wheat, peas, other grain and seed crops, fodder crops, and commercial vegetables (includes market gardens).
Dairy	Dairy is the main dairy platform, predominantly used for milking. Dairy may include areas of grazed forage crops and maize for silage.
Dry stock (other pasture)	All other (non-dairy platform) pasture, including dry-stock farms for sheep, beef, deer, goats, horses, dairy support (defined by the absence of a dairy platform), and cut and carry.
Exotic forest	Plantations of exotic tree species grown for pulp and timber production, generally radiata pine but can include other exotic species (e.g. redwood, Douglas fir). Usually harvested using clear-felling methods.
Indigenous vegetation	Native forest, tussock, shrubland and scrub dominated by indigenous species. Undisturbed or unfertilised in recent decades.
Urban open space	Open areas of grass in urban areas, including parks, school grounds, and playgrounds.

3 Objective

- To develop a prototype model for inter-operable land-use classifications using detailed information about land-use classes. This includes:
  - confirming and refining attributes and land-use categories for state of the environment soil quality monitoring developed by Cavanagh and Whitehead (2022)
  - developing guidance for the use of the prototype model.

4 The process

Workshops were held with the LMF to:

a confirm and refine, via expert elicitation, the attributes and land-use categories developed by Cavanagh and Whitehead (2022)

b test and validate the semantic model against the information captured in (a)

c test the prototype model against (a) and (b), and incorporate any associated feedback from LMF.

The finalised attributes and land-use classes are described in section 5, and the development and description of the model in section 6. Mapping of the developed categories with other existing land-use / land-cover schema is provided in section 7.

The model is stored in a dedicated version control repository (i.e. MWLR's institutional GitHub account[4]). As part of the model development, and given the high current use of Excel to capture site information (Cavanagh & Whitehead 2022), an Excel template that outlines the attribute and value information required to develop robust land-use categorisations was developed as an additional output.

5 Finalised attributes and land-use classes

In the context of soil quality monitoring, the purpose of land-use classification is to constrain land management activities to a more defined range of activities than may be typically associated with certain land uses. This enables an assessment of the effect of that range of activities (land use) on soil quality. This description of 'land-use categories' of land aligns with the reference to land-use 'type' in the NEMS.

Finer detail in those land management activities can help to interpret soil quality results or contribute to understanding how or to what extent certain land management activities are leading to positive or negative changes in soil quality. Further, there has often been a focus on higher-intensity land use, which reflects concerns about the effects of land use raised at the initiation of the 500 Soils programme, and means that some lower-intensity land uses are not actively included in soil quality monitoring programmes.

The following sections include key text and tables from Cavanagh & Whitehead 2022, modified based on workshop discussions and subsequent comments received during the course of this project.

5.1 Attributes of land use

A wide range of attributes considered relevant to understanding soil quality monitoring results (either for determining land use or for interpreting results) were compiled. These were subsequently assessed and grouped into:

- 'unchanging' site attributes (e.g. slope, soil 'type' – collected at time of site establishment)
- 'varying' site attributes (e.g. vegetation cover useful for determining land use – collected at time of sampling)
- 'nice to have' attributes, mainly to assist with the interpretation of soil quality results (e.g. time since last cultivation).

Note that some attributes are only relevant for, or define, certain land-use categories.

[4] The repository is currently only accessible by invitation, which is a result of the project still being in progress. The repository will eventually be made openly available, but in the interim, please email Brandon Whitehead (whiteheadb@landcareresearch.co.nz) to request access permission.

A description of the values for the key attributes is provided in Table 2. These 'standardised' values have been developed based on consideration of:

- Australia and New Zealand Standard Industrial Classification classes
- groupings in the StatsNZ Agricultural Production Survey
- primary sector groupings
- pragmatism of what people undertaking sampling may know, and what is required for the purposes of soil quality monitoring

while allowing for a higher level of detail than strictly needed to be captured where it is easily obtained.

Because vegetation descriptors are more extensive, these are shown separately in Table 3. Feedback on vegetation cover was that this shouldn't be constrained to a specific land-use category in case there are exceptions to the norm. Therefore, the dominant vegetation cover included in Table 3 is grouped in the land-use category within which it is most likely to fall, but is not a delineating attribute. These attributes and values provide the basis for the Excel spreadsheet template developed to capture land-use information from councils.

Table 2. Summary of values for the different key attributes, and whether they are used for land-use identification. Italics represent attributes discussed but not currently incorporated into the model.

Attribute	Land-use classification	Values	Comments
Active land management for production purposes	Y	Yes/no	Purpose is to delineate land used for production purposes (e.g. agricultural crops, forestry). Excludes activities associated with honey production (as these are unlikely to influence soil quality).
Enterprise / farm system	Y – critical parameter	Based on proposed land-use categories: dairy; dry stock; perennial horticulture – tree, vine or berry crops; arable cropping; vegetable cropping; plantation forestry	The land manager/owner is the primary source of information. Potentially, valuation information based on the predominant economic activity on the farm could be used as an additional or alternative source of information. Additional information could be added to weight the quality of information based on the source (i.e. more confidence is given to information from the land manager than from remote data).
Sampling site representativeness check	Y	Yes/no	Used to identify whether the sampling site is located on land within the farm system that is representative of the identified enterprise/farm system. If no (e.g. if the sampling site is located in an orchard block on a dairy farm), then the land use would be identified as perennial horticulture. Similarly, if the sampling site is located on a conservation block on a dry-stock farm, then it may be considered as conservation or land in transition – the classification will depend on the time the block was 'retired' and the extent of grazing.
Sampling site land use	Y	Based on proposed land-use categories: dairy; dry stock; perennial horticulture – tree, vine or berry crops; arable cropping; vegetable cropping; plantation forestry	
Site condition	N	Bare ground, planted, recently cultivated/harvested (crops), vegetated, recently harvested (forestry)	To use in addition to vegetation cover
Dominant vegetation cover	N	See Table 3	
Grazing	*Y*	*Yes/No*	*Based on evidence of stock (e.g. trampling, browse)*

Attribute	Land-use classification	Values	Comments
Stock type	Y	Beef cattle; dairy cows; cattle – immature; cows; sheep; bulls; deer; other (e.g. goats, alpaca, horses, llamas); *pest deer; pest goats or other pest species*; unknown	The age class of livestock could be included, probably as an additional attribute if this was useful. Information is anticipated to come from the land manager, and is of most interest where a farm only runs one age-class or one stock type (e.g. finishing, calf-rearing, sheep breeding).
Stock unit density[a]	N	*See Appendix 1 for further details*	Provided by land manager; should be representative of sampling sites.
Cultivation frequency	N	1 year – more than, less than or equal to	This is implied from dominant vegetation type, and is used as an approximation for the frequency of cultivation.
Cropping index number[b]	N	1 to 9, resampled to 4 categories	Specific values are grouped into different categories (e.g. short-term arable/pastoral, long-term arable/pastoral). Determining the cropping index number requires that land use between sampling time points is known.
Irrigation infrastructure	Not currently	Yes/no; none/existing	Specify type of irrigator – fixed (e.g. pivot irrigator), travelling irrigator, pods, effluent irrigators, drip-feed (e.g. orchards, vineyards).
Dairy infrastructure	Y	Yes/no; none/existing	Infrastructure includes, milking sheds, races (tracks/trails cows use to go to and from milking area), tanker tracks, effluent ponds (identified from fence construction).
Time since harvesting (plantation forestry only)	N	Source: from forestry-block manager, consents and/or could be calculated from diameter at breast height (DBH) measures on-site, inferred from tree height for small trees of <2 m, or 0 for harvested site.	For DBH measurements. Scion could also create look-up tables to convert DBH to age on a regional basis (then time since harvest = age+1). Also need to ensure DBH is generally representative of the site, noting that variation across a slope can exist.
Forest rotation (forestry only)	N	Source: could be from resource consent, forest owner. Values are numeric (e.g. 2nd).	
Lifestyle block[c]	Potentially	Yes/no	Most likely obtained from economic data.
Carbon farming [c]	*Potentially*	*Yes/no*	
Used for conservation [c]	*Potentially*	*Yes/No*	*Erosion control, biodiversity – riparian*

[a] Stock unit is a common unit used to express stocking rate where 1 su = one breeding ewe, consuming 550 kg DM per year (Morris 2013). See Appendix 1 for further detail.

[b] See Appendix 1 for further details on the cropping index number.

[c] This is useful to record as secondary information, and for capturing the source of that information (e.g. district plan zones, valuation data), as there can be wide-ranging definitions of 'lifestyle'. See also Table 3 for further discussion in relation to the rural residential land-use category.

Table 3. Summary of vegetation class descriptors – loosely grouped in a left to right descending hierarchy according to different land-use classes[a]

Perennial horticulture					
Fruit and nut trees	Pip fruit	Stone fruit	Citrus	Other	
Vines	Grapes				
	Kiwifruit				
Berry fruit					
Short-term cropping					
Vegetables	Brassica	Alliums	Leafy greens	Roots & tubers	Stalks, vines, bulbs
		Onions		Potatoes	Includes celery, courgettes (or zucchini), melons, pumpkins, herbs, rhubarb, squash and sweetcorn
				Carrots	
				Other	
Arable crops	Cereal/grain crops	Fodder[b] or forage crop	Seed crop	Exotic pasture grass	
	Wheat		Includes pastoral, vegetable or arable seed crop	Ryegrass/clover	
	Barley			Annual or perennial ryegrass	
	Maize				
Livestock systems (dairy, dry stock)					
Exotic pasture species	Forage or fodder[b] crop	Cereal/grain crops	Tussock grassland		
Ryegrass/clover	Chicory				
Annual or perennial ryegrass	Fodder beet				
	Kale				
	Lucerne				

	Plantain	
	Swedes	
	Turnip	
Plantation forestry		
Exotic tree species		
Pinus spp.		
Douglas fir		
Eucalyptus spp.		
Other (e.g. macrocarpa, *Cupressus* spp.)		
Conservation and natural environments		
Indigenous forest	Indigenous scrub or shrub (note: this could also be considered land in transition)	Indigenous tussock or grassland
	Mānuka or kānuka	
Land in transition [c]		
Mixed indigenous and exotic forest	*Mixed indigenous and exotic scrub or shrub*	*Mixed indigenous tussock or grassland*

[a] A condensed version of dominant vegetation cover was used in the Excel template for land-use information for simplicity.

[b] Fodder is feed that is harvested and taken to the animal; forage is browsed by the animal while still on the land. For most New Zealand farms, forage is pasture or some other mono crop (such as chicory or brassica), which the livestock graze on. Fodder is hay, silage, haylage, or some other feed product that is brought onto the property (grain, palm kernel expeller, etc.).

[c] A greater range of vegetation covers could be included for this land use.

5.2 Land-use categories

In the context of soil quality monitoring, the purpose of land-use classification is to constrain land management activities to a more defined range of activities than may be typically associated with certain land uses. This enables assessment of the effect of that range of activities (land use) on soil quality. This description of 'land use categories' of also aligns with the reference to land use 'type' in the NEMS.

Finer detail in those land management activities can help to interpret soil quality results or contribute to understanding how or to what extent certain land management activities are leading to positive or negative changes in soil quality. Further, this land-use categorisation is based on land-use activities that most influence soil quality, and includes only a subset of land use that is relevant to those typically sampled for SOE soil quality monitoring (i.e. not all land uses that occur across New Zealand are represented).

These land-use categories take into account the range of activities (or specific land uses) that may occur at a 'typical' location within a farming system of a particular type. For example, the arable cropping category allows for both vegetable and livestock rotations to occur as part of the wider arable cropping system. Similarly, livestock categories allow for rotations of arable or vegetable crops. Some regions (e.g. Canterbury and Horizons) have land use that can comprise approximately 50:50 arable cropping and livestock rotations at the sampling site location over time; this land use is captured in the arable and mixed cropping class. If livestock grazing occurs more than 50% of the time it would be classed as dry stock.

While the focus of this project does not include land-use mapping, there is connectivity between the categories used and those used for land-use mapping, because determining the area of land under different land uses assists councils in the design of their monitoring programme. Design, in this regard, relates to determining the range of land-use categories relevant to monitor for the purpose of assessing the SOE, and representativeness based on the number of sites per land-use area, etc. However, it should also be noted that land-use mapping will be undertaken using remote data sources that capture the land use at a specific point in time, rather than necessarily the land-use 'type', so a site classified as dry stock for soil quality monitoring could show as arable cropping if the remote data source captures an arable crop rotation.

Alongside considerations of the individual land-use categories, there needs to be consideration of and clarity around which soil quality indicator target values may be appropriate for which land-use categories (see also Cavanagh et al. 2023).

Based on the workshop discussions, the proposed categories are shown in Table 4, along with the attributes required to identify these land uses; these are linked in the semantic model/ontology. Note that some land-use categories are included to recognise land uses that monitoring sites may transition into rather than being primary land uses for sampling.

Table 4. Summary of land-use category definitions for state of the environment soil quality monitoring, and attributes used to confirm land use. Italics indicates land uses that were discussed but are currently not incorporated into the model.

Category	NEMS class	Potential sub-groups	Definition	Attributes required for delineating land use	Range of activities/additional description
Conservation and natural environments	Indigenous vegetation	Forest Scrub and shrubs Native grassland	Native forest, tussock, shrubland, and scrub dominated by indigenous species. Undisturbed or unfertilised in recent decades. May include cut-over forest.	Enterprise; active land management; vegetation cover	The original intent was for this class to be a 'reference' class (i.e. comparison of soil condition prior to development for forestry or agriculture). The extent to which it is used for this purpose is unclear.
Plantation forestry	Exotic forest	Exotic forestry	Plantations of exotic tree species grown for pulp and timber production, generally radiata pine, but can include other exotic species (e.g. redwood, Douglas fir). Usually harvested using clear-felling methods.[a]	Enterprise; active land management; vegetation cover	In the first instance, exotic forests planted for carbon farming will fall into this category up to a tree age of 28–30 years (i.e. a typical forest rotation cycle). These sites can also be pulled out separately if information on whether it is a carbon farm or not is desired.
Perennial horticulture	Horticulture	Tree crops Vine crops Berry fruit	Permanent tree, vine or berry crops[a]	Enterprise; active land management; vegetation cover	
Short-rotation cropping[b]	Cropping	Arable and mixed cropping	Predominantly grain, seed or fodder crops; over time may include short-term (c. 1–3 years) pasture and livestock rotations, and/or vegetable rotations. Pasture and livestock rotations may occur up to 50% of the time. Includes maize, barley, wheat, peas, other grain and seed crops, and fodder crops. May be used for dairy support.[c]	Enterprise; active land management; vegetation cover	Separating out likely higher-intensity cropping (vegetables) from lower-intensity (arable), but recognising that vegetables (particularly processed crops like potatoes, peas, beans) will be grown in arable cropping rotations, and also that rotations with pasture and livestock may occur up to roughly 50% of the time.

Category	NEMS class	Potential sub-groups	Definition	Attributes required for delineating land use	Range of activities/additional description
		Vegetable cropping	Predominantly rotations of vegetable crop grown for human consumption; may include livestock rotations but less likely.	Enterprise; active land management; vegetation cover; cultivation frequency (but note might need to be inferred from crop).	
Dairy	Dairy	Bovine	Dairy is the area on which milking cows are grazed during the milking season. Dairy may include rotations of grazed forage crops and maize for silage, and dry-stock grazing. Where the land is permanently used for dry-stock grazing it should be classified under dry-stock land use.[d]	Enterprise; active land management; vegetation cover; stock type	This class specifically includes the potential for forage/fodder/arable crop rotations as part of the grazing system, and recognises that some 'dairy support' activities (e.g. raising young stock, winter grazing of non-milking stock) may also occur on the milking platform area.
		Non-bovine	*Land used for raising non-bovine stock for milking. Non-bovine dairy may include areas of grazed forage crops and maize for silage.*	*Enterprise; active land management; stock type*	*Not anticipated to be covered with existing soil quality monitoring.*
Dry stock	Dry stock	Flat–rolling	All other (non-milking platform) pasture, including dry-stock farms for sheep, beef, deer, goats, horses, dairy support,[d] and cut and carry. Includes slope <15°. May include rotations for arable or vegetable crops.[d]	Enterprise; active land management; vegetation cover; stock type	This class specifically includes the potential for forage, fodder, arable or vegetable crop rotations as part of the grazing system. Can be aggregated based on stocking intensity as desired if this information is captured.
		Hill country	As above for flat–rolling, but designates land on a slope >15°, and anthropogenic inputs are anticipated to be reduced. High-country farming will be captured under production for relatively natural systems.	Enterprise; active land management; vegetation cover; stock type	

Category	NEMS class	Potential sub-groups	Definition	Attributes required for delineating land use	Range of activities/additional description
Recreation and culture	Urban open space	Urban open space – grassland	Open areas of grass in urban areas, including parks, school grounds and playgrounds	Enterprise; active land management; vegetation cover	Need to be clear on purpose of SOE monitoring for this land use; needs to also consider potential for open space to be brownfield/ex-landfill, etc. The NEMS currently limits this land-use class to grassland, but it may be more relevant to include grassland with trees. This land use should be based primarily on non-native vegetation; recreational areas with primarily indigenous vegetation should be a sub-category of conservation and natural environments.
Rural residential[e]		*With agriculture* *Without agriculture*	Residential properties with low-intensity (non-commercial) land management practices (e.g. hobby farm, on land in rural or peri-urban areas).	Enterprise; active land management; vegetation cover	May best describe the land use that monitoring sites on commercial production land may transition to.
Production from relatively natural environments		Grazing	This captures high-country farming with domestic stock grazing on native vegetation where there has been limited or no deliberate attempt at pasture modification. Some change in species composition may have occurred.	Enterprise; active land management; vegetation cover	Minimal anthropogenic inputs (e.g. fertiliser, lime) are expected for this land use. As well as tussock, gorse, broom, mānuka, kānuka, and matagouri could also be present on hill/high country paddocks used for grazing.
		Other	*Could include indigenous forestry, honey production.*		
Carbon farming		*Exotic trees* *Indigenous*			
Land in transition		*Native plantings* *Natural regeneration / unmanaged*	*Vegetation cover could be exotic or indigenous*	*Enterprise; active land management; vegetation cover*	*Not currently monitored, but useful to include for completeness as some existing sites have, or may transition into, this land use.*

[a] Based on the NEMS-SQ definition.

[b] NEMS-SQ description for cropping: annual crops, usually grown on a rotational system that can include a short-term (c. 1–3 years) pasture rotation. Includes maize, barley, wheat, peas, other grain and seed crops, fodder crops, and commercial vegetables (includes market gardens).

[c] Modified from NEMS-SQ definition; see Table 1 for original definition.

[d] Dairy support is land that is used to support non-lactating dairy stock (dry cows, heifers & calves). It will include any feed required, and will often include winter crops and potentially summer crops (location/irrigation dependent), along with cereal crops, such as maize, barley, wheat. It can also include feed that is cut and carried to the milking platform.

[5]The rural residential categorisation is based partly on the rural/lifestyle block description from the user guide for the NES for soil contaminants (MfE 2012), where rural residential land use is applicable to the residential vicinity of farmhouses but not the productive parts of agricultural land. The descriptions from the Australian Land Use and Management classification[5] for rural residential may also be useful, specifically being rural allotments with houses built (or being built) and agricultural activity at the sub-commercial and/or hobby scale (excluding backyard/domestic garden areas or livestock as pets). An option for rural residential without agriculture is also used, along with a land area size cut-off. Rural residential is considered to apply to a land area of 2 ha or less; land area larger than this should be classified under a different category relevant to the land use occurring at the site.

[5] https://www.agriculture.gov.au/abares/aclump/land-use/alum-classification

6 Model development

The development of the semantic model proceeded in a stepwise fashion. Once the land-use categories, definitions, and attributes were confirmed (i.e. Tables 2-4), that information was encoded into a vocabulary using constructs from the Web Ontology Language (OWL) as well as annotation properties from the Simple Knowledge Organization System (SKOS), (see Figure 1). The semantic model was created with a focus on terms, definitions, and the relevant hierarchies each term may participate in (i.e. a controlled vocabulary).

```
@prefix : <http://www.mwlr.nz/soil-quality#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
@base <http://www.mwlr.nz/soil-quality> .

<http://www.mwlr.nz/soil-quality> rdf:type owl:Ontology ;
       owl:imports <http://www.w3.org/2002/07/owl> ,
                   <http://www.w3.org/2004/02/skos/core> ;
       rdfs:comment "initial land use classification and related entities
ontology"@en ;
       owl:versionInfo 0.2 .

#################################################################
#    Classes
#################################################################
http://www.mwlr.nz/soil-quality#Active_Land_Management
:Active_Land_Management rdf:type owl:Class ;
       rdfs:subClassOf :Land_Management_Practice ;
       skos:editorialNote "Currently excluded is also activities associated with
honey production (as these are unlikely to influence soil quality)"@en ;
       skos:example "Activities that would constitute active land management for
production purposes i.e. agricultural crops, forestry, include cultivation."@en ;
       skos:prefLabel "Active land management for production purposes"@en ;
       skos:scopeNote "Purpose is to delineate undisturbed from other land-use
classes"@en .

###  http://www.mwlr.nz/soil-quality#Alliums
:Alliums rdf:type owl:Class ;
       rdfs:subClassOf :Vegetables ;
       skos:example "onions"@en ;
       skos:prefLabel "Alliums"@en .
```

Figure 1. Model code snippet, as an example of developing the controlled vocabulary.

The controlled vocabulary was then used in developing a spreadsheet template. The vocabulary terms were associated with the column names as well as the closed set of values available to populate each cell in that column. The template serves to guide and assist with data entry and validation for survey values from each site to facilitate programmatically deriving the corresponding land-use classification.

A Python script was developed to automate deriving a land-use classification based on rules in a decision tree. The rules provide a mechanism to evaluate the set of values for

each site via the spreadsheet template, which is based on the controlled vocabulary, and to provide all possible land-use classifications based on the entered site data.

The decision tree is implemented in two tiers. The first tier is primarily based on the value entered for 'Enterprise/farm system' and whether that is representative of the sampling location. This first set of evaluations runs as follows.

1 If 'Active Land Management' has value 'no', the land-use classification is determined to be 'conservation and natural environments'.

2 If 'Sampling Site representativeness check' has value 'yes' AND 'Enterprise/farm system' has a value that matches one of the 'farm system terms', the land-use classification is determined to be whichever 'farm system term' matched.

3 If 'Sampling Site representativeness check' has value 'no', then the 'Site-specific landuse' value is matched to 'farm system term' and the land-use classification is determined to be whichever 'farm system term' matched that value.

Once these have been completed, the second tier looks at the other data values and attempts to determine the land use based on these values, irrespective of the previous tier's evaluation. The second set of evaluations runs as follows.

4 If the 'Dominant vegetation cover' values AND the 'Stock type' values match the vocabulary terms associated with 'dairy', then dairy is added as a potential land-use classification to the list of possible land uses in the spreadsheet.

5 If the 'Dominant vegetation cover' values AND the 'Stock type' values match the vocabulary terms associated with 'stock type', then stock type is added as a potential land-use classification to the list of possible land uses in the spreadsheet.

6 The remaining check is to see if the 'Dominant vegetation cover' value matches any of the vocabulary terms associated with 'perennial cropping', 'Plantation forestry', 'Short-rotation cropping', or 'Urban open space'. If there is a match with any of those land-use terms, the associated land use is added to the list of possible land uses in the spreadsheet.

7 After all evaluation steps have been completed, if the 'Landuse category' field remains empty, the script will add 'No land use match found', save the spreadsheet template with a date stamp in the filename, and terminate.

The populated template serves as one of the outputs for this proof of concept.

All documents related to the model are available via a GitHub repository currently residing under MWLR's institutional account. This repository houses the semantic model, a copy of the spreadsheet template, all vocabulary subsets, and the Python script used to generate the derived land-use classification.

7 Mapping across different schema

As noted earlier, although this project does not focus on land-use mapping using remote data, there is connectivity between the categories used and land-use mapping to determine the area of land under different land uses to help councils design their monitoring programme. A mapping of the SOE SQ classes to common remote data sources (e.g. the Land Cover Database) is provided below.

Table 5. Mapping of state of the environment soil quality land-use classes to selected Land Cover Database (LCDB) categories; LCDB categories not shown in the table below are unlikely to be sampled for soil quality monitoring purposes.

LCDB Code	LCDB class name	LCDB class description	SOE SQ class
2	Urban Parkland / Open Space	Mainly grassed or sparsely treed, amenity, utility and recreation areas. The class includes parks and playing fields, public gardens, cemeteries, golf courses, berms, and other vegetated areas usually within or associated with built-up areas.	Some areas could be sampled as Culture and Recreation.
30	Short-rotation Cropland	Land regularly cultivated for the production of cereal, root, and seed crops, vegetables, strawberries and field nurseries, often including intervening grassland, fallow land, and other covers not delineated separately.	Short-rotation cropping -delineated as Vegetables or Arable and mixed when possible.
33	Orchards, Vineyards or Other Perennial Crops	Land managed for the production of grapes, pip, citrus and stone fruit, nuts, olives, berries, kiwifruit, and other perennial crops.	Perennial horticulture – delineated as orchards, vine crops, berries.
40	High-producing Exotic Grassland	Exotic sward grassland of good pastoral quality and vigour reflecting relatively high soil fertility and intensive grazing management.	Dairy, dry stock
41	Low-producing Grassland	Exotic sward grassland and indigenous short tussock grassland of poor pastoral quality reflecting lower soil fertility and extensive grazing management or non-agricultural use.	Dry stock or production from relatively natural environments.
44	Depleted Grassland	Areas, of mainly former short tussock grassland in the drier eastern South Island high country, degraded by over-grazing, fire, rabbits and weed invasion, among which *Hieracium* species are conspicuous. Short tussocks usually occur, as do exotic grasses, but bare ground is more prominent.	Dry stock or production from relatively natural environments.
52	Mānuka and/or Kānuka	Scrub dominated by mānuka and/or kānuka.	Conservation and natural environments / production from relatively natural environments

LCDB Code	LCDB class name	LCDB class description	SOE SQ class
54	Broadleaved Indigenous Hardwoods	Lowland scrub communities dominated by indigenous mixed broadleaved shrubs such as wineberry, māhoe, five-finger, *Pittosporum* spp., fuchsia, tutu, tītoki, and tree ferns. This class is usually indicative of advanced succession towards indigenous forest.	Conservation and natural environments
56	Mixed Exotic Shrubland	Communities of introduced shrubs and climbers such as boxthorn, hawthorn, elderberry, blackberry, sweet briar, buddleja, and old man's beard.	Unlikely to be sampled
58	Matagouri or Grey Scrub	Scrub and shrubland comprising small-leaved, often divaricating shrubs such as matagouri, *Coprosma* spp., *Muehlenbeckia* spp., *Casinnia* spp., and *Parsonsia* spp. These, from a distance, often have a grey appearance.	Conservation and natural environments / production from relatively natural environments
64	Forest – Harvested	Predominantly bare ground arising from the harvesting of exotic forest or, less commonly, the clearing of indigenous forest. Replanting of exotic forest (or conversion to a new land use) is not evident, nor is the future use of land cleared of indigenous forest.	Plantation forestry
68	Deciduous Hardwoods	Exotic deciduous woodlands, predominantly of willows or poplars but also of oak, elm, ash or other species. Commonly alongside inland water (or as part of wetlands), or as erosion-control, shelter, and amenity plantings.	Unlikely to be sampled
69	Indigenous Forest	Tall forest dominated by indigenous conifer, broadleaved or beech species.	Conservation and natural environments
71	Exotic Forest	Planted or naturalised forest (i.e. wilding pines).	Plantation forestry (excluding wilding pines)

Table 6. Mapping of state of the environment soil quality land-use classes to LAWA LCDB groupings

LAWA broad classes	LAWA medium classes	LAWA detailed classes	Proposed land-use class for SQ monitoring
Urban / bare / lightly vegetated surfaces	Artificial bare surfaces	Transport infrastructure	NA
		Surface mine or dump	NA
	Natural bare / lightly vegetated surfaces	Sand or gravel	NA
		Landslide	NA
		Gravel or rock	NA
		Permanent snow and ice	NA
		Alpine grass / herbfield	NA
	Urban area	Built-up area (settlement)	NA
		Urban parkland / open space	Recreation and culture
Cropland	Cropping/horticulture	Short-rotation cropland	Short-rotation cropping
		Orchards, vineyards or other perennial crops	Perennial horticulture
Forest	Exotic forest	Forest – harvested	Forestry
		Exotic forest	Forestry (excluding wildings)
		Deciduous hardwoods	Unlikely to be sampled
	Indigenous forest	Indigenous forest	Conservation and natural environments
		Broadleaved indigenous hardwoods	Conservation and natural environments
Grassland / other herbaceous vegetation	Exotic grassland	Depleted grassland	Dry stock / dairy / rural residential
		High-producing exotic grassland	Dry stock / dairy
		Low-producing grassland	Dry stock / dairy*/ production from relatively natural environments / rural residential

LAWA broad classes	LAWA medium classes	LAWA detailed classes	Proposed land-use class for SQ monitoring
Grassland / other herbaceous vegetation (cont.)	Other herbaceous vegetation	Herbaceous freshwater vegetation	Unlikely to be sampled
		Flaxland	Unlikely to be sampled
		Herbaceous saline vegetation	Unlikely to be sampled
	Tussock grassland	Tall tussock grassland	Unlikely to be sampled
Scrub/shrubland	Exotic scrub / shrubland	Gorse and/or broom	Unlikely to be sampled
		Mixed exotic shrubland	Unlikely to be sampled
	Indigenous scrub / shrubland	Mānuka and/or kānuka	Conservation and natural environments / production from relatively natural environments
		Matagouri or grey scrub	Conservation and natural environments / production from relatively natural environments
		Fernland	Not sampled
		Sub-alpine shrubland	Unlikely to be sampled
		Mangrove	Not sampled
Water bodies	Water bodies	Lake or pond	Not sampled
		River	Not sampled
		Estuarine open water	Not sampled
		Not land	Not sampled

Source https://www.lawa.org.nz/explore-data/land-cover/.

* Dairy is most likely to fall on high-producing grassland.

The LCDB also underpins the Land Use and Carbon Analysis System (LUCAS) national land-use map (MfE 2012), with the latter providing finer resolution of different forest types and grassland with woody biomass for the purposes of international reporting to meet climate change obligations. A mapping of the SOE soil quality land-use classes to the LUCAS land-use map categories is shown in Table 7.

Table 7. Mapping of state of the environment soil quality land-use classes to LUCAS land-use map categories

LUCAS class name	LUCAS class description	SOE SQ class
Natural forest	Areas that at 1 January 1990 were: • tall indigenous forest • self-sown exotic trees such as wilding conifers and grey willows established before 1 January 1990 • broadleaved hardwood shrubland, mānuka/kānuka shrubland and other woody shrubland (≥30% cover, with potential to reach ≥5 m at maturity *in situ* under current land management within 30–40 years) • areas of bare ground of any size, which were previously forested but due to natural disturbances (e.g. erosion, storms, fire) have lost vegetation cover • roads/tracks less than 30 m width within the above categories, and areas that subsequently meet the above criteria on land that was forest land at 1990 (classed as natural forest or pre-1990 planted forest at 1990)	Some areas would fall under conservation and natural environments
Pre-1990 planted forest	• radiata pine, Douglas fir, eucalypts or other planted species (with potential to reach ≥5 m height at maturity *in situ*) planted before 1 January 1990, or replanted on land that was forest land as at 31 December 1989 • exotic forest species that were planted after 31 December 1989 into land that was natural forest • riparian or erosion control plantings that meet the forest definition and were planted before 1 January 1990 • harvested areas within pre-1990 forest land (assumes these will be replanted, unless deforestation is later detected) • includes roads, tracks, skid sites, and other temporarily un-stocked areas within forest that are less than the minimum area of 5 ha or width of 30 m • areas of bare ground of any size that were previously forested at 31 December 1989 but due to natural disturbances (e.g., erosion, storms, fire), have lost vegetation cover	Some areas would fall under exotic forestry
Post-1989 forest	• exotic forest (with the potential to reach ≥5 m height at maturity *in situ*) planted or established on land that was non-forest land as at 31 December 1989 (e.g. radiata pine, Douglas fir, eucalypts or other planted species) • harvested areas within post-1989 forest land (assumes these will be replanted, unless deforestation is later detected) • forests arising from natural regeneration of indigenous tree species as a result of land management change after 31 December 1989	Some areas would fall under exotic forestry

LUCAS class name	LUCAS class description	SOE SQ class
	• self-sown exotic trees such as wilding conifers or grey willows established after 31 December 1989 • riparian or erosion control plantings that meet the forest definition and that were planted after 31 December 1989 • includes roads, tracks, skid sites, and other temporarily un-stocked areas within the forest that are less than the minimum area of 5 ha or width of 30 m • areas of bare ground of any size that were previously forested (established after 31 December 1989) but due to natural disturbances (e.g. erosion, storms, fire), have lost vegetation cover	
Grassland – with woody biomass	• grassland with matagouri and sweet briar, broadleaved hardwood shrubland, mānuka/kānuka shrubland, coastal and other woody shrubland (<5 m tall and any percentage cover) where, under current management or environmental conditions (climate and/or soil), it is expected the forest criteria will not be met over a 30–40-year time period • above timberline shrubland vegetation and intermixed with montane herbfields (does not have the potential to reach >5 m height *in situ*) • grassland with tall tree species (<30% cover), such as golf courses in rural areas (and except where the Land Cover Databases [LCDB1 and LCBD2] have classified these as settlements) • grassland with riparian or erosion control plantings (<30% cover) • linear shelterbelts that are >1 ha in area and >30 m mean width • areas of bare ground of any size that previously contained grassland with woody biomass but due to natural disturbances (e.g. erosion, fire) have lost vegetation cover	Unclear; some areas may map to dry stock, production from natural environments, or recreation and culture
Grassland – high producing	• grassland with high-quality pasture species • includes linear shelterbelts that are <1 ha in area and <30 m mean width (larger shelterbelts are mapped separately as grassland – with woody biomass) • areas of bare ground of any size that were previously grassland but due to natural disturbances (e.g. erosion) have lost vegetation cover	Dairy / dry stock
Grassland – low producing	• low-fertility grassland and tussock grasslands • mostly on hill country • montane herbfields either higher than above timberline vegetation or where the herbfields are not mixed up with woody vegetation • includes linear shelterbelts that are <1 ha in area and <30 m mean width (larger shelterbelts are mapped separately as grassland – with woody biomass) • other areas of limited vegetation cover and significant bare soil, including erosion and coastal herbaceous sand dune vegetation	Dry stock or production from relatively natural environments
Cropland – perennial	• all orchards and vineyards • linear shelterbelts associated with perennial cropland	Perennial horticulture – delineated as orchards, vine crops, berries
Cropland – annual	• all annual crops • all cultivated bare ground • linear shelterbelts associated with annual cropland	Arable and mixed cropping / vegetables

LUCAS class name	LUCAS class description	SOE SQ class
Settlements	• built-up areas and impervious surfaces • grassland within settlements, including recreational areas, urban parklands and open spaces that do not meet the forest definition • major roading infrastructure • airports and runways • dam infrastructure • urban subdivisions under construction	Some areas (grassland) would map to culture and recreation

8 Summary and next steps

This project has demonstrated a process to develop, and the development of, a prototype model using controlled vocabulary to enable robust land-use classification for SOE soil quality monitoring. The purpose of land-use classification for soil quality monitoring is to constrain land management activities to a more defined range of activities than may be typically associated with certain land use types.

This classification scheme reflects the nature of agricultural production, and the fact that crop rotations (e.g. arable crops grown within a predominantly pastoral system) occur. This differs from classical land-use classification, and many remote data sources, which are based on land use at a point in time and may result in a different classification (e.g. arable or pastoral) at a sampling site at different points in time, and in turn a potential assumption about a change in land use.

An Excel spreadsheet template that can help councils collect the required land-use data in a standardised manner was developed and can be used to run though the land-use classification model or provide data that can be directly incorporated into council databases.

A critical element of robust and flexible land-use classification is the collection and capture of the 'right' information. This was not the specific focus of the current project, although the specification of attributes and land-use categories alongside the Excel spreadsheet template will be helpful. The next steps for the collection and capture of site attributes echo those of Cavanagh and Whitehead (2022).

8.1 Collection and capture of site attributes

Further refinement of or agreement on appropriate methodological 'standardisation' for collecting site attributes is required (e.g. slope class vs clinometer). Capturing the source of information for the observation alongside the 'value' of the attribute (e.g. the specific crop type and whether that was determined on the basis of on-site observation, or from the land manager, or by some other means) is necessary to judge the 'robustness' of that information and consequently of the land-use classification.

Given the confidence that can be placed in the capture of some of the land-use information (e.g. purpose of using the land – enterprise) obtained from the land manager, councils, may also wish to consider how they might more easily and consistently capture critical information for land-use delineation. This could include:

- developing a minimum set of questions that are consistently asked during phone conversations while arranging a time for sampling
- formal agreement between the council and land manager as to what information is provided by the land manager and what information is given back to the land manager
- developing web portals to enable land managers to provide more detailed land management information – this system may become increasingly relevant with the ongoing development of farm environmental plans and the information required to develop them.

Alternatively – and preferably in the longer term – the use of field applications (e.g. Survey 123 for *in situ* collection of field information) would be beneficial and potentially eliminate a host of post-processing steps. The development of a specific soil quality monitoring interface that captures the required information could be scoped by MWLR through a separate advice grant.

A further consideration is that given the clearer identification of attributes and land-use categories outlined by this project, it would be useful for councils to review the land-use information they currently hold from previous sampling to ascertain the robustness and consistency of historical determinations of land use.

8.2 Further model development

Although the semantic model is currently considered stable, we prefer that it not be thought of as completed, or as a static entity. We hope the community of practice (ideally LMF) can continue to develop the resource as needed, perhaps with releases conceptually similar to other more traditional software projects. Further model development could include developing more specific definitions and relationship types, as well as further fleshing out of the mapping between the concepts captured in this project with other relevant vocabularies either currently available – i.e. the tables in section 7 – or planning to be made available.

This prototype model could be extended to include a wider range of attributes to allow for different land-use classifications that are not covered in the current project, and to include Māori terms for land forms, features and descriptors related to land use, soil type, soil class, and health aspects (e.g. Harmsworth & Roskruge 2014) to enable inter-operability between different land-use classification schemes.

Other areas of improvement, or further development, could include developing a different mechanism for capturing the data required in the spreadsheet template, as well as incorporating uncertainty or probabilistic values to observational values based on domain expertise. The former is currently a manual effort but could be made to be query based, probably programmatically. Also, as noted above, the use of field applications (e.g. Survey

123) would ultimately be more efficient. The latter would require discussion on how likely it is that an observation would be considered with a high trust value, based on rules agreed by subject matter experts (again, likely to be within the LMF).

9 Acknowledgements

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Appendix 1 – Further detail on selected attributes

Stock units

A stock unit is a common unit used to express stocking rate, where 1 su = one breeding ewe, consuming 550 kg DM per year (Morris 2013). The following table provides an indication of expected stock units based on different grassland types. Further information on the 'conversion' of different animal types into stocking units is also available[6] (Figure A1).

Table A1. Area, pasture production, and number of livestock carried on three grassland regions

Region	Area (millions of hectares)	Pasture production (tonnes DM[1] per hectare)	Livestock (millions)			Stock units[2] per hectare
			Sheep	Beef	Dairy	
High country	4.5	2.0	2.5	0.1	-	0.7
Hill country	5.0	7.0	20.3	1.9	0.2	7.5
Flat to rolling	4.5	11.0	26.7	2.9	3.4	14.0

[1]DM = dry matter.

[2]Since most farmers have both sheep and cattle, the stock unit (su) is the common unit used to express stocking rate where 1 su = one breeding ewe, consuming 550 kg DM per year.

Source: Morris et al. 2013

[6] https://help.farmfocus.nz/en/articles/5384038-stock-units

SHEEP:

MA Ewes	1.0
2th Ewes	1.0
Dry Ewes	0.8
In-lamb ewe hoggets	1.0
Dry ewe hoggets	0.8
Ram hoggets	1.0
Wether hoggets	0.7
Rams	0.8
Other sheep	0.8

CATTLE:

MA cows	6.0
Dry MA cows	5.0
In-calf R2yr heifers	6.0
Dry R2yr heifers	5.0
R1yr heifers	4.0
MA steers	5.5
R2yr steers	5.0
R1yr steers	4.0
MA bulls	6.0
R2yr bulls	5.5
R1yr bulls	4.5
Other cattle	5.0

DEER:

MA hinds	1.9
Dry MA hinds	1.7
R2yr hinds	1.9
Dry R2yr hinds	1.7
R1yr hinds	1.2
MA stags	1.7
R2yr stags	1.7
R1yr stags	1.4
Breeding stags	1.7
Other deer	1.7

Figure A1. Summary of stock units for different animals.
Source: https://help.farmfocus.nz/en/articles/5384038-stock-units

Cropping index number

The cropping index number convention has arisen out of a parallel soil quality monitoring programme based on time under arable and pastoral land use and undertaken by Environment Canterbury (Lawrence-Smith et al. 2014). The cropping index number refers to the number of consecutive years a paddock had been under arable or pastoral production immediately prior to sampling (Table A2).

Table A2. Classification of paddocks on the basis of cropping index number (CIN)

CIN	Cropping history
1	>9 years pasture
2	7–9 years pasture
3	4–6 years pasture
4	1–3 years pasture
5	1–3 years arable
6	4–6 years arable
7	7–9 years arable
8	>9 years arable

Source: Lawrence-Smith et al. 2014

When assigning the CIN to paddocks, Lawrence-Smith et al. (2014) applied specific rules. For example, a single-year ryegrass seed crop (or other seed crops such as white clover, chicory, plantain, tall fescue, brown top) was treated as a crop, rather than pasture, but if a ryegrass (or other seed crop) was retained and harvested for seed in a second year, or was used for grazing in the second year, then both the first and second year were recorded as pasture (i.e. they were considered a pastoral break in the arable rotation). It was assumed

that 18 months of continuous crop growth in the absence of tillage provides for increased levels of fresh organic matter that help to restore or improve soil quality.

For the purposes of the hierarchical analysis, paddocks were separated into six land-use categories based on three primary criteria:

- the primary land use; pasture (CINs 1–4) or cropping (CINs 5–8)
- the duration of the primary land use; short-term (CINs 3–6) versus long-term (CINs 1, 2, 7, and 8)
- the livestock system; dairy versus sheep/beef.

This gives rise to the following six land-use classes:

- long-term arable
- short-term arable
- short-term sheep/beef pasture
- short-term dairy pasture
- long-term sheep/beef pasture
- long-term dairy pasture.

Appendix references

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