Manaaki Whenua
Landcare Research

Land-use classification for state of the environment soil quality monitoring and reporting

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Land-use classification for state of the environment soil quality monitoring and reporting

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Contents

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 Gisborne District Council under Envirolink grant 2222-GSDC170.

Objectives

- To develop clearly defined land-use categories that enable consistent classification, regionally and nationally, for SOE soil quality monitoring and reporting.
- To scope a tool to provide different contextual views on land-use data (including historical) and link alternative land-use classification systems.

The process

- Previous research on land-use categorisation and classification systems was briefly reviewed.
- A workshop was held with Land Monitoring Forum members on 8 February 2022 to identify the key attributes, and the ability to collect and capture those attributes, relevant for defining land-use classes for soil quality SOE reporting.
- A workshop was held to discuss the proposed set of attributes and land-use categories.
- A short survey was conducted to obtain information on how site attributes were currently captured and stored alongside soil quality results to scope the 'technology' aspects of the proposed tool.

Results

- Some of the inconsistencies in classification arise from a lack of clarity in the meaning of the terms 'land use', 'land management', and 'land cover'. Land use is the *purpose* for which the land cover is committed, land management is *how* the land is used to achieve that purpose (e.g. cultivation), and land cover simply desscribes the *physical surface* of the earth, including various combinations of vegetation types and other surface types, (e.g. permanent snow and ice, sand or gravel, transport infrastructure, etc.).. However, ambiguity creeps in because some agricultural land uses have characteristic land-cover patterns, enabling discrimination in land-cover mapping.

- The key attributes identified as being important for determining land use are:
  - whether the land is actively managed
  - a description of the main enterprise for the farm
  - confirmation the soil quality sampling site was located on a paddock that was representative of the typical activities of the farm
  - dominant vegetation cover
  - slope and elevation (for delineating anticipated lower and higher intensity dry-stock systems)
  - cultivation frequency
  - irrigation infrastructure
  - dairy infrastructure.

  Standardised values for these attributes were also identified.
- In addition, the following attributes were identified as being useful for interpreting soil quality results:
  - soil order
  - time since harvest (forestry)
  - cropping index number
  - more detailed information on other land management activities, such as fertiliser application.
- The proposed land-use categories are shown in Table S1. They are broadly similar to the National Environmental Monitoring Standard for soil quality and trace element monitoring (NEMS).

Table S1. Proposed land-use categories for regional council soil quality monitoring. The description of land-use categories draws on the NEMS description where applicable. The NEMS description is provided for comparison where the land-use category description differs or is not applicable.

Category	Potential sub-groups	Description
Undisturbed indigenous	Forest, scrub and shrubs, grassland	NEMS: Native forest, tussock, shrubland and scrub dominated by indigenous species. Undisturbed or unfertilised in recent decades.
Plantation forestry	Exotic forestry, potentially future sub-class	NEMS: 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.
Orchards and viticulture / perennial horticulture	Tree crops, vine crops, berry fruit	Permanent tree or vine crops (NEMS – permanent row orchard and vines)
Short-rotation cropping[1]	Arable	Predominantly grain, seed or fodder crops; may include a livestock rotation and/or vegetable rotation.
	Vegetable	Predominantly vegetable rotation; may include livestock rotation but less likely.
Dairy		NEMS: Dairy is the main dairy platform, predominantly used for milking. Dairy may include areas of grazed forage crops and maize for silage.
Dry stock	Flat-rolling, hill/high 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 low altitude (<600 m); hill/high country includes slope >15°, and/or 'high' (>600 m) altitude
Urban open space	Grassland, grassland with trees?	NEMS: Open areas of grass in urban areas including parks, school grounds, and playgrounds

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

- Two other land-use classes were identified as being potentially useful to enable description of land uses that existing sites might transition into: lifestyle and regenerating.

Conclusions and next steps

- This project identified that to ensure consistency in land-use classification, a consistent set of information (the key attributes) needs to be collected and captured in a systematic manner. This requires a critical change in the way councils currently collect this information. (The Tools project will assist with this.)
- Given the confidence that can be placed in the capture of some of land-use information obtained from the land manager (e.g. the purpose of using the land – enterprise), councils may also wish to consider how they might more easily and consistently capture critical information for land-use delineation from land managers.
- In the longer term it would be preferable to use field applications (e.g. Survey 123 for collection of site information). The development of a specific soil quality monitoring interface that captures the required information could be scoped by Manaaki Whenua – Landcare Research (MWLR) through an Envirolink advice grant.
- In relation to the plantation forestry class, Scion could be contracted to provide regional look-up tables for tree age based on diameter at breast height (DBH) measures, and subsequently time since harvest.
- Finally, 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.
- An Envirolink Tools project following on from this project will commence on 1 July 2022. It will include:
    - confirmation of the attributes and land-use categories developed in the project with the Land Monitoring Forum, and further standardisation of collection methods (as appropriate)
    - the potential creation of a spreadsheet template to facilitate the capture of site information
    - encoding of the identified relationships between attributes and land-use categories to develop open-source ontology modules (which allow these ontologies to be further extended at a later point), probably on Github
    - the development of guidance on the use of ontology modules in council workflows, probably using a spreadsheet application and/or a GIS application (in light of current systems used by councils).

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 the soil quality guidelines in 2009 (Hill and Sparling (2009). The programme was initially designed to give regions flexibility in reporting on 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 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). For example, market gardens could be captured in any one of three categories: horticulture, cropping, or as a separate category. And the basis for classifying dairy and dry stock can be variable. For instance, dairy may be considered the milking platform only (i.e. milking cows), with dairy run-off (i.e. non-milking dairy cows) included as dry stock. However, the term 'dry stock' is more often used to refer to sheep, beef, and deer farming, although there can be a wide range of intensity of land management within this general class (from intensive management to high country farming with minimal land management; see also Cavanagh et al. 2017, and Cavanagh et al. 2020 for more details). The inconsistency is driven by a number of factors including vagueness in descriptions of the land uses, variation in land use across regions, and changing land uses.

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 website and national Environmental Domain reports), which is supported by all 16 regional authorities.

The current project builds on the approach used in Stevenson et al. (2020), which required the curation of land-use information provided by individual councils. Specifically, a mapping approach was used to provide a normalised land-use classification scheme to identify a set of national land-use categories consistent with previous national reporting (i.e. curated land uses). This process enabled categorisation of most samples, with only some unique terms requiring exclusion or manual allocation to a curated land-use category.

Gisborne District Council has just commenced its soil quality monitoring programme and this report will assist with the development of that, as well as meeting national objectives outlined above. This medium advice grant project was undertaken for Gisborne District Council under Envirolink grant 2222-GSDC170.

2 Background

In considering the relevance of land-use classification for soil quality monitoring it is relevant to consider the *aim* of that monitoring. The Resource Management Act 1991 (RMA) provides the current driver for soil quality monitoring. Specifically, section 30 empowers regional councils to control land for the purposes of soil conservation. In this context, soil conservation includes both soil health and soil intactness (erosion). In addition, the Environmental Reporting Act 2015 requires regular reporting on the land domain, which comprises soil and underlying rock, animals, plants, and structures associated with the land. However, no specific objectives for the purpose of that reporting are given.

The LMF (Hill & Sparling 2009) considered the primary regional objectives for soil quality monitoring to be to:

- provide an early-warning system to identify the negative effects of primary land uses on long-term soil productivity (physical, chemical, biological)
- track specific, identified issues relating to the effects of land use on long-term soil productivity (which may also be district or area specific)
- utilise these results for SOE reporting and policy development
- integrate with other regional monitoring (e.g. water, especially groundwater).

A similar set of objectives have been included in the National Environmental Monitoring Standard for Soil Quality and Trace Elements (NEMS) as potential regional programme objectives. They include:

- to provide a representative assessment of the quality of the region's soil resource state and trends over time
- to assess soil quality across a range of land uses and soils representative of the region's soil resource
- to provide an early warning system to identify the effects of primary land uses on long-term soil quality (physical, chemical, biological) and soil trace elements
- to assist in the detection of spatial and temporal changes in soil quality and soil trace elements
- to integrate with other regional monitoring (e.g. groundwater monitoring)
- to collect scientifically robust data
- to provide data that can be aggregated for national reporting.

In the early stages of the development of monitoring programmes, soil quality issues identified as being common across all regions were:

- structural decline
- nutrient depletion
- organic matter depletion
- nutrient saturation/excess, biological activity
- soil acidification (Sparling et al. 2001).

Land-use priorities were structural decline, nutrient saturation, and biological activity (particularly under dairy, intensive beef rearing, horticulture, forestry, and deer farming). Nutrient depletion and acidification were potential concerns under forestry (Sparling et al. 2001). It is interesting to note that lacking from both the LMF and NEMS objectives is a clear statement on what actions (e.g. policy response, land management response) are intended to be taken if soil quality is observed to deteriorate.

3 Objectives

This project aims to develop clearly defined land-use categories that enable consistent classification regionally and nationally for SOE soil quality monitoring and reporting. This will also inform the preliminary scoping of a tool that allows for mapping across land-use categories that have been developed for a different purpose, to be progressed through a subsequent Tools project.

4 The process

The following approach was used to develop land-use categories that are appropriate for SOE soil quality monitoring, and to scope a tool to provide different contextual views on land-use data (including historical) and link alternative land-use classification systems.

- Previous research on land-use categorisation (e.g. Rutledge et al. 2009) and classification systems (e.g. cropping index number used by Environment Canterbury, industry classifications, such as farm classes used by Beef + Lamb, and United Nations guidelines) was briefly reviewed.
- An initial workshop was held with LMF members on 8 February 2022 to:
    - identify the key attributes relevant for defining land-use classes for soil quality SOE reporting
    - discuss the ability to define those attributes simply and routinely
    - identify alternative land-use classification systems that may be useful to link soil quality SOE land-use classifications to, for example, land-cover classes.
- From this workshop an initial set of attributes and land-use categories were developed and presented at a subsequent workshop on 28 April, with a further refinement of the short-rotation cropping category achieved through a further workshop on 12 May.
- To scope the 'technology' aspects of the tool, a short survey was sent out to all councils to obtain information on how site attributes are currently captured and stored alongside soil quality results.

The outcomes of the review, workshop discussions, and survey are presented in this report.

5 Literature review

5.1 Definitions

'Land use', 'land cover' and 'land management' are often (erroneously) used interchangeably in discussions about land use. This erroneous use seems to largely 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,[1] 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) (Lesslie 2004). This may also be defined as a series of operations on land, carried out by humans, with the intention of obtaining products and/or benefits through using land resources (de Bie 2000, cited in Rutledge et al. 2009).

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). Some land management practices, such as stubble disposal practices and tillage rotation systems, may be distinguished by characteristic land-cover patterns and linked to particular issues.

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.

Some land uses, such as agriculture, have a characteristic land-cover pattern and can appear in land-cover classifications. Other land uses, such as nature conservation, are not readily discriminated by a characteristic land-cover pattern. For example, where the land cover is woodland, the land use may be timber production, grazing or nature conservation.

The OECD description of land-use classification is useful because it makes explicit the connection between land use and land cover, defining land-use classification as 'a classification providing information on land cover, *and the types of human activity involved in land use*. It may also facilitate the assessment of environmental impacts on, and potential or alternative uses of, land' (United Nations 1997).

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

5.2 SOE soil quality monitoring

In considering the relevance of land-use classification for soil quality monitoring, it is relevant to consider how land use has been defined previously in this context.

5.2.1 Land use in SOE soil quality monitoring

Since the commencement of research to develop programmes for national and regional soil quality monitoring, land use and soil type have been key considerations in the selection of sites and the stratification of sites for the analysis of data. (Stratification on the basis of soil type is not within the scope of this discussion.) A summary of land-use categories used in key documents that have underpinned the development of SOE soil quality monitoring is shown in Table 1. No explicit definitions of land-use categories were provided for the 500 Soils programme, but descriptions were provided in the review of the programme (Hill et al. 2003) and in the development of national guidance for soil quality monitoring (Hill & Sparling 2009). Descriptions for the land-use categories identified in the Soil Quality and Trace Element monitoring NEMS are provided in Table 2.

Table 1. Land-use categories identified in key documents that have underpinned SOE soil quality monitoring

500 Soils[a]	Hill et al. 2003[b]		LMF Guide (Hill & Sparling 2009)[c]	NEMS (2022)[d]
	Level 1a[1]	Level 1b		
Arable cropping Mixed cropping	Primarily horticulture	Cropping[2]	Cropping and horticulture	Cropping
Horticulture		Orchards, vineyards, berry-fruit		Horticulture
Dairy	Primarily pastoral	Intensive – dairy, intensive beef	Intensive pasture[3]	Dairy – milking platform (may include grazed fodder crops, maize for silage)
Dry stock		Extensive – sheep and beef, deer	Extensive pasture[4]	Dry stock (other pasture), all other pasture incl. dairy support (non-milking platform)
Tussock	Tussock grassland	Tussock grassland	(Potentially incorporated into extensive pasture)	(Indigenous vegetation)
Forest	Planted forest	Planted forest	Plantation forest	Exotic forest
Indigenous	Indigenous vegetation[5]	Indigenous vegetation[5]	Indigenous vegetation[5]	Indigenous vegetation – forest, scrub, tussock (unfertilised in recent decades)
Scrub	Scrub–shrubland	Scrub–shrubland[5]	(If indigenous dominated, included in indigenous vegetation)	
Urban	–	–	–	Urban open spaces

[a] Sparling et al. 2001, Table 14.1

[b] Hill et al. 2003, Table 6

[c] Hill & Sparling 2009

[d] Soil Quality and Trace Element Monitoring NEMS

[1] Level 1 was considered appropriate for national, and potentially regional, reporting and was linked to land-use classes used for the Land Cover Database (LCDB1).

[2] Level 2 split is between arable, and mixed (rotations including pasture ley) and vegetable cropping

[2] Permanent grass-legume pasture.

[3] Permanent pasture or grasslands, including tussock.

[4] Indigenous forest, coastal wetland, inland wetland, mangroves.

[5] Level 2 split is between exotic and native scrub/shrubland.

For pastoral systems, Hill et al. (2003) suggested intensive and extensive pasture could be approximated using Land Use Capability (LUC, from the New Zealand Land Resource Inventory database): LUC 1–4 approximate intensive pasture and LUC 5–8 extensive pasture, with recognition that AgriBase farm-type data were also becoming readily available in many regions.

In addition to the land-use category assigned by council staff, additional information on land management practices is intended to be gathered at each time of sampling through a survey provided to land owners/managers (Hill & Sparling 2009; NEMS). For agricultural and horticultural land uses this includes a general description of the management approach, stock type and stocking rate, and information on drainage, tillage, irrigation, and fertiliser use. Within the NEMS, information on the date of last fertiliser application, stock grazing, cultivation and harvesting, and proportion of bare ground is also required to be collected at the time of sampling.

Table 2. 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.

Arable cropping index

In parallel with the development of soil quality monitoring based on the 500 Soils programme, Environment Canterbury has undertaken an Arable & Pastoral Soil Quality Monitoring Programme (Lawrence-Smith et al. 2014). Classification of land use within this programme is based on the use of cropping index numbers, which refer to the number of consecutive years a paddock had been under arable or pastoral production immediately prior to sampling (Table 3).

Table 3. Classification of paddocks on the basis of cropping index number (CIN) (Lawrence-Smith et al 2014)

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

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.

5.3 Alternative land-use or land-cover classifications used in New Zealand

5.3.1 Land Cover Database (LCDB)

Land use for soil quality monitoring has been linked to LCDB categories, largely to enable assessment of the spatial representativeness of soil quality monitoring sites (Sparling et al. 2001; Hill et al. 2003).

As described on the Land Resource Information System (LRIS) portal:[2]

> *The New Zealand Land Cover Database (LCDB) is a multi-temporal, thematic classification of New Zealand's land cover. It identifies 33 mainland land cover classes (35 classes once the offshore Chatham Islands are included). The classification was revised between versions 1, 2, and 3 but has been consistent thereafter, and always with backward compatibility maintained. Land cover features are described by a polygon boundary, a land cover code, and a land cover name at each nominal time step; summer 1996/97, summer 2001/02, summer 2008/09, summer 2012/13, and summer 2018/19. The data set is designed to complement in theme, scale and accuracy, New Zealand's 1:50,000 topographic database (www.linz.govt.nz/land/maps/topographic-maps/topo50...).*

The LCDB is considered to be suitable for use in national and regional environment monitoring, forest and shrubland inventory, biodiversity assessment, trend analysis, and infrastructure planning. 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.

However, challenges with more finely delineating certain land uses relevant to soil quality monitoring have been encountered (e.g. delineation of different types of cropping such as market gardens vs arable or mixed cropping, and intensive vs extensive pastoral systems), leading to the suggestion that intensive and extensive pasture could be approximated using Land Use Capability (from the NZLRI database), with LUC 1–4 approximating intensive pasture and LUC 5–8 extensive pasture (Hill et al. 2003). LCDB and additional spatial layers, including slope, were used to delineate pastoral systems in recently developed guidance on soil carbon monitoring (see more detail below under 'Soil Organic Carbon Monitoring Programme for agricultural soils').

[2] LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand - LCDB | | Environment and Land GIS | LRIS Portal (scinfo.org.nz)

Table 4. Correlations of land-use categories relevant for SOE soil quality monitoring between different versions of LCDB, excerpted from LCDB Class correlations*

	LCDB v1	LCDB v2		LCDB v3		LCDB v4 onward	
	Class Name	Class Code	Class Name	Class Code	Class Name	Class Code	Class Name
Other						0	Not land (used in Version 5.0 onwards)
Cropland		30	Short-rotation Cropland	30	Short-rotation Cropland	30	Short-rotation Cropland
	Primarily Horticulture	31	Vineyard	33	Orchard Vineyard & Other Perennial Crops	33	Orchard Vineyard & Other Perennial Crops
		32	Orchard and Other Perennial Crops				
Grassland, Sedgeland and Marshland	Primarily Pastoral	40	High Producing Exotic Grassland	40	High Producing Exotic Grassland	40	High Producing Exotic Grassland
		41	Low Producing Grassland	41	Low Producing Grassland	41	Low Producing Grassland
	Tussock Grassland	43	Tall Tussock Grassland	43	Tall Tussock Grassland	43	Tall Tussock Grassland
		44	Depleted Grassland	44	Depleted Grassland	44	Depleted Grassland
	Inland Wetland	45	Herbaceous Freshwater Vegetation	45	Herbaceous Freshwater Vegetation	45	Herbaceous Freshwater Vegetation
	Coastal Wetland	46	Herbaceous Saline Vegetation	46	Herbaceous Saline Vegetation	46	Herbaceous Saline Vegetation
		47	Flaxland	47	Flaxland	47	Flaxland
Scrub and Shrubland	Scrub	50	Fernland	50	Fernland	50	Fernland
		51	Gorse and/or Broom	51	Gorse and/or Broom	51	Gorse and/or Broom
		52	Manuka and/or Kanuka	52	Manuka and/or Kanuka	52	Manuka and/or Kanuka
		53	Matagouri	58	Matagouri or Grey Scrub	58	Matagouri or Grey Scrub
		57	Grey Scrub				
		54	Broadleaved Indigenous Hardwoods	54	Broadleaved Indigenous Hardwoods	54	Broadleaved Indigenous Hardwoods
		55	Sub Alpine Shrubland	55	Sub Alpine Shrubland	55	Sub Alpine Shrubland
		56	Mixed Exotic Shrubland	56	Mixed Exotic Shrubland	56	Mixed Exotic Shrubland
		55[1]	Peat Shrubland (Chatham Islands only)			80	Peat Shrubland (Chatham Islands only)
		56[1]	Dune Shrubland (Chatham Islands only)			81	Dune Shrubland (Chatham Islands only)
Forest		60	Minor Shelterbelts	71	Exotic Forest	71	Exotic Forest
	Major Shelterbelts	61	Major Shelterbelts				
	Planted Forest	62	Afforestation (not imaged)				
		63	Afforestation (imaged, post LCDB1)				
		65	Pine Forest - Open Canopy				
		66	Pine Forest - Closed Canopy				
		67	Other Exotic Forest				
		64	Forest - Harvested	64	Forest - Harvested	64	Forest - Harvested
	Willows and Poplars	68	Deciduous Hardwoods	68	Deciduous Hardwoods	68	Deciduous Hardwoods
	Indigenous Forest	69	Indigenous Forest	69	Indigenous Forest	69	Indigenous Forest
		70	Mangrove	70	Mangrove	70	Mangrove

* LCDB Class Correlations - LCDB | | Environment and Land GIS | LRIS Portal (scinfo.org.nz)

For further reference, the arrangement of LCDB classes currently used specifically for the purposes of regional and national land-cover reporting (e.g. in Land, Air, Water Aotearoa; LAWA) are given in Table 5. The 33 LCDB classes are aggregated into six broad and 12 medium-level classes to represent different land-cover types.

Table 5. Arrangement of land-cover classes for SOE reporting

Broad classes	Medium classes	Detailed classes
Urban/bare/lightly vegetated surfaces	Artificial bare surfaces	Transport infrastructure
		Surface mine or dump
	Natural bare/lightly vegetated surfaces	Sand or gravel
		Landslide
		Gravel or rock
		Permanent snow and ice
		Alpine grass/herbfield
	Urban area	Built-up area (settlement)
		Urban parkland/open space
Cropland	Cropping/horticulture	Short-rotation cropland
		Orchards, vineyards or other perennial crops
Forest	Exotic forest	Forest - harvested
		Exotic forest
		Deciduous hardwoods
	Indigenous forest	Indigenous forest
		Broadleaved indigenous hardwoods
Grassland / other herbaceous vegetation	Exotic grassland	Depleted grassland
		High-producing exotic grassland
		Low-producing grassland
	Other herbaceous vegetation	Herbaceous freshwater vegetation
		Flaxland
		Herbaceous saline vegetation
	Tussock grassland	Tall tussock grassland
Scrub/shrubland	Exotic scrub/shrubland	Gorse and/or broom
		Mixed exotic shrubland
	Indigenous scrub/shrubland	Mānuka and/or kānuka
		Matagouri or grey scrub
		Fernland
		Sub-alpine shrubland
		Mangrove
Water bodies	Water bodies	Lake or pond
		River
		Estuarine open water
		Not land

Source: LAWA 2021

5.3.2 Soil Organic Carbon Monitoring Programme for agricultural soils

A reference guide for a national soil organic carbon monitoring programme for agricultural soils has recently been developed (Hedley et al. 2020). This guide divides agricultural land into five broad land-use classes ('strata', Table 6), so that estimates can be made for each of these sectors, as well as being assembled to provide an overview for all agricultural land.

Table 6. Land-use classes selected for soil organic carbon monitoring to assess change in each sector class and for all managed agricultural land

No.	Land Use Class	Definition
1	Cropland	Defined by the 'Short-rotation cropland' LCDB 2012 class.
2	Horticulture	Defined by the 'Orchard, vineyard or other perennial crop' LCDB 2012 class.
3	Dairy pasture	Defined by the map of Manderson et al. (2019) intersected by the grassland classes as defined by the LCDB 2012 coverage ('High producing exotic grassland', 'Low producing grassland', and 'Depleted grassland').
4	Flat-rolling dry-stock pasture	Defined by the LCDB 2012 grassland class coverage ('High producing exotic grassland', 'Low producing grassland', and 'Depleted grassland'), with areas removed where they are in the hill country layer (defined from the geospatial layer above), and also removed where they are in the dairy layer (defined from the geospatial layer above).
5	Hill-country dry-stock pasture	Defined by the intersection of the LCDB ('High producing exotic grassland', 'Low producing grassland', and 'Depleted grassland'), with a slope mask defining areas above 15 degrees.

5.3.3 *Soil Description Handbook*

The *Soil Description Handbook* (Milne et al. 1995) is referenced in Hill & Sparling 2009 and the NEMS as providing the detail on methods to use for determining various site characteristics. This handbook also includes descriptions of different land uses, but these differ from land-use categories considered for soil quality monitoring. The *Soil Description Handbook* is currently being updated and revised, including sections on land use. A driver for the land-use classes is considering land use as it affects soil properties rather than for mapping purposes (pers. comm., Malcolm McLeod, MWLR), so there would appear to be an opportunity to align land-use categories in the *Soil Description Handbook* and SOE soil quality monitoring, because they have similar drivers.

5.3.4 Industry classifications

DairyNZ and Beef + Lamb also have classifications systems. Dairy NZ describes five farming systems based on the extent of imported feed (Table 7), while Beef + Lamb describe eight different farming systems, including a mixed cropping class where the dominant economic activity for the farm is derived from arable farming (Table 8).

Table 7. DairyNZ farm system classifications

System	Description
System 1: All grass self-contained, all stock on the dairy platform	No feed is imported. No supplement fed to the herd except supplement harvested off the effective milking area, and dry cows are not grazed off the effective milking area.
System 2: Feed imported, either supplement or grazing off, fed to dry cows	Approx. 4–14% of total feed is imported. Large variation in %, as in high rainfall areas and cold climates such as Southland most of the cows are wintered off.
System 3: Feed imported to extend lactation (typically autumn feed) and for dry cows.	Approx. 10–20% of total feed is imported. Westland: feed to extend lactation may be imported in spring rather than autumn.
System 4: Feed imported and used at both ends of lactation and for dry cows.	Approx. 20–30% of total feed is imported onto the farm.
System 5: Imported feed used all year, throughout lactation and for dry cows.	Approx. 25–40% (but can be up to 55%) of total feed is imported.

Table 8. Description of farm classes used by Beef + Lamb NZ

Farm class	Description
1. South Island high country	Extensive run country at high altitude carrying fine wool sheep, with wool as the main source of revenue. Located mainly in Marlborough, Canterbury, and Otago.
2. South Island hill country	Mainly mid-micron wool sheep, mostly carrying between two and seven stock units per hectare. Three-quarters of the stock units wintered are sheep and one-quarter beef cattle.
3. North Island hard hill country	Steep hill country or low-fertility soils with most farms carrying 6–10 stock units per hectare. While some stock are finished, a significant proportion are sold in store condition.
4. North Island hill country	Easier hill country or higher-fertility soils than Class 3. Mostly carrying between 7 and 13 stock units per hectare. A high proportion of sale stock sold is in forward store or prime condition.
5. North Island intensive finishing farms	Easy-contour farmland with the potential for high production. Mostly carrying between 8 and 15 stock units per hectare. A high proportion of stock are sent to slaughter and replacements are often bought in.
6. South Island finishing-breeding farms	A more extensive type of finishing farm, also encompassing some irrigation units and frequently with some cash cropping. Carrying capacity ranges from 6 to 11 stock units per hectare on dryland farms and over 12 stock units per hectare on irrigated units. Mainly in Canterbury and Otago. This is the dominant farm class in the South Island.
7. South Island intensive finishing farms	High-producing-grassland farms carrying about 10–14 stock units per hectare, with some cash crop. Located mainly in Southland, south and west Otago.
8. South Island mixed cropping and finishing farms	Located mainly on the Canterbury Plains. A high proportion of their revenue is derived from grain and small seed production as well as stock finishing.

5.4 Land-use classification

Various research has been undertaken in New Zealand on land-use classification and land-use mapping. Rutledge et al. 2009 is a pivotal paper with regard to geospatial approaches to land-use classification, and it provides an excellent overview of approaches to land-use classification. The authors describe four approaches to land-use classification:

- categorial approaches, which depict land use as discrete classes with no relationships among them
- hierarchical approaches, which depict land use as a nested set of classes (higher-level classes, such as urban, become divided into more specific classes, such as residential, commercial)
- multidimensional approaches, which store multi-attribute information for defined unit areas and allow recombination to generate different land-use classes
- semantic classifications, which derive from linguistic theory and describe land use using a rich collection of words and formal grammar from which different interpretations (i.e. classifications) could be derived.

Rutledge et al. 2009 outlined previous attempts to classify land use in New Zealand, noting that the reason for failure was largely attributed to a single classification not being useful in any other capacity. These authors concluded that a semantic approach to land-use classification would be most useful in New Zealand, as it has the ability to include a diverse range of information, to incorporate new information as it becomes available, and to generate a range of classifications, including reference or official classifications, to meet a variety of needs while retaining the capacity to translate and compare among them.

Subsequent to the assessment of Rutledge et al. 2009, the New Zealand Land Use Database (LUDB) Project was funded as a 2-year Envirolink Tools project running from January 2010 to December 2011. This included identifying gaps and areas for prioritisation for developing the LUDB, which included a survey of information used by councils to determine land use (Morgan et al. 2010): 27 different sources of land-use information were reported to be used, with the top five being (in order of frequency):

- Land Cover Database (LCDB)
- AgriBase
- remote sensing (aerial or satellite photos)
- New Zealand Land Resource Inventory (NZLRI – Land Use Capability)
- Statistics NZ (the Census).

A land-use classification agreed with councils was undertaken as part of this project, and also drew on six existing land-use classifications:

- Land Use New Zealand
- Creating Futures Land Use
- AgriBase
- Environment Canterbury Land Use for Water Quality
- LINZ Land Use for Rating Valuation

- Land Use and Carbon Analysis System (LUCAS) Price et al. 2010).

The agreed land-use classification is shown in Appendix 2. However, beyond the descriptions provided in that table it is unclear how and what information specifically was used to delineate the different land-use classes. However, the focus on the project was not so much to develop a national classification as to focus on the process of land-use classification and enable flexible land-use classification (see Figure 1). This project focused on the use of publicly available and nationally consistent data sets for input data, including the LCDB, Land Resource Inventory (Land Use Capability), Land Environments of New Zealand, and Census data. A working model was developed, with documentation for users (Rutledge et al. 2011). However, it seems that the technological requirements of the database, potentially alongside the challenges of integrating the input data to develop robust classifications, resulted in the database not continuing to be used.

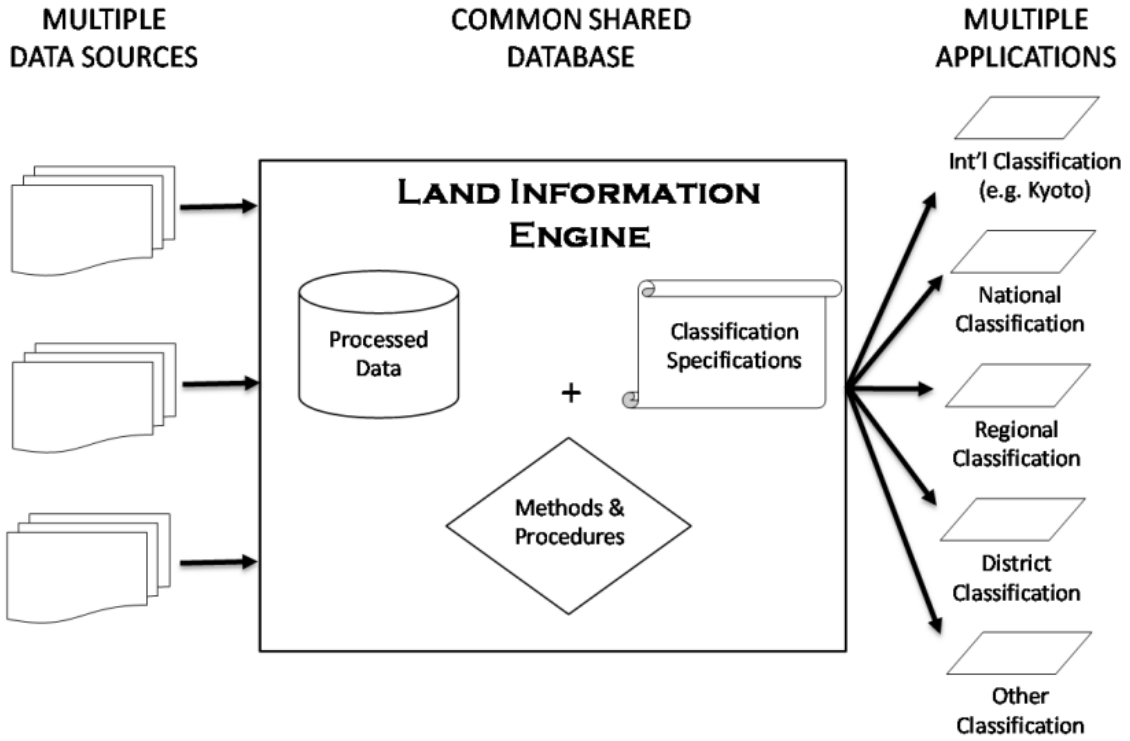

Figure 1. Conceptual model of the national land-use database. Source: Price et al. 2010

Following the LUDB programme, the Innovative Data Analysis (IDA) programme was funded by the Ministry of Business, Innovation and Employment over 2014–2018. This programme aimed to 'research and develop processes to integrate and harmonise high priority heterogeneous land resource and biodiversity datasets to support a step change in the quality of environmental reporting' (Medyckyj-Scott 2018).

This programme included the development of the NZ land-use classifier (Manderson et al. 2018). This tool was based on a software framework using Python scripts (pyLUC) that contained all the classification rules as well as links (URLs) to original data sources (thus providing information on the provenance of classification). It was shown to successfully

reconstruct three different national land-use classifications. The approach requires the data sources to be stored on the LRIS portal, and was suggested to be most useful in the final stages of land-use classification development (Manderson et al. 2018).

Further projects leading on from IDA included an improvement of the grassland information in the LUCAS project (Newsome et al. 2018; Manderson et al. 2019). This project used national-scale pasture yield simulation modelling, with a fuzzy-logic-based framework, to classify high- and low-producing grassland into a general farm class (dairy, other livestock, and grassland not otherwise used for agriculture). Further work scoped approaches for developing a national land-use intensity indicator (Manderson et al. 2020).

In an international context, there are numerous examples of different land-use classifications, which are largely hierarchical and include a mix of land cover and land use (Table 9). For example, in 2012 ISO 19144-2:2012, Geographic Information – Classification systems – Part 2: Land Cover Meta Language (LCML), was published. LCML provides a common reference framework to allow different land-cover classification systems to be described according to their physiognomic properties, without replacing the classification system (e.g. a mapping framework). ISO 19144-2:2012 is heavily based on the Food and Agriculture Organization's Land Cover Classification System (LCCS) (Di Gregorio & Jansen 2000).

LCCS is hierarchical and divided into eight classes based on three criteria: presence of vegetation, edaphic conditions, and artificiality of cover (Di Gregorio & Jansen 2000). LCCS is an atemporal classification system: it can refer only to properties of entities that persist through time, even though they exhibit change. For example, using an atemporal classification system one might assert 'this area has 50% forest cover', but would not be able to assert 'this area lost 80% of its forest in the last 5 years' (Camara 2020).

Significantly, LCCS suffers a similar, somewhat arbitrary, conflation of land-cover and land-use concepts as other national or international classifications, such as CORINE, NLUD, GLC2000, and Aotearoa New Zealand's own LCDB, probably stemming from an early exemplar in the US Geological Survey's Land Use and Land Cover Classification developed by Anderson et al. (1976) (Fisher et al. 2005).

Table 9. Examples of different international high-level land-use classification

OECD	Australian land-use management	UK	USGS
Agricultural land	Conservation and natural environments	Agricultural	Agricultural
Forest and other wooded land	Production from relatively natural environments	Forestry	Rangeland
Built-up and related land, excluding scattered farm buildings	Dryland agriculture and plantations	Minerals	Forest
Wet open land	Irrigated agriculture and plantations	Recreation and leisure	Water areas
Dry open land with special vegetation cover	Intensive uses (primarily built-up areas)	Transport	Wetland
Open land without, or with insignificant, vegetation cover	Water	Utilities and infrastructure	Barren land
Waters		Residential	tundra
		Community services	Perennial snow or ice
		Retail	Urban or built-up land
		Business and industry	
		Previously developed land	
		Defence	
		Unused land	

5.5 Summary

As is evident from this brief review, there has been – and continues to be – a considerable amount of research in the land-use space in New Zealand. While there is a desire to avoid being constrained to a single classification and to enable flexible classification, the reality has been that the focus on land-use 'classification' appears to largely revolve around the availability of different input layers, often using increasingly sophisticated methods to garner land-use information, while rarely describing the purpose of the land-use classification.

There seems to be a real desire to enable and inter-operate over multiple classification schemes: this is often implicit in the singular, purpose-driven classifications described in the available research. Unfortunately, a broader discussion focusing on identifying the attributes of land use relevant to a specific purpose or domain is lacking. Similarly, a more focused discussion examining different types of data and observations, along with their associated values, supporting a category or classification is also either lacking or steeped in domain knowledge; what Kastens et al. (2009) call 'professional vision'.

As a result, this approach appears to lead to the generation of multiple land-use classifications that differ from each other for no good reason, other than reflecting the limits of the input data. Shifting the focus from what can be developed with existing data to what information is required to define land use for the relevant purposes could also help to guide strategic data collection.

The focus in this project is to identify the core attributes of soil quality data and relevant land-use categories, as well as the relationship between soil quality data and the derived land-use categories to enable robust, reproducible, and consistent classification of land use.

Further, this project adopts a 'bottom-up' approach, recognising that council staff will need to talk with land managers to gain access to the sampling site, and will also be on-site to collect soil samples. This contrasts with the 'top-down,' or data-driven, approach used for mapping land use at a regional or national level, which is largely divorced from any interaction with land managers. There needs to be a connection between these two approaches in order to determine the representativeness of sampling of different land uses in a region, which includes consideration of the area of that land use.

6 Proposed attributes and land-use classes

In the context of soil quality monitoring, the purpose of land-use classification is effectively to constrain land management activities to a more defined range of activities than may be typically associated with certain land uses. This then enables assessment of the effect of that range of activities (land use) on soil quality. This description of 'land use' categories of land 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, there has often been a focus on higher-intensity land use, which reflects concerns around 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.

6.1 Attributes of land use

From the workshop discussions a wide range of attributes that were considered relevant for 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.

It is further noted that some attributes are only relevant for, or define, certain land-use categories.

Workshop discussions indicated a preference for fewer, broad, land-use categories, while retaining the ability to capture more specific information to enable more detailed classifications. Hence, the range of attributes captured includes attributes that may only be applicable to certain land uses.

A full set of site attributes that were either discussed in the workshop or identified during review of information is shown in Table 10, alongside an assessment of their utility for land-use categorisation, interpretation of soil quality results, source of information, and commentary on the ability to robustly capture the required information. A number of attributes (e.g. fertiliser application rate) were identified as being 'nice to have (primarily for interpretation of results) but difficult to obtain'. However, future opportunities for the more ready capture of this information may exist through leveraging information such as that being captured in farm plans, or used in Overseer.

For some of this more detailed land management information it is also useful to consider the frequency with which sampling of a soil quality monitoring site occurs. This is typically on a 3–5-year cycle, and so the level of information to assist interpretation needs to be commensurate with that frequency. For instance, is it sufficient to ensure the site being sampled is not within 4 weeks of fertiliser application, as per NEMS, rather than seeking detailed information on fertiliser application rate?. It is also worth noting that in the NEMS some desired information (e.g. date of last cultivation) is to be included on forms for site descriptions to be completed at the time of sampling

Finally, given that some information is arguably most robustly obtained from the land manager, it may be worth considering how this information can be more systematically captured (e.g. a minimum set of questions asked at the time of confirming the sampling date to ensure critical information is captured).

For the 'key attributes', further description of the values for these individual attributes is provided in Table 11. 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 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. Other sources of land-use classification (such as the Food and Agriculture Organization crop list, Australian land-use and management classifications) were also considered. Because vegetation descriptors are more extensive, these are shown separately in Table 12.

Table 10. Summary of attributes evaluated, use for land use classification or interpretation of results, and consideration of the source of information to determine the attributes

Attribute	Rationale or comment	Land-use classification	Interpretation of results	Info source
Active land management for production purposes?	Aims at distinguishing undisturbed land from other land uses, but also excluding mānuka plantations that are actively managed (and also excluding pest or weed control as activities)	Y	N	Land manager /owner; could use data layers that capture different types of conservation land; e.g. protected areas layer (noting it doesn't include some local government reserves, etc.)
Enterprise / farm system	Need to be able to confirm land-use classification: because oil-quality monitoring occurs over time, need to understand the 'system' the site is operating in, and thus the likely range of management activities/land uses, rather than the specific use of the land solely at the time of sampling	Y – critical parameter	Y	Land manager /owner; potentially valuation layer from LINZ
Site representativeness check	To confirm if site is representative of the enterprise; if not, need link to identifier for land use – could be on-site observation (e.g. orchard on dairy farm) or land manager	N	Y	On-site observation
Site land use	Only relevant if site is not representative of enterprise / broader farm system	Y	Y	Land manager/owner; on-site observation
Site condition	Separating from vegetation cover to capture if bare, cultivated or planted/has vegetation.		Could be	On-site observation
Dominant vegetation cover	Critical parameter	Y	Could be	On-site observation
Stock type	Used both for land-use delineation and potentially for interpretation of soil quality results	Y	Y, compaction	Land manager/owner; on-site observation
Stocking intensity	Potentially easy to get from land manager	N	Y	Land manager/owner
Cultivation frequency	Intended to delineate more intensive cropping practices (e.g. vegetables) from arable crops	Y	Y	Either land manager or inferred from vegetation cover/crop type
Cropping index number	Determined as per ECan documentation; but key (secondary to cultivation) frequency challenge is it requires information on vegetation/crop type for each year, including between sampling occasions, and so is more difficult to obtain.	Maybe	y	Probably land manager conversation/survey

Attribute	Rationale or comment	Land-use classification	Interpretation of results	Info source
Irrigation infrastructure	Useful to assist interpretation of soil quality results, and could be used to classify land use based on irrigated vs non-irrigated. Likely useful to capture type of irrigation (e.g. centre pivot, travelling irrigator).	Not currently	Could be	On-site observation for specific site
Dairy infrastructure	Assists land-use classification, although absence doesn't mean it's not dairy	Y		On-site observation; land manager – but anywhere in proximity
Time since harvesting (forestry only)	Potentially useful to evaluate soil quality results	N	Y	Calculated from diameter at breast height (DBH) measured on-site and regional look-up tables that could easily be developed by Scion based on existing data (for pine).
Lifestyle block	Considered to be a useful secondary property. Mostly appears to be identified through economic data, with the primary source of income for the relevant land parcel being unrelated to agricultural production. Is potentially most useful if an existing agricultural production site becomes a lifestyle block.	Potentially	Potentially	Landowner/manager; valuation data
Site characterisation attributes (i.e. will be unchanged from site establishment therefore only need to be captured once)				
Slope	Can be used to delineate higher-intensity land use (typically occurring on low slopes) from lower-intensity land use, particularly for livestock systems	Y	Potentially	On-site observation preferred, digital elevation model (DEM) as alternative or LIDAR
Altitude	Can be used to delineate higher-intensity land use (typically occurring on lower altitude) from lower-intensity land use, particularly for livestock systems	Y	N	On-site observation; spatial layer based on GPS position also an option.
Soil order	Interpretation of results/assessment of representativeness of sampling; also some soil quality target values vary with soil order	N	Y	Site characterisation parameter; on-site observation best
Parent rock	May be loosely relevant in context of erosion	N	Potentially	Could be S-map, Fundamental Soils Layer (FSL)
Nice to have – mainly to assist with interpretation of soils results, but difficult to obtain				
Productivity	Considered to be potentially useful, in conjunction with stocking intensity, with respect to extent of imported feed on property. Unclear as to how consistently this could be ascertained.	N	Potentially	Land owner/manager; if dairy, could ask land manager to self-classify into DairyNZ class to ascertain level of imported feed.

Attribute	Rationale or comment	Land-use classification	Interpretation of results	Info source
Erosion potential?	May be useful in assessment of site and evaluation of capability vs actual use.	N	Potentially	Certain LUC classes
Method of pasture resowing		N	Potentially useful	Landowner/manager; potentially agricultural production survey?
Time under bare ground		N	Yes	Land manager
Time since last cultivation			Potentially	Probably land manager conversation/survey; could be inferred from CIN?
Fertiliser application rate	Maybe the question/focus is when was this sampling site last fertilised? Has the sampling site been fertilised in the last x weeks?	No	Potentially	Probably land manager; what time-frame is relevant?
Traffic frequency	Difficult to identify; cropping frequency/crop type could probably be used as a surrogate for this	No	Potentially	Probably land manager; what time-frame is relevant?
Cropping intensity	Probably a combination of fertiliser application rate, irrigation frequency, cultivation; question, is how would this be defined?	No	Potentially	Probably land manager; what time-frame is relevant?

Table 11. Summary of values for the different key attributes, and whether they are used for land-use identification

Attribute	Land-use classification	Values	Comments
Active land management for production purposes?	Y	Yes, no	Purpose is to delineate undisturbed from other land-use classes
Enterprise/farm system	Y – critical parameter	Based on proposed land-use categories: dairy; dry stock; vegetable cropping, perennial cropping; arable cropping; forestry	Currently assuming 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.
Site representativeness check	Y	Yes; no	If no, need to identify land use using groupings for enterprise/farm system
Site condition	N	Bare ground, planted, recently cultivated/harvested (crops), vegetated, recently harvested (forestry)	To use in addition to vegetation cover
Dominant vegetation cover	Y	See Table 3	
Stock type	Y	Beef cattle; dairy cows; cattle – immature; cows; sheep; bulls; deer; other (e.g. goats, alpaca, horses, llamas)	Could include age class of livestock
Stocking intensity	N	<3 head per hectare	
Cultivation frequency	Y	1 year – more than, less than or equal to	
Cropping index number	N	1 to 9, resampled to 4 categories	Specific values are grouped up to different categories (e.g. short-term arable/pastoral, long-term arable/pastoral)
Irrigation infrastructure	Not currently	Yes/no; none/existing	Specify type of irrigator
Dairy infrastructure	Y	Yes/no; none/existing	
Time since harvesting (forestry only)	N	Calculated from DBH measures on-site, or inferred from tree height for small trees of <2m, or 0 for harvested site.	Need Scion to create look-up tables to convert DBH to age (easily done) (then time since harvest = age+1
Lifestyle block	Potentially	Yes/no	Most likely obtained from economic data

Table 12. Summary of vegetation class descriptors – loosely grouped in a left to right descending hierarchy according to different land-use classes

Perennial horticulture					
Fruit and nut trees	Pip fruit	Stone fruit	Citrus	Other	
Vines	Grapes				
	Kiwifruit				
Berry fruit					
Short-term cropping					
Vegetables	Brassica	Alliums (onions)	Leafy greens	Roots & tuber	Stalks vines bulbs
				Potatoes	Includes celeriac, celery, courgettes (or zucchini), gherkins, marrows, melons, pumpkins, chokos, fennel, parsley, herbs, rhubarb, squash and sweetcorn
				Carrots	
				Other	
Arable crops	Wheat	Maize	Other fodder[1], forage or seed crop	Pasture grass	
Livestock systems (dairy, dry stock)					
Pasture grass	Forage or fodder[1] crop	Other feed crop (e.g. sunflower, maize)			
	Chicory				
	Fodder beet				
	Kale				
	Lucerne				
	Plantain				
	Swedes				
	Turnip				

Exotic forestry			
Site condition?	Harvested (i.e. bare ground)	Planted?	
		Tree height <1 m	
		Tree height <3 m	
		Tree height >3 m	
Vegetation cover	Exotic tree species	Indigenous tree species	
	Pinus spp.		
	Douglas fir		
	Eucalyptus spp.		
Undisturbed			
Vegetation cover	Indigenous forest	Indigenous scrub or shrub	Indigenous tussock or grassland
		Mānuka or kānuka	

[1] Fodder is feed that is harvested and taken to the animal; forage is browsed by the animal while still on the land. For most NZ 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 kernels, etc.).

6.2 Developing land-use categories

Workshop discussions indicated a preference for fewer, broad, land-use categories while retaining the ability to capture more specific information to enable detailed classifications. The proposed categories are shown in Table 13, along with the attributes required to identify these land uses; the specific values of attributes associated with the dominant land-use categories are shown in Figures 2-7.

The land uses were confirmed through a post-workshop meeting and a small meeting specifically to discuss the short-rotation cropping category. Table 13 includes some categories that were mentioned during workshop discussion (e.g. native plantings, mānuka plantings) that are not necessarily specific to land uses being targeted for soil quality monitoring: they may be land uses that soil quality monitoring sites transition into. Overall, the main categories do not differ markedly from those specified in the NEMS, and reflect the sentiment of having a simple set of land uses to report on. Further, in many cases the land-use descriptions used in the NEMS were deemed to be appropriate for the general land use and have been retained in Table 13. Some points of discussion in developing these categories are provided in the following text.

The dry-stock category has long been recognised as encompassing a wide range of land management activities and intensities of land use. The current project adopts the approach used for the national soil carbon monitoring programme in which the dry-stock category is split into anticipated lower-input dry-stock farming (defined by dry-stock farming located on slope>15^{o}). Further, while it is anticipated that the bulk of sites monitored will be sheep or sheep & beef and have a similar management intensity, other types of stock, such as deer or horses, may also be associated with lower-intensity land use; capturing this information allows for further delineation into additional low-intensity dry-stock land use.

There was debate about the inclusion of dairy support in the dry-stock category and/or restriction of dairy to the milking platform. The rationale for inclusion in the dry-stock category relates to dairy support activities being associated with grazing of non-milking (dry) stock, and having more similar land management activities to those used for grazing meat cattle than for the more intensive milking platform. However, for other purposes dairy support may be considered part of the wider dairy industry, noting that some raising of 'dry stock' may also occur within land used for the milking platform, and that it may be relevant to report on the 'entirety' of the dairy production system. Thus, where possible it would be useful to identify dairy support activities separately to allow aggregation, as appropriate, for reporting purposes.

A further challenge in identifying dairy support may be that it comprises a livestock rotation on an arable farm and/or could be land leased from a lifestyle block owner. Alternatively, if dairy support is also considered to include growing fodder crops (e.g. cut-and-carry lucerne) for feeding to milking animals, then there are further overlaps with the arable land-use category. It may also be useful to seek further advice from agricultural consultants on the nature of dairy support activities to assist with either delineating land uses or understanding overlaps between different land-use classes. There are similar overlaps for the finishing of meat animals, which may occur as a livestock rotation on an arable farm (see, for example, Table 8, Class 8 – Mixed cropping for beef and lamb industry classes).

It should also be noted that while we have used the general categories of dairy and dry stock, these terms don't strictly convey the land *use* (i.e. the purpose of using the land), which might more accurately be defined as dairy or milk production and meat and wool production (if you exclude dairy support) for dry stock. Further, it should be noted that 'dairy' in the context of soil quality monitoring is implicitly assumed to be cows, but more broadly it could encompass other animals used for milking such as goats.

There was considerable reticence to having 'lifestyle block' as a separate land-use category, recognising the range of activities that occur on these properties. In this regard it also fails to achieve the purpose of land-use categorisation for soil quality monitoring, which is to help constrain the range of land management activities that occur within a category. However, transition of some monitoring sites into lifestyle blocks can result in low-intensity land use (e.g. grazing by a few sheep or horses to control grass growth, mown grass paddocks) that are potentially best captured as a generic 'lifestyle block' category. Further, lifestyle blocks remain of interest in discussions on urbanisation and the loss of commercial production land, so capturing information on whether a particular block is a lifestyle block is useful.

A separate workshop was held to discuss the short rotation cropping land-use category, and specifically whether there is value in further delineating this category into more intensive cropping activities, such as vegetable growing, and less intensive cropping activities, such as arable cropping, and if it is possible to consistently distinguish these categories. Cultivation frequency was considered one of the key indicators of intensity, with vegetable cropping considered to most often have more than one cultivation event per year, while cultivation for arable cropping would more typically be no more than once per year. It was concluded from the discussion that it should be reasonably achievable to distinguish these land uses, although further 'field' testing may be required to validate this.

As noted above, there can be some overlap in activities between different categories, in that both short-rotation cropping systems (but mainly arable cropping) could include a livestock rotation, and arable cropping may also include a vegetable rotation (either for seed production or food product, such as processed potatoes). The key point of differentiation should be the dominant land-use activity – the dominant 'purpose' (e.g. vegetable growing, arable cropping) for which the land is being used. Mixed cropping land use (specifically, short-rotation cropping with a livestock rotation) has been used by some councils, but with further discussion it was considered too difficult to positively identify whether a livestock rotation had occurred in the years between sampling and that it commonly occurs in arable systems. As a result, a separate mixed cropping land use was not included.

The cropping index number (CIN) approach currently used by Environment Canterbury (see Table 3 and surrounding text) was also discussed, and was considered to be useful supplemental information to help provide an indication of the time since cultivation for a number of land-use categories (dairy, dry stock, short-rotation cropping). The key requirement for using this approach is to be able to obtain information on land management activities in the years between samplings.

The urban open-space category has been retained, largely because it is specified in the NEMS. However, there was debate about the relevance of this category and the priority for

monitoring this land use by councils. Arguably it is another component of the broader environment that should be monitored, but further consideration of the purpose of monitoring this land use is required to avoid monitoring sites with potentially confounding influences. For example, some urban grasslands, such as golf-greens and sports fields, are more actively managed (e.g. have fertiliser and/or pesticides applied or used). Also, some urban green spaces have been built on brownfield, particularly old landfill sites, which may mean the soils are lightly contaminated beyond simple diffuse contamination. In essence, selection of any urban open space needs to carefully consider both the site history and the current activity to determine whether it is representative for the purposes of monitoring soil quality. The NEMS also specifies grassland only, but it may be that grassland with trees (e.g. botanic gardens or other urban parks) associated with 'light intensity' recreational use and management may be a more appropriate land use to monitor.

Finally, there was discussion on the undisturbed indigenous vegetation land-use category, in particular the purpose of monitoring these sites and the 'quality' of some of these sites. The general purpose was given as being reference sites against which changes from 'natural' conditions could be measured. Indigenous forest has typically been the primary vegetation type sampled in this category, but sites with tussock and scrub have also been captured in this category. It may be that some of these sites have been misclassified due to incomplete data capture or provision during subsequent collation of data.

For example, in the original description for 500 Soils sites from Canterbury, the land form is described as dry high country with the primary land use described in the text as being sheep and beef grazing (Sparling et al. 2001). However, in the tables land uses are described based on vegetation cover: tussock, scrub, improved pasture. It is this latter information that appears to have formed the primary source of information on land use in site records, and tussock and scrub have subsequently been 'misclassified' into an assumed undisturbed indigenous vegetation land-use category. This example serves to illustrate the consequences of incomplete capture of information and the challenge of classifying land use based solely on vegetation cover without consideration of the actual land use (i.e. the purpose for which the land is being used).

A further consideration is that vegetation type is often considered to influence soil properties, although there appear to have been no detailed studies on soil properties in undisturbed land under different indigenous vegetation types in New Zealand to validate or invalidate the use of undisturbed indigenous forest sites as reference sites for different agricultural land uses.

The second point of discussion was on the 'quality' of the indigenous vegetation sites. This arose from recognition that some of these monitoring sites can be located in remnant forest areas, which may be relatively small and surrounded by agricultural land uses. This latter aspect may result in the remnant forest area being influenced by agricultural activities (e.g. fertiliser drift), resulting in misleading soil analysis results. It may therefore be relevant for councils to critically assess any undisturbed indigenous sites to ensure the sampling sites are situated in suitably representative areas.

Table 13. Summary of land-use categories definitions and attributes used to confirm land use

Category	Potential sub-groups	Definition	Attributes required for delineating land use	Comments
Undisturbed indigenous	Forest Scrub and shrubs Grassland	NEMS: Native forest, tussock, shrubland and scrub dominated by indigenous species. Undisturbed or unfertilised in recent decades.	Enterprise; active land management; vegetation cover	Changed from indigenous vegetation.
Plantation forestry	Exotic forestry	NEMS: 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.	Enterprise; active land management; vegetation cover	Forests planted for carbon farming would likely fall into this category up to a tree age of 28–30 years, a typical forest rotation cycle
	Potential future sub-class – Indigenous forestry?			This class would only be relevant if indigenous species were deliberately planted for wood production
Orchards and viticulture / perennial horticulture	Tree crops Vine crops Berry fruit?	Permanent tree or vine crops (NEMS – Permanent-row orchard and vines)	Enterprise; active land management; vegetation cover	A separate sub-class may be desirable for berry fruits
Short-rotation cropping*	Arable	Predominantly grain, seed or fodder crops; may include a livestock rotation and/or vegetable rotation	Enterprise; active land management; vegetation cover; cultivation frequency (but note might need to be inferred from crop)	Separating out likely higher-intensity cropping (vegetables) from lower (intensity) arable, but recognising that vegetables (particularly potatoes) may be grown in arable cropping rotations
	Vegetable	Predominantly vegetable rotation; may include livestock rotation but less likely	Enterprise; active land management; vegetation cover; cultivation frequency (but note might need to be inferred from crop)	
Dairy		NEMS: Dairy is the main dairy platform, predominantly used for milking. Dairy may include areas of grazed forage	Enterprise; active land management; vegetation cover; stock type	

Category	Potential sub-groups	Definition	Attributes required for delineating land use	Comments
		crops and maize for silage.		
Dry stock	Flat-rolling	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, includes slope <15°, and low altitude (<600 m)	Enterprise; active land management; vegetation cover; stock type	
	Hill high country	As above for dry stock, but includes slope >15°, and/or 'high' (>600 m) altitude	Enterprise; active land management; vegetation cover; stock type	Gorse, broom, mānuka, kānuka, matagouri could also be present on hill/high country paddocks used for grazing
Urban open space	Grassland	NEMS: 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; needs to also consider potential for open space to be brownfield/ex-landfill, etc.
	Grassland with trees			Not currently captured, but depending on purpose of monitoring in urban areas, there may be a more relevant description
Potential class – lifestyle		Low-intensity land management practices on land primarily used for residential purposes in rural or peri-urban areas		May potentially be required to best describe the land use that monitoring sites on commercial production land may transition to.
Potential class – Regenerating	Exotic trees Native plantings Natural regeneration /unmanaged	Specifically carbon farming 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.
Potential class – Production from relatively natural environments			Enterprise; active land management; vegetation cover	Could include indigenous forestry, honey production

* NEM 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).

Figures 2-7 are diagrammatic representations of the attributes and attribute values that define the individual land-use categories. The format assists with identifying the relationship between the high-level category (dark grey) from any sub-classes (light-grey) and the required attributes (orange) and attribute values for subsequent coding of these relationships.

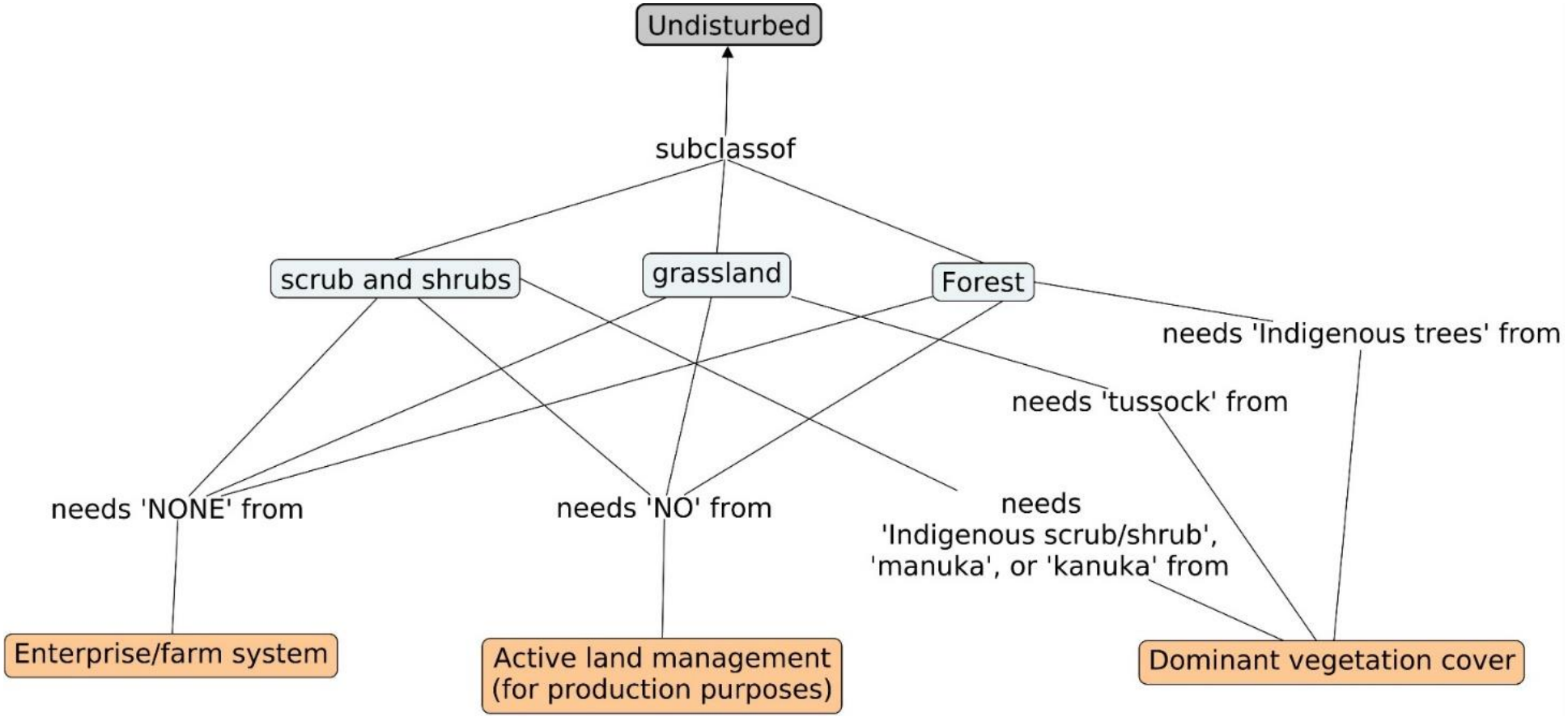

Figure 2. Diagrammatic representation of the attributes (orange) and attribute values for the undisturbed land-use category (dark grey) and associated sub-classes (light-blue).

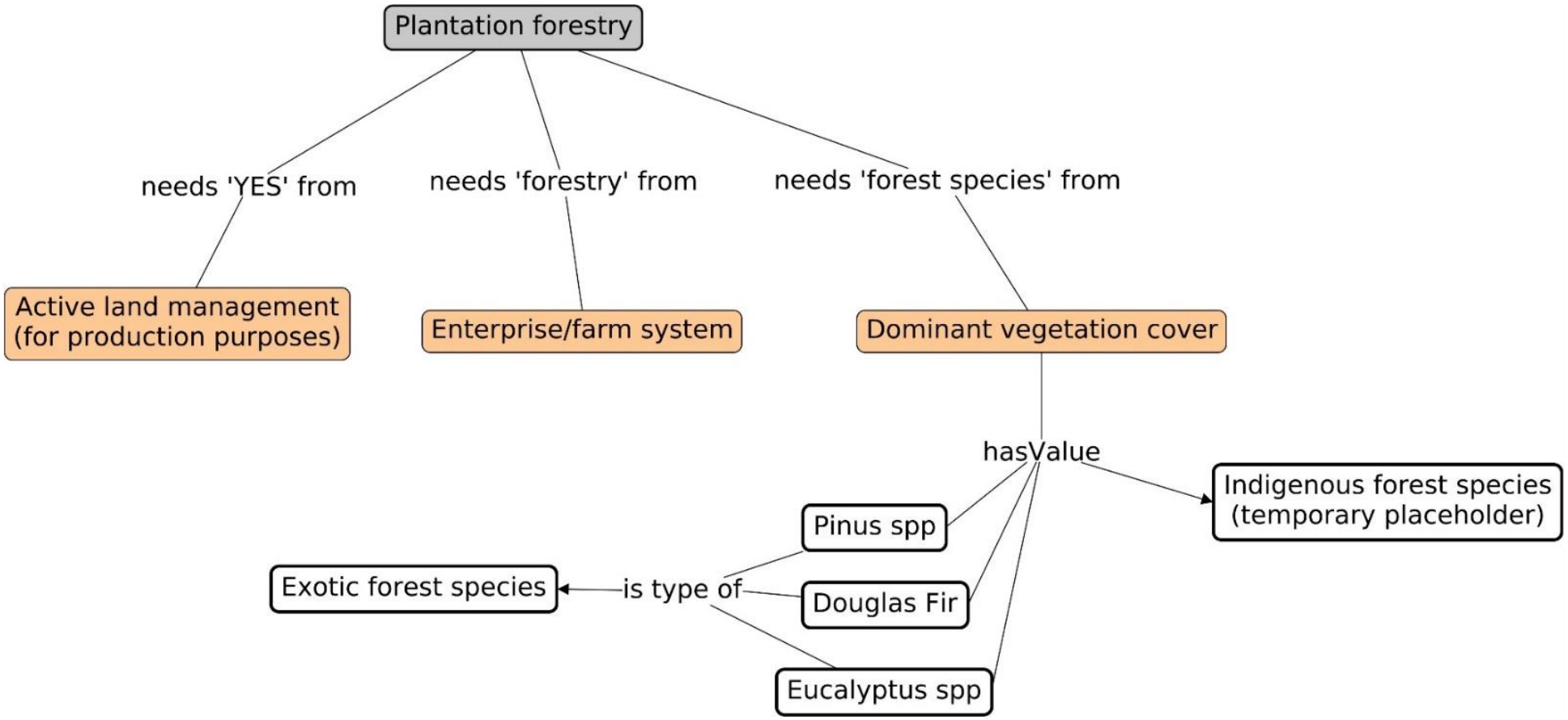

Figure 3. Diagrammatic representation of the attributes (orange) and attribute values for the plantation forestry land-use category.

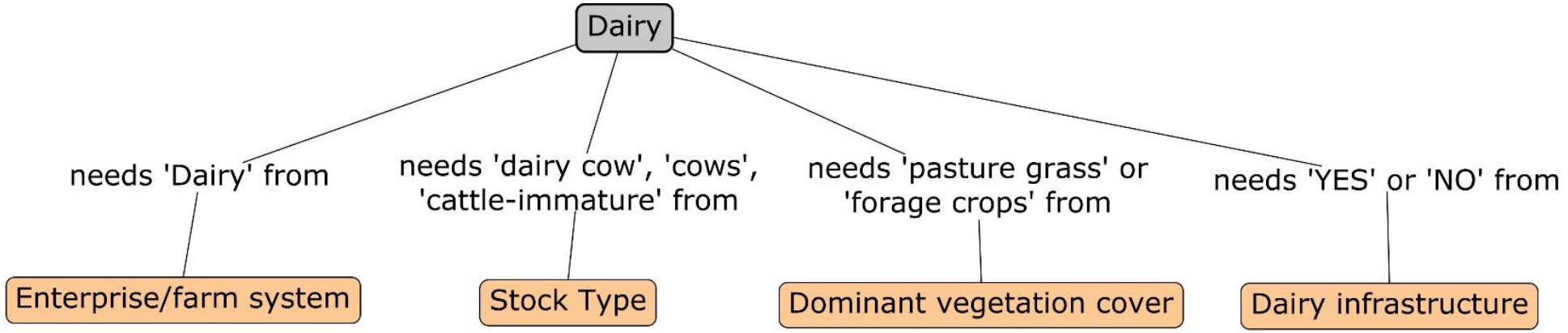

Figure 4. Diagrammatic representation of the attributes (orange) and attribute values for the dairy land-use category.

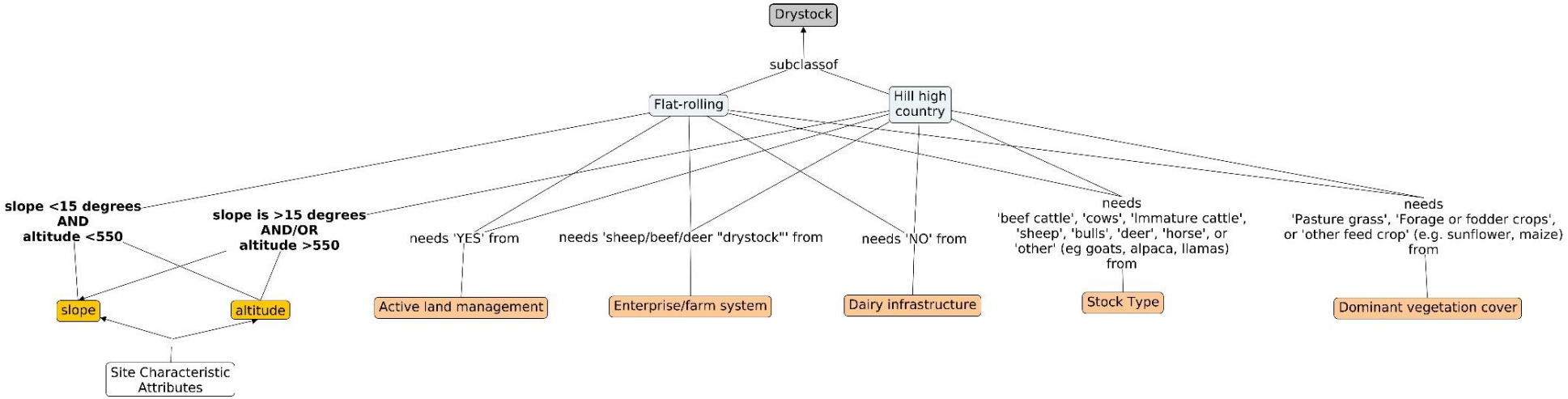

Figure 5. Diagrammatic representation of the attributes (orange) and attribute values for the dry-stock land-use category (dark grey) and associated sub-classes (light-blue).

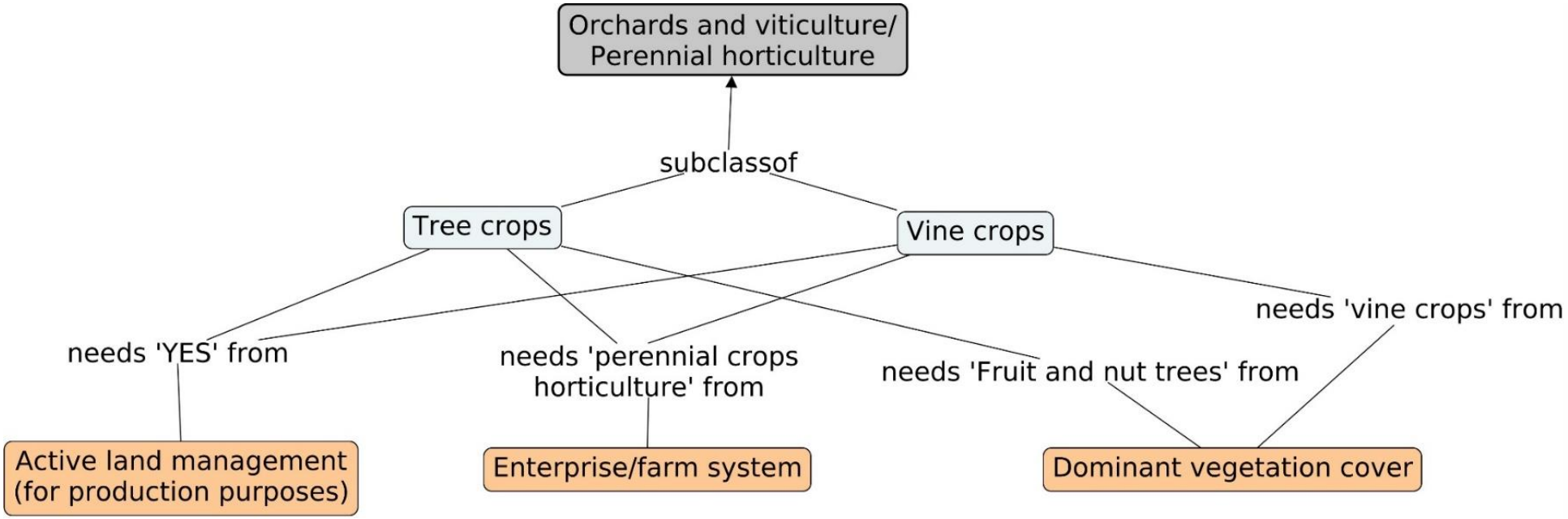

Figure 6. Diagrammatic representation of the attributes (orange) and attribute values for the perennial horticulture land use category (dark grey) and associated sub-classes (light-blue).

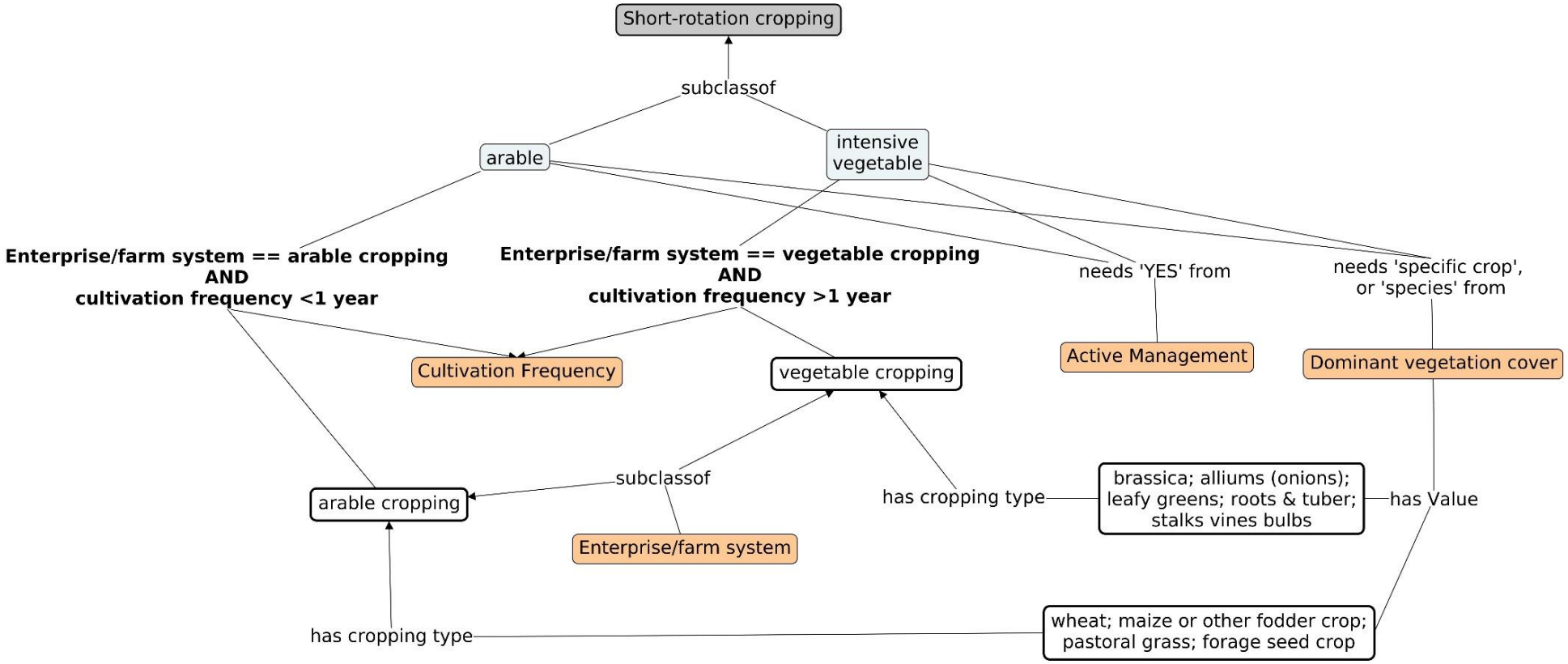

Figure 7. Diagrammatic representation of the attributes (orange) and attribute values for the short-rotation cropping land-use category (dark grey) and associated sub-classes (light-blue).

6.3 Collection of site attributes

6.3.1 General

This project has identified that to achieve more robust and consistent land-use classification (while allowing for greater flexibility in classification) requires a combination of:

- clearer identification of what information is used to determine land use
- greater definition and standardisation of the required information
- appropriate capture of that information (systems and type).

Specifically, it requires the deliberate and thoughtful collection and capture of the 'right' information, which encompasses:

- what is collected – attributes (see Table 11)
- how it is collected – standardisation of terminologies (see Tables 11, 12) and consistency in the approach of collection as required (e.g. use of slope class vs clinometer vs DEM or LIDAR for information on slope at the monitoring site)
- capturing the source of information (e.g. whether crop type was determined on the basis of on-site observation, from the land manager, or by some other means; capturing this information contributes to understanding 'error' of classification)
- systems used to capture the information (e.g. databases, Excel; see section 6.3.2).

An example of the capture of attribute information alongside the information source and method is shown for a limited number of attributes in Table 14.

Table 14. Example of the capture of attribute information alongside the information source and method for a limited number of attributes

Active land management for production purposes?	Info source	Enterprise/ farm system	Info source	Slope	Method
Yes	LM	Dairy	LM	20	Clinometer
Yes	LM	Dry stock	LM	B	LUC slope class

LM = land manager

If this collection and capture of critical information is done consistently, a combination of attributes can be used to define the land-use category with some indication of the confidence of classification.

6.3.2 Survey results

As part of this project a brief survey of soil quality site information and the associated workflows and tools/infrastructure was developed and sent out to council representatives. Twelve councils provided responses, as summarised in Table 15. For the purposes of delineating land use, responses to questions 1 and 2 are pertinent. The

remaining questions help to inform the subsequent follow-up EnviroLink Tools project focused on creating a tool for cross-council use.

The responses to questions 1 and 2 were highly variable. While nearly all council members signalled they collect information prior to sampling (83%), the actual information collected varied from *ad hoc* questioning of the land manager to incorporating data from external sources (e.g. LCDB, NZLRI, regional maps). Information is predominantly collected by hand (75%) and subsequently incorporated into a digital medium manually, predominantly using a spreadsheet application (75%).

From questions 3 to 5 it is evident that nearly all councils use a spreadsheet application at some point for data interaction, analysis, visualisation, and/or archiving. It is also clear that a majority of councils utilise GIS software in some capacity to visualise and/or analyse their soil quality data, but more information is needed to determine the extent of this use.

Table 15. Summary of responses to survey sent to councils regarding capture and use of site land-use information

Question		YES	NO	Comments
1) Is any site information captured prior to sampling?	If yes, what information and how is it collected?	10	2	Primarily information on land use and current site conditions obtained from landowner/manager in phone call seeking permission for sampling
2) How is the information in the field collected?	– by hand?	9		
	– in a personal/field notebook?	6	1	
	– by hand using some sort of sample sheet?	9		
	If yes, is the sheet the same for all sites, or does it vary by project or purpose or...other?	5		Majority are the same for all sites
	– electronically in the field	3	5	Survey 123 or One Note / Excel for notes
	– using a field application/tablet	4	5	Survey 123, ArcGIS collector
	If yes, is it linked to an authoritative database, or does it produce its own one-off data per field run?	3		
	– sensor logs		8	
	– other	1	3	
3) What site data are used for further data analysis (e.g. soil type/order, slope, land use?) Specify.	n = 9	Soil order and land use most commonly used, with information such as disturbance, irrigation, slope used in specific situations		

Question		YES	NO	Comments
4) How is this site data used, manipulated, viewed, etc.?				
alongside soil quality results	– in GIS application? (if yes specify type e.g. ArcGIS, QGIS, SAGA, other)	6	3	ArcGIS or ArcGISpro used by all councils who used GIS
	– in stats package (if yes specify R, SPSS, SAS, minitab, matlab, other)	7	3	Some councils indicated programme is too young to use stats
	– in Excel	9		
separately from soil quality results	– in GIS application? (if yes specify type e.g. ArcGIS, QGIS, SAGA, other)	5	4	ARCGIS
	– in stats package (if yes specify R, SPSS, SAS, Excel, minitab, matlab, other)	4	5	
	– in Excel	5	3	
5) Where are the site and soil quality results data stored 'permanently' or archived?	– database (PostgresSQL, MySQL, MS SQL Server, etc.)	7	2	A range of systems are used, including Hilltop, MS Access, Aquarius, internal council databases
	– Excel or other similar spreadsheet application	7	1	
	– if paper, how are these saved or archived?	3	3	
	– other (please specify)	1		
6) Are any site data permanently stored separately to soil quality results?	If yes, what attributes and how?	5	5	Primarily site contact details

6.3.3 Scoping for proposed tool

The current project has developed the concepts and definitions of the semantic model, as illustrated diagrammatically in Figures 2–7. The Envirolink Tools project will focus on encoding the information presented in those figures as ontology modules, serialised using the W3C Terse RDF Triple Language[3] (ttl; pronounced 'turtle'). As it is currently envisioned, the ontology modules will encode all relevant classes along with their plain English (natural language) definitions. Whenever possible, data relationships will be situated in the model using well-defined predicates (relationships) currently available from the W3C's SKOS, RDF and OWL standard languages. SKOS, RDF, and OWL provide a framework for building semantic models, which allows for human–machine understanding and reuse.

[3] https://www.w3.org/TR/turtle/

The ontology modules could also take the form of a type of ontological module called a data shape using the W3C's Shapes Constraint Language (SHACL). SHACL data shapes are also encoded as ontologies and serialised using ttl.

Once the serialisation has been completed and reviewed for content accuracy and efficacy by LMF, the ontologies will be made openly available on a version control system, probably GitHub. Using an open version control system allows for open discussion about modifications and updates, as well as timely maintenance and updates to the ontologies as a *living* knowledge structure. As it is currently envisaged, this model will be governed collaboratively, probably by the LMF with technical support from MWLR.

Guidance on the use of ontology modules in council workflows, probably using a spreadsheet application and/or a GIS application (in light of current systems used by councils) will be developed. This will enable the soil quality (or other) monitoring data to be put in the context of general land-use map classes (for monitoring land-use change or intensification) or land-cover classes by being able to translate those data from the soil quality land-use classes.

7 Next steps

7.1 Collection and capture of site attributes

Based on the survey and workshop discussions it appears that site attribute information is variably collected and retained. A critical change required for councils to ensure consistency in land-use classification is that a consistent set of information (the key attributes) be collected and captured in a systematic manner. Further, agreement on the appropriate methodological 'standardisation' for collecting those attributes is required (e.g. slope class vs clinometer). Finally, 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 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 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 these.

Given the high current use of Excel to capture site information, options for streamlining the collection and capture of information could include the development of an Excel template (e.g. as part of the Tools project discussed in section 7.2) that outlines the information required, and includes standardised values for response, for use by councils. Alternatively, and preferable in the longer term, is the use of field applications (e.g. Survey 123 for the collection of information). The development of a specific soil quality monitoring interface that captures the required information could be scoped by MWLR through a separate advice grant.

In relation to the plantation forestry class, if councils have an interest in pursuing more specific information on the time since harvest, which is considered to be a key factor influencing soil properties (S. Smaill, Scion, pers. comm), then Scion could be contracted to provide regional look-up tables to convert diameter at breast height (DBH) to age (which is easily done, given the availability of existing data), and then time since harvest is determined as age+1.

Finally, in light of the clearer identification of attributes and land-use categories outlined through 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. This information is critical for identifying whether a monitoring site has undergone an actual land-use change, or was monitored at different phases (e.g. pasture vs forage or fodder crop in a livestock system or arable cropping system) within the same land use.

7.2 Envirolink Tools project

This project will commence on 1 July 2022, and will build on the classifications and descriptions developed in the current project. The Tools project will develop a vocabulary, or semantic model (a machine-readable model of concepts and relations) to support land-use classification for use with regional council SOE soil quality monitoring, as described in section 6.3.3.

A first phase in the Tools project will be working with councils to reconfirm the attributes and values developed in the current project prior to encoding those relationships in ontology modules. A further component will be to develop appropriate methodological 'standardisation' for collection of the attributes, as required.

As noted above, the ontology modules will provide the definitive knowledge base for the descriptions of land use. It is intended that the ontologies will be made openly available on a version control system, probably GitHub, which will allow for open discussion about modifications and updates to the ontologies to provide a *living* knowledge structure. In this manner, these ontologies can be further extended to include additional land-use or allow inclusion of Māori terms for landforms, features and descriptors related to land use, soil types, soil classes. As it is currently envisaged, this model will be governed collaboratively, probably by the LMF with technical support from MWLR.

Documentation of best practices, how to's and specific examples will be provided to assist councils with applying the ontology modules in their own workflows, probably using a spreadsheet application and/or a GIS application, such that the soil quality (or other) monitoring data can be put in the context of general land-use map classes (for monitoring land-use change or intensification) or land-cover classes by being able to translate those data from the soil quality land-use classes. This prototype model can be extended to include a wider range of attributes to allow for different land-use classifications that are not covered in the current project.

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Appendix 1 – Site characteristics

Table A1. Summary of site characteristic (excluding location) information specified to be collected at soil quality monitoring sites

LMF 2009	NEMS
Soil series and soil classification	Soil order (NZSC) – from existing soil map information
	S-map family/sibling; soil series – depending on availability, from existing soil maps
Farm system (e.g. dairy farm)	Farm primary system / enterprise (e.g. dairy farm)
Current land use	Sampling site current land-use type
Land use during the previous 10 years	
	Current livestock
Present vegetation	Current vegetation
	Irrigation
	Effluent irrigation
	Site land use
	Duration of current land use
Slope	Slope
Elevation	Elevation
Landform (as per Milne 1995)	Landform (as per Milne 1995)
Annual precipitation	Annual precipitation
Parent material	Parent material (based on available geological map information and field verification)
Soil drainage class (as per Milne 1995)	Soil drainage class (as per Milne 1995)
	A' horizon (topsoil) thickness (depth)
	Total potential rooting depth
	Nature of the limiting layer restricting roots
The nature and date of any extreme events such as flooding, landslips	The nature and date of any extreme events (e.g. flooding, landslips) in the past 5 years

	Date of last fertiliser application (type and amount in kg/ha if available)
	Date of last cultivation/harvesting/pasture renewal
	Date of last grazing
	Area of bare ground at sampling (% in surrounding 1 ha area)

Appendix 2 – Land-use classification used for LUDB

CLASS	DEFINITION	UNITS
Aquaculture	Marine and freshwater areas used for managed production of fish, mussels, prawns, etc. for human consumption or use.	Categorical
Arable	Managed growth of plants, typically on an annual basis, for human consumption or use. Typically includes production of wheat, barley, oats, maize, pulses, herbage seeds, brassicas, borage, and vegetable seeds.	Categorical
Beef Production	Managed herding of domesticated cattle (typically species of the genus *Bos*) for human consumption or use.	Categorical Or Density (Beef Cattle per hectare) Or Stocking Rate (Stock Units per hectare)
Biofuel Cropping	Managed growth of plants or other biological material to produce biomass for energy production.	Categorical
Carbon Storage	Managed growth of plant species for atmospheric capture and long-term sequestration of carbon.	Categorical Or Categorical + Age (if important, e.g. for carbon accounting purposes)
Commercial	Sale of goods and services to households (= final production in economic terms).	Categorical
Cropping	Managed growth of plants, typically on a seasonal basis, for human consumption or use. Typically includes crops such as beans, cabbages, capsicums, carrots, cauliflowers, celery, courgettes, cucumbers, garlic, lettuces, melons, onions, peas, pumpkins, radishes, spinach, spring onions, squash, swedes, and turnips.	Categorical
Dairy	Managed herding of domesticated female cattle (generally of the species *Bos taurus*) to produce milk solids for processing into various products for human consumption or use.	Categorical Or Density (Dairy Cows per hectare) Or Stocking Rate (Stock Units per hectare)
Deer	Managed herding of domesticated deer (family *Cervidae*) for human consumption or use. Main products are venison and velvet for medicinal purposes.	Categorical Or Density (Deer per hectare) Or Stocking Rate (Stock Units per hectare)

CLASS	DEFINITION	UNITS
Forestry – Exotic	Managed growth of non-native (= exotic) woody plant species for production of wood, fibre and other materials or compounds for human use. Predominantly *Pinus radiata* but also includes Douglas fir (*Pseudotsuga* spp.), cypress (family *Cupressaceae*), and eucalypts (*Eucalyptus* spp).	Categorical Or Category + Forest Age (e.g., 10 year old Exotic Forest)
Forestry – Native	Managed growth of native (= indigenous) woody plant species for production of wood, fibre and other materials or compounds for human use.	Categorical
Covered Production	Managed growth of plants within sheltered (e.g. climate-controlled, glass-walled structures) or semi-sheltered structures for human consumption or use.	Categorical
Horses	Breeding and training of horses (genus: *Equus*) for riding, showing, farm work, etc. Note: could be refined into multiple categories, e.g. 'Thoroughbred Horse Production', etc.	Categorical Or Density (Horses per hectare)
Horticulture	Managed growth of plants, typically on a perennial basis, to produce products suitable for human consumption or use. Typical examples include apples, avocados, berries, citrus, olives, pears, and kiwifruit. Known areas of kiwifruit production or viticulture will be classified as 'Kiwifruit Production' or 'Viticulture', respectively, instead of 'Horticulture'. Note: could add refined categories in the future.	Categorical
Industrial and Manufacturing	Construction and assembly of various goods for sale to other manufacturers or wholesalers/retailers.	Categorical
Kiwifruit Production	Managed production of kiwifruit, which are the edible berry of a cultivar group of the woody vine *Actinidia deliciosa*, for human consumption.	Categorical
Lifestyle Blocks	Areas with low density (typically 4 dwellings per hectare or less) residential development. Note: some lifestyle blocks continue to support agricultural production to varying degrees.	Categorical Or Density (dwellings per hectare)
Marine	Areas permanently under sea water (= salt water). Note: technically a land cover but from past experience it is useful to delineate such areas for future refinement. Obviously coastal areas/tidal areas are more problematic to classify.	Categorical
Mines and Quarries	Production of minerals, aggregates, sands, gravels or other abiotic materials for use in manufacturing and construction.	Categorical
Nursery	Managed production of seedlings, saplings and other early growth forms of plants for sale to others, including retailers or households.	Categorical
Other	Not otherwise classified. Note: most classifications have an 'other' category for similar purposes but its use should be avoided as much as possible.	Categorical

CLASS	DEFINITION	UNITS
Urban Parks	Areas of land in urban settings for the enjoyment of the public, having facilities for rest and recreation.	Categorical
Pigs	Managed production of pigs (genus *Sus*) for human consumption or use.	Categorical
Ports	Areas used for the loading and unloading of goods and people onto boats or ships.	Categorical
Poultry	Managed production of domesticated fowl including chickens, turkeys, geese, or ducks for meat, eggs, and other products (feathers) for human consumption or use.	Categorical
Protected Areas	Areas legally protected to conserve particular values or features such as biodiversity or historic sites. Note: could be refined based on specific reason for protection e.g. National Park, Scenic Reserve, etc.	Categorical
Recreational	Leisure, renewal, sport or other activities undertaken for pleasure and amusement	Categorical
Residential	Land mainly covered by residential buildings, irrespective of whether they are actually occupied or temporarily vacant, including residential land, attached private gardens and small green areas and parking facilities and small playgrounds mainly reserved and used by the inhabitants of the buildings.	Categorical Or Dwellings per hectare
Sheep	Managed production of domesticated sheep (*Ovis* spp.) for meat, wool and other products suitable for human consumption or use	Categorical Or Density (Sheep per hectare) Or Stocking Rate (Stock Units per hectare)
Sheep & Beef	Managed production of sheep and beef cattle to produce meat, wool and other products suitable for human consumption or use. This category is used for combined sheep & beef production.	Categorical Or Density (Deer per hectare) Or Stocking Rate (Stock Units per hectare)
Transport	Conveyance of people and goods from one place to another.	Categorical
Urban	Permanent human settlements containing a mixture of uses including residential, commercial, industrial, and community services. Areas definitively identified as residential, commercial, or manufacturing will be classed accordingly.	Categorical
Viticulture	Managed growth of perennial, deciduous woody vines (*Vitis* species) for human consumption and use. Note: viticulture could also occur in areas designated 'Horticultural' where this specific use could not be distinguished.	Categorical