Matching Farm Production Data to Land Use Capability for Auckland

Douglas Hicks and Fiona Curran-Cournane

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Te Kaunihera o Tāmaki Makaurau

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Executive summary

The primary sector makes up around three quarters of New Zealand's exports, of which 56 per cent is food production. Auckland's small land area (2% of New Zealand) contributes 25 per cent of its vegetable production. Maintaining and increasing agricultural productivity entails the promotion of sustainable land management. A new policy in the Auckland Unitary Plan (B8. 2.5) encourages '*land management practices that retain the physical and chemical capability of soils*', recognising the significance of this valuable resource.

Land use capability (LUC) classification is one of the tools used by land and water advisors to help farmers and communities sustain land management on individual farms and within whole catchments. LUC maps have been historically, and are currently, used by researchers, rural industry, policy-makers and planners to advise decision-makers about the region's productive capability. For rural parts of Auckland the maps help underpin land use planning decisions whether it be for resource consents, plan change procedures (often supplemented by LUC site inspection and mapping) or while preparing district, regional or unitary plans. It is therefore imperative that LUC maps be underpinned by defensible and robust science that is able to withstand close scrutiny through planning hearings and court procedures.

In Auckland there have been issues with using and interpreting existing LUC maps for planning and policy purposes:

- different LUC units are mapped on similar soils, north and south of the city
- attached estimates of productive potential (livestock carrying capacity, radiata pine site index, maintenance fertilizer requirement) vary for LUC units on similar soils north and south of Auckland
- no estimates of vegetable, fruit or crop yield are attached to the LUC units on productive soils
- there are many instances where estimates overlap – or are the same – for LUC units which clearly differ in physical characteristics (so might be expected to differ in productive potential).

In response to the issues, the objectives of this report are to:

1. Update estimates of LUC units' productive potential, so they match measured yields.
2. Standardise estimates for LUC units on similar soils, so they become consistent north and south of Auckland.
3. Develop a way to express productive potential of LUC classes throughout Auckland.
4. Attach outputs to the region-wide geospatial LUC layer for Auckland.

The report documents how pasture yield data from field trials have been used to create new pasture yield estimates and updated livestock carrying capacities. Vegetable, fruit and crop yields for LUC units are not included in the report because measured yields are not readily available.

Meanwhile, the new pasture yield estimates provide a way to compare productive potential of LUC classes 1 to 8 throughout Auckland. They will not only defensibly inform future policy and land use planning decisions, but will also assist with land management advice to rural communities about the impacts of various farm management scenarios, such as retiring marginal land or fencing off certain distances from streams, on agricultural production.

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1.0 Introduction

The primary sector makes up around three quarters of New Zealand's exports of which 56 per cent is food production (Scrimgeour, 2014). Separate export figures are not available by region but Auckland's small land area (2% of New Zealand) contributes 25 per cent of vegetable production, 1 per cent of grain harvest, under 1 per cent of sheep, 3 per cent of beef cattle, 2 per cent of dairy cows and 1 per cent of other livestock, mainly deer (Statistics New Zealand, 2014).

As New Zealand's fastest growing city, the urban area continues to expand in Auckland and disproportionately encroaches onto high class elite and prime land. In 2007, Auckland's agricultural land was 205,000 ha, half the region's land area and four times the extent of urban land (Thompson and Hicks, 2009). To date, 8.3 per cent (10,399ha) of Auckland's elite and prime land has been built on, over 8 per cent between 1975 and 2012. Future growth forecasts indicate this encroachment will continue (Curran-Cournane et al., 2014) impacting Auckland's self-sufficiency as a food producing region.

Land use capability (LUC) classification is one of the tools used by land and water advisors to help farmers and communities sustain land management on individual farms and within whole catchments. LUC maps have been historically, and are currently, used by researchers, rural industry, policy-makers and planners to formulate policy, prepare plans, and advise decision makers about the region's productive capability. For rural parts of Auckland they help underpin land use planning decisions whether it be for resource consents, plan change procedures (often supplemented by LUC site inspection and mapping) or whilst preparing district, regional or unitary plans.It is therefore imperative that LUC maps be underpinned by defensible and robust science that is able to withstand close scrutiny through planning hearings and court procedures.

The land use capability (LUC) classification was first developed in the USA, applied in many other countries, and adapted for use in New Zealand by the Soil Conservation and Rivers Control Council (SCRCC, later National Water and Soil Conservation Authority, NWASCA). Land is categorised into eight classes according to its long-term capability to sustain one or more productive land uses (Lynn et al., 2009). LUC class 1 is defined as being the most versatile (multiple-use) land with minimal physical limitations. Versatility decreases, and limitations increase, moving from LUC classes 1 to 8. LUC class 8 is land with extreme limitations that preclude productive use. Each LUC class is divided into subclasses which identify the main limitation to use. Just four are recorded in New Zealand: e = erosion, w = wetness, s = soil and c = climate. More specific (and numerous) sub-classes are recorded in other countries' classifications (Klingebeil and Montgomery, 1961). Classes and sub-classes are divided into units. Units group areas of land which have the same geology, soils and slope. Underlying assumptions are that each LUC unit is suitable for the same crops, pasture or forestry species; produces similar yields; and will require the same kind of land management or conservation treatment.

Since 1980 users of LUC classification have referred to 1:63,360 land use capability maps, prepared nationwide between 1969-1979 by Ministry of Works and Development (MWD) which provided technical services to NWASCA. Since the demise of these organisations in 1988, and subsequent to a brief period of maintenance by Department of Scientific and Industrial

Research (DSIR) 1989-1992, the maps have been maintained by the crown research institute Landcare Research (LCR) and in recent years made available as geospatial layers on its Land Resource Information Systems (LRIS) portal.

In Auckland the main limitations with using and interpreting existing LUC maps for planning and policy purposes are:

- Different LUC units are mapped on similar soils, north and south of the city. This is a historical artefact of 1969-1979 mapping, when separate classifications were used for different parts of the country instead of a uniform national classification.
- Estimates of productive potential (livestock carrying capacity, radiata pine site index, maintenance fertiliser requirement) for various land uses are attached to LUC units. However, the estimates vary for LUC units on similar soils north and south of Auckland.
- No estimates of vegetable, fruit or crop yield are attached to the LUC units on productive soils.
- Estimates for each LUC unit are expressed as a range e.g. 13-15 stock units a hectare. There are many instances where ranges overlap – or are the same – for LUC units which clearly differ in physical characteristics (so might be expected to differ in productive potential).

In response to the limitations, the objectives of this report are to:

1. Update estimates of LUC units' productive potential, so they match measured yields,
2. Standardise estimates for LUC units on similar soils, so they become consistent north and south of Auckland,
3. Develop a way to express productive potential of LUC classes throughout Auckland,
4. Attach outputs to the region-wide geospatial LUC layer for Auckland.

The report documents how pasture yield data from field trials have been used to create new pasture yield estimates and updated livestock carrying capacities. Vegetable, fruit and crop yields for LUC units are not included in the report because measured yields are not readily available in published form. Yield data would have to be obtained from growers in order to estimate the range of yields obtainable for Auckland's elite (LUC class 1) and prime land and (LUC classes 2 and 3 land).

2.0 Review of previous work

The New Zealand Land Resource Inventory (NZLRI) is a spatial database that describes land resource inventory and land use capability for New Zealand at regional scales of 1:63,360 to 1:50,000 (Lynn et al., 2009). It is the same as a series of maps (NZLRI worksheets) printed between 1969 and 1979, except that the database includes 1985-1999 updates for limited areas (Northland, South Auckland, Wellington, Marlborough, Gisborne). The database contains stock carrying capacities (SCC) for each LUC unit. The SCC are expressed as three land use management scenarios: present average (PA), top farmer (TP) and attainable potential (AP). All three are estimates by farm advisory officers who provided a "ball-park" range of carrying capacities, based on their personal knowledge of stock numbers on farms at the time (Jessen and Booth, 1980). The ranges are unsupported by field-collected data. Vogeler et al (2016) recognise that the SCC are estimates which '*were done by a group of experts separately for each of the regions of New Zealand, and thus, they have some degree of subjectivity*'.

SCC has a history of being used for research and modelling (Barlow, 1985, Eyles, 1977, Lilburne et al., 2016, Vogeler et al., 2014, Vogeler et al., 2016). Some of the models estimate dry matter yield (DMY, expressed as kg/ha/yr) multiplying SCC by dry matter intake (DMI) of a standard stock unit (SU). Barlow (1985) uses 550 kg/yr. Coop (1965) indicates that this figure is appropriate for flat to rolling land where pasture utilisation is close to maximum, but 750 kg/yr should be used in hill country to allow for feed wastage on ground that is difficult for stock to access. DMI for a standard stocking unit can be about 10 per cent higher than 550 kg on flat land
(Parker, 1998). Fleming (2003) retains the 550 kg/yr figure for flat to rolling paddocks and 750 kg/yr for hills from Coop (1965). Hicks (2010b) comments that DMI needs to be adjusted as low as 1000 kg/yr where hill country is lightly grazed or reverting.
Several recent papers demonstrate annual pasture yields or seasonal growth patterns for land use capability classes in different parts of New Zealand. For example, Cichota et al (2014) use NZLRI stock carrying capacities for individual LUC units to calculate an area-weighted average livestock carrying capacity for each LUC class in a region, and multiply by dry matter intake of 550 kg per stock unit, to estimate annual dry matter production per hectare. Vogeler et al (2016) estimate annual DMY for various LUC units from SCC as described above, and compare estimates with predictions by the APSIM pasture growth model. Their model uses seasonal climate and soil moisture data from "representative" pasture measurement sites in three regions (Waikato, Canterbury, Southland) to generate seasonal pasture growth curves for LUC classes 2, 4 and 6.

Some regional councils input SCC in conjunction with the NZLRI LUC classification and maps when using the model Overseer to estimate nitrogen leaching allowances. For example, in the Horizons Regional Council One Plan, land with higher natural capital, i.e. with higher average attainable stock-carrying capacity (LUC classes 1-4), is given a higher nutrient loss allowance than land with lower natural capital, or lower average attainable stock-carrying capacity (LUC classes 5-7) (Horizons Regional Council, 2012). However, Lilburne et al., (2016) highlight various limitations with the use of LUC class in setting nitrogen loss limits which include 1) that LUC classes 1-4 are assessed on arable suitability rather than pastoral suitability, 2) the variability of pastoral productivity within an LUC class, 3) LUC classes do not correspond well with nitrogen loss rates, 4) rain-fed productivity is lower than irrigated productivity and 5) the large areas of certain LUC classes. These authors suggest modifications to the natural capital approach will be needed if applying the Horizons One Plan approach to other regions across the country (Lilburne et al., 2016).

When undertaking model simulations to generate pasture yields for LUC units it is important to understand the reliability of inputs used, outputs obtained and model limitations. For all the models reviewed:

- Model input for scaling up or down from one LUC class to another, is a single area-weighted pasture yield estimate derived from numerous stock carrying capacity estimates (not field-collected data).

- NZLRI stock carrying capacities for many LUC units overlap or are the same (despite obvious differences amongst the units).

- Model output (pasture yield) is assumed to apply to all areas that have the same LUC class. The reality is that such areas differ in landform, soil and climate from the pasture measurement site where model calibration data (for these three parameters) were obtained. Therefore they are unlikely to have the same pasture yield (large variations in yield may be expected amongst LUC units within each class).

Rather than use any of the models, it was decided to obtain annual pasture yield estimates for Auckland's LUC units by running a simple procedure which inputs measured annual pasture yields on known soils at given rainfalls, and adjusts them for differences in mean annual rainfall, slope, land stability and soil drainage. The procedure's information sources are described in Section 3.

3.0 Information sources

For each LUC suite in north and south Auckland, a pasture trial site was identified which has one of the soils present in that suite (Appendix 1). Suites (land use capability units on similar terrain) are defined, and soils listed for them, by Harmsworth (1996) in north Auckland. LUC units in south Auckland are matched with the north Auckland suites by reference to Jessen (1984).

Pasture measurement trial sites with reliable yields and site information that could be matched with Auckland LUC suites were identified by consulting various published or unpublished sources. Locations, yield data, site information, and source documents are listed in Appendix 1. Many were old pasture trial sites operated by Ministry of Agriculture and Fisheries (MAF), DSIR or MWD 1970s-1980s. The results together with good site descriptions were usually published in agricultural research journals. Others were farms monitored by rural industry organisations such as Dairy NZ or Beef and Lamb NZ in the 1990s-2000s. Some results from these sources appeared on websites at the time of monitoring, but were accompanied by little site information. Neither organisation has retained records of pasture yields or site information from its monitor farms in past years (G. Templeton and M. Aspin pers. comms.). The organisations' commercial consultants (Dexcel and Farmax) collect data for a limited number of monitored farms (currently two Dairy, three Beef and Lamb in the Auckland region), utilising it for web-based pasture growth forecasts at a regional scale.

Data from the selected sites were run through a spreadsheet previously used by one of the authors (DLH) for more than twenty years to supply pasture yield estimates for farm plans (including Auckland Council farm plans). New pasture yield estimates for most LUC units in the region are listed in Appendix 2. Operation of the spreadsheet is described in Section 4.

4.0 Methods

4.1 Landform

Landforms on which the LUC suite is mapped at farm scale are selected from the following range:

- Floodway (frequently, regularly or occasionally flooded)
- Terrace (rarely flooded, flood-free, elevated and dissected)
- Dune (stable, old, young)
- Colluvial footslope (frequent, regular, occasional deposition)
- Footslope or downland (undulating, rolling, strongly rolling)
- Upper slope or ridge (undulating, rolling, strongly rolling)
- Earthflow and slump terrain (stable, inactive, actively eroding)
- Moderate hillslope (stable, inactive, actively eroding)
- Steep face (stable, inactive, actively eroding).

One of the above landforms is matched to each LUC unit in a suite, after referring to the descriptions in Jessen (1984) and Harmsworth (1996).

4.2 Slope

To create an initial estimate for each landform selected, mean annual dry matter yield (MADMY) at the trial site is adjusted by:

- 100 kg per degree of difference between slope at the trial site and the landform's median slope.

This factor is obtained from the closest trial site where change in pasture yield with slope has been measured. For Auckland, that is the Whatawhata hill country research station (Gillingham and During, 1973, Gillingham, 1974). Each landform has a range of slope angles, with corresponding yield reductions. So slope reduction factor is used to estimate yield for the landform's median slope (obtained from NZLRI slope classes). The result is applied to landforms which are stable and do not have drainage limitations.

4.3 Instability

On each landform MADMY is scaled by an appropriate instability factor:

1.0 on flood-protected (drained) wetlands and stream flats

0.8 on flood-prone (semi- or undrained) wetlands and stream flats

1.0 on flood-free (elevated) terraces

0.9 on sheetwash-prone terraces

1.0 on stable weathered sand dunes

0.8 on old windblow-prone sand dunes

0.7 on young windblow-prone sand dunes

1.0 on stable downlands and colluvial footslopes

0.9 on windblow or sheetwash-prone downlands and colluvial footslopes

1.0 on stable footslopes, upper slopes or ridges

0.9 on earthflow and slump-prone footslopes or upper slopes

0.9 on gully and slip-prone footslopes or upper slopes

1.0 on stable hillslopes

0.8 on earthflow and slump-prone hillslopes

0.8 on gully and slip-prone hillslopes

1.0 on stable steep faces

0.6 on slip and debris-avalanche-prone steep faces

These factors incorporate percentage reductions in dry matter yield on unstable (revegetated), eroded (revegetating) and eroding (near-bare) surfaces. The closest trial site to Auckland where such reductions have been measured is in Taranaki (De Rose et al 1996). Proportions of each surface within the listed landforms vary. So instability reduction factors are calculated using the average proportions on each landform measured by an Auckland-wide point sample (Thompson and Hicks 2009).

4.4 Drainage

For landforms containing seasonally or permanently wet soil, MADMY is scaled down by:

- 0.8 where pasture yield is limited by short-duration rise of water table
- 0.6 where limited by seasonal rise
- 0.4 where limited by year-round presence

These factors approximate the range of pasture yield depressions measured at such sites, in trials published by various researchers and summarised in Haynes (1995).

4.5 Rainfall

For each landform (slope, instability and drainage-adjusted), MADMYs are generated at 100mm increments, for the range of mean annual rainfalls throughout Auckland region (1000mm to 2000mm). The adjustments are:

- 1.00 @ 2000 mm mean annual rainfall
- 1.00 @ 1900 mm
- 0.99 @ 1800 mm
- 0.99 @ 1700 mm
- 0.98 @ 1600 mm
- 0.97 @ 1500 mm
- 0.96 @ 1400 mm
- 0.94 @ 1300 mm
- 0.93 @ 1200 mm
- 0.91 @ 1100 mm
- 0.88 @ 1000 mm

They are derived from a curve fitted by Hicks (2010a) to the upper limit of pasture yields from MAF's long-term trial sites nationwide (Fleming, 2003, Milligan, 1981, Molloy, 1981, Radcliffe, 1971, Radcliffe, 1968).

4.6 Pasture composition

For most LUC suites, it has been possible to generate two MADMYs, one from an improved pasture trial site (ryegrass-clover) and another from a semi-improved site (ryegrass-clover mixed with paspalum, kikuyu, browntop, lotus etc). Where data are only available for one type of pasture, the other is estimated by setting:

- semi-improved pasture at 80 per cent of improved or
- improved at 125 per cent of semi-improved.

There are few trial sites in the Auckland region where a third MADMY could be generated for un-improved pasture, so estimates are made by setting:

- un-improved pasture at 50 per cent of improved or
- at 63 per cent of semi-improved.

These are the upper limits of semi-improved or un-improved pasture yield relative to improved, at a range of trial sites around New Zealand where control plots are present (Hicks, 2010b).

4.7 Livestock carrying capacity

Livestock carrying capacities (SCC) are estimated for un-improved, semi-improved and improved pasture on each LUC unit, by applying the following annual feed consumptions:

- 550 kg dry matter per stock unit on improved pasture (intensively grazed with little feed wastage)
- 750 kg dry matter per stock unit on semi-improved pasture (well grazed but about 30% of feed not utilised)
- 950 kg dry matter per stock unit on un-improved pasture (extensively grazed).

Standard figures of 550 and 750 kg for feed budgeting are recommended by a range of technical publications e.g. Fleming (2003). They are based on numerous MAF research investigations e.g. Barlow (1985) and Coop (1965). The 950 kg figure is unsupported by research, but has produced a close match between pasture yield estimates and stock numbers carried, when applied by one of the authors (DLH) to several extensively grazed farms in Wairarapa, Taranaki and Auckland hill country.

4.8 Specimen MADMYs and SSCs

Appendix 2 contains specimen MADMYs and SSCs for each FARM LUC (farm-scale land use capability class, subclass and suffix) in Auckland's region. They are set at 1500mm (Auckland's median annual rainfall) to enable comparison of pasture yields and livestock carrying capacities.

FARM LUC is convertible to NZLRI LUC (regional-scale land use capability class, subclass and unit) by referring to Hicks and Vujcich (2017).

5.0 Discussion

There are two principles to keep in mind when discussing the pasture yield estimates in Appendix 2. Firstly, land use capability classification expresses the land's capability for sustained primary production. Classes 1 to 4 sustain arable uses (vegetables, fruit, grain and fodder crops) as well as non-arable. The limitations to arable use (soil properties, erosion risk, insufficient or excessive drainage, climate constraints) increase moving from Class 1 to Class 4. Classes 5 to 8 sustain non-arable uses (intensive or extensive grazing, commercial or conservation forestry). The limitations to non-arable use likewise increase moving from Class 5 to Class 8.

Secondly, attainable yields for any crop (including pasture or timber) vary greatly within Class 1 land (and any other Class), in response to the local soil (suitability for crop), landform (ease of cultivation, grazing or logging), and climate (temperature range, rainfall variation, wind and frost frequency). There are no typical or average yields for a LUC class. How LUC affects yields for a particular crop (including grass or tree species) can only be seen, if yield comparisons amongst LUC classes are controlled for soil, landform and climate.

Pasture yields in Appendix 2 are only comparable:

- At a constant temperature regime (growing degree days). In reality there will be variations, even across such a small compact region as Auckland, where incoming solar radiation varies from 340-380 cal/cm^2/day (Coulter, 1960).

- For the same mean annual rainfall (MAR). Auckland's MAR varies from 1200 to 2200mm in response to westerly exposure and relief.

- On LUC suites i.e. on similar landforms. For instance, a class 2 LUC unit on a floodplain may be compared with a class 3 unit on a floodplain; but not with a class 3 unit on ash-mantled or stony lava flow terrain.

- For LUC units within the same LUC suite, if they have similar soils. For instance, a class 2 unit on one estuarine gley soil is comparable with a class 3 unit on another estuarine gley soil, but not with a class 3 unit on a fluvial gley or peaty gley soil.

The following Tables 1 to 6 present comparisons which meet these criteria. Reading down columns in each table, it is clear that pasture yields steadily decrease moving from Class 1 to Class 8. Table 7 summarises the range of pasture yield by LUC class for the entire Auckland region.

Table 1. Changes in pasture yield moving from Class 1 to 8 on floodplains, low terraces, and swamps

Soil order	**Sulphuric or Orthic Gley soil**	**Gley Recent or Gley Raw soil**	**Organic or peaty Gley soil**
Examples of soil	*Takahiwai, Kaipara*	*Whakapara, Whangamaire*	*Otonga, Ruakaka*
LUC class	*t dm/ha/yr*	*t dm/ha/yr*	*t dm/ha/yr*
1	no class 1	no class 1	no class 1
2	14.3	13.1	11.7
3	10.7	10.5	9.4
4	7.2	7.9	7.0
5	7.0	6.3	4.6
6	4.2	3.7	2.7
7	2.7	2.4	1.7
8	no class 8	no class 8	no class 8

Table 2. Changes in pasture yield moving from Class 1 to 8 on elevated terraces

Soil order	**Yellow or mottled Ultic soil**	**Perch-gley or densipan Ultic soil**	**Allophanic or Granular over buried Ultic soil**
Examples of soil *LUC class*	*Whareora, Waipuna* *t dm/ha/yr*	*Kara, Clevedon* *t dm/ha/yr*	*Otao, Karaka* *t dm/ha/yr*
1	no class 1	no class 1	>12.8->13.4
2	12.1	no class 2	12.9-13.4
3	10.3	10.9-11.8	11.9-13.1
4	9.4	8.1-8.8	11.3-12.6
5	8.7	5.5-5.9	9.6-10.4
6	7.0	no class 6	no class 6
7	6.6	no class 7	no class 7
8	0	no class 8	no class 8

Table 3. Changes in pasture yield moving from Class 1 to 8 on young, old and dissected sand dune terrain

Soil order	**Sandy Recent or Raw soil**	**Sandy Brown soil**	**Sandy Ultic soil**
Examples of soil *LUC class*	*Pinaki, Parore* *t dm/ha/yr*	*Houhora, Red Hill* *t dm/ha/yr*	*Tangitiki, Horea* *t dm/ha/yr*
1	no class 1	no class 1	no class 1
2	14.5	no class 2	no class 2
3	11.6	14.3	9.3
4	8.7	13.4	8.4
5	7.6	12.9	7.9
6	6.6	8.1	4.8
7	5.1	4.7	2.7
8	0	0	0

Table 4. Changes in pasture yield moving from Class 1 to 8 on ash-mantled or stony lava flow terrain

Soil order	**Tephric Recent or Raw soil**	**Stony Allophanic or Brown soil**	**Allophanic or Brown soil**	**Granular or Brown soil**	**Oxidic Granular or Oxidic soil**
Examples of soil	*Rangitoto*	*Papakauri, Ohaeawai stony*	*Kiripaka, Ohaeawai, Kapu*	*Patumahoe, Mauku, Whatitiri*	*Waiotu, Bald Hill*
LUC class	*t dm/ha/yr*	*t dm/ha/yr*	*t dm/ha/yr*	*t dm/ha/yr*	*t dm/ha/yr*
1	no class 1	no class 1	>13.4	>12.9	no class 1
2	no class 2	no class 2	13.4	12.9	no class 2
3	no class 3	>10.2	13.1	11.9	10.0-12.1
4	no class 4	10.2	12.6	11.3	7.5-10.1
5 (downland)	<8.9	9.8	11.1	9.6	5.0-9.1
5 (slopes)	<7.1	7.1	8.9	7.7	7.3
6	<6.6	6.6	8.0	7.2	6.8
7	<4.6	4.6	no class 7	no class 7	no class 7
8	0	no class 8	no class 8	no class 8	no class 8

Table 5. Changes in pasture yield moving from Class 1 to 8 on soft rock footslopes, hillsides and steep faces

Soil order	**Perch-gley Ultic soil**	**Albic or Densipan Ultic soil**	**Brown or Ultic soil on mudstone**	**Brown or Ultic soil on sandstone**	**Melanic or Ultic soil on limestone**
Examples of soil	*Waikare, Mahurangi*	*Hukerenui, Wharekohe*	*Okaka, Aponga*	*Warkworth, Whangaripo*	*Motatau, Rockvale*
LUC class	*t dm/ha/yr*	*t dm/ha/yr*	*t dm/ha/yr*	*t dm/ha/yr*	*t dm/ha/yr*
1	no class 1	no class 1	no class 1	no class 1	no class 1
2	no class 2	no class 2	no class 2	no class 2	no class 2
3	12.0	11.1	11.9	10.0	12.1
4	9.0	8.4	9.4	7.9	9.6
5 (ridges)	5.9	5.5	11.4	9.5	11.6
5 (slopes)	4.6	4.3	8.7	7.2	8.9
6	no class 6	no class 6	6.9	5.7	7.1
7	no class 7	no class 7	4.3	3.3	4.4
8	no class 8	no class 8	0	0	0

Table 6. Changes in pasture yield moving from Class 1 to 8 on hard rock footslopes hillsides and steep faces

Soil order	**Perch-gley Ultic soil**	**Albic or Densipan Ultic soil**	**Brown or Ultic soil on shales and quartzites**	**Brown or Ultic soil on greywackes**	**Granular or Oxidic soil on old volcanics**
Examples of soil *LUC class*	*Waikare, Mahurangi* *t dm/ha/yr*	*Hukerenui, Wharekohe* *t dm/ha/yr*	*Otangaroa, Omaiko* *t dm/ha/yr*	*Marua, Rangiora* *t dm/ha/yr*	*Parau, Cornwallis* *t dm/ha/yr*
1	no class 1	no class 1	no class 1	no class 1	no class 1
2	no class 2	no class 2	no class 2	no class 2	no class 2
3	12.0	11.1	?	11.8	11.3
4	9.0	8.4	?	9.6	9.1
5 (ridges)	5.9	5.5	?	11.4	10.8
5 (slopes)	4.6	4.3	?	8.2	7.7
6	no class 6	no class 6	?	5.7-6.1	5.3-5.7
7	no class 7	no class 7	?	3.1-3.7	2.7-3.4
8	no class 8	no class 8	0	0	0

Table 7. Range of pasture yields moving from Class 1 to 8 within the Auckland region

LUC class	***t dm/ha/yr***
1	>11.7 - >14.5
2	11.7 - 14.5
3	9.3 - 14.3
4	7.0 - 13.4
5	4.3 -12.9
6	2.7 - 8.1
7	1.7 - 6.6
8	0

In Table 7, only the lower limit of pasture yields is given for LUC class 1 because near Auckland there are few trial sites on the corresponding soils (Allophanic and Granular). Otherwise, Tables 1 to 7 provide good comparisons of pasture yield amongst LUC classes in the Auckland region because necessary controls (page 14) have been applied to comparisons. Yield estimates are derived from pasture measurements, not retro-fitted to stock carrying capacity estimates. The calculation procedure adjusts yield estimates for individual LUC units in preference to making area-weighted estimates for entire LUC classes. The adjustments are derived from published scientific investigations of how slope angle, geological instability, soil drainage and rainfall affect pasture growth.

The new stock carrying capacity estimates in Appendix 2 are made by applying scientifically accepted figures for livestock dry matter intake plus wastage (combination = feed requirement per stock unit) to pasture yield estimates for individual LUC units. In most instances, albeit some exceptions, they provide realistic matches with the rates at which farmers actually stock their properties at the present day (pers. comms. from farmers to DLH).

Many of the pasture yield estimates in Appendix 2 have changed slightly compared with 'ad hoc' estimates previously made for individual farm plans, because new pasture yield data has become available over the past twenty years. Few have changed substantially. They may be regarded as more reliable than the previous ‘ad hoc’ estimates, because all estimates in Appendix 2 have been made from a standard dataset, using a standard method.

6.0 Conclusion

To support sustainable management of rural land in the Auckland region, estimates of land use capability classes' production (or productive potential) need to be under-pinned by defensible science that is able to withstand close scrutiny through planning hearings and court procedures.

Livestock carrying capacity (SCC) estimates attached to LUC units on 1:63,360 New Zealand Land Resource Inventory maps have been used for many years. SCC (expressed as average farmer, top farmer, and attainable potential) has had many practical uses for farm management through the 1970s-1980s. While SCC is recognised as close to the stock numbers carried (or that could be) on farms in those years, grazing management has now changed considerably, and economics of livestock production has changed greatly.

One option is to continue using an estimate of agricultural output such as SCC, assuming it integrates the physical factors which cause production to vary, notably growing degree days, rainfall, landform relief, and different soils e.g. Cichota et al (2014). Estimates of pasture yield made by this means are derived from SCCs which are also estimates, not supported by farm-collected stock data. The SCC estimates are now too divergent from present day farm management, to use for pasture yield models.

Another option is to feed field-measured crop, grass or timber yields into a computer model which simulates seasonal or year-to-year changes in production, utilising physical equations which describe the effects of temperature, rainfall, relief and soil properties on plant growth. An instance is the APSIM model as run by Vogeler et al (2016). This approach is scientifically sound but would be difficult to implement at regional scale in New Zealand, because for many soils, the data needed for simulation runs are incomplete or lacking.

A third option is to take the same input data (measured crop, grass or timber yields) for the limited sites where it is measured, and scale the yields to different sites in a region (expressed as LUC units within LUC suites), by applying factors which describe how yield goes up or down, as temperature, rainfall, relief and soil change. Such factors are empirical (as opposed to physical equations), though can be calculated from published studies of pasture yield, and have the advantage that they do not entail prolonged or extensive collection of new data. This option has been trialled for the Auckland region, utilising a previously unpublished spreadsheet which one of the authors (DLH) has used to estimate pasture yields on individual farms for over twenty years. When divided by feed requirement (dry matter intake plus wastage), the pasture yield estimates correspond closely with stock numbers being grazed by farmers at the present day (farmers' pers. comms.).

A region-wide NZLRI-FARMLUC conversion layer was entered into Auckland Council's GIS in 2016. It enables spatial depictions of MADMYs and SSCs attached to the region-wide geospatial NZLRI LUC layer for Auckland. It is essential to remember that any such depictions are illustrative only, i.e. they show the comparative pasture yields and livestock carrying capacities attainable, given a standard annual rainfall, were all the land in pasture.

For any polygon in the 1: 50, 000 NZLRI LUC layer, actual MADMYs and SSCs can only be estimated by mapping FARM LUC at farm scale, ascertaining extent and composition of pasture, and adjusting estimates to actual farm rainfall.

The third option is a practical and robust means to compare pasture production provided the comparisons are made between LUC units in the same suite i.e. with similar climate, underlying geology, relief and soil. The authors suggest that a similar approach could be undertaken using timber yields from trial sites in the Auckland region; and finally using crop yields for arable LUC classes 1 to 4, if suitable yield data are obtainable from local growers.

Meanwhile, the new pasture yield estimates provide a way to compare productive potential of UC classes 1 to 8 throughout Auckland. They will not only defensibly inform future policy and land use planning decisions within Auckland but will also assist with land management advice to rural communities about the impacts of various farm management scenarios, such as retiring marginal land or fencing off certain distances from streams, on agricultural production.

7.0 Acknowledgements

The authors would like to acknowledge all organisations and individuals who conducted the pasture field trials listed in Appendix 1. Our new estimates very much depend on their painstaking field collection of data in past years. The individuals named in Appendix 1 as having published trial results, or supplied unpublished yields together with site information, deserve particular credit.

Des Woolley and Reza Kalbasi, Geospatial Team at Auckland Council, are thanked for their geospatial data visualisation when they created maps of the new pasture production yield estimates (IDMY etc) and stock carrying capacity estimates (ISCC etc), by attaching them to the NZLRI LUC – FARM LUC conversion layer in GeoMaps. Mr Tony Edhouse, Research and Evaluation Unit at Auckland Council, is thanked for undertaking the layout and format of our pre-review and final reports. Mr Ian Lynn of Landcare Research is thanked for his helpful comments and suggestions when reviewing the report. Adopting most of them has greatly aided explaining how our new estimates link to the FARM LUC (farm-scale) and NZLRI (regional-scale) land use capability classifications.

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Appendix 1: Pasture trial sites relevant to Auckland land use capability

APPENDIX 1	**PASTURE TRIAL SITES RELEVANT TO AUCKLAND LAND USE CAPABILITY UNITS (checked version, February 2017)**													
A	**TRIAL SITES USED TO MAKE ESTIMATES (SUFFICIENT SITE INFORMATION IN SOURCE DOCUMENTS)**													
Site	**Trial series**	**Source**	**Duration (years)**	**Pasture composition :**	**Fertiliser treatment :**	**Grazed by :**	**Mean yield : kg dm/ha/yr**	**Mean rainfall : mm/yr**	**Slope : class & degrees (if given)**	**Soil : name**	**texture**	**LUC suite : number**	**name**	**subdivision (for attaching yields)**
Whatawhata	MAF hill country	Gillingham & During 1973	3	ryegrass-clover	phosphate & lime	sheep & cattle	12100-12800	1592	near-flat ridge, 0 degree	Dunmore	silt loam	pt 5	greywacke terrain	granular over buried ultic
Whatawhata	MAF hill country	Gillingham & During 1973	3	ryegrass-browntop	phosphate & lime	sheep & cattle	6750 - 7800	1592	moderate slope, 25 degree	Marua	clay loam	5	greywacke terrain	brown or ultic
Whatawhata	MAF hill country	Gillinham 1974	3	browntop-paspalum	phosphate & lime	sheep & cattle	6400 - 7100	1592	steep, 30 degree	Waingaro	steepland soil	pt 5	greywacke terrain	recent or immature ultic
Dargaville	MAF long-term	Baars 1976	12	ryegrass-paspalum-clover	phosphate & lime	dairy cattle	17160	1247	flat	Kaipara	clay	2b	estuarine plains with gley & saline soils	sulphuric or orthic gley
Helensville	MAF long-term	Piggott et al 1978	10	ryegrass-clover	phosphate & lime	sheep & cattle	12760	1336	undulating-rolling	Red Hill	sand	1b	old stable sand dunes	sandy brown
Rukuhia	MAF long-term	Baars 1976b	16	ryegrass-clover	phosphate & lime	dairy cattle	10220	1262	undulating	Hamilton	clay loam	pt 3	old terraces with complex soils	granular over buried ultic
Kaikohe	MAF pasture composition	Baars 1979	4	ryegrass-clover	phosphate & lime	sheep	9820	1690	flat to undulating	Whareora	clay loam	3	old terraces with complex soils	yellow or mottled ultic
Kaikohe	MAF pasture composition	Baars 1979	4	ryegrass-clover-kikuyu	phosphate & lime	sheep	10365	1690	flat to undulating	Whareora	clay loam	3	old terraces with complex soils	yellow or mottled ultic
Kaikohe	MAF pasture composition	Baars 1979	4	clover-kikuyu	phosphate & lime	sheep	9947	1690	flat to undulating	Whareora	clay loam	3	old terraces with complex soils	yellow or mottled ultic
Kaikohe	MAF pasture composition	Lambert et al 1979	9	ryegrass	phosphate & lime	sheep	11505-12330	1710	rolling, 0-20 degrees	Wharekohe & Hukerenui	silt loam	4g	podzols on sedimentary rock	albic or densipan ultic
Kaikohe	MAF pasture composition	Lambert et al 1979	9	paspalum	phosphate & lime	sheep	12214-12600	1710	rolling, 0-20 degrees	Wharekohe & Hukerenui	silt loam	4g	podzols on sedimentary rock	albic or densipan ultic
Kaikohe	MAF pasture composition	Lambert et al 1979	9	kikuyu	phosphate & lime	sheep	11608-11355	1710	rolling, 0-20 degrees	Wharekohe & Hukerenui	silt loam	4g	podzols on sedimentary rock	albic or densipan ultic
Kaikohe	MAF pasture improvement	Rumball 1979	2	ryegrass-clover	phosphate & lime	sheep	12900	1751	flat-undulating	Wairoro? (=Whakapara)	clay loam	2a & 2c	floodplains and low terraces	gley recent or gley raw
Kapiro	MAF pasture improvement	Baars 1982	6	ryegrass-clover	phosphate & lime	sheep and/or cattle	9970	1658	undulating	Okaihau	friable clay	pt 6	young basalt volcanic terrain	oxidic granular or oxidic
Opuawhanga	MAF pasture improvement	Baars 1982	6	ryegrass-clover	phosphate & lime	sheep and/or cattle	9400	1753	undulating-rolling	Rangiroa? (=Rangiora)	clay	5	greywacke terrain	brown or ultic
Kaikohe	MAF pasture improvement	Baars 1982	6	ryegrass-clover	phosphate & lime	sheep and/or cattle	7010-8810	1700	undulating-rolling	Awarua	clay	7a	old stable basalt-andesite volcanics	granular or oxidic
Kaikohe	MAF pasture improvement	Baars 1982	5	ryegrass-clover	phosphate & lime	sheep and/or cattle	10900	1700	undulating	Kiripaka	silt loam	6	young basalt volcanic terrain	allophanic or oxidic brown
Kaiwaka	MAF pasture improvement	Baars 1982	5	ryegrass-clover	phosphate & lime	sheep and/or cattle	11480	1362	undulating-rolling	Waikare	clay	pt 4g	podzols on sedimentary rock	perch-gley ultic
Kaiwaka	MAF pasture improvement	Baars 1982	4	ryegrass-clover	phosphate & lime	sheep and/or cattle	10640	1362	undulating-rolling	Wharekohe	silt loam	4g	podzols on sedimentary rock	albic or densipan ultic
Mangere	MAF pasture improvement	Baars 1982	7	ryegrass-clover	phosphate & lime	sheep and/or cattle	10160	1300	undulating	Ohaeawai	bouldery silt loam	6	young basalt volcanic terrain	stony allophanic or oxidic brown
Waitakaruru	MAF pasture improvement	Baars 1982	4	ryegrass-clover	phosphate & lime	sheep and/or cattle	11160	1219	flat	Hauraki	peaty clay	2e	peats	organic or peaty gley
Ngataki	MAF pasture composition	Ussher unpubl 1985	1	prairie grass-clover	phosphate & lime	sheep & cattle	22000	1096	undulating	Tangitiki & Te Kopuru	sandy loam	pt 1c	old stable terraces and escarpments on sand	sandy ultic or sandy podsol
Ngataki	MAF pasture composition	Ussher unpubl 1985	1	ryegrass-clover	phosphate & lime	sheep & cattle	17000	1096	undulating	Tangitiki & Te Kopuru	sandy loam	pt 1c	old stable terraces and escarpments on sand	sandy ultic or sandy podsol
Ngataki	MAF pasture composition	Ussher unpubl 1985	1	kikuyu	phosphate & lime	sheep & cattle	8000	1096	undulating	Tangitiki & Te Kopuru	sandy loam	pt 1c	old stable terraces and escarpments on sand	sandy ultic or sandy podsol
Kaitaia	MAF pasture composition	Ussher unpubl 1985	2	red clover	phosphate & lime	dairy cattle	22000	1351	flat	Awanui	clay loam	2a & 2c	floodplains and low terraces	gley recent or gley raw
Kaitaia	MAF pasture composition	Ussher unpubl 1985	1	ryegrass-white & red clover	phosphate & lime	dairy cattle	22000	1351	flat	Awanui	clay loam	2a & 2c	floodplains and low terraces	gley recent or gley raw
Kaitaia	MAF pasture composition	Ussher unpubl 1985	1	prairie grass-red clover	phosphate & lime	dairy cattle	24000	1351	flat	Awanui	clay loam	2a & 2c	floodplains and low terraces	gley recent or gley raw
Kaitaia	MAF pasture composition	Ussher unpubl 1985	1	kikuyu	phosphate & lime	dairy cattle	11000	1351	flat	Awanui	clay loam	2a & 2c	floodplains and low terraces	gley recent or gley raw
Puketona	MAF phosphate	Smith et al 1990	6	ryegrass-clover	rock phosphate cf. super	sheep	7017	1792	undulating-rolling	Hukerenui	silt loam	pt 4g	podzols on greywacke	albic or densipan ultic
Kaikohe	MAF phosphate	Smith et al 1990	6	ryegrass-clover	rock phosphate cf. super	sheep	12800	1751	undulating-rolling	Hukerenui	silt loam	4g	podzols on sedimentary rock	albic or densipan ultic
Awarua	MAF phosphate	Smith et al 1990	6	ryegrass-clover	rock phosphate cf. super	sheep	4868	1460	undulating-rolling	Awarua	clay	7a	old stable basalt-andesite volcanics	granular or oxidic
Wellsford	MAF phosphate	Smith et al 1990	6	ryegrass-clover	rock phosphate cf. super	sheep	9228	1635	rolling	Whangaripo	clay	4a	interbedded sandstone and mudstone	brown or ultic
Warkworth	MAF phosphate	Smith et al 1990	6	ryegrass-clover	rock phosphate cf. super	sheep	7795	1725	rolling	Warkworth	clay	4a	interbedded sandstone and mudstone	brown or ultic
Helensville	MAF phosphate	Smith et al 1990	6	ryegrass-clover	rock phosphate cf. super	sheep	check	1396	undulating-rolling	Red Hill	sand	1b	old stable sand dunes	sandy brown
Te Toro	MAF pasture composition	Auld unpubl 1996	5	ryegrass-clover	phosphate & lime	dairy cattle	11898	1257	undulating-rolling	Horea & Pollok	sandy clay loam	1c	old stable terraces and escarpments on sand	sandy ultic or sandy podsol
Te Toro	MAF pasture composition	Auld unpubl 1996	5	kikuyu	phosphate & lime	dairy cattle	11164	1257	undulating-rolling	Horea & Pollok	sandy clay loam	1c	old stable terraces and escarpments on sand	sandy ultic or sandy podsol
Ruawai	Pasture Assessment	Piggot unpubl 1992	4	improved, cage-cut	nitrate, phosphate, lime	dairy cattle	17000	1133	flat	Kaipara	clay	2b & 2d	estuarine plains with gley & saline soils	sulphuric or orthic gley
Ruawai	Pasture Assessment	Piggot unpubl 1992	4	improved, whole-farm	nitrate, phosphate, lime	dairy cattle	?	1133	flat	Kaipara	clay	2b & 2d	estuarine plains with gley & saline soils	sulphuric or orthic gley
Ararua	Pasture Assessment	Piggot unpubl 1996	5	ryegrass-clover, cage-cut	nitrate, phosphate, lime	dairy cattle	12200	1235	undulating	Waikare	clay	4e & 4f	limestone complexed with sedimentary rocks	melanic or ultic
Ararua	Pasture Assessment	Piggot unpubl 1996	5	ryegrass-clover, whole-farm	nitrate, phosphate, lime	dairy cattle	9100	1235	undulating	Waikare	clay	4e & 4f	limestone complexed with sedimentary rocks	melanic or ultic
Ocean Beach	Pasture Assessment	Piggot unpubl 1997	1	ryegrass-kikuyu, cage-cut	nitrate, phosphate, lime	dairy cattle	15400	1459	undulating-rolling	Marsden	sand	1a	young unstable sand dunes	sandy recent or sandy raw
Ocean Beach	Pasture Assessment	Piggot unpubl 1997	1	ryegrass-kikuyu, whole-farm	nitrate, phosphate, lime	dairy cattle	11700	1459	undulating-rolling	Marsden	sand	1a	young unstable sand dunes	sandy recent or sandy raw
Glorit	Pasture Assessment	Piggot unpubl 2000	6	improved	nitrate, phosphate, lime	dairy cattle	11300	1327	flat	Kaipara	clay	2b & 2d	estuarine plains with gley & saline soils	sulphuric or orthic gley
Glorit	Pasture Assessment	Piggot unpubl 2000	6	improved, irrigated	nitrate, phosphate, lime	dairy cattle	12800	1327	flat	Kaipara	clay	2b & 2d	estuarine plains with gley & saline soils	sulphuric or orthic gley
Waiteitei	Pasture Assessment	Piggot unpubl 2000	7	improved	nitrate, phosphate, lime	dairy cattle	11300	1453	rolling	Whangaripo or Warkworth?	clay loam	4a	interbedded sandstone and mudstone	brown or ultic
Waiteitei	Pasture Assessment	Piggot unpubl 2000	7	improved, irrigated	nitrate, phosphate, lime	dairy cattle	17200	1453	rolling	Whangaripo or Warkworth?	clay loam	4a	interbedded sandstone and mudstone	brown or ultic
Waipu	Pasture Assessment	Piggot unpubl 2000	7	improved	nitrate, phosphate, lime	dairy cattle	14000	1315	flat	Waipu? = Kara	clay	pt 3	old terraces with complex soils	perch-gley ultic
Waipu	Pasture Assessment	Piggot unpubl 2000	7	improved	nitrate, phosphate, lime	dairy cattle	15200	1315	rolling	Waipu? = Wharekohe	silt loam	pt 3	old terraces with complex soils	albic or densipan ultic
Kerikeri	Pasture Assessment	Piggot unpubl 2000	7	improved	nitrate, phosphate, lime	dairy cattle	12600	1658	flat-undulating	Okaihau	friable clay	pt 6	young basalt volcanic terrain	oxidic granular or oxidic
Kerikeri	Pasture Assessment	Piggot unpubl 2000	7	improved, irrigated	nitrate, phosphate, lime	dairy cattle	15000	1658	flat-undulating	Okaihau	friable clay	pt 6	young basalt volcanic terrain	oxidic granular or oxidic
Te Ngaio	Pasture Assessment	Piggot unpubl 2001	10	ryegrass-clover, irrigated	nitrate, phosphate, lime	dairy cattle	15500	1584	flat-undulating	Waiotu	friable clay	pt 6	young basalt volcanic terrain	oxidic granular or oxidic
Te Ngaio	Pasture Assessment	Piggot unpubl 2001	10	kikuyu, irrigated	nitrate, phosphate, lime	dairy cattle	15700	1584	flat-undulating	Waiotu	friable clay	pt 6	young basalt volcanic terrain	oxidic granular or oxidic
Dargaville	DairyNZ	Dexcel website 2004	6	ryegrass	nitrate, phosphate, lime	dairy cattle	16920	1231	flat	Kaipara	clay	2b & 2d	estuarine plains with gley & saline soils	sulphuric or orthic gley
Dargaville	DairyNZ	Dexcel website 2004	6	kikuyu	nitrate, phosphate, lime	dairy cattle	19640	1231	flat	Kaipara	clay	2b & 2d	estuarine plains with gley & saline soils	sulphuric or orthic gley
Dargaville	DairyNZ	Dexcel website 2004	6	ryegrass-kikuyu, whole-farm	nitrate, phosphate, lime	dairy cattle	18600	1231	flat	Kaipara	clay	2b & 2d	estuarine plains with gley & saline soils	sulphuric or orthic gley
Pukekohe	DairyNZ	Dexcel website 2004	3	improved	nitrate, phosphate, lime	dairy cattle	13660	1360	undulating-rolling	Patumahoe	clay loam	pt 6	young basalt volcanic terrain	granular or oxidic brown
Ruakura	DairyNZ	Dexcel website 2004	3	improved	nitrate, phosphate, lime	dairy cattle	16420	1264	flat-undulating	Hamilton	clay loam	pt 3	old terraces with complex soils	granular over buried ultic
B	**TRIAL SITES NOT USED (INADEQUATE SITE INFORMATION IN SOURCE DOCUMENTS)**													
Maungaturoto	DairyNZ	Dexcel website 2008	5	improved	nitrate, phosphate, lime	dairy cattle	9600	?	?	ultic or melanic?	?	4c or 4f?	?	?
Ruakaka	DairyNZ	Dexcel website 2008	5	improved	nitrate, phosphate, lime	dairy cattle	13300	?	?	sandy brown or organic?	?	1b or 2e?	?	?
Paengaroa	DairyNZ	Dexcel website 2008	?	improved	nitrate, phosphate, lime	dairy cattle	14200	?	?	allophanic or pumice?	?	6?	?	?
Papamoa	DairyNZ	Dexcel website 2008	?	improved	nitrate, phosphate, lime	dairy cattle	16000	?	?	sandy recent?	?	1a?	?	?
Pongakawa	DairyNZ	Dexcel website 2004	7	improved	nitrate, phosphate, lime	dairy cattle	16000	?	?	organic?	?	2e?	?	?
Various	Sheep&BeefNZ	Farmax website 2016	no site information											

Appendix 2: Pasture yields and stocking rates for Auckland farm-scale land use capability

APPENDIX 2 — **PASTURE YIELDS AND STOCKING RATES FOR AUCKLAND FARM-SCALE LAND USE CAPABILITY (checked version, February 2017)**

See Appendix 1 of Hicks and Vujcich 2016 for FARM LUC - NZLRI LUC correlations

See report accompanying this appendix for pasture growth & stocking rate estimation procedure

Landform & geology	**NZSC soil order & group**	**Other distinguishing characteristics**	**FARM LUC :**			**Pasture growth (t dm ha/yr) :**			**Stocking rate (su/ha) :**		
			Class	**Subclass**	**Yield suffix**	**Un-improved**	**Semi-improved**	**Improved**	**Un-improved**	**Semi-improved**	**Improved**
			(used on post-2011 farm maps)		(used only for GIS operations)	Model inputs : mean annual pasture yields from long-term trial sites (Appendix 1)					
						Model outputs : set at 1500 mm mean annual rainfall (to enable comparisons amongst LUC classes/subclasses/units)					
ESTUARIES, FLOODWAYS, SWAMPS, STREAMBANKS											
estuary-margin mud, sand or shell	sulphuric raw	occasionally flooded	5	a	~	3.5	5.6	7.0	4	7	13
		regularly flooded	6	a	~	2.6	4.2	5.3	3	6	10
		frequently flooded	7	a	~	1.7	2.7	3.4	2	4	6
	sandy raw	sandy or shelly	6	a+r	~	no data					
floodway sand, silt or clay	gley or fluvial raw	occasionally flooded	5	f	@	3.2	5.0	6.3	3	7	11
		regularly flooded	6	f	@	2.3	3.7	4.6	2	5	8
		frequently flooded	7	f	@	1.5	2.4	3.0	2	3	5
swamp peat	mesic or humic organic	semi-drained swamp	5	o	(	2.3	3.7	4.6	2	5	8
		seasonal swamp	6	o	(	1.7	2.7	3.4	2	4	6
		permanent swamp	7	o	(	1.1	1.7	2.1	1	2	4
dune peat	sandy organic	semi-drained swamp	5	o	)	2.9	4.6	5.8	3	6	10
		seasonal swamp	6	o	)	2.1	3.4	4.3	2	5	8
		permanent swamp	7	o	)	1.4	2.2	2.8	1	3	5
streambank deposits	various soils	stable	5	b		3.2	5.0	6.3	3	7	11
		unstable, moderate	6	b		2.3	3.7	4.6	2	5	8
		unstable, steep	7	b		1.5	2.4	3.0	2	3	5
		unstable, near-vertical	8	b		-	-	-	-	-	-
RECLAIMED FLATS, FLOODPLAINS, DRAINED SWAMPS											
estuarine alluvium	sulphuric gley	free-draining	2	a+e	~	6.0	9.5	11.9	6	13	22
		poorly drained	3	a+e	~	4.5	7.1	8.9	5	9	16
		seasonally wet	4	a+e	~	3.0	4.7	5.9	3	6	11
	sandy recent or orthic melanic	sandy or shelly	5	a+r	~	no data					
stream alluvium	fluvial recent or recent gley	free-draining	2	w+e	@	6.6	10.5	13.1	7	14	24
		poorly drained	3	w+e	@	5.3	8.4	10.5	6	11	19
		seasonally wet	4	w+e	@	4.0	6.3	7.9	4	8	14
peat or peaty alluvium	mesic or humic organic	free-draining	2	o+e	(	4.9	7.8	9.8	5	10	18
		poorly drained	3	o+e	(	3.9	6.2	7.8	4	8	14
		seasonally wet	4	o+e	(	2.9	4.6	5.8	3	6	10
sandy peat or peaty sand	sandy organic	free-draining	2	o+e	)	6.0	9.6	12.0	6	13	22
		poorly drained	3	o+e	)	4.9	7.7	9.6	5	10	18
		seasonally wet	4	o+e	)	3.7	5.8	7.3	4	8	13
LOW FLAT TERRACES											
shallow stream alluvium	recent or orthic gley	free-draining	2	a	~	7.2	11.4	14.3	8	15	26
(over weathered estuarine alluvium)		poorly drained	3	a	~	5.4	8.6	10.8	6	11	20
		seasonally wet	4	a	~	3.7	5.8	7.3	4	8	13
shallow stream alluvium	orthic brown, allophanic or granular	free-draining	2	w	@	7.8	12.4	15.5	8	17	28
(over weathered stream alluvium)		poorly drained	3	w	@	6.3	10.0	12.5	7	13	23
		seasonally wet	4	w	@	4.7	7.5	9.4	5	10	17
shallow peat	mesic or humic organic	free-draining	2	o	(	5.9	9.4	11.8	6	13	21
(over weathered stream alluvium)		poorly drained	3	o	(	4.7	7.4	9.3	5	10	17
		seasonally wet	4	o	(	3.5	5.6	7.0	4	7	13
sandy peat or peaty sand	sandy organic	free-draining	2	o	)	7.3	11.6	14.5	8	15	26
(over estuarine alluvium or dunesand)		poorly drained	3	o	)	5.9	9.3	11.6	6	12	21
		seasonally wet	4	o	)	4.4	7.0	8.8	5	9	16
	humus pan podsol	cemented pan	5	p	"	2.8	4.4	5.5	3	6	10
HIGH DISSECTED TERRACES											
weathered alluvium	yellow ultic	flat to undulating, free-draining	2	p	+	6.1	9.7	12.1	6	13	22
		flat to undulating, slow-draining	3	p	+	6.1	9.7	12.1	6	13	22
		rolling, free to slow-draining	3	p+t	+	5.2	8.2	10.3	5	11	19
		strongly rolling, free to slow-draining	4	p+t	+	4.7	7.5	9.4	5	10	17
shallow waterlaid or airfall ash	orthic or impeded allophanic	flat to undulating	1, 2	c	$	6.7	10.7	13.4	7	14	24
(over weathered alluvium)		rolling	3	c+t	$	6.6	10.5	13.1	7	14	24
		strongly rolling	4	c+t	$	6.4	10.1	12.6	7	13	23
	orthic or impeded granular	flat to undulating	1, 2	c	=	6.5	10.3	12.9	7	14	23
		rolling	3	c+t	=	6.0	9.5	11.9	6	13	22
		strongly rolling	4	c+t	=	5.7	9.0	11.3	6	12	20
with seasonally impeded drainage	perch-gley ultic, allophanic or granular	deep topsoil	3	p+w	'	5.9	9.4	11.8	6	13	21
		shallow topsoil	4	p+w	'	4.4	7.0	8.8	5	9	16
	albic or densipan ultic	deep topsoil	3	p	"	5.5	8.7	10.9	6	12	20
		shallow topsoil	4	p	"	4.1	6.5	8.1	4	9	15
		cemented pan	5	p	"	2.8	4.4	5.5	3	6	10
on terrace scarps and gullies	various soils	stable	5	b+g		5.5	8.7	10.9	6	12	20
		unstable, moderate	6	b+g		4.4	7.0	8.8	5	9	16
		unstable, steep	7	b+g		4.2	6.6	8.3	4	9	15
		unstable, near-vertical	8	b+g		-	-	-			

APPENDIX 2	**PASTURE YIELDS AND STOCKING RATES FOR AUCKLAND FARM-SCALE LAND USE CAPABILITY (checked version, February 2017)**											**Page 2 of 4**
See Appendix 1 of Hicks and Vujcich 2016 for FARM LUC - NZLRI LUC correlations						**See report accompanying this appendix for pasture growth & stocking rate estimation procedure**						
Landform & geology	**NZSC soil order & group**	**Other distinguishing characteristics**	**FARM LUC :**			**Pasture growth (t dm ha/yr) :**			**Stocking rate (su/ha) :**			
			Class	**Subclass**	**Yield suffix**	**Un-improved**	**Semi-improved**	**Improved**	**Un-improved**	**Semi-improved**	**Improved**	
			(used on post-2011 farm maps)		(used only for	Model inputs : mean annual pasture yields from long-term trial sites (Appendix 1)						
					GIS operations)	Model outputs : set at 1500 mm mean annual rainfall (to enable comparisons amongst LUC classes/subclasses/units)						
SAND DUNES												
windblown sand (active or recent)	sandy recent or sandy raw	vegetated, undulating to rolling	5	d	%	4.8	7.6	9.5	5	10	17	
		vegetated, strongly rolling	6	d	%	4.2	6.6	8.3	4	9	15	
		re-veg. or re-activating (inland)	7	d	%	3.2	5.1	6.4	3	7	12	
		reactivating or bare (coastal)	8	d	%	-	-	-				
windblown sand (old dunes)	sandy or orthic brown	undulating to rolling	3	x+d	&	7.2	11.4	14.3	8	15	26	
(includes ash mixed with sand)		strongly rolling	4	x+d	&	6.7	10.7	13.4	7	14	24	
		moderate, stable	5	x+s	&	6.5	10.3	12.9	7	14	23	
		moderate, unstable	6	x+g	&	5.1	8.1	10.1	5	11	18	
		steep	7	x+l	&	3.0	4.7	5.9	3	6	11	
weathered sand (dissected dunes)	orthic granular	flat, ash-mantled	2	c+x	=	6.5	10.3	12.9	7	14	23	
(includes thin ash over sand)		undulating to rolling, ash-mantled	3	c+x	=	6.0	9.5	11.9	6	13	22	
		strongly rolling, ash-mantled	4	c+x	=	5.7	9.0	11.3	6	12	20	
	sandy ultic	undulating to rolling	3	x+t	'	4.7	7.4	9.3	5	10	17	
		strongly rolling	4	x+t	'	4.2	6.7	8.4	4	9	15	
		moderate, stable	5	x+s	'	4.0	6.3	7.9	4	8	14	
		moderate, unstable	6	x+g	'	3.1	4.9	6.1	3	7	11	
		steep	7	x+l	'	1.7	2.7	3.4	2	4	6	
		coastal cliffs	8	x+c	'	-	-	-	-	-	-	
	perch-gley ultic or densipan podsol	uncemented pan, deep topsoil	3	p	"	5.5	8.7	10.9	6	12	20	
		uncemented pan, shallow topsoil	4	p	"	4.1	6.5	8.1	4	9	15	
		uncemented pan, on undulating slopes	3	p+t	"	5.4	8.6	10.8	6	11	20	
		uncemented pan, on rolling slopes	4	p+t	"	4.0	6.4	8.0	4	9	15	
		cemented pan	5	p	"	2.8	4.4	5.5	3	6	10	
LAVA FLOWS, SCORIA CONES & ASH-MANTLED DOWNLANDS												
recent ash	tephric recent or raw	shallow, loamy	5	r+s	!	4.5	7.1	8.9	5	9	16	
		shallower, loamy	6	r+g	!	4.2	6.6	8.3	4	9	15	
recent scoria & basalt	tephric recent or raw	v. shallow, sandy to gritty	7	r+g	!	2.9	4.6	5.8	3	6	10	
		stony to rocky	8	r	!	-	-	-	-	-	-	
weathered basalt & scoria	orthic allophanic or oxidic brown	flat to rolling, shallow soil	3	r	!	6.4	10.2	12.8	7	14	23	
		flat to rolling, shallower	4	r	!	6.4	10.2	12.8	7	14	23	
		undulating to rolling, v. shallow	5	r	!	6.2	9.8	12.3	6	13	22	
		undulating to rolling, stones at surface	6	r	!	6.2	9.8	12.3	6	13	22	
		moderate, stable	5	r+s	!	4.5	7.1	8.9	5	9	16	
		moderate, unstable	6	r+g	!	4.2	6.6	8.3	4	9	15	
		steep	7	r+g	!	2.9	4.6	5.8	3	6	10	
weathered ash	orthic allophanic	flat to undulating	1	1c	$	6.7	10.7	13.4	7	14	24	
		undulating	2	2c	$	6.7	10.7	13.4	7	14	24	
		rolling	3	3c+t	$	6.6	10.5	13.1	7	14	24	
		strongly rolling	4	4c+t	$	6.4	10.1	12.6	7	13	23	
		moderate, stable	5	5c+s	$	5.6	8.9	11.1	6	12	20	
		moderate, unstable	6	6c+g	$	5.0	8.0	10.0	5	11	18	
	orthic granular	flat to undulating	1	1c	=	6.5	10.3	12.9	7	14	23	
		undulating	2	2c	=	6.5	10.3	12.9	7	14	23	
		rolling	3	3c+t	=	6.0	9.5	11.9	6	13	22	
		strongly rolling	4	4c+t	=	5.7	9.0	11.3	6	12	20	
		moderate, stable	5	5c+s	=	4.9	7.7	9.6	5	10	18	
		moderate, unstable	6	6c+g	=	4.5	7.2	9.0	5	10	16	
older ash on basalt or other rocks	oxidic brown or orthic oxidic	undulating, with deep topsoil	3	p	'	5.0	8.0	10.0	5	11	18	
		undulating, with shallow topsoil	4	p	'	3.8	6.0	7.5	4	8	14	
		rolling, with deep topsoil	3	p+t	'	4.9	7.8	9.8	5	10	18	
		rolling, with shallow topsoil	4	p+t	'	3.4	5.4	6.8	4	7	12	
		moderate, stable	5	p+s	'	4.6	7.3	9.1	5	10	17	
		moderate, unstable	6	p+g	'	4.3	6.8	8.5	5	9	15	
	orthic, perch-gley or gley oxidic	iron pan	5	p	"	2.5	4.0	5.0	3	5	9	

APPENDIX 2	PASTURE YIELDS AND STOCKING RATES FOR AUCKLAND FARM-SCALE LAND USE CAPABILITY (checked version, February 2017)											
See Appendix 1 of Hicks and Vujcich 2016 for FARM LUC - NZLRI LUC correlations						**See report accompanying this appendix for pasture growth & stocking rate estimation procedure**						
Landform & geology	**NZSC soil order & group**	**Other distinguishing characteristics**	**FARM LUC :**			**Pasture growth (t dm ha/yr) :**			**Stocking rate (su/ha) :**			
			Class	**Subclass**	**Yield suffix**	**Un-improved**	**Semi-improved**	**Improved**	**Un-improved**	**Semi-improved**	**Improved**	
			(used on post-2011 farm maps)		(used only for	Model inputs : mean annual pasture yields from long-term trial sites (Appendix 1)						
					GIS operations)	Model outputs : set at 1500 mm mean annual rainfall (to enable comparisons amongst LUC classes/subclasses/units)						
FOOTSLOPES, SPURS AND RIDGES												
any sedimentary rock type	perch-gley ultic or melanic	undulating, with deep topsoil	3	p+w	'	6.0	9.6	12.0	6	13	22	
		undulating, with shallow topsoil	4	p+w	'	4.5	7.2	9.0	5	10	16	
		rolling, with deep topsoil	3	p+w	'	5.9	9.3	11.6	6	12	21	
		rolling, with shallow topsoil	4	p+w	'	4.4	7.0	8.8	5	9	16	
	albic ultic	undulating, with deep topsoil	3	p	"	5.6	8.9	11.1	6	12	20	
		undulating, with shallow topsoil	4	p	"	4.2	6.7	8.4	4	9	15	
		rolling, with deep topsoil	3	p+t	"	5.4	8.6	10.8	6	11	20	
		rolling, with shallow topsoil	4	p+t	"	4.0	6.4	8.0	4	9	15	
	densipan ultic	cemented pan	5	p	"	2.8	4.4	5.5	3	6	10	
any volcanic rock type	perch-gley or oxidic granular	undulating, with deep topsoil	3	p	"	5.0	8.0	10.0	5	11	18	
		undulating, with shallow topsoil	4	p	"	3.8	6.0	7.5	4	8	14	
		rolling, with deep topsoil	3	p+t	"	4.9	7.8	9.8	5	10	18	
		rolling, with shallow topsoil	4	p+t	"	3.4	5.4	6.8	4	7	12	
	orthic, perch-gley or gley oxidic	iron pan	5	p	"	2.5	4.0	5.0	3	5	9	
claystone, mudstone, shale	orthic brown or yellow ultic	colluvial footslopes	3	e	>	6.0	9.5	11.9	6	13	22	
(includes complex with other rocks)		regolithic footslopes	4	t	>	4.7	7.5	9.4	5	10	17	
		spurs & ridges	5	s	>	5.7	9.1	11.4	6	12	21	
shattered shale & sandstone	acid brown or yellow ultic	colluvial footslopes	3	e	>	6.0	9.5	11.9	6	13	22	
(includes complex with other rocks)		regolithic footslopes	4	t	>	4.7	7.5	9.4	5	10	17	
		spurs & ridges	5	s	>	5.7	9.1	11.4	6	12	21	
banded or massive sandstone	acid brown or yellow ultic	colluvial footslopes	3	e	<	5.0	8.0	10.0	5	11	18	
(includes complex with other rocks)		regolithic footslopes	4	t	<	4.0	6.3	7.9	4	8	14	
		spurs & ridges	5	s	<	4.8	7.6	9.5	5	10	17	
limestone	orthic or rendzic melanic	colluvial footslopes	3	e	^	6.1	9.7	12.1	6	13	22	
(includes complex with other rocks)		regolithic footslopes	4	t	^	4.9	7.7	9.6	5	10	18	
		spurs & ridges (shallow or stony)	5	s	^	5.9	9.3	11.6	6	12	21	
quartzite	yellow ultic	colluvial footslopes	3	e	<	no data						
(usually as complex with other rocks)		regolithic footslopes	4	t	<	no data						
		spurs & ridges	5	s	<	no data						
greywacke	orthic brown or yellow ultic	colluvial footslopes	3	e	*	5.9	9.4	11.8	6	13	21	
		regolithic footslopes	4	t	*	4.9	7.7	9.6	5	10	18	
		spurs & ridges	5	s	*	5.7	9.1	11.4	6	12	21	
		plateaux	5, 6	c	*	4.6	7.3	9.1	5	10	17	
dolerite or andesite	orthic or oxidic granular	colluvial footslopes	3	e	#	5.7	9.0	11.3	6	12	20	
		regolithic footslopes	4	t	#	4.6	7.3	9.1	5	10	17	
		spurs & ridges	5	s	#	5.4	8.6	10.8	6	11	20	
		plateaux	5, 6	c	#	4.3	6.9	8.6	5	9	16	
dacite	orthic brown or yellow ultic	colluvial footslopes	3	e		no data						
		regolithic footslopes	4	t		no data						
		spurs & ridges	5	s		no data						
		plateaux	5, 6	c		no data						

APPENDIX 2 — **PASTURE YIELDS AND STOCKING RATES FOR AUCKLAND FARM-SCALE LAND USE CAPABILITY (checked version, February 2017)**

See Appendix 1 of Hicks and Vujcich 2016 for FARM LUC - NZLRI LUC correlations

See report accompanying this appendix for pasture growth & stocking rate estimation procedure

Landform & geology	NZSC soil order & group	Other distinguishing characteristics	FARM LUC : Class	Subclass	Yield suffix	Pasture growth (t dm ha/yr) : Un-improved	Semi-improved	Improved	Stocking rate (su/ha) : Un-improved	Semi-improved	Improved
			(used on post-2011 farm maps)		(used only for GIS operations)	Model inputs : mean annual pasture yields from long-term trial sites (Appendix 1); Model outputs : set at 1500 mm mean annual rainfall (to enable comparisons amongst LUC classes/subclasses/units)					
HILLSLOPES AND STEEP FACES											
claystone, mudstone, shale	yellow ultic	stable	5	g	>	5.2	8.2	10.3	5	11	19
(includes complex with other rocks)		formerly unstable	5	g+u	>	5.5	8.7	10.9	6	12	20
		unstable (slips, gullies)	6	l	>	3.9	6.2	7.8	4	8	14
		unstable (earthflows, gullies)	6	g+u	>	4.3	6.9	8.6	5	9	16
	orthic recent or immature ultic	unstable steep scarps	7	r	>	1.6	2.5	3.1	2	3	6
		unstable broken slopes	7	g+u	>	2.7	4.3	5.4	3	6	10
shattered shale & sandstone	yellow ultic	stable	5	g	>	5.2	8.2	10.3	5	11	19
(includes complex with other rocks)		formerly unstable	5	g+u	>	5.5	8.7	10.9	6	12	20
		unstable (slips, gullies)	6	l	>	3.9	6.2	7.8	4	8	14
		unstable (earthflows, gullies)	6	g+u	>	4.3	6.9	8.6	5	9	16
	orthic recent or immature ultic	unstable steep scarps	7	r	>	1.6	2.5	3.1	2	3	6
		unstable broken slopes	7	g+u	>	2.7	4.3	5.4	3	6	10
banded or massive sandstone	yellow ultic	stable	5	g	<	4.2	6.7	8.4	4	9	15
(includes complex with other rocks)		formerly unstable	5	g+u	<	4.5	7.2	9.0	5	10	16
		unstable (slips, gullies)	6	l	<	3.2	5.1	6.4	3	7	12
		unstable (earthslips, gullies)	6	g+u	<	3.6	5.7	7.1	4	8	13
	orthic recent or immature ultic	steep faces	7	l	<	2.1	3.3	4.1	2	4	8
		with shallow or stony soil	7	r	<	1.1	1.8	2.3	1	2	4
		rock outcrops & bluffs	8	k	<	-	-	-	-	-	-
		coastal faces	7, 8	r+c, k+c	<	-	-	-	-	-	-
limestone	orthic or rendzic melanic	stable	5	g	^	5.3	8.4	10.5	6	11	19
(includes complex with other rocks)		formerly unstable	5	g+u	^	5.6	8.9	11.1	6	12	20
		with shallow or stony soil	6	r	^	3.8	6.0	7.5	4	8	14
		unstable (slips, gullies)	6	l	^	4.0	6.4	8.0	4	9	15
		unstable (earthslips, gullies)	6	g+u	^	4.5	7.1	8.9	5	9	16
	orthic recent or immature melanic	steep faces	7	r	^	1.6	2.5	3.1	2	3	6
		unstable broken slopes	7	g+u	^	2.8	4.4	5.5	3	6	10
quartzite	yellow ultic	stable	5	r	<	no data					
(usually as complex with other rocks)		unstable (slips, gullies)	6	r+l	<	no data					
	orthic recent or immature ultic	steep faces	7	r+k	<	no data					
greywacke	orthic brown or yellow ultic	stable	5	g	*	5.2	8.2	10.3	5	11	19
		unstable (slips, earthslips, gullies)	6	l	*	3.8	6.1	7.6	4	8	14
		with shallow or stony soil	6	r	*	3.6	5.7	7.1	4	8	13
		coastal slopes	6	r+c	*	3.6	5.7	7.1	4	8	13
	orthic brown or immature ultic	steep faces	7	l	*	2.3	3.7	4.6	2	5	8
		with shallow or stony soil	7	r	*	2.0	3.1	3.9	2	4	7
		rock outcrops & bluffs	8	k	*	-	-	-	-	-	-
		coastal faces	7, 8	r+c, k+c	*	-	-	-	-	-	-
dolerite or andesite	orthic or oxidic granular	stable	5	g	#	4.9	7.7	9.6	5	10	18
		unstable (slips, earthslips, gullies)	6	l	#	3.6	5.7	7.1	4	8	13
		unstable, with shallow or stony soil	6	r	#	3.3	5.3	6.6	4	7	12
		coastal slopes	6	r+c	#	3.3	5.3	6.6	4	7	12
	oxidic brown or immature granular	steep faces	7	l	#	2.1	3.4	4.3	2	5	8
		with shallow or stony soil	7	r	#	1.7	2.7	3.4	2	4	6
		rock outcrops & bluffs	8	k	#	-	-	-	-	-	-
		coastal faces	7, 8	r+c, k+c	#	-	-	-	-	-	-
as complex with other rocks	oxidic brown or orthic granular	stable	5	r, u	#	no data					
	(complexed with ultic soils)	unstable (slips, earthflows, gullies)	6	g+u	#	no data					
		unstable, with shallow stony soil	6	r+l	#	no data					
	oxidic brown or immature granular	unstable broken slopes	7	u	#	no data					
	(complexed with ultic soils)										
dacite	orthic brown or yellow ultic	stable	5	g		no data					
		unstable (slips, earthslips, gullies)	6	l		no data					
		unstable, with shallow stony soil	6	r		no data					
		coastal slopes	6	r+c		no data					
	orthic recent or immature ultic	steep faces	7	l		no data					
		with shallow or stony soil	7	r		no data					
		rock outcrops & bluffs	8	k		no data					
		coastal faces	7, 8	r+c, k+c		no data					
as complex with other rocks	orthic brown or yellow ultic	stable	5	r, u		no data					
	(complexed with ultic soils from sedimentary	unstable (slips, earthflows, gullies)	6	g+u		no data					
		unstable, with shallow stony soil	6	r+l		no data					
	orthic recent or immature ultic	unstable broken slopes	7	u		no data					
	(complexed with ultic soils from sedimentary rocks)										

Find out more: phone 09 301 0101, email rimu@aucklandcouncil.govt.nz or visit aucklandcouncil.govt.nz and knowledgeauckland.org.nz

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Te Kaunihera o Tāmaki Makaurau