Manaaki Whenua
Landcare Research

# Land fragmentation environmental reporting indicator – technical methods for analysis from 2002 to 2019

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# Land fragmentation environmental reporting indicator – technical methods for analysis from 2002 to 2019

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Sam Carrick, John Drewry, Michelle Barnes, James Barringer, Robbie Price, Anne-Gaelle Ausseil

*Manaaki Whenua – Landcare Research*

Haydon Jones, Dan Borman

*Waikato Regional Council*

| *Reviewed by:* | *Approved for release by:* |
|---|---|
| Stella Belliss | Gerard Grealish |
| Researcher | Research Priority Area Leader |
| Manaaki Whenua – Landcare Research | Manaaki Whenua – Landcare Research |

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# Summary


## Project and Client

- The Ministry for the Environment (MfE), Statistics New Zealand (Stats NZ), and regional authorities require development of robust methods and analytical processes to underpin regional and national environmental reporting indicators, including land fragmentation.
- Land fragmentation is defined as any division of one or more aspects of a land resource available for primary production, such as through subdivision and residential development, including expansion of urban areas.

  MfE and Stats NZ contracted Manaaki Whenua – Landcare Research (MWLR) to implement, refine, and document a method for national analyses of land fragmentation indicators for consistent national environmental reporting.

## Objectives

- To quantify changes over time in the frequency distribution of different size parcel categories as an indicator of land fragmentation.
- To quantify the impact of land fragmentation on the areal availability of the highly productive land resource.

## Methods

- This report is largely based on the methodology developed by Rutledge et al. (2015), refined by Jones et al. (2018) and further developed here.
- The land fragmentation methodology in this report is designed to evaluate for all land types (Land Use Capability classes 1 to 7), although the Our Land 2021 report and indicator webpages will focus on the Highly Productive Land component (Land Use Capability classes 1 to 3), which is farmland highly suitable to support a range of agricultural, pastoral, arable and horticultural primary production activities.
- Methods and indicators were developed to monitor land fragmentation and report its effects on land supply for primary production at progressively restrictive levels: Level 1 Maximum Land Supply, Level 2 Known Land Supply, and Level 3 Likely Land Supply.
- Level 1 Maximum Land Supply was determined from national area minus selected biophysical networks, such as polygon features related to transport, rivers and other waterbodies.
- Level 2 Known Land Supply was determined from Maximum Land Supply minus urban areas, the protected natural area estate, and land parcels with an associated land use restriction.
- Level 3 Likely Land Supply (excludes likely areas of diffuse rural residential development) was determined from Known Land Supply minus land parcels below a size threshold with an electoral address.
- Publicly available spatial data, comprising 27 input spatial data layers, were used as authoritative and independent data, to avoid issues including lack of access to data or inconsistent data.

- Four timesteps were evaluated: 2002, 2008, 2012, and 2019.
- A workflow was developed to produce a data layer for each level of analysis. The ArcGIS modelling platform was used, and associated Python code was developed.
- An in-depth quality assurance process was conducted to check consistency of the analysis methods, GIS models and code. This quality assurance was at three levels: i) input data layers for each timestep; ii) comparison of the consistency in the method; (iii) and comparison of GIS models / code in previous work (Rutledge et al. 2015; Price 2015; Jones et al. 2018) with the method and models used in this project.

**Results**

- The key outputs of the project are the indicator data layers and the full documentation of the method, to ensure repeatability, accuracy, and consistency for the indicators.
- The Maximum Land Supply (Level 1) has increased by c. 25,000 ha since 2002, however the Known Land Supply (Level 2) has decreased by c. 1.239M ha over this period, primarily reflecting expansion in the protected natural areas.
- The Likely Land Supply (Level 3) analysis shows a further decrease of c. 50,000 ha in the area potentially available for primary production since 2002, reflecting an increase in the area of 'diffuse' residential land occurring outside of urban areas.

**Conclusions**

- The method can deliver a robust, repeatable analysis of temporal changes in Land Fragmentation using open-source publicly available datasets.
- Over four timesteps there is a consistent decrease in the area potentially available for primary production, reflecting the effect of expansion in the area of protected area estate, urban and diffuse residential land-use.
- Care needs to be taken in interpretation of some changes, due to data resolution limitations, including retrospective sourcing of the input datasets, uneven timesteps, and some potentially informative datasets not being publicly available.

**Recommendations**

- Planning to identify future timesteps is crucial to ensure input data layers are identified and archived, for example, the current approach by LINZ is for the publicly available LINZ Primary Parcel dataset to be regularly updated by overwriting the previous dataset.
- Land fragmentation analysis could be conducted at the local authority scale, providing increased resolution of 'hotspot' areas for land fragmentation.
- A forecasting component could be added by collating local authority planning zones for future urban and peri-urban development.
- An approach could be added to evaluate the potential changes in reverse sensitivity buffers created by increased land fragmentation.

# 1 Introduction

The Ministry for the Environment (MfE), Statistics New Zealand (Stats NZ), and regional authorities require development of robust methods and analytical processes to underpin regional and national environmental reporting indicators.

Both MFE and Stats NZ are required to report on the state of the environment under a 3-yearly cycle, using a pressure-state-impact framework, by the Environmental Reporting Act 2015. A report on the land domain must be published in April 2021. They have contracted Manaaki Whenua – Landcare Research (MWLR) to produce regional and national analyses and summary statistics for the land fragmentation indicator. Based on the pan-Regional Council consultation in Rutledge et al. (2015), we define land fragmentation as:

> *Any division of one or more aspects of a land resource that is available for primary production, such as through subdivision and residential development, including expansion of urban areas.*

The land fragmentation methodology in this report is designed to evaluate for all land types (Land Use Capability classes 1 to 7), although the Our Land 2021 report and indicator webpages will focus on the Highly Productive Land component (Land Use Capability classes 1 to 3), which is farmland highly suitable to support a range of agricultural, pastoral, arable and horticultural primary production activities. This report summarises the technical methods that underpin this analysis, and the baseline method for updating future timesteps to meet future report requirements.

## 1.1 Background

Internationally urban expansion is a cause of soil degradation, reduced availability of fertile agricultural land, reduced food production and food security for local cities, and reduced visual quality and greenspace of rural communities (Brabec & Smith 2002; Nixon & Newman 2016; Curran-Cournane et al. 2018). For example, in Melbourne's 'foodbowl', the land surrounding the urban fringe, local vegetable production could reduce from 82% of Greater Melbourne's needs to 21% by 2050 due to urban sprawl (Sheridan et al. 2015; Curran-Cournane et al. 2018). By the same time, Melbourne will require 60% more food to meet the growing population's needs (Sheridan et al. 2015).

In British Columbia, Canada, high quality agricultural land is scarce, with land preservation being an issue for many decades. For example, loss of food production on the scarce areas of prime land near Vancouver has been an ongoing issue (Nixon & Newman 2016). Recognising that development would occur on the best agricultural land, an agricultural land reserve was established in 1973 (Androkovich 2013). British Columbia's Agricultural Land Reserve is one of the earliest international examples of agricultural land preservation through land use regulation (Nixon & Newman 2016).

In Europe, land fragmentation is increasing across the 39 European Environment Agency countries, particularly affecting rural and sparsely populated areas, although there was a slow down between 2012 and 2015 (European Environment Agency 2019b). In 2015, there were approximately 1.5 fragmented landscape elements per $km^2$ in the European Union, which was a 3.7% increase compared with 2009 (European Environment Agency 2019a).

Arable lands, permanent croplands, pastures and farmland mosaics were most affected by strong fragmentation in 2015 in the European Union. Between 2009 and 2015, the area of strongly fragmented landscape increased most in Croatia, as well as in Greece, Hungary, and Poland (European Environment Agency 2019a). The indicator measures landscape fragmentation due to transport infrastructure and sealed areas. It has been developed using a measure of parts of the landscape interrupted by a 'fragmentation geometry', defined as the presence of impervious surfaces and traffic infrastructure, including medium sized roads (European Environment Agency 2019a), with further details available elsewhere (Jaeger et al. 2008).

Hart et al. (2013) reported that international research typically focuses on two types of land (or rural) fragmentation. The first focus is the changing of rural landscapes due to urban and residential development; the second focus is on the impact of land fragmentation on the number, size and spatial distribution of land parcels owned or managed by a single farmer for farm efficiency (Hart et al. 2013). Other research includes indicators of urban sprawl, including of the loss of prime farmland, and density of new urbanisation (Hasse & Lathrop 2003).

In New Zealand, urban expansion and encroachment onto rural land on the fringes of urban areas has been a long-standing concern (Coleman 1967; Cox 1968; Leamy 1970, 1974, 1975). More recent reviews of the issues, pressure and policy response have also been published (Rutledge et al. 2010; Mackay et al. 2011; Collins et al. 2014; Curran-Cournane et al. 2018).

Urban areas are often sited near ports and close to high quality soils, used for food production to feed the urban dwellers and for export/trade. As a result, urban and peri-urban development is often in conflict with agricultural use. Issues from development in urban areas and the surrounding areas of some large cities, such as Auckland, Hamilton, and Wellington, include the loss of versatile soils for food production including vegetables and horticulture (Rutledge et al. 2010; Andrew & Dymond 2013; Curran-Cournane et al. 2016; 2018).

Horticulture is typically more vulnerable to urban expansion than other sectors. For example, from 2002 to 2016, New Zealand's land area used for vegetables decreased 29 percent, from about 100,000 ha to about 70,000 ha (MPI & MfE 2019). In Auckland, most Land Use Capability Class 1 land is near Pukekohe, representing 86% of the Auckland region's Class 1 land (Curran-Cournane et al. 2014). Soil in this land class, along with the local climate, is valuable for vegetable production. Curran-Cournane et al. (2014) estimated that the Class 1 land that had been converted to developments or had lodged development applications, was 13% of the Auckland region's land use capability Class 1 land.

Curran-Cournane et al. (2018) argued the urgent need for a national policy statement to protect highly productive land, and to address the absence, for environmental reporting, of land indicators that pertain to versatile land. In the same year, the 'Our Land' national environmental report identified two main pressures facing highly productive land on the edge of towns and cities:

- expansion of urban areas with the accompanying loss of productive land

- change of land use on the fringes of urban areas, particularly the increase in lifestyle blocks

In response, on release of the Our Land 2018 report, the Minister for the Environment announced the instigation of work towards a proposed National Policy Statement on Highly Productive Land. This NPS has been through public consultation and is due to be put forward for Government consideration in 2021.

## 1.2 Previous work on development of a land fragmentation indicator

Development of 'land' environment indicators has been initiated through the Environmental Monitoring and Reporting (EMaR) initiative. EMaR is a partnership between Local Government New Zealand, Regional Councils, and MfE. The pan-regional council Land Monitoring Forum (LMF) is responsible for the EMaR 'Land' project, which aimed to achieve nationally consistent and integrated regional-level land and soil monitoring and reporting across New Zealand. The LMF represents professional and technical experts from all regional councils and unitary authorities throughout New Zealand in roles relating to land and soil science, research, monitoring, and input into policy development (Jones et al. 2018; Curran-Cournane et al. 2018). The EMaR land project has identified that their suite of land and soil environment indicators will include indicators that monitor and report on a) rural fragmentation, and b) urban expansion onto rural land (Curran-Cournane et al. 2018).

In 2013 the LMF and MWLR undertook an Envirolink Tools funded project to develop a set of national guidelines for consistent monitoring of land fragmentation, bringing together a collaboration on behalf of all 16 regional councils and unitary authorities. The aims were to develop national guidelines and methodologies for monitoring land fragmentation trends and an associated tool to assist councils with processing and analysing data to monitor and report on land fragmentation trends consistently. Two reports were produced:

1 Hart et al. (2013) reviewed the state of knowledge, issues, policies and monitoring of land fragmentation in New Zealand. They identified how several regional authorities operative or proposed regional policy statements (RPS), plans, and rules address land fragmentation. Monitoring of land fragmentation (if any) was summarised. They also identified that a range of definitions for land fragmentation were used, and that the relative importance between councils, varied widely. Twelve of 16 regional authorities had operative or proposed Regional Policy Statement objectives and policies to address land fragmentation. However, only three of them monitored and reported on land fragmentation.

2 Rutledge et al. (2015) established national guidelines for monitoring and reporting the effects of land fragmentation. These guidelines provided standard methods and example code of how to implement in ArcGIS. They also showed how these could be adapted to suit the requirements of each regional council system.

While the report of Rutledge et al. (2015) set out the rationale and method for establishing a land fragmentation indicator, it did not go as far as implementing a published national analysis. Since then, in 2018, Waikato Regional Council tested the implementation of this method as a pilot national analysis for EMaR, over four timesteps in the interval 2001–2017 (Jones et al. 2018). These results were presented at the 2018 New Zealand Soil Science Society conference, and as a short informal report to MfE. However, because this was a pilot project, the source data layers, methods, GIS code, output files, and any modifications to the Rutledge method were not formally published to the requirements needed for national environmental reporting. Following Rutledge et al. (2015), the current gaps in monitoring and reporting land fragmentation need to be addressed by developing and implementing nationally consistent methods to:

- ensure consistent characterisation of land fragmentation and its drivers at local, regional and national scales
- quantify the effects of land fragmentation on land and soil resources, and
- understand the implications for allocation of land resources and long-term productive opportunities, and thresholds for productive use options.

Implementation of national guidelines for monitoring land fragmentation will:

- provide consistent monitoring trends nationally, regionally, and locally
- support nationally consistent State of Environment monitoring and reporting
- inform policy decisions by helping identify where land fragmentation policies are effective and where they are not
- improve communication of the impacts of land fragmentation on primary production, particularly farmland.

This project implements and tests the usability of the Rutledge et al. (2015) guidelines nationally and regionally, documents issues and quality assurance, and refines the guidelines, where needed.

# 2 Purpose and objectives

The purpose of this technical report is to consolidate the previous work of Rutledge et al. (2015) and Jones et al. (2018) by formally detailing and publishing methods for national analysis of land fragmentation for the 2002 to 2019 time period, thus establishing consistent national environmental reporting requirements.

The objectives of the project were:

1 Assessment of land fragmentation

Quantify changes over time in the frequency distribution of different size parcel categories as an indicator of land fragmentation.

2 Assess the effect of land fragmentation on highly productive land (HPL)

Quantify the impact of land fragmentation on the areal availability of the highly productive land resource. This will be assessed as a potential decline in the highly productive land availability if a) the area of urban and diffuse residential land parcels on HPL increase over time, and/or b) the number of land parcels on HPL get progressively smaller over time.

# 3 Terms and definitions

Several terms are used in this report, with definitions presented in Table 1 below.

**Table 1 Terms, abbreviations and definitions used in the land fragmentation indicator analysis**

| Term | Definition | Source |
|---|---|---|
| **Land terms** | | |
| Land fragmentation | Any division of one or more aspects of a land resource that is available for primary production, such as through subdivision and residential development, including expansion of urban areas. | Rutledge et al. (2015) |
| Primary Production | Primary Production means:<br>(a) any aquaculture, agricultural, pastoral, horticultural, mining, quarrying or forestry activities; and<br>(b) includes initial processing, as an ancillary activity, of commodities that result from the listed activities in (a);<br>(c) includes any land and buildings used for the production of the commodities from (a) and used for the initial processing of the commodities in (b); but<br>(d) excludes further processing of those commodities into a different product<br>In this project the focus is on identifying land potentially available for agricultural, pastoral, horticultural, or forestry activities that underpin the wider primary production sector. Note that if analysis is targeted at assessing the Highly Productive Land resource, then the focus is on identifying land potentially available for Farmland use, defined below. | MfE (2019) |
| Farmland | Section 6 of the Overseas Investment Act 2005 defines farm land as land (other than residential (but not otherwise sensitive) land) that is used exclusively or principally for agricultural, horticultural or pastoral purposes, or for the keeping of bees, poultry or livestock.<br>Land used principally or exclusively for forestry or silvicultural purposes, or aquaculture is not farmland | LINZ (2020a) |
| Residential activity | The use of land and building(s) for peoples living accommodation | MfE (2019) |
| Dwelling | A dwelling means any building or structure, or part thereof, that is used (or intended to be used) for the purpose of human habitation. | StatsNZ (2020a) |
| Presence of a dwelling | Stats NZ defines a dwelling address consists of the distinguishing details of the physical location of a dwelling and can include street number, name, and type; suburb or rural locality; and city, town or district.<br>In this project electoral address points are used to indicate presence of a dwelling on a land parcel | StatsNZ (2020b)<br>Jones et al. (2018) |

| Term | Definition | Source |
|---|---|---|
| Urban land | In the majority of cases, an urban area is characterised by:<br>• high population density<br>• small land holdings (regularly less than 0.4 ha), and<br>• zoning that is compatible with high density commercial or residential activity<br>Refer also to section 4.4 this report | LINZ (2020b) |
| NZ Primary Parcels | LINZ cadastral dataset that is NZ's official system used to record and locate boundaries of land under various tenure systems. This layer provides the current primary (non-overlapping) parcel polygons and some associated descriptive data that details the appellation (legal description), parcel intent, and parcel size. | LINZ (2020d) |
| Land parcels potentially available for primary production | Defined as NZ primary land parcels with the following parcel intent designations: 'DCDB', 'Fee Simple Title', 'Māori', 'Licence/Permit', 'Legalisation', 'Lease', 'Lease 20 years or more' and 'Statutory' | Rutledge et al. (2015); Jones et al. (2018) |
| Land Use Capability (LUC) | Classifies land into eight classes according to those properties that determine its capacity for long-term sustained primary production taking and into account the physical limitations of the land | Lynn et al. (2009) |
| Highly productive land (HPL) | Land Use Capability (LUC) classes 1, 2 and 3<br>In this project, when analysis is targeted at assessing Highly Productive Land, the focus is on the potential restrictions for use as farmland, defined above. | MPI & MfE (2019) |
| Highly versatile Land (HVL) | LUC classes 1 and 2 as a subset within the primary HPL definition | Lynn et al. (2009)<br>Jones et al (2018) |
| Protected Areas Crown Property | The LINZ Protected Area GIS layer contains land and marine areas, most of which are administered by the Department of Conservation Te Papa Atawhai (DOC) and are protected by the Conservation, Reserves, National Parks, Marine Mammal and Marine Reserves Acts. All the areas have been identified spatially. The dataset includes reserves, but it is not a complete set. Privately owned reserves are excluded from the dataset as they are not crown land. Also, the dataset does not contain a complete list of reserves "vested" in Local Authorities or "controlled and managed" by other organisations | LINZ (2020c) |
| **Other terms** | | |
| Environmental Monitoring and Reporting (EMaR) | Environmental Monitoring and Reporting (EMaR) initiative: a partnership between Local Government New Zealand Regional Sector and the Ministry for the Environment to achieve more consistent environmental data collection | |
| GIS | Geographic Information System | |
| Land Monitoring Forum (LMF) | A cross-regional authority Special Interest Group dedicated to soil and land science and monitoring | |
| LINZ | Land Information New Zealand | |
| LCDB | The New Zealand Land Cover Database: a multi-temporal digital thematic map of land cover and land use | |
| MfE | New Zealand Ministry for the Environment | |

| Term | Definition | Source |
|---|---|---|
| MPI | New Zealand Ministry for Primary Industries | |
| MWLR | Manaaki Whenua – Landcare Research | |
| Stats NZ | Stats NZ administers the Statistics Act 1975 and leads the Official Statistics System. | |
| WRC | Waikato Regional Council | |

# 4 Methods

Our approach is largely based on the methodology developed by Rutledge et al. (2015), refined by Jones et al. (2018) and further developed in consultation with this project's advisory group, comprising members of MfE, Stats NZ, and regional authorities.

Rutledge et al. (2015) defined land fragmentation as:

> *Any division of one or more aspects of a land resource.*

They note this definition suggests a process whereby larger, contiguous areas become progressively smaller and likely more isolated from each other as a result of both natural and man-made disturbance events.

The main purpose of the guidelines developed in Rutledge et al. (2015) was to help regional councils assess current and future land supply for different types of primary production, considering both direct and indirect effects of land fragmentation. Direct effects included any changes to the potential land uses that result from changes to biophysical features, property rights or ownership at that location. Indirect effects included any changes to the potential land use at a location that result from changes to adjacent or neighbouring locations. Direct and indirect effects can occur independently or in tandem.

Guidelines were developed to monitor land fragmentation and report its effects on land supply for primary production based on the following four key principles:

1 Develop methods and indicators usable by all regional councils to support consistent, national monitoring and reporting
2 Keep indicators and reporting simple and increase complexity only as needs warrant
3 Avoid where possible the use of interchangeable terms, such as 'high class' or 'highly versatile' soils, that can have various definitions when referenced in regional policy statements, scientific literature etc.
4 Use only nationally consistent, publicly available, and authoritative underpinning data.

The purpose of the method published in Rutledge et al. (2015) was to provide standard methods that could be adapted to suit the requirements of each regional council system, whilst allowing for national consistency. The methods included procedures for a) compiling a centralised regional land fragmentation database, and b) generating indicators for reporting. The authors noted that these were an initial set of standard methods and basic indicators, and expected that the underpinning database, methods and indicators would be further enhanced and tailored to meet specific needs.

## 4.1 Indicator analysis approach

The national guidelines developed by Rutledge et al. (2015) provided methods and indicators to monitor land fragmentation and report its effects on land supply for primary production at four more progressively restrictive levels: Maximum Land Supply > Known Land Supply > Likely Land Supply > Restricted Land Supply (Figure 1, Table 2).

The first three levels estimate direct effects of land fragmentation, e.g. changes that reduce the total land supply by splitting, dividing, or reducing available land below thresholds useful for different types of primary production.

Restricted Land Supply (level 4) was not analysed in this report. Restricted Land Supply estimates indirect effects of land fragmentation by considering potential reverse sensitivity effects of one land use upon another.

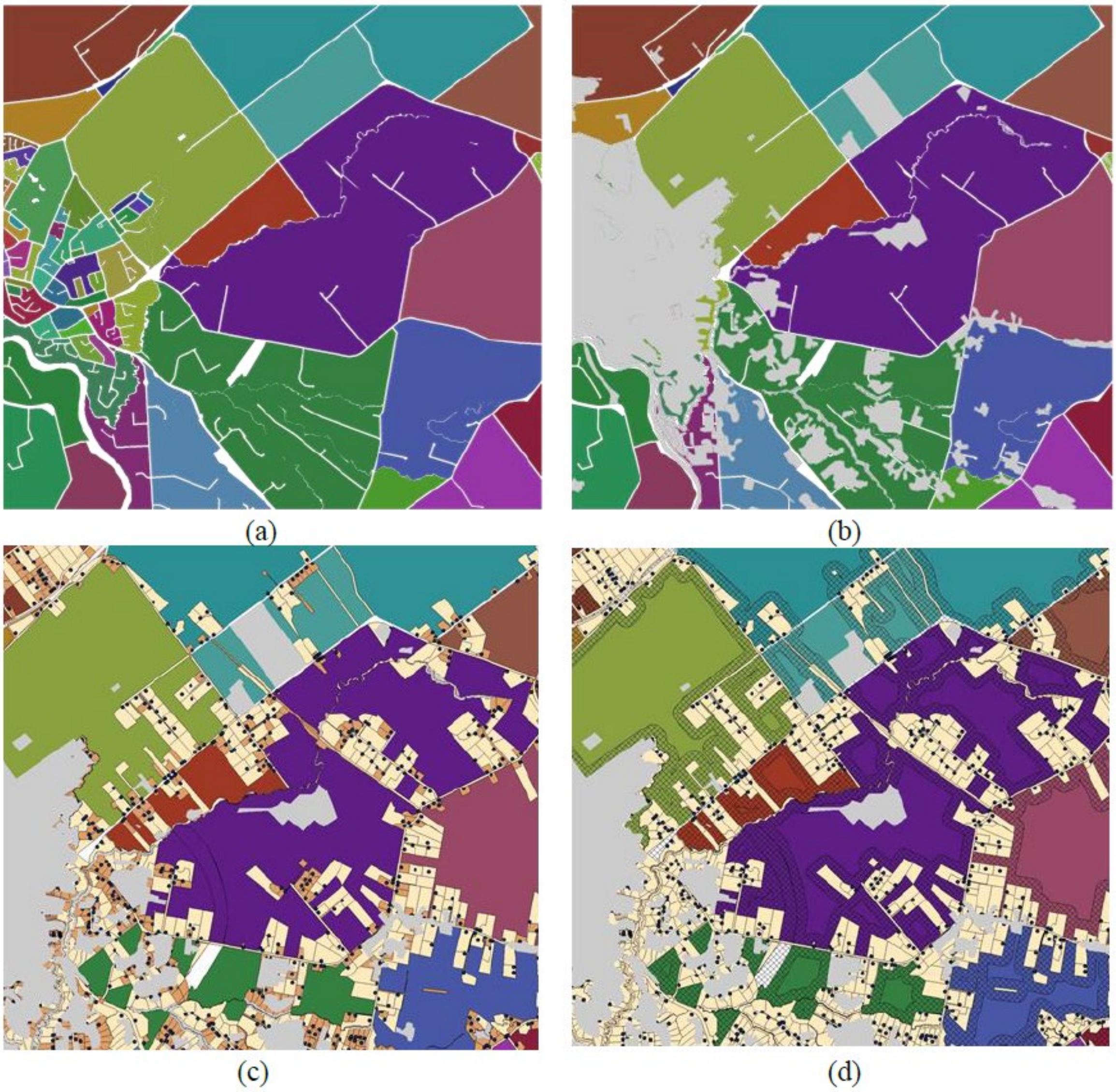


**Figure 1. From Rutledge et al. (2015). Example of land fragmentation southeast of Hamilton showing (a) Level 1: Maximum Land Supply, (b) level 2: Known Land Supply, (c) Level 3: Likely Land Supply and (d) Level 4: Restricted Land Supply. White areas represent water and transport networks, grey areas represent urban and protected areas, orange and beige represent parcels ≤ 1 hectare and ≤ 4 hectares in size, respectively, and crosshatched areas represent buffer areas ≤ 100 meters from parcels ≤ 4 hectares in size. This current report does not assess level 4 on Restricted Land Supply.**

**Table 2. Overall land fragmentation monitoring and reporting framework (adapted from Rutledge et al. 2015)**

| Method | Interpretation |
|---|---|
| | Level 1: Maximum Land Supply |
| National Area minus Selected Biophysical Networks | Estimate land supply using a mosaic created by dividing the national parcel coverage into areas of contiguous polygons after a combination of selected biophysical networks has been removed (e.g. transport, rivers & streams, etc.)<br>National mosaic polygons represent the largest contiguous land areas potentially available for primary production without considering any additional constraints, e.g. current land use/cover, property rights/subdivision, ownership<br>National mosaic polygons can be tracked over time by assigning unique IDs to assess broad trends in regional land fragmentation |
| | Level 2: Known Land Supply |
| Maximum Land Supply minus urban areas, land parcels with an associated land use restriction, and Protected Natural Areas | Estimate land supply from the Maximum Land Supply excluding known urban/built-up, protected areas and land parcels with an associated land use restriction.<br>Known Land Supply includes areas not currently under primary production but potentially available for conversion, e.g. unprotected indigenous forest, weeds, etc. |
| | Level 3: Likely Land Supply |
| Known Land Supply minus Parcels ≤ Size Threshold with an Electoral Address | Estimate land supply excluding likely areas of diffuse residential development (e.g. rural residential) from Known Land Supply using indirect evidence<br>Parcel size threshold can vary to reflect operational requirements of different types of primary production, e.g. availability of Highly Productive Farmland<br>Parcels of appropriate sizes without Electoral Address Points can also be used to assess future potential for land fragmentation, e.g. subdivided land still under primary production |

In summary, Maximum Land Supply (Level 1) represents the largest contiguous land areas potentially available for primary production. Polygon features including water (rivers, lakes, ponds) and transport networks (roads, railways) are removed. Known Land Supply (Level 2) is land supply from Level 1 but excluding known land parcels with an associated land use restriction, urban and built-up areas, and the protected natural areas. Likely Land Supply (Level 3) is land supply from Level 2 but excluding likely areas of diffuse residential development.

The method outlines a workflow to produce a dataset for each of three levels of analysis as described above. The dataset for each level is analysed for a set of three standard indicators.

The indicator analysis at the higher levels (1 and 2) are a standard output, but indicators at level 3 require definition of specified parcel size class thresholds (refer to section 4.4). Each of the levels of analysis can be analysed at both national, regional, or class level for three indicators:

- land supply (ha)
- number of parcels
- parcel size distribution.

### 4.1.1 Adaptions and new developments

Jones et al. (2018) adapted the method of Rutledge et al. (2015), as part of the Environmental Monitoring and Reporting (EMaR) pilot project. Their modifications included:

- Analysis was limited to Levels 1, 2 and 3, with a new parcel size class classification developed for Level 3 (refer to section 4.4)
- Only the land supply (ha) indicator was used for analysis at each region and class level
- At Level 3 analysis the outputs were also analysed in terms of the LUC classification for each parcel size class (refer to section 4.4)
- A lower parcel size threshold for the definition of land potentially available for primary production was defined to exclude land most likely to be used for diffuse residential (i.e. 2 ha or less with a dwelling)
- The following parcel intents were also included in addition to 'DCDB', 'Fee Simple Title' and 'Maori', for the definition of land available for production to avoid their exclusion: 'Licence/permit', 'Legalisation', 'Lease', 'Lease 20 years or more' and 'Statutory'
- The partitioning of the land area available for primary production in level 3 analysis into meaningful parcel size classes for the examination of rural land fragmentation (refer to section 4.4)
- The most recent Land Cover Database data (i.e. LCDB 4.1 from 2012) was applied to the 2017 timestep due to the lack of more recent land cover data
- The Protected Areas Network (PAN-NZ) database was not used because it is not publicly available or regularly updated and was replaced by the DoC Public Conservation Areas (Layer ID 754, 2017/18 year). This is less comprehensive but meets the publicly available dataset principle
- The DoC conservation areas data layer was applied to all time steps due to the unavailability of historic timesteps (and were assumed not to have changed significantly in the urban fringe area)
- The Manifold GIS modelling platform was used.

In our latest 2019 analysis, we made the following additional adaptations:

- The modelling platform used was ESRI ArcGIS and associated Python code, based on the unpublished modelling analysis (Price 2015) that was developed behind the Rutledge et al. (2015) report.
- We replaced the 2017 timestep that was used in Jones et al. (2018) with a 2019 timestep, to keep consistency with the LCDB timesteps (refer to section 4.1.3).
- We conducted an in-depth quality assurance process, to check for consistency of the analysis methods, GIS models and code described in Rutledge et al. (2015), with the GIS models and code of Price (2015) and with Jones et al. (2018). This is all fully documented in the Appendices.
- The Chatham Islands were not included, due to lack of available data associated with some of the input layers.

- LUC class 8 land was excluded from assessing land available for primary production as, by definition in Lynn et al. (2009), LUC class 8 land does not meet the definition of suitable for primary production (Table 1).
- Land parcel classification for diffuse residential parcels size classification were adjusted from previous research. The urban diffuse residential class boundary was adjusted from ≤0.5 ha in Jones et al. (2018) to ≤0.4 ha to align with the definition of urban land in Table 1.
- The LINZ Protected Areas layer and QEII National Trust layer were used instead of the DoC Public Conservation Areas layer.

A key principle of the land fragmentation indicator was use of public datasets. Benefits of public data include uniform, authoritative and independent data, and avoiding issues including lack of access to data, inconsistent data, or restricted use of data (Rutledge et al. 2015). A summary of the data layers used in the analysis are presented in Table 3. Further details for each timestep are presented in the next section and appendices.

**Table 3. Summary of data input layers in the analysis**

| Spatial Data Layer | Source | Update Frequency |
|---|---|---|
| NZ Primary Parcels | LINZ | ~Monthly |
| Topo50 NZ River Polygons | LINZ | At least annually |
| Topo50 NZ Lake Polygons | LINZ | At least annually |
| Topo50 NZ Pond Polygons | LINZ | At least annually |
| Topo50 NZ Canal Polygons | LINZ | At least annually |
| Topo50 NZ Reservoir Polygons | LINZ | At least annually |
| Topo50 NZ Lagoon Polygons | LINZ | At least annually |
| Land Cover Database v5.0, Mainland New Zealand | MWLR | 4–6 years (funding dependent) |
| Regional Council Boundary Annual Pattern High Resolution Clipped 2020 | StatsNZ | Annual |
| NZLRI Land Use Capability | MWLR | Static (last updated on LRIS in 2010) |
| Topo50 NZ Airport Polygons | LINZ | At least annually |
| Topo50 NZ Building Polygons | LINZ | At least annually |
| Topo50 NZ Cemetery Polygons | LINZ | At least annually |
| Topo50 NZ Golf Course Polygons | LINZ | At least annually |
| Topo50 NZ Gravel Pit Polygons | LINZ | At least annually |
| Topo50 NZ Landfill Polygons | LINZ | At least annually |
| Topo50 NZ Mine Polygons | LINZ | At least annually |
| Topo50 NZ Quarry Polygons | LINZ | At least annually |
| Topo50 NZ Showground Polygons | LINZ | At least annually |
| Topo50 NZ Sportsfield Polygons | LINZ | At least annually |
| Topo50 NZ Racetrack Polygons | LINZ | At least annually |
| Topo50 NZ Rifle Range Polygons | LINZ | At least annually |
| Protected Areas | LINZ | At least annually |

| Spatial Data Layer | Source | Update Frequency |
|---|---|---|
| QEII Natural Trust areas | QEII | ~Quarterly |
| Topo50 NZ Pumice Pit Polygons | LINZ | At least annually |
| Topo50 NZ Residential Area Polygons | LINZ | At least annually |
| NZ Street Address (Electoral) and NZ Street Address | LINZ | ~Monthly |

### 4.1.2 Time steps

The land fragmentation was analysed at four timesteps, based on the date of the NZ Primary Parcel layer (Table 4). Details for each individual input layer, at each level of analysis and for each timestep, are provided in the Appendices.

**Table 4. Analysis timesteps in relation to source date of parcel layer and LCDB version**

| Indicator timestep | LINZ primary parcel layer date | LCDB version | LCDB analysis period relevant to applied LCDB field | LCDB field applied |
|---|---|---|---|---|
| 2002 | May 2002 | LCDBv5.0 | Summer 2001/02 | Name_2001 |
| 2008 | August 2008 | LCDBv5.0 | Summer 2008/09 | Name_2008 |
| 2012 | August 2012 | LCDBv5.0 | Summer 2012/13 | Name_2012 |
| 2019 | March 2019 | LCDBv5.0 | Summer 2018/19 | Name_2018 |

### 4.1.3 Analysis assumptions and potential limitations

Potential limitations:

- We assume that primary production is not undertaken on land parcels 2 ha or less in size with a dwelling (i.e. 'diffuse residential' land). Refer to section 4.4.
- Changes made by LINZ to parcel intent definitions in 2007 and 2012 has complicated time-step comparisons. Correlations of parcel intent between timesteps have been made following the guidance provided by LINZ (2020f).
- All data layers have a nominal mapping accuracy. The LINZ Primary Parcel layer has a nominal accuracy of 0.1-1m in urban areas and 1-100m in rural areas (LINZ 2020d). The LCDB data set is designed to complement in theme, scale and accuracy, New Zealand's 1:50,000 scale topographic database (i.e. the Topo50 map series used in this project). LCDB v5.0 has a nominal 1 ha minimum mapping unit, with base imagery and elevation data varying between 5 to 15 m resolution (LRIS 2020).
- LINZ notes that its linkages between land titles and cadastral survey registries were previously separately managed, and then were bought together in the Landonline system in 2001. LINZ notes that this left data inconsistency and gaps, which it has worked to improve over time. LINZ currently believes more than 97% of titles are correctly linked to some form of parcel; however there is a small chance of an error with some parcels (LINZ 2020e).

- The Protected Areas Network (PAN-NZ) database is possibly a more comprehensive spatial coverage of conservation land, than the LINZ Protected Areas, but was not used because it is not publicly available and has not been updated since 2014.
- The current LINZ Protected Areas and QEII National Trust data were combined and applied to all time steps (herein termed 'protected area layer'). The process used to backdate these protected areas to their presence or absence at the different timesteps of this study is described in Appendix 2.
- We note that some parcels with a restricted intent may at times be used for low intensity grazing, such some 'hydro' or protected areas parcels. However, without a detailed, publicly available and regularly updated national landuse layer it is currently not possible to distinguish these parcels. We also recognise the parcel intent is not for primary production, so any grazing use is likely to be temporary.
- Rutledge et al. (2015) note that the use of public data has benefits and limitations. Benefits include reliance on uniform, authoritative and independent (i.e. non-council) data; avoidance of data access issues; and varying frequencies of data updates to support monitoring of both longer-term and shorter-term trends. Limitations include any inherent limitations in the primary data used as well as the need to use inference in some cases. Despite these limitations, reliance on public data avoids common issues associated with proprietary data including lack of access to data, inconsistent data, or restricted use of data.
- LINZ do not keep previous versions of the key primary land parcel layers in the publicly available service; instead each new update to the parcel layer replaces the previous date. However, these have been downloaded annually and kept by a private company (Ollivier and Co). This company has provided our project with the original primary land parcel and Topo50 files downloaded from LINZ. The parcel layers are not available prior to 2002, as this is the first date that Ollivier and Co started archiving land parcel layers from the LINZ Landonline system, which was established in 2001. Any differences in the LINZ land parcel layers for each of our timesteps are noted in the quality assurance record (refer to Appendices for details). In addition, a change in the way LINZ supplied the Topo50 data layers meant that the 2012 Topo50 data layers were not available from Ollivier and Co, instead the 2012 Topo50 data layers were sourced from Waikato Regional Council.
- When analysing the effect of urban land use on highly productive land (HPL) it is important to note that the original LUC mapping did not map the existing urban area at that time, instead spatially denoting this as 'Town'. Therefore, it is only possible to quantify the effect on HPL of urban expansion beyond the original LUC 'Town' mapped area. We created a subcategory 'New Urban' within the mapped urban land area that can be used to report on change in urban areas that have developed on HPL land since the original LUC mapping. This is suitable for this project, where we are focussed on the degree of change in urban areas since 2002.

## 4.2 Level 1 analysis

Level 1 estimates the Maximum Land Supply using a mosaic created by dividing all combined input datasets into areas of contiguous polygons after a combination of selected biophysical networks have been removed (e.g. transport infrastructure, rivers and streams, etc). The national mosaic polygons represent the largest contiguous land areas potentially available for primary production without considering any additional constraints, e.g. current land use/cover, property rights/subdivision, ownership.

The Regional Council Boundary and NZLRI Land Use Capability datasets were combined with the NZ Primary Parcels to be used for reporting indicators but are not used as exclusion features at any stage. The Regional Council Boundaries are used as the authoritative extent of New Zealand land coverage.

A summary of the Level 1 methodology and techniques for our method for each of the 2019, 2012, 2008 and 2002 timesteps are presented below. Detailed tables including input data layers, and comparison with Rutledge et al. (2015), are presented in the Appendices.

Key method points are:

- The technique begins with the curation of input datasets, making copies of original datasets, performing dissolves on relevant fields of most input datasets, creating identification fields to indicate the presence of features or other attributes, and populating these fields with indicators.
- All input datasets listed in Table 3 are then combined. This combined dataset is then dissolved on the relevant fields for analyses, a repair geometry is performed, urban and residential land is flagged, feature areas are calculated in hectares and a join table for regional identification of whole parcels is created.
- A spatial dataset containing estimated available land is then output for Level 1. This involves the removal of water and transport related polygon features from the combined dataset. LCDB features containing the attributes 'Transport Infrastructure', 'river', 'lake or pond' are removed from the field related to the relevant time step, along with 'hydro', 'road', "railway', 'streambed', and 'riverbed' polygons from the LINZ NZ Primary Parcels. Separate LINZ topographic datasets for 'lakes', 'ponds', 'canals', 'lagoons', 'reservoirs' and 'rivers' are also removed in their entirety.
- All remaining land at Level 1 is summed by parcel ID. The remaining unique parcel IDs associated with all available land at Level 1 are then joined back to the original combined dataset, using an inner join. The resulting dataset contains all whole parcels associated with the available land at Level 1, for further spatial analyses.

## 4.3 Level 2 analysis

Level 2 estimates the Known Land Supply by the removal of all known urban/built-up land, land parcels with an associated land use restriction and protected area land from the Level 1 output. Known Land Supply will include areas not currently under primary production but potentially available for conversion, e.g. unprotected indigenous forest, weeds, etc.

A summary of the Level 2 methodology and techniques for our method for each of the 2019, 2012, 2008, and 2002 timesteps are presented below. Detailed tables including input data layers, and comparison with Rutledge et al. (2015), are presented in the Appendices.

Key method points are:

- Level 2 involves the removal of all industrial/urban/built-up features, protected area land which is legally protected and land parcels likely restricted by an associated land use from the Level 1 national mosaic of land parcels.
- Urban area features removed to produce this dataset include LCDB features containing the attributes 'built-up area (settlement)' and 'urban parkland/open space', as well as LINZ Topo50 data layer features of ‘residential area’, ‘building’, ‘airport’, ‘cemetery’, ‘golf course’, ‘rifle range’, ‘racetrack’, ‘showgrounds’ and ‘sportsfield’.
- The entirety of the protected area layer is also removed. The protected area layer was created from two publicly available datasets, the LINZ Protected Areas dataset and the QEII National Trust digital boundaries. Details of how this layer was prepared is described in Appendix 2.
- Remaining land parcels likely restricted by an associated land use that are also removed include:  LINZ Topo50 features ‘gravel pit’, ‘landfill’, ‘mine’, ‘pumice pit’, ‘quarry’ and LCDB features containing the attributes 'surface mine or dump';
- All parcels are removed that do not have a LINZ Primary Parcel intent of either 'DCDB', 'fee simple title', 'maori', 'statutory', 'legalisation', 'lease', 'lease 20 years or more', 'licence/permit'
- A spatial dataset containing estimated available land is then output for Level 2. All remaining land at Level 2 is summed by parcel ID. The remaining unique parcel IDs associated with all available land at Level 2 are then joined back to the original combined dataset, using an inner join. The resulting dataset contains all whole parcels associated with the available land at Level 2, for further spatial analyses.

## 4.4 Level 3 analysis

Level 3 estimates the Likely Land Supply potentially available for primary production by excluding likely areas of diffuse residential development (e.g. rural residential) from the Level two output.

A summary of the Level 3 methodology and techniques for our method for each of the 2019, 2012, 2008 and 2002 timesteps are presented below. Detailed tables including input data layers, and comparison with Rutledge et al. (2015), are presented in the Appendices.

Key method points are:

- A spatial dataset containing estimated available land is output for Level 3 through the removal from the Level 2 output, all areas of diffuse residential development, identified as land parcels that have one or more electoral address points and are ≤2 ha in area. Electoral address points are used to indicate the presence of a residential dwelling (Table 1). Level 3 analysis leaves only land considered to be potentially available for primary production.
- All remaining land at Level 3 is summed by parcel ID. The remaining unique parcel IDs associated with all available land at Level 3 are then joined back to the original combined dataset, using an inner join. The resulting dataset contains all whole parcels associated with the available land at Level 3, for further spatial analyses.

- An important step in processing of Level 3 outputs is to ensure parcel selection is based on original whole parcel features. Parcel groupings are based on Level 2 output whole parcel sums, calculated before the combining of parcels with LUC and Regional Council Boundary datasets and sub-parcel exclusion features.
- A change in the analysis model from Rutledge et al. (2015) was including urban and diffuse residential statistic data to all output datasets. Positive urban identification was based on the urban features defined in the level 2 analysis. Diffuse residential are reported as parcels outside of the urban defined area that had legal parcel sizes ≤2 ha with one or more electoral address points (refer to section 4.4.1).

### 4.4.1 Level 3 land-parcel-size classification

There is no 'off-the-shelf' land-parcel-size classification. This project adopted the classification developed in previous research by EMaR (Jones et al. 2018), based on discussions with the technical advisory group, current reporting requirements, and Rutledge et al. (2015). Land parcel sizes are presented in Table 5. Parcel size classes partitioning residential land area based on the EMaR Land working definition (Jones et al. 2018), are presented in Table 6.

**Table 5. Land parcel classification and sizes for primary production**

| Broad parcel size classes | Detailed parcel size classes |
|---|---|
| Very small | A. 0.0 to ≤2.0 ha |
| Small | B. >2.0 to ≤4.0 ha |
| | C. >4.0 to ≤8.0 ha |
| Medium | D. >8.0 to ≤20.0 ha |
| | E. >20.0 to ≤40.0 ha |
| Large | F. >40.0 to ≤100 ha |
| | G. >100 ha |

The parcel size class boundaries in Table 5 were informed by information from different sources:

- A histogram analysis of land parcel frequency distribution (Appendix 5). This had frequency 'peaks' aligning with the class boundaries in Table 5.
- Class boundaries in Table 5 approximately align to historical parcel areas based on the area in units of acres (1 ha = 2.47 acres). For example, 2 ha is slightly smaller than 5 acres; 4 ha, 10 acres; 8 ha, 20 acres; and 40 ha is slightly smaller than 100 acres.
- The classes broadly correlate to groupings of different land-use recorded in the Agribase® dataset (AsureQuality 2020). The 'broad acre' farm types tended to be classed in the medium to large categories of Table 5. At the individual parcel level 80% of dairy farmland parcels were greater than 8 ha; c. 70% of sheep and beef; c. 75% of arable and c. 60% of forestry. At the aggregated farm level the association was stronger for dairy (c. 99% >8 ha), arable and forestry (c. 80% of farms).

- In contrast, rural lifestyle and horticulture land-use tended to be predominantly in the small parcel size class. For example, c. 90% of land parcels identified as lifestyle in Agribase® 2020 were ≤8 ha; 51% of vegetable farm parcels; 65% of farms classed as fruit; and 80% of flower farms. The distribution was similar at the aggregated farm level. Viticulture shows a different distribution, with greater than 65% of land parcels being >8 ha (c. 70% at the farm level).
- Analysis of Agribase® 2020 shows a similar pattern to that found by Rutledge et al. (2015), when analysing Agribase® 2014 data.

The very small parcel size class (i.e. ≤2.0 ha) in Table 5 was further classified for those parcels identified as having an electoral address point, with these parcels classed as 'diffuse residential land' in Table 6. Note that this 'diffuse residential' data comes from those parcels excluded when going from level two to three output (as explained in section 4.4).

**Table 6. Parcel size classes partitioning diffuse residential land area**

| Broad parcel size classes | Detailed parcel size classes |
|---|---|
| Urban residential | X1. 0.0 to ≤0.2 ha (with a dwelling) |
| | X2. >0.2 to ≤0.4 ha (with a dwelling) |
| Rural residential | X3. >0.4 to ≤1.0 ha (with a dwelling) |
| | X4. >1.0 to ≤2.0 ha (with a dwelling) |
| Non-residential | X5. All land >2.0 ha (with or without a dwelling) |

The Table 6 classification is based on the following rationale:

- The 0.4 ha boundary is used to identify 'diffuse urban' land, consistent with a 'peak' in the total land parcel frequency distribution, reflecting the 'traditional' 1 acre land parcel size. This parcel size boundary is also used elsewhere in Government, being used as a defining criterion for urban land in the Overseas Investment Act (LINZ 2020b).
- The Stats NZ Urban / Rural classification identifies a similar parcel size for identifying urban land, described as usually having a population density of >200 address points per square kilometre (i.e. 1 address / 0.5 ha). Rural settlements are described as usually having a population density of >100 address points per square kilometre.
- The upper boundary of 2 ha for diffuse residential was a noticeable 'peak' in the histogram analysis (Appendix 5) of land parcel frequency distribution identified as lifestyle in Agribase® 2020, probably reflecting a historical land parcel class of 5 acres.
- Parcels of this size range are commonly identified as 'rural residential' in the planning zones of a number of local authorities (MfE 2017), for example, Auckland Council 'Rural countryside living zone', and the rural residential zones of Tasman, Waimakariri, Hastings, Queenstown and Dunedin councils. We note though that minimum parcel size for rural residential / rural lifestyle zoning is variable between local authorities across New Zealand. Reflecting this, the National Planning Standards (MfE 2019) identifies a 'rural lifestyle' zone but leaves parcel size rules for individual councils.

- Analysis of Agribase® 2020 indicates that for parcels ≤2 ha, lifestyle is the predominant land use, with c. 45% of land parcels below this threshold. Primary production land uses are associated with parcels ≤2 ha, at between 8% (arable, viticulture) to 30% (Flowers) of a particular land-use. However, when aggregated at the reported farm level, this drops to <1% of dairy, arable, sheep and beef, and forestry farms; 3% of viticulture farms; 12% of vegetable and fruit farms, and c. 26% of flower farms. In terms of land area, lifestyle is the predominant land area with c. 31,000 ha on parcels ≤2 ha in size, compared to 112 ha of vegetable farms; 593 ha of fruit farms; and 121 ha of land classed as flower farm land use.

### 4.4.2 Highly productive land classification

The land fragmentation methodology in this report is designed to evaluate for all land types (Land Use Capability classes 1 to 7), although the Our Land 2021 report and indicator webpages will focus on the HPL component, which is farmland highly suitable to support a range of agricultural, pastoral, arable and horticultural primary production activities (Table 1).

The New Zealand Land Resource Inventory (NZLRI) was produced and mapped across New Zealand from 1975 into the 1980s. Based on the NZLRI, land was then classified using the Land Use Capability (LUC) system. Under the LUC, land is categorised into eight classes according to its long-term capability to sustain one or more productive uses. Land that is classified as Class 1 under the LUC system is the most versatile and has the fewest limitations for use, while Class 8 is the least versatile with the highest limitations for use (Lynn et al. 2009). The baseline distribution of different LUC areas for New Zealand are summarised in Table 7.

**Table 7. Baseline LUC areas for New Zealand within the combined datasets, prior to the fragmentation analysis outlined in this report. Percentages do not round to 100% as land unsuitable for primary production (LUC class 8) and other New Zealand Land Resource Inventory classes such as water features and mines are excluded.**

| | Land use capability class (hectares) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | town |
| New Zealand | 187,114 (0.7%) | 1,201,446 (4.5%) | 2,441,866 (9.2%) | 2,775,064 (10.5%) | 209,854 (0.8%) | 7,467,891 (28.2%) | 5,680,561 (21.4%) | 145,727 (0.5%) |

Highly Productive Land (HPL) is land classified as having Land Use Capability (LUC) classes 1, 2 and 3. This definition is based on the interim default criteria for identifying HPL in the proposed NPS HPL (MPI & MfE 2019).

Previous publications have used different terms and methods for classification of HPL. Regional council policies have also varied in the methods used. We note that the previous Our Land 2018 report was based on the analyses of Dymond and Andrew (2013), which used a different approach to both mapping of urban land, lifestyle blocks and classification of HPL. That approach preceded the EMaR work to develop a pan-regional council method to monitor land fragmentation, as published in Rutledge et al. (2015).

They also did not use LUC to identify HPL, instead using a 'high class soils' layer developed using the method of Webb et al. (1995).

The proposed NPS HPL will establish a baseline national standard approach. For this reason, we have adopted the LUC classes 1–3 for our analysis on the effects of fragmentation on HPL. As a subset of HPL, we have also included analysis of the effects on just LUC 1 and 2 land, which is termed highly versatile land (Table 1). LUC 1 and 2 land is widely recognised as the land with the least capability limitations for horticultural and arable land use. This highly versatile land is also scarcer, being estimated at 5.2% of NZ compared with 14.4% for LUC 1–3 land (Table 7). Several councils also specifically identify LUC 1 and 2 for protection in existing district and regional plans. Further details from regional authorities' regional policy statements are available in Hart et al. (2013).

### 4.4.3 Mapping of highly productive land

At the initial level 1 analysis step, NZLRI Land Use Capability (LUC) and Regional Council Boundary datasets were combined with the NZ Primary Parcels. The LUC and Regional Council boundaries were not used as exclusion features at any stage, but could be used as attributes for reporting indicators. This meant that at any of the three levels of analysis described above, the effects of fragmentation could be reported in terms of both LUC class, as well as by region. Key method points to be aware of include:

- When analysing the effect of urban land use on highly productive land (HPL) it is important to note that the original NZLRI mapping did not map the existing urban area, instead spatially denoting this as 'Town'. Therefore, it is only possible to quantify the effect on HPL of urban expansion beyond the original LUC 'Town' mapped area. We created a subcategory 'New Urban' within the mapped urban land area that can be used to report on change in urban areas that have developed on HPL land since the original LUC 'Town' area was mapped. This is suitable for this project, where we are focussed on the degree of change in urban areas since 2002.

- Regional boundaries are defined strictly as the jurisdictional boundary of each region. In some cases, a unique parcel ID may exist across multiple regional boundaries. This may result in either: 1) Land area figures for some cross-boundary parcels only reflecting the land area occurring in the region of interest; or 2) A cross-boundary land parcel that may have had its area within the region of interest excluded as unavailable for use as farmland, for example a protected natural area. This case would result in the land parcel ID being excluded from the region of interest, and therefore not being included in the parcel count for that region.

  Provision for in depth regional analysis has been made available for potential future analysis, where, if required, regional boundaries may be defined by including the entirety of all parcels intersecting with a jurisdictional regional boundary of interest.

- No percentage threshold regarding the minimum area of HPL inside a parcel has been set, for both mapping abundance of HPL according to parcel size classes, and for unique parcel count figures that contain HPL. This allows for the total hectares of LUC values to be presented wholly and accurately alongside counts of all participating parcels. Scenarios where large quantities of LUC land are potentially excluded can also be avoided, for example, if a minimum HPL threshold of say 25% of the parcel area was used, this would be 0.5 ha in a 2 ha parcel, but 25ha in the >100 ha class.

Provision has been made in the modelling whereby it is possible for future analysis to study the effect of fragmentation on contiguous HPL areas. In this approach the focus is on reporting the size of individual HPL polygons, or a grouping of contiguous HPL, and analysing the number and size of parcels which intersect with the HPL polygon.

## 4.5 Quality assurance

The quality assurance process involved three major steps:

a Comparison of the consistency between the previous GIS models and code (Price 2015; Jones et al. 2018) with the original concepts and code published in Rutledge et al. (2015). Refer to section 4.5.1

b Curating of input data layers. Specific notes on curation of individual data layers for each timestep are contained in the Appendices.

c Quality assurance on output data layers and tables. Refer to section 4.5.2

### 4.5.1 Summary of the techniques for 2012 QA comparison

For quality assurance, the 2012 timestep at Level 3 was used for the evaluation because initially more metadata (from the Jones et al. 2018 EMaR analysis) were available for comparison purposes. Full details of the QA analysis are presented in Appendix 2.

The following is a summary of the QA findings and considerations when comparing this projects MWLR Level 3 output dataset produced for the 2012 timestep, with the 2012 Level 3 output provided by Jones et al. (2018):

- *Regional boundaries and parcel data:*. In the NZ Primary Parcels dataset, there are instances where land parcels separated by regional boundaries are multi-part, in order to keep all parcel IDs unique and their whole areas intact in a single record. A comparison of the MWLR and Jones et al. (2018) produced datasets reveals that after combining all input datasets, both datasets have been treated the same, where polygon features are now single-part. This necessitated that a method be developed where whole parcels are treated as though they are intact for in-depth regional level analyses.
- *Area sums based on whole parcels:* When combining all input datasets, the split of whole parcels into multiple single-part features will require any analyses performed to take repeating attributes and unique parcel IDs into account. This may also require a reference to original sums of whole parcels to answer areal research questions or a method of obtaining original sums via code. It appears both datasets have these whole parcel area references.

- *Address point flags for whole parcels:* In order to avoid cases of parcels being incorrectly identified as not containing one or more address points, the NZ Primary Parcels must not be altered from their original multi-part state before being flagged as containing one or more address points (i.e. the presence or absence of one address flag needs to be associated with one unique parcel ID). This appears to be the case for both datasets compared.
- *Differences in parcel selection for Level 3 exclusion*: The initial MWLR analysis excluded parcels based on whole parcel sizes minus the parts of whole parcels already taken out via previous exclusion processes. In contrast, the Jones et al. (2018) analysis excluded parcels based on original whole parcel sizes, pre-Level one and two exclusion. This process has since been revised to adopt the Jones et al. (2018) approach to Level 3 parcel exclusion.
- *Features containing no parcel data*: The MWLR analysis revealed 19 features with a parcel ID of '0'. On inspection, all these features appear to be gaps in the original parcel data supply. In contrast, the Jones et al. (2018) analysis had zero features – identical polygons appear to have been erased from the dataset. For future analyses it was determined that gaps in parcel data may be summed and counted as areas of 'unknown parcel intent'.
- *Pumice Pit Polygons*: On comparison of both datasets it was discovered that Pumice Pit Polygons were not included as input features in the initial MWLR analysis; these are now included in the present analysis.
- *Water features*: By removing representations of Lakes and Rivers using both LCDB and LINZ topographic data it is possible that the same feature has been removed twice. In the case of lakes and ponds checking showed that combining these features from both data sources did give the best overall representation of the occurrence of individual features in the landscape. There was found to be differences in the minimum and average size of features between the two types of datasets, suggesting different features have been captured between them. The minimum size of LCDB lakes/ponds was 0.05ha, with the average size being 31.44ha. The minimum size of Topo50 ponds was 0.01ha, with the average size being 0.82ha and the minimum size of Topo50 lakes was 0.0002ha, with the average size being 6.72ha. It was also determined that 74% of all lake or pond features were Topo50 lake or pond features that did not intersect with LCDB lake or pond features and these only took up 10% of the total area of lakes and ponds in the combined dataset. Furthermore, 87% of the total area of lakes or ponds included areas occupied by both LCDB and Topo50 features. This however, translated to only 12% of all lake or pond features between the two data sources coinciding.

  In the case of rivers, 31% of the total area of rivers included areas occupied by both LCDB and Topo50 features. This translated to 27% of all river features between the two data sources coinciding. On closer inspection of differences between the two layers it was determined that braided rivers likely accounted for much of this difference and that much of these areas mapped by both data sources would not be land available for primary production.
- *Features with null regional code identities*: Both approaches had zero features.
- *Total feature numbers*: The MWLR analysis has a difference in the total number of features (1,184,671 less features). This was determined to be most likely due to the

entirety of the LCDB dataset having been included in the Jones et al. (2018) dataset. In contrast, only the LCDB features necessary for use as exclusion features were included in the MWLR dataset.

- *Area sum analysis*: Both feature classes inside the same gdb (ArcGIS origin) with an original projected coordinate system NZGD 2000 New Zealand Transverse Mercator produced the same areal figure, when querying a feature originating in the same dataset using ArcGIS auto-generated square metre area sums.
- *National sums*: The Jones et al. (2018) dataset had higher areal sums for most regions. This was expected, due to the difference in the exclusion process producing the Level 3 output. Differences might also be expected due to a difference in the regional boundary being used (Jones et al. (2018) used the 2017 Regional Council boundary, where the MWLR dataset contained the 2020 boundary).
- Differences in minimum, maximum, and mean of areal sums are also to be expected as the entire LCDB dataset has not been included in the MWLR analysis but is included in the Jones et al. (2018) analysis.
- The MWLR dataset has an extra 788 ha at the national level, compared to the Jones et al. (2018) output. As expected, the Jones et al. (2018) dataset had higher area sums for most regions. However, the MWLR dataset had a higher sum of 3,723 ha in the Canterbury region. This was identified as mostly due to parcel overlaps. QA has since reduced this to 660 ha. Parcel overlaps have been revisited and addressed since this analysis.

### 4.5.2 ISO standards, metadata and data dictionaries

All metadata were recorded to ISO 19113 using ESRI metadata editing tools and supplied as ISO compliant ESRI XML files with the datasets. Delivery also included more human readable Dublin Core metadata, CSV data dictionaries and any other ancillary/explanatory metadata.

Full details are contained in Appendix 3, with a data dictionary presented for feature class and data table (csv) outputs (Table 16), level parcel sum join tables (Table 17), and a region origin join (Table 18).

# 6 Results

## 6.1 Level 1 and Level 2

Summary results for Level 1 and Level 2 analysis are presented in Table 8 for each timestep. The results show the Maximum Land Supply (level 1) has increased by c. 25,000 ha since 2002, however the Known Land Supply (level 2) has decreased by c. 1.239M ha over this period. This largely reflects the increase in the protected natural areas over this time period, and a relatively smaller expansion of c. 23,000 ha in the urban area (Table 10).

**Table 8. Summary of level 1 and level 2 national scale land supply for each timestep**

| New Zealand | 2002 | 2008 | 2012 | 2019 |
|---|---|---|---|---|
| Level 1: Maximum Land Supply (ha) | 25,565,331 | 25,574,458 | 25,573,933 | 25,591,157 |
| Level 2: Known Land Supply (ha) | 17,704,912 | 16,990,639 | 16,614,414 | 16,465,612 |

## 6.2 Level 3: Likely Land Supply

Results for Level 3 for each year are presented in Table 9. These show an overall decrease of c. 50,000 ha in the area potentially available for primary production since 2002, reflecting the increase in area of the non-urban area residential land (≤2 ha with an electoral address), as shown in Table 10.

**Table 9. Summary of level 3 Likely Land Supply for each timestep**

| New Zealand | 2002 | 2008 | 2012 | 2019 |
|---|---|---|---|---|
| Level 3: Likely Land Supply (ha) | 17,659,695 | 16,918,345 | 16,534,149 | 16,370,142 |

**Table 10. Summary of urban and diffuse residential land area for each timestep**

| New Zealand | 2002 | 2008 | 2012 | 2019 |
|---|---|---|---|---|
| Urban land (ha) | 183,491 | 196,214 | 199,369 | 206,565 |
| Non-urban area residential land (ha) | 45,217 | 72,294 | 80,266 | 95,470 |

## 6.3 Guidelines to using the results to answer specific questions

To assist with future application of the results from this analysis we have provided some examples below of questions that could be posed, and guidance of the data source that would be applicable. Possible questions include:

1 Is the area available for all land-uses changing with time?

Answer data source: Use Level 1 output (i.e. Maximum Land Supply).

2 Is the land available for primary production changing with time?

Answer data source: Use Level 3 output (i.e. Likely Land Supply).

3 Is the land used primarily for urban and diffuse residential use changing?

Answer data source: Use Level 1 output, where the ISURBAN field = 1 or use Level 2 output where the ISRESIDENTIAL field = 1

Both urban and diffuse residential can be reported as separate indicators.

4 Is land available for primary production becoming increasingly fragmented?

Answer data source: For analyses to include changes in diffuse residential land use level 2 output with unique parcel counts and feature area sums grouped by Table 5 or Table 6 classes. For analysis of land available for primary production only, use level 3 output with unique parcel counts and feature area sums grouped by Table 5 classes

5 How much HPL and highly versatile land (HVL– LUC 1 and 2) is occupied by predominantly urban and diffuse residential use?

Answer data source: use LUC attribute analysis of output from Question 3.

6 Is HPL and HVL available for Farmland use becoming increasingly fragmented?

Answer data source: use LUC attribute analysis from level 2 or 3 output (as per Question 4) – can also use unique parcel count totals for HPL and HVL, and counts for each parcel size class (grouped by Table 5 and Table 6).

7 Are some regions seeing greater change?

Answer data source: use regional table outputs from levels 1 to 3 to analyse any of above questions from a regional perspective.

# 7 Conclusions

The method proposed by Rutledge et al. (2015) can deliver a robust, repeatable analysis of temporal changes in Land Fragmentation using open-source publicly available datasets. The availability of the previous GIS models and code has enabled a thorough quality assurance assessment of the underpinning input datasets, analysis methods, and results.

From this analysis over four timesteps from 2002 to 2019, we conclude there is a consistent decrease in the area potentially available for primary production, reflecting the effect of expansion in the area of urban and diffuse residential land-use. As a consequence, the availability of highly productive land is also decreasing. Fragmentation of land parcels is also consistently increasing, through an increase in the total number of land parcels, and a consistent decrease in the average parcel area.

Key potential limitations of the approach to consider include:

- Retrospective sourcing of the input datasets means they are not all from the same date for each timestep
- Timesteps are not evenly spaced, being based on availability of LCDB timesteps
- Reliance on publicly available datasets means some potentially informative datasets cannot be used
- This is a national scale assessment, using national datasets, meaning care needs to be taken with the detail of interpretation, for example, reporting change to the hectare resolution
- Care needs to be taken in interpretation of changes of parcel size and linking these to changes in, or implications for, specific types of land use
- Care needs to be taken in interpretation of the diffuse residential land analysis, as the threshold of land parcel size used means there may be some parcels captured that do include small areas of land used for primary production.

# 8 Recommendations

To build on the analysis presented here, we recommend the following as useful future directions:

- Planning to identify future timesteps is crucial to ensure input data layers are identified and archived for, ideally, around the same time point. This is particularly important for the LINZ Primary Parcel dataset, where the current approach by LINZ is for the publicly available dataset to be regularly updated by overwriting the previous dataset.
- The land fragmentation analysis could also be conducted at the local authority scale, providing increased resolution to compliment the national and regional scales included in the current analysis.
- A forecasting component could be added by collating local authority planning zones for future urban and peri-urban development. A start could be to focus only on case

studies in the medium and high growth areas identified through the NPS Urban development.

- Level 4 analysis from Rutledge et al. (2015) could be added to evaluate the potential changes in reverse sensitivity buffers created by increased land fragmentation.
- Further work could be undertaken to provide a consistent national geospatial definition for urban area, and the diffuse residential area. We suggest the Stats NZ Urban / Rural Profile Classification (Stats NZ 2020c) would be a possible additional dataset to inform future Land Fragmentation analysis, provided it is available at each timestep. In the same line further work could be done to create a more comprehensive and nationally consistent Protected Natural Areas layer, that is regularly updated.
- Research could be conducted to link the effect of fragmentation on a range of issues, for example, habitat connectivity, reverse sensitivity, and water quality.

## 9 Acknowledgements

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# Appendix 1 – Details of methods for level 1, 2 and 3

## Methodology, summary techniques and input data

**Table 11. Methodology and summary techniques per current analysis level, compared to the original method and model approach of Rutledge et al. (2015).**

| Level | Methodology: Rutledge et al. (2015) | Models: Rutledge et al. (2015) | Current 2002, 2008, 2012 and 2019 analysis |
|---|---|---|---|
| Level 1 Methodology | Estimate land supply using a regional mosaic created by dividing the region into polygons using a combination of selected biophysical networks (e.g. transport, rivers & streams, etc.) Regional mosaic polygons represent the largest contiguous land areas potentially available for primary production without considering any additional constraints, e.g. current land use/cover, property rights/subdivision, ownership. Regional mosaic polygons can be tracked over time by assigning unique IDs to assess broad trends in regional land fragmentation. | Three separate regional mosaics have been created with unique IDs for all dissolved polygons; a) one excluding all water data inputs only, b) one excluding transport data inputs only and c) one excluding all water and all transport inputs only (excluded data inputs become negative space). | Level 1 involves the selection of non-water and non-transport related features from a combinatorial/Base ID dataset, dissolved on all fields participating in analyses. Features not selected for this layer are water and transport related features from LCDB, LINZ NZ Primary Parcels dataset and separate LINZ Topo50 datasets for lakes, ponds, canals, lagoons, reservoirs, and rivers. |
| Level 1 Summary Technique | Select from data layer Land Cover Database polygons where field Name_2012 = 'Transport Infrastructure'. Save selection. Select from data layer Land Cover Database polygons where field Name_2012 = 'River' or 'Lake or Pond' and then save. Select from data layer Primary Land Parcels polygons where field parcel_intent = 'Railway' and save. Select from data layer Primary Land Parcels polygons where field parcel_intent = 'Riverbed' or 'Streambed' and then save. Union data layers Regional Council Annual Pattern Clipped High Definition, Topo50 Lake Polygons, saved layers above, Topo50 Pond Polygons, Primary Hydro Parcels, Primary Road Parcels, Topo50 | All data inputs are unioned in the last model 'Step05a Parcels First Combinatorial' and assumed to be queried from that point on, for analysis. Three different regional mosaics have also been created by using the chosen water and transport inputs as erase features (a, b, and c in above cell) on the regional boundary AOI dataset, the remaining polygons are then dissolved. Each water/transport input originally has its own ID field and binary identifier. The | Curation of input datasets, includes making copies of original datasets, performing dissolves on relevant fields (except the parcel layers pre union), creating binary ID fields to indicate the presence of features and populating binary fields with indicators. All input datasets are then unioned and an identity is performed on the NZ mainland Regional boundary polygons. The combined dataset is then dissolved on the relevant fields for analyses, a repair geometry is performed, urban and residential land is flagged, feature areas are calculated in hectares and a join table for regional identification of whole parcel is created. An SQL query is run to select all land to be included in the Level 1 estimated available land dataset: Select* from Combinatorial_03 where |

| Level | Methodology: Rutledge et al. (2015) | Models: Rutledge et al. (2015) | Current 2002, 2008, 2012 and 2019 analysis |
|---|---|---|---|
| Level 1 Summary Technique (cont.) | River Polygons to create new data layer Max_Land_Supply_Union. Select from data layer Max_Land_Supply_Union all polygons that are not Topo50 Lake Polygons, saved layers above, Topo50 Pond Polygons, Primary Hydro Parcels, Primary Road Parcels, or Topo50 River Polygons and then Save Selection as new data layer Max_Land_Supply. | resulting dissolved mosaic polygons are assigned with object IDs for ID. | LINZ_HYDRO = 0 And LINZ_ROAD = 0 And LINZ_RAILWAY = 0 And LINZ_STREAMBED = 0 And LINZ_RIVERBED = 0 And ISNZ_Pond_Polygons__Topo__1_50k_ = 0 And ISNZ_Lake_Polygons__Topo__1_50k_ = 0 And ISNZ_River_Polygons__Topo__1_50k_ = 0 And ISNZ_Canal_Polygons__Topo__1_50k_ = 0 And ISNZ_Lagoon_Polygons__Topo__1_50k_ = 0 And ISNZ_Reservoir_Polygons__Topo__1_50k_ = 0 And Name_YYYY NOT IN ('Transport Infrastructure', 'River', 'Lake or Pond'). All remaining land at Level 1 is summed by parcel ID. The remaining unique parcel IDs associated with all available land at Level 1 are then joined back to the original combined dataset, using an inner join. The resulting dataset contains all whole parcels associated with the available land at Level 1, for further spatial analyses. |
| Level 2 Methodology | Estimate land supply excluding known urban/built-up and protected areas from the Maximum Land Supply. Known Land Supply includes areas not currently under primary production but potentially available for conversion, e.g. unprotected indigenous forest, weeds, etc. | No specific output (mosaic) for Level ll: Known Land Supply. Analysis of this level is assumed to result from the unioning and querying of all data inputs in the last model - 'Step05a Parcels First Combinatorial'. | Level 2 involves the selection of all features not legally protected or not likely restricted by land use from the Combinatorial_level1 dataset. Features not selected for this layer are industrial/urban related polygons from LCDB, parcels with an associated parcel_intent attribute indicating a restriction on land use or land cover, the entirety of separate LINZ Topo50 datasets; airport, building, cemetery, golf course, gravel pit, landfill mine, pumice pit, rifle range, racetrack, showground, sportsfield, quarry and residential area. The entirety of the Protected Areas layer containing features relevant to the time step being processed. |

| Level | Methodology: Rutledge et al. (2015) | Models: Rutledge et al. (2015) | Current 2002, 2008, 2012 and 2019 analysis |
|---|---|---|---|
| Level 2 Summary Technique | Select from data layer Land Cover Database polygons where field Name_2012 = 'Built-up Area (settlement)' or 'Surface Mine or Dump' or "Urban Parkland/Open Space' and then save. Select from Primary Land Parcels polygons where parcel_intent = 'DCDB' or 'Fee Simple Title" or 'Maori' and then Reverse Selection and then save. Union data layers Max_Land_Supply, Parcels_Excluded (saved from above), LCDB_Urban (saved from above), Protected Areas,  and Topo50 Airport,Building,Cemetery, Dump, Golf Course, Gravel Pits, Landfill,,  Mine, Pumice Pitand Residential Area Polygons to create new data layer Known_Land_Supply_Union.<br>Select from data layer Known_Land_Supply_Union all polygons that are not Parcels_Excluded, LCDB_Urban, Protected Areas,  or Topo50 Airport, Building, Cemetery, Dump, Golf Course, Gravel Pits, Landfill,, Mine, Pumice Pit or Residential Area Polygons . Save Selection as new data layer Known_Land_Supply. | All data inputs are unioned in the last model - 'Step05a Parcels First Combinatorial' and assumed to be queried from that point on, for analysis. Note some input data layers described in the methodology did not appear to be coded in the model (see Table 12) | An SQL query is run to select all land to be included in the Level 2 estimated available land dataset: Select* from Combinatorial_Level1_land where ISNZ_Airport_Polygons__Topo__1_50k_ = 0 And ISNZ_Building_Polygons__Topo__1_50k_ = 0 And ISNZ_Cemetery_Polygons__Topo__1_50k_ = 0 And ISNZ_Golf_Course_Polygons__Topo__1_50k_ = 0 And ISNZ_Gravel_Pit_Polygons__Topo__1_50k_ = 0 And ISNZ_Landfill_Polygons__Topo__1_50k_ = 0 And ISNZ_Mine_Polygons__Topo__1_50k_ = 0 And ISNZ_Residential_Area_Polygons__Topo__1_50k_ = 0 And ISNZ_Rifle_Range_Polygons__Topo__1_50k_ = 0 And ISNZ_Racetrack_Polygons__Topo__1_50k_ = 0 And ISNZ_Showground_Polygons__Topo__1_50k_ = 0 And ISNZ_Sportsfield_Polygons__Topo__1_50k_ = 0 And ISNZ_Quarry_Polygons__Topo__1_50k_ = 0 And ISNZ_Pumice_Pit_Polygons__Topo__1_50k_ = 0 And ISPROTECTED = 0 And ISRESTRICTED = 0 And Name_YYYY NOT IN ('Built-up Area (settlement)', 'Surface Mine or Dump', 'Urban Parkland/Open Space'). All remaining land at Level 2 is summed by parcel ID. The remaining unique parcel IDs associated with all available land at Level 2 are then joined back to the original combined dataset, using an inner join. The resulting dataset contains all whole parcels associated with the available land at Level 2, for further spatial analyses. |

| Level | Methodology: Rutledge et al. (2015) | Models: Rutledge et al. (2015) | Current 2002, 2008, 2012 and 2019 analysis |
|---|---|---|---|
| Level 3 Methodology | Estimate land supply excluding likely areas of diffuse rural residential development (e.g. lifestyle blocks) from Known Land Supply using indirect evidence. Parcel size threshold can vary to reflect operational requirements of different types of primary production. Parcels of appropriate sizes without Electoral Address Points can also be used to assess future potential for land fragmentation, e.g. subdivided land still under primary production. Parcels ≤ Size Threshold with Electoral Address | No specific output for Level III: Likely Land Supply. Analysis of this level is assumed to result from the unioning and querying of all data inputs in the last model - 'Step05a Parcels First Combinatorial'. | Level 3 involves the selection of all features >2ha OR selection of all features with no address point(s) contained by parcels which are ≤2ha from the Combinatorial_level2_land dataset. Parcels flagged as containing address points are based on original whole parcel features (grouped by parcel ID) and parcel selection for exclusion is based on original whole parcel sums. |
| Level 3 Summary Technique | Select from Primary Land Parcels polygons where parcel_intent = 'DCDB' or 'Fee Simple Title" or 'Maori' and then save selection. Union data layers Known_Land_Supply and saved selection from above to create new data layer. Select from the new layer all polygons where with parcel size ≤ n hectares (with an address point) and then Reverse Selection and then save new data layer. Repeat previous step 3 for AreaMin ≤ n ≤ AreaMax in specified increments. | A field is created within the NZ Parcels dataset on import of parcels, to ID parcels with an electorate address. Parcels are later selected which contain one or more address points and are identified via the added field. All data inputs are also unioned in the last model - 'Step05a Parcels First Combinatorial' and assumed to be queried from that point on, for analysis. | An SQL query is run to select all landto be included in the Level 3 estimated available land dataset: Select* from Combinatorial_Level2_land where PARCEL_PRI NOT IN ('0-2') Or (ISADDRESS = 0 And PARCEL_PRI IN ('0-2')).. All remaining land at Level 3 is summed by parcel ID. The remaining unique parcel IDs associated with all available land at Level 3 are then joined back to the original combined dataset, using an inner join. The resulting dataset contains all whole parcels associated with the available land at Level 3, for further spatial analyses. |

**Table 12. Data input per current analysis level, compared to the original method and models of Rutledge et al. (2015).**

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| 2014 Regional Council Boundary Annual Pattern High Resolution Clipped, Statistics NZ, annual. All datasets are clipped to each individual region, all processes appear to be completed as per clipped region. | Layer ID 104253. 2020. Regional Council 2020 Clipped (generalised). Statistics NZ. Coastline version unspecified in Stats metadata. 'REGC2020_V1_00_NAME: 'Area Outside Region' is excluded from the analyses due to lack of data in those areas. This includes the Chatham Islands and the Three Kings Islands. This dataset is effectively used as an authoritative coastline in EMaR and Rutledge. Used in an identity of all other datasets in EMaR. | Same as 2019 | Same as 2019 | Same as 2019 |
| 2012/13 of LCDB v4.0 – MWLR, 4–5 years. LCDB water and transport features look to not have been included in the water and transport mosaics. All LCDB polygons (for AOI) unioned in later 5a Combinatorial instead. | Layer ID 104400. LCDB v5.0 - Land Cover Database version 5.0, Mainland New Zealand. LRIS. Utilising only LCDB exclusion features for Level 1 and 2. | Same as 2019 | Same as 2019 | Same as 2019 |

| | | | | |
|---|---|---|---|---|
| 2014 NZ Parcels, LINZ, monthly has been used: (NZ_CRS_2014_06_28.gdb\NZ_Parcels) instead of NZ Primary land parcels (NZ Parcels contains primary and non-primary approved, current or historic linear parcels as well as hydro and road features). However, the dataset has been queried to suit the methodology: topology_type = 'Primary' AND (status = 'Current' OR status = 'Approved as to Survey'). Parcel_intent = 'Hydro', 'Riverbed', 'Streambed', 'Railway', 'Road' have been used as exclusion features in level 1 from this dataset. | Corax NZ Primary Parcels dataset, from a March 2019 bulk data extract from LINZ. Supplied by Kim Ollivier.<br>Parcel 'ID' is named 'par_id' - this has been changed back to 'id' to run in models 11/09. No missing feature data.<br>Geometry check conducted on the dataset - no repair necessary<br>31 gaps, 64 overlaps. Topology check report to be provided with gdb. Overlaps >0.7ha have been fixed. The rest have been removed (added to small gaps of unknown parcel_intent). Currently no information as to how topology was dealt with in EMaR. Not dealt with in Rutledge.<br>Spatial index added 11/09.<br>Attribute index 'Parcels19_index' added to id, parcel_intent and Shape_Area 11/09. | Corax NZ Primary Parcels dataset, from an August 2012 bulk data extract from LINZ. Supplied by Kim Ollivier.<br>Parcel 'id' is named 'par_id' - this has been changed back to 'id' to run in models 02/09. No missing feature data.<br>Geometry repair conducted on a self intersection and an empty geometry (report to be provided with gdb).<br>135 gaps, 399 overlaps. Topology check report to be provided with gdb. Overlaps >1ha have been fixed. The rest have been removed (added to small gaps of unknown parcel_intent).<br>Spatial index added 02/09.<br>Attribute index 'Parcels12_index' added to id, parcel_intent and Shape_Area 02/09. | Corax NZ Primary Parcels dataset, from an August 2008 bulk data extract from LINZ. Supplied by Kim Ollivier.<br>Parcel 'id' is named 'par_id' - this has been changed back to 'id' to run in models 02/09. No missing feature data.<br>80 gaps, 141 overlaps. Topology check report to be provided with gdb. Overlaps >1ha have been fixed. The rest have been removed (added to small gaps of unknown parcel_intent).<br>Geometry repair had been conducted on dataset prior to purchase (as per the feature class metadata).<br>Spatial index added 02/09.<br>Attribute index 'Parcels08_index' added to id, parcel_intent and Shape_Area 02/09. | Corax NZ Primary Parcels dataset, dated May 2002. Supplied by Kim Ollivier.<br>'id' looks to be 'par_id' - this has been changed back to 'id' to run in models 02/09.<br>Dataset required geometry repair on self intersections (report to be provided with gdb).<br>919 gaps, 1,241 overlaps. Topology check report to be provided with gdb. Overlaps >1ha have been fixed. The rest have been removed (added to small gaps of unknown parcel_intent). A 29,431.79 ha hole has been found in the dataset near Reefton (present in original and curated versions of the dataset). However, this is a Protected Area polygon, so is part of the Level 2 exclusion. This has been filled with attributes from the 2008 Parcels dataset used in this project.<br>Spatial index added 02/09.<br>Attribute index 'Parcels01_index' added to id, parcel_intent and Shape_Area 02/09. |

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| 2014 NZ Lake Polygons (Topo 1:50k), LINZ, at least annually. (LINZ_Topographic_2014\\nzmainland-lake-polygons-topo-150k\\nz-mainland-lake-polygons-topo-150k.shp) | NZ Lake Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Lake Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Lake Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Lake Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |
| 2014 NZ Pond Polygons (Topo 1:50k), LINZ, at least annually. (LINZ_Topographic_2014\\nzmainland-pond-polygons-topo-150k\\nz-mainland-pond-polygons-topo-150k.shp) | NZ Pond Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Pond Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Pond Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Pond Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |
| 2014 NZ Parcels, LINZ, monthly. parcel_intent = 'Hydro' input has been used to identify hydro exclusion features. | | | | |
| 2014 NZ Parcels, LINZ, monthly. parcel_intent = 'Road' input has been used to identify road exclusion features. | | | | |
| 2014 NZ River Polygons, LINZ, at least annually. (\LINZ_Topographic_2014\\nzmainland-river-polygons-topo-150k\\nz-mainland-river-polygons-topo-150k.shp) | NZ River Polygons (Topo 1:50k), LINZ,supplied by Kim Ollivier, TopoV19: March 2019 | NZ River Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ River Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ River Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |
| Appears to not have been used | NZ Canal Polygons (Topo 1:50k), LINZ,supplied by Kim Ollivier, TopoV19: March 2019 | NZ Canal Polygons (Topo 1:50k), LINZ,supplied by Kim Ollivier, TopoV17: 2015 | NZ Canal Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Canal Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000 |
| | NZ Lagoon Polygons (Topo 1:50k), LINZ,supplied by Kim Ollivier, TopoV19: March 2019 | NZ Lagoon Polygons (Topo 1:50k), LINZ,supplied by Kim Ollivier, TopoV17: 2015 | NZ Lagoon Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Lagoon Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000 |

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| Appears to not have been used | NZ Reservoir Polygons (Topo 1:50k), LINZ,supplied by Kim Ollivier, TopoV19: March 2019 | NZ Reservoir Polygons (Topo 1:50k), LINZ,supplied by Kim Ollivier, TopoV17: 2015 | NZ Reservoir Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Reservoir Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000 |
| Appears to not have been used | NZ Airport Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Airport Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Airport Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Airport Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |
| Appears to not have been used | NZ Building Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Building Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Building Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Building Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. NZ Building Void Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. The Building void polygons are erased out of the Building polygons as part of the Topographic Data curation process for 2002. |
| Appears to not have been used | NZ Cemetery Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Cemetery Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Cemetery Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Cemetery Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| Appears to not have been used | NZ Residential Area Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Residential Area Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Residential Area Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Residential Area Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. NZ Residential Area Void Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. The Residential Area void polygons are erased out of the Residential Area polygons as part of the Topographic Data curation process for 2002. |
| Appears to not have been used | NZ Rifle Range Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV19: March 2019 | NZ Rifle Range Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV17: 2015 | NZ Rifle Range Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV15: Aug 2008 | NZ Rifle Range Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. |
| Appears to not have been used | NZ Racetrack Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV19: March 2019 | NZ Racetrack Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV17: 2015 | NZ Racetrack Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV15: Aug 2008 | NZ Racetrack Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. NZ Racetrack Void Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. The Racetrack void polygons are erased out of the Racetrack polygons as part of the Topographic Data curation process for 2002. |

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| Appears to not have been used | NZ Showground Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV19: March 2019 | NZ Showground Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV17: 2015 | NZ Showground Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV15: Aug 2008 | NZ Showground Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. |
| Appears to not have been used | NZ Sportsfield Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV19: March 2019 | NZ Sportsfield Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV17: 2015 | NZ Sportsfield Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV15: Aug 2008 | NZ Sportsfield Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. |
| Appears to not have been used | NZ Quarry Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV19: March 2019 | NZ Quarry Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV17: 2015 | NZ Quarry Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV15: Aug 2008 | NZ Quarry Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. |
| Appears to not have been used | Layer ID 50674. Updated 28 January 2020. Dumping Ground Polygons (Hydro, 1:4k - 1:22k). LINZ. A hydrographic dataset. Won't use as not in EMaR. | Not used | Not used | Not used |
| Appears to not have been used | NZ Golf Course Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Golf Course Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Golf Course Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Golf Course Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| Appears to not have been used | NZ Gravel Pit Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Gravel Pit Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Gravel Pit Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Gravel Pit Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. NZ Gravel Pit Void Polygons (Topo 1:50k), LINZ, supplied by Kim Olivier, TopoV02: 2000. The Gravel Pit void polygons are erased out of the Gravel Pit polygons as part of the Topographic Data curation process for 2002. |
| Appears to not have been used | NZ Landfill Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Landfill Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Landfill Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Landfill Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |
| Appears to not have been used | NZ Pumice Pit Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Pumice Pit Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Pumice Pit Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Pumice Pit Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |
| Appears to not have been used | NZ Mine Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV19: March 2019 | NZ Mine Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 | NZ Mine Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV15: Aug 2008 | NZ Mine Polygons (Topo 1:50k), LINZ, supplied by Kim Ollivier, TopoV02: 2000. |

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| 2014 Protected Areas, various, at least annually. (PANNZ_2014.gdb\\PANNZ_BETA_2014100) | Layer ID 53564. Updated 11 July 2020. Protected Areas, LINZ has been combined with the QEII National Trust dataset (last update likely to be quarter April-June 2020). The exceptional case of Te Urewera (now existing as a legal enitiy in its own right, since 2014) has also been added back in to the combined dataset. Features from these datasets containing a time stamp indicating an initiation of legal protection before (or during) 2019 have been included. The combined dataset is named All_Protected_2019_dissolved Alternatives included: Layer ID 754. Updated 03 January 2017. DOC Public Conservation Areas, Koordinates | Layer ID 53564. Updated 11 July 2020. Protected Areas, LINZ has been combined with the QEII National Trust dataset (last update likely to be quarter April-June 2020). The exceptional case of Te Urewera (now existing as a legal enitiy in its own right, since 2014) has also been added back in to the combined dataset. Features from these datasets containing a time stamp indicating an initiation of legal protection before (or during) 2012 have been included. The combined dataset is named All_Protected_2012_dissolved Alternatives included: Layer ID 754. Updated 03 January 2017. DOC Public Conservation Areas, Koordinates | Layer ID 53564. Updated 11 July 2020. Protected Areas, LINZ has been combined with the QEII National Trust dataset (last update likely to be quarter April-June 2020). The exceptional case of Te Urewera (now existing as a legal enitiy in its own right, since 2014) has also been added back in to the combined dataset. Features from these datasets containing a time stamp indicating an initiation of legal protection before (or during) 2008 have been included. The combined dataset is named All_Protected_2008_dissolved Alternatives included: Layer ID 754. Updated 03 January 2017. DOC Public Conservation Areas, Koordinates | Layer ID 53564. Updated 11 July 2020. Protected Areas, LINZ has been combined with the QEII National Trust dataset (last update likely to be quarter April-June 2020). The exceptional case of Te Urewera (now existing as a legal enitiy in its own right, since 2014) has also been added back in to the combined dataset. Features from these datasets containing a time stamp indicating an initiation of legal protection before (or during) 2002 have been included. The combined dataset is named All_Protected_2002_dissolved Alternatives included: Layer ID 754. Updated 03 January 2017. DOC Public Conservation Areas, Koordinates |
| 2014 Electoral Addresses, LINZ, monthly (NZ_CRS_2014_06_28.gdb\\NZ_Street_Address_Electoral) | NZ Street Address, March 2019, LINZ, supplied by Kim Ollivier. | NZ Street Address Electoral, August 2012, LINZ, supplied by Kim Ollivier. | NZ Street Address Electoral, August 2008, LINZ, supplied by Kim Ollivier. | NZ Street Address Electoral, May 2002, LINZ, supplied by Kim Ollivier. |

| Rutledge et al. (2015) Data inputs (models) | 2019 Data inputs (models) | 2012 Data inputs (models) | 2008 Data inputs (models) | 2002 Data inputs (models) |
|---|---|---|---|---|
| Layer ID 48135. Last updated 25 May 2010, NZLRI South Island, Edition 2 (all attributes) but contains NI data also. (N:\\Projects\\BaseData\\NZ\\LRI\\v2014\\NZLRI_20100525.gdb\\NZLRI) Whole dataset imported and unioned in Step05a Parcels First Combinatorial. | Layer ID 48076. Last updated 25 May 2010, NZLRI Land Use Capability, LRIS. LUC1C field used for LUC analysis (land capability class code). LCORR field contains null values. | Same as 2019 | Same as 2019 | Same as 2019 |

## Appendix 2 – Protected area layer methodology

The protected area dataset was created from 2 publicly available datasets, the LINZ Protected Areas dataset (LINZ 2020c) and the QEII National Trust digital boundaries (QEII 2020). In addition, a boundary of the former Te Urewera National Park drawn from a pre-2014 Department of Conservation Estate dataset held by MWLR was used to define the extent of the current Te Urewera.

These datasets record dates at which reserves were formed, but the LINZ dataset also contains some overlapping entities, for example areas that are both National Park and Wilderness Area, and also contains marine and offshore island protected areas not relevant to the current analysis. A separate GIS workflow was developed in ArcGIS ModelBuilder to identify and include mainland targets and overlapping areas so that they would not be double accounted, and then determine the earliest time step of our analysis when areas in each dataset became protected. The outputs from the workflow are four spatial datasets of reserved land matching the time steps of the fragmentation analysis.

The workflow to resolve timing and status of reserved land is as follows:

In the LINZ Protected Area dataset an attribute TimeClass was created and assigned a value between 0 and 4 depending on the Start Date attribute which records the date of reserve status. The table below shows the assignment of TimeClass with relation to year of reserve designation.

| Date of Reserve Status | TimeClass |
|---|---|
| Before June 2002 | 1 |
| Between July 2002 AND June 2008 | 2 |
| Between July 2008 AND June 2012 | 3 |
| Since June 2012 | 4 |

The LINZ Protected area dataset with new attributes was then DISSOLVED on the TimeClass attribute to resolve any overlapping areas in the same time step. This still left some overlapping or partially overlapping protected areas that spanned time steps. A new dataset was created, one for each time step in our analysis, that contained only those reserved areas within each period, meaning that within these four layers there are no overlapping polygons. Each was assigned an attribute (e.g., IsPro2002) that is set to 1 for all polygons in that time step. These 4 layers were then joined back together using a UNION to create a single spatial layer with no overlaps that correctly records whether land parcels have protected status at one or more time step in the analysis, and any overlapping or part-overlapping areas are correctly identified as protected or not protected at all time steps.

Because there are no overlapping reserves in the QEII National Trust Dataset a set of attributes was created and assigned as for the LINZ datasets to reflect reserved status at each time step. For Te Uruwera, we assumed no change in boundary through the transition from the Conservation Estate to Te Urewera in 2014, and again created and assigned four variables that reflected reserved status at all four time steps.

With all three inputs (LINZ, QEII and Te Urewera) pre-processed in this way, we were able to UNION all three layers into a single reserved dataset.

A final additional attribute was created and assigned a value of 1 (Protected) or 0 (Not Protected) for all reserve areas in the combined dataset.

The final step in the workflow is to SELECT by TimeClass and DISSOLVE to create four datasets of all reserved land at each time step with no overlaps.

# Appendix 3 – Data and quality assurance

## Quality assurance for levels 1, 2 and 3

For quality assurance, 2012 was chosen because more metadata from WRC were available for comparison purposes. Full details are presented for each level in Table 13 to Table 15.

### Quality assurance for level 1

**Table 13. Level 1 data and quality assurance for 2012**

| Methodology and data input EMaR land, November 2018 | 2012 QA notes. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| Methodology<br>"Excludes water bodies and transport infrastructure (lakes, rivers, ponds, roads, railway, stream/river bed) from LINZ and LCDB. We didn't bother doing anything with the "regional mosaic polygons" as we considered these too coarse for our purposes." No regional mosaics - most datasets are given binary ID fields, non UID and ID fields are stripped and all datasets for all levels of analysis are initially combined via 'identity' with the regional boundary dataset as the input feature. This is a similar approach to what is seen in the models produced for the Rutledge analysis. An additional Level 1 SQL query is later run, selecting all features (other than the identified water and transport infrastructure related features) into a new table. | Methodology<br>Level 1 involves the selection of non-water and non-transport related features from a non-dissolved combinatorial/Base ID dataset for each time step. Features not selected for this layer are water and transport related features from LCDB, LINZ NZ Primary Parcels dataset and separate LINZ topographic datasets for lakes, ponds, and rivers. |

| Methodology and data input EMaR land, November 2018 | 2012 QA notes. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| Summary Technique<br>SQL via Manifold, 2012 example: SELECT [mfd_id], [REGC2017_NAME], [REG_AREA_SQ_KM], [GIS_REG_AREA_SQ_KM], [TA2017_NAME], [TA_AREA_SQ_KM], [GIS_TA_AREA_SQ_KM], [LINZ_PUMICE], [LINZ_MINE], [LINZ_AIRPRT], [LINZ_GOLFCRS], [LINZ_GRVPIT], [LINZ_CEMTRY], [LINZ_LNDFILL], [LINZ_RESAREA], [LINZ_POND], [LINZ_RIVER], [LINZ_BLDNG], [LINZ_LAKE], [LINZ_ROAD], [LINZ_HYDRO], [PARCEL_INT], [ADDR], [PLP_M2], [PID], [DOC_RESRV], [LUC], [Name_2001], [Name_2008], [Name_2012], [CREATED], [OID], [Geom]<br>INTO [BUILD BASE LVL 1 Table]<br>FROM [LAWA FRAG IND BASE ID DATA 2012 Table]<br>WHERE<br>[LINZ_LAKE] = 0 AND<br>[NAME_2012] NOT IN ('Transport Infrastructure', 'River', 'Lake or Pond') AND -- Stream and River are required in this supply as there are a few residual not in hydrology<br>StringToUpperCase([parcel_int]) NOT IN ('RAILWAY', 'STREAMBED', 'RIVERBED') AND<br>-- Hydro is in a seperate layer<br>[LINZ_HYDRO] = 0 AND<br>-- Road is in a seperate layer<br>[LINZ_ROAD] = 0 AND [LINZ_POND] = 0 AND<br>[LINZ_RIVER] = 0<br>THREADS SystemCpuCount();<br>-- 02/10/18 Added [GIS_REG_AREA_SQ_KM] and [GIS_TA_AREA_SQ_KM] | Summary Technique<br>Curation of input datasets, includes making copies of original datasets, performing dissolves on relevant fields (except the parcel layers pre union), creating binary ID fields to indicate the presence of features and populating binary fields with indicators. All input datasets are then unioned and an identity is performed on the NZ mainland Regional boundary polygons. The combined dataset is then dissolved on the relevant fields for analyses, a repair geometry is performed and join tables for total parcel sums for each level and regional identification are created based on whole parcels. An SQL query is run to select all land to be included for Level 1 Analyses: Select* from Combinatorial_03 where LINZ_HYDRO = 0 And LINZ_ROAD = 0 And LINZ_RAILWAY = 0 And LINZ_STREAMBED = 0 And LINZ_RIVERBED = 0 And ISNZ_Pond_Polygons__Topo__1_50k_ = 0 And ISNZ_Lake_Polygons__Topo__1_50k_ = 0 And ISNZ_River_Polygons__Topo__1_50k_ = 0 And Name_2012 NOT IN ('Transport Infrastructure', 'River', 'Lake or Pond'). Level 1 combinatorial and total parcel area (on 'id') groupings are calculated for the output Combinatorial_Level1 dataset. DBF files are also output for analyses from the Combinatorial_level1 table. |
| 2017 Regional Council Boundary Annual Pattern High Resolution Clipped, Statistics NZ, annual. 2017 Regional boundaries are incorporated into the ID table. The same dataset is used for all time steps: "We used the most recent version of the regional boundary (high-resolution) for all time steps to allow consistent comparison." | The 2017 Regional Council Boundary dataset supplied by WRC appears to be missing the Northland, Auckland and Waikato Regions. The 2020 dataset downloaded from StatsNZ has been used in place of this. |
| LCDB v4.1, MWLR, 4-5 years. All LCDB 4.1 features are included in the ID table (all relevant previous time steps and all attributes) likely in order "to future proof the dataset in case we wanted to do | Downloaded from LRIS. Layer ID 48423. LCDB v4.1 - Land Cover Database version 4.1, Mainland New Zealand has been used. 12/13 timestep for 2012 verification year. Utilising only LCDB exclusion features for Level 1 and 2. |

| Methodology and data input EMaR land, November 2018 | 2012 QA notes. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| something with the dataset that involved other land uses." "We used LCDB4.1 for all timesteps but matching the LCDB year to the corresponding timestep." | |
| NZ Primary Land Parcels , LINZ, monthly. NZ Primary Land Parcels do not include the Primary Hydro and Road features which are present in the NZ Primary Parcels dataset. NZ Primary Parcels dataset is used as per the Rutledge et al. (2015) methodology, so Primary Land, Road and Hydro parcels have been presumably used. | NZ Primary Land Parcels 2012, LINZ, monthly, supplied by WRC. Dataset has been appended to the Hydro and Road Parcels in order to run the dataset with existing models. field names 'parcel_int' (parcel_intent) and 'id' from the Hydro and Road datasets have been used in the models. The curated version of the Land Parcels dataset has been used as the un-curated version is missing data for 455,000 features. The curated version has a par_id field in place of an ID field which doesn't appear to match 'id's' from the other parcel datasets but it does appear to be a unique ID (so has been used in place of 'id'). The curated dataset also has 982 less features than the un-curated dataset. The combined Land/Hydro/Road dataset also required geometry repair on ring direction to run unions (report to be provided with gdb). Topology check report to be provided with gdb. |
| NZ Lake Polygons (Topo 1:50k), LINZ, at least annually. | NZ Lake Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Pond Polygons (Topo 1:50k), LINZ, at least annually. | NZ Pond Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Primary Hydro Parcels, LINZ, monthly. | NZ Primary Hydro Parcels 2012, LINZ, monthly, supplied by WRC. Checked for potential duplicate IDs and appended to the NZ Primary Land Parcel dataset. |
| NZ Primary Road Parcels, LINZ, monthly. | NZ Primary Road Parcels 2012, LINZ, monthly, supplied by WRC. Checked for potential duplicate IDs and appended to the NZ Primary Land Parcel dataset. |
| NZ River Polygons (Topo 1:50k), LINZ, at least annually | NZ River Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |

## Quality assurance for level 2

**Table 14. Level 2 data and quality assurance for 2012**

| Methodology and data input EMaR land, November 2018 | 2012 quality assurance notes developed in 2019 method.<br>(2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| Methodology<br>"Excludes urban/industrial areas and conservation estate. Similar approach as Rutledge et al. but we did make some corrections. The original method excluded large areas of leasehold land which we corrected." (see cells below) Following the creation of the combined base dataset, an additional Level 2 SQL query is run , selecting all features (other than the identified urban/built-up, restricted and protected area features) into a new table from the table created at level 1. | Methodology<br>Level 2 involves the selection of all features not legally protected or not likely restricted by land use from a combinatorial/Base ID dataset, dissolved on all participating fields. Features not selected for this layer are industrial/urban related polygons from LCDB, parcels with an associated parcel_intent attribute indicating a restriction on land use or land cover, the entirety of separate LINZ datasets; airport, building, cemetery, golf course, gravel pit, landfill mine, pumice pit and residential area and the entirety of the LINZ supplied Protected Areas dataset. |
| Summary Technique<br>SQL via Manifold, 2008 example:<br>SELECT [mfd_id], [REGC2017_NAME], [REG_AREA_SQ_KM], [GIS_REG_AREA_SQ_KM], [TA2017_NAME], [TA_AREA_SQ_KM], [GIS_TA_AREA_SQ_KM], [LINZ_PUMICE], [LINZ_MINE], [LINZ_AIRPRT], [LINZ_GOLFCRS], [LINZ_GRVPIT], [LINZ_CEMTRY], [LINZ_LNDFILL], [LINZ_RESAREA], [LINZ_POND], [LINZ_RIVER], [LINZ_BLDNG], [LINZ_LAKE], [LINZ_ROAD], [LINZ_HYDRO], PARCEL_INT], [ADDR], [PLP_M2], [PID], [DOC_RESRV], [LUC], [Name_2001], [Name_2008], [Name_2012], [CREATED], [OID], [Geom]<br>INTO [BUILD BASE LVL 2 Table]<br>FROM [BUILD BASE LVL 1 Table]<br>WHERE<br>[LINZ_AIRPRT] = 0 AND<br>[LINZ_BLDNG] = 0 AND<br>[LINZ_CEMTRY] = 0 AND<br>[LINZ_GOLFCRS] = 0 AND<br>[LINZ_GRVPIT] = 0 AND<br>[LINZ_LNDFILL] = 0 AND | Summary Technique<br>An SQL query is run to select all land to be included for Level 2 Analyses: Select* from Combinatorial_Level1 where ISNZ_Airport_Polygons__Topo__1_50k_ = 0 And ISNZ_Building_Polygons__Topo__1_50k_ = 0 And ISNZ_Cemetery_Polygons__Topo__1_50k_ = 0 And ISNZ_Golf_Course_Polygons__Topo__1_50k_ = 0 And ISNZ_Gravel_Pit_Polygons__Topo__1_50k_ = 0 And ISNZ_Landfill_Polygons__Topo__1_50k_ = 0 And ISNZ_Mine_Polygons__Topo__1_50k_ = 0 And ISNZ_Residential_Area_Polygons__Topo__1_50k_ = 0 And ISPROTECTED = 0 And ISRESTRICTED = 0 And Name_2012 NOT IN ('Built-up Area (settlement)', 'Surface Mine or Dump', 'Urban Parkland/Open Space'). Level 2 combinatorial and total parcel area (on 'id') groupings are calculated for the output Combinatorial_Level2 dataset. DBF files are also output for analyses from the Combinatorial_level2 table.<br>The query to produce ISRESTRICTED ids includes parcel_intent IN ('DCDB','Fee Simple Title','Maori','Statutory','Legalisation','Lease','Lease 20 years or More','Licence/Permit') all being set to ISRESTRICTED = 0 |

| Methodology and data input EMaR land, November 2018 | 2012 quality assurance notes developed in 2019 method. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| [NAME_2008] NOT IN ('Built-up Area (settlement)', 'Surface Mine or Dump', 'Urban Parkland/Open Space') AND<br>[LINZ_MINE] = 0 AND<br>[LINZ_PUMICE] = 0 AND<br>[LINZ_RESAREA] = 0 AND<br>StringToUpperCase([parcel_int]) IN ('DCDB', 'FSIM', 'MAOR'<br>-- Additional to be retained following discussion of initial results (Haydon/Dan - October 2018)<br>--'STATUTORY', 'LEGALISATION', 'LEASE 20 YEARS OR MORE', 'LICENCE/PERMIT', 'LEASE') AND<br>'STAT', 'LEGL', 'LETW', 'LICN', 'LEAS') AND<br>[DOC_RESRV] = 0<br>THREADS SystemCpuCount();<br>-- 02/10/18 Added [GIS_REG_AREA_SQ_KM] and [GIS_TA_AREA_SQ_KM] | |
| NZ Airport Polygons (Topo 1:50k), LINZ, at least annually. | NZ Airport Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Building Polygons (Topo 1:50k), LINZ, at least annually. | NZ Building Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Cemetery Polygons (Topo 1:50k), LINZ, at least annually. | NZ Cemetery Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Residential Areas Polygons (Topo 1:50k), LINZ, at least annually. Not referenced in Rutledge. | NZ Residential Area Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Golf Course Polygons (Topo 1:50k), LINZ, at least annually. | NZ Golf Course Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Gravel Pit Polygons (Topo 1:50k), LINZ, at least annually. | NZ Gravel Pit Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Landfill Polygons (Topo 1:50k), LINZ, at least annually. | NZ landfill Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Pumice Pit Polygons (Topo 1:50k), LINZ, at least annually. | NZ Pumice Pit Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| NZ Mine Polygons (Topo 1:50k), LINZ, at least annually. | NZ Mine Polygons (Topo 1:50k), LINZ, supplied by WRC. 2012 |
| Reserve Area. Origins unknown. Supplied with 2001 data supply but not present in all queries. | |
| Layer ID 754. (Circa 2017/18). DOC Public Conservation Areas, Koordinates, added 05 May 2009, last updated 03 Jan 2017. PAN-NZ database was not used as it is not publicly available. The current conservation estate data is applied to all time steps due to the unavailability of | DOC Public Conservation Areas supplied by WRC. Required a geometry repair on void polygons - report to be provided with gdb |

| Methodology and data input EMaR land, November 2018 | 2012 quality assurance notes developed in 2019 method. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| historic conservation estate data (and is assumed not to have changed significantly in the urban fringe area). "No other sources were used for the protected areas layer." | |

## Quality assurance for level 3

**Table 15. Level 3 data and quality assurance for 2012**

| Methodology and data input EMaR land, November 2018 | 2012 quality assurance notes developed in 2019 method. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| Methodology<br>Excludes all parcels 2 ha or less with an electoral address point (i.e. residential area), leaving only land considered to be potentially available for production. Electoral address points are used to indicate the presence of a dwelling. "Exclusion on the basis of whole parcels, not part parcels resulting from previous levels.." Following the creation of the combined base dataset, an additional Level 3 SQL query is run, selecting all unique parcel IDs (other than those associated with all parcels 2 ha or less with an electoral address point) into a temporary table from the table created at level 2. This ID table is then joined, using an inner join, to the records present at level 2. Resulting records are inserted into a new level 3 table. | Methodology<br>Level 3 involves the selection of all features >2 ha OR selection of all features with no address point(s) contained by parcels which are <=2 ha from a combinatorial/Base ID dataset, dissolved on all fields participating in analyses. Parcels flagged as containing address points are based on original whole parcel features (grouped by parcel ID) and parcel groupings are based on Level 2 output whole parcel sums (pre combining of parcels with LUC and Regional Council Boundary datasets but post removal of sub-parcel exclusion features). |
| Summary Technique<br>SQL via Manifold, 2008 example: SELECT DISTINCT [PID] AS [UID]<br>INTO [~TMP]<br>FROM [BUILD BASE LVL 2 Table]<br>-- Checked with Haydon 04th April 2018<br>WHERE ([ADDR] = 0 AND [PLP_M2]/10000 <= 2) OR [PLP_M2]/10000 > 2<br>THREADS SystemCpuCount();<br>ALTER TABLE [~TMP] (<br>   ADD INDEX [UID_x] BTREEDUP ([UID])<br>   )<br>;<br>CREATE TABLE [BUILD BASE LVL 3 Table] (<br>        [mfd_id] INT64,<br>        [REGC2017_NAME] VARCHAR,<br>        [REG_AREA_SQ_KM] FLOAT64,<br>        [GIS_REG_AREA_SQ_KM] FLOAT64, | Summary Technique<br>An SQL query is run to select all land to be included for Level 3 Analyses: Select* from Combinatorial_Level2 (joined on 'id' = 'id_L2_sum) to 'Level2_parcel_sum' where LEVEL2_PARCEL_GROUP IN ('>3', '2-3') Or (ISADDRESS = 0 And LEVEL2_PARCEL_GROUP IN ('0-1', '1-2')). Level 3 combinatorial and total parcel area (on 'id') groupings are calculated for the output Combinatorial_Level3 dataset. DBF files are also output for analyses from the Combinatorial_level3 table. |

| Methodology and data input EMaR land, November 2018 | 2012 quality assurance notes developed in 2019 method. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| [TA2017_NAME] VARCHAR,<br>[TA_AREA_SQ_KM] FLOAT64,<br>[GIS_TA_AREA_SQ_KM] FLOAT64,<br>[LINZ_PUMICE] INT32,<br>[LINZ_MINE] INT32,<br>[LINZ_AIRPRT] INT32,<br>[LINZ_GOLFCRS] INT32,<br>[LINZ_GRVPIT] INT32,<br>[LINZ_CEMTRY] INT32,<br>[LINZ_LNDFILL] INT32,<br>[LINZ_RESAREA] INT32,<br>[LINZ_POND] INT32,<br>[LINZ_RIVER] INT32,<br>[LINZ_BLDNG] INT32,<br>[LINZ_LAKE] INT32,<br>[LINZ_ROAD] INT32,<br>[LINZ_HYDRO] INT32,<br>[PARCEL_INT] VARCHAR,<br>[ADDR] INT32,<br>[PLP_M2] FLOAT64,<br>[PID] INT32,<br>[DOC_RESRV] INT32,<br>[LUC] VARCHAR,<br>[Name_2001] VARCHAR,<br>[Name_2008] VARCHAR,<br>[Name_2012] VARCHAR,<br>[CREATED] DATETIME,<br>[OID] INT32, | |

| Methodology and data input EMaR land, November 2018 | 2012 quality assurance notes developed in 2019 method. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| [Geom] GEOM,<br>INDEX [mfd_id_x] BTREE ([mfd_id]),<br>INDEX [Geom_x] RTREE ([Geom]),<br>INDEX [PID_x] BTREEDUP ([PID]),<br>INDEX [OID_x] BTREE ([OID]),<br>INDEX [REGC2017_NAME_x] BTREEDUP ([REGC2017_NAME]),<br>INDEX [Name_2001_x] BTREEDUPNULL ([Name_2001]),<br>INDEX [PARCEL_INT_x] BTREEDUPNULL ([PARCEL_INT]),<br>INDEX [ADDR_x] BTREEDUP ([ADDR]),<br>INDEX [PLP_M2_x] BTREEDUPNULL ([PLP_M2]),<br>INDEX [LUC_x] BTREEDUPNULL ([LUC])<br>);<br>INSERT INTO [BUILD BASE LVL 3 Table] (<br>[REGC2017_NAME], [REG_AREA_SQ_KM], [GIS_REG_AREA_SQ_KM], [TA2017_NAME], [TA_AREA_SQ_KM], [GIS_TA_AREA_SQ_KM], [LINZ_PUMICE], [LINZ_MINE], [LINZ_AIRPRT], [LINZ_GOLFCRS],<br>[LINZ_GRVPIT], [LINZ_CEMTRY], [LINZ_LNDFILL], [LINZ_RESAREA], [LINZ_POND], [LINZ_RIVER], [LINZ_BLDNG], [LINZ_LAKE], [LINZ_ROAD], [LINZ_HYDRO], [PARCEL_INT], [ADDR], [PLP_M2], [PID], [DOC_RESRV],<br>[LUC], [Name_2001], [Name_2008], [Name_2012], [CREATED], [OID], [Geom]<br>) SELECT<br>[REGC2017_NAME], [REG_AREA_SQ_KM], [GIS_REG_AREA_SQ_KM], [TA2017_NAME], [TA_AREA_SQ_KM], [GIS_TA_AREA_SQ_KM], [LINZ_PUMICE], [LINZ_MINE], [LINZ_AIRPRT], [LINZ_GOLFCRS],<br>[LINZ_GRVPIT], [LINZ_CEMTRY], [LINZ_LNDFILL], [LINZ_RESAREA], [LINZ_POND], [LINZ_RIVER], [LINZ_BLDNG], [LINZ_LAKE], [LINZ_ROAD], [LINZ_HYDRO], [PARCEL_INT], [ADDR], [PLP_M2], [PID], [DOC_RESRV],<br>[LUC], [Name_2001], [Name_2008], [Name_2012], [CREATED], [OID], [Geom]<br>FROM [BUILD BASE LVL 2 Table] | |

| Methodology and data input EMaR land, November 2018 | 2012 quality assurance notes developed in 2019 method. (2012 chosen because more metadata from WRC for a comparison purpose) |
|---|---|
| INNER JOIN [~TMP]<br>ON [BUILD BASE LVL 2 Table].[PID] = [~TMP].[UID]<br>THREADS SystemCpuCount();<br>DROP TABLE [~TMP]; | |
| NZ Street Address (Electoral), LINZ, monthly. | NZ Street Address Electoral 2012, LINZ, supplied by WRC. |

# Appendix 4 – Data dictionary

## Data dictionary

### Table 16. Feature class and csv outputs

| Included in Deliverable | Feature Class & csv Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| All | OBJECTID | N | Object ID | | The unique, not null integer field used to uniquely identify rows in tables in the feature class |
| All | Shape | Y | Geometry | | The shape field defines what type of shape is stored in the feature class. In this case, polygons. |
| All | REGC2020_V1_00 | Y | Text | 2 | Regional identifier (numeric code) |
| All | REGC2020_V1_00_NAME_ASCII | Y | Text | 200 | Regional identifier (name without macrons) |
| All | LAND_AREA_SQ_KM | Y | Double | | Total land area in Kilometres squared, within each regional identifier |
| All | AREA_SQ_KM | Y | Double | | Total area in Kilometres squared, within each regional identifier |
| All | ISNZ_Airport_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Airport polygons. 1 = present, 0 = absent |
| All | ISNZ_Cemetery_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Cemetery polygons. 1 = present, 0 = absent |
| All | ISNZ_Golf_Course_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Golf Course polygons. 1 = present, 0 = absent |
| All | ISNZ_Gravel_Pit_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Gravel Pit polygons. 1 = present, 0 = absent |
| All | ISNZ_Lake_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Lake polygons. 1 = present, 0 = absent |
| All | ISNZ_Landfill_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Landfill polygons. 1 = present, 0 = absent |
| All | ISNZ_Mine_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Mine polygons. 1 = present, 0 = absent |
| All | ISNZ_Pond_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Pond polygons. 1 = present, 0 = absent |

| Included in Deliverable | Feature Class & csv Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| All | ISNZ_Residential_Area_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Residential Area polygons. 1 = present, 0 = absent |
| All | ISNZ_River_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k River polygons. 1 = present, 0 = absent |
| All | ISNZ_Pumice_Pit_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Pumice Pit polygons. 1 = present, 0 = absent |
| All | ISNZ_Canal_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Canal polygons. 1 = present, 0 = absent |
| All | ISNZ_Lagoon_Pit_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Lagoon polygons. 1 = present, 0 = absent |
| All | ISNZ_Quarry_Pit_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Quarry polygons. 1 = present, 0 = absent |
| All | ISNZ_Racetrack_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Racetrack polygons. 1 = present, 0 = absent |
| All | ISNZ_Reservoir_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Reservoir polygons. 1 = present, 0 = absent |
| All | ISNZ_Rifle_Range_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Rifle Range polygons. 1 = present, 0 = absent |
| All | ISNZ_Showground_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Showground polygons. 1 = present, 0 = absent |
| All | ISNZ_Sportsfield_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Sportfield polygons. 1 = present, 0 = absent |
| All | ISNZ_Building_Polygons__Topo__1_50k_ | Y | Short | | Binary field identifying the presence of LINZ topo 1:50k Building polygons. 1 = present, 0 = absent |
| All | Name_2018 | Y | Text | 50 | The LCDB v5.0 land cover classification (name) as at 2018/19. Only features necessary for exclusion will be present. |
| All | Name_2012 | Y | Text | 50 | The LCDB v5.0 land cover classification (name) as at 2012/13. Only features necessary for exclusion will be present. |
| All | Name_2008 | Y | Text | 50 | The LCDB v5.0 land cover classification (name) as at 2008/09. Only features necessary for exclusion will be present. |
| All | Name_2001 | Y | Text | 50 | The LCDB v5.0 land cover classification (name) as at 2001/02. Only features necessary for exclusion will be present. |

| Included in Deliverable | Feature Class & csv Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| All | ISPROTECTED | Y | Short | | Binary field identifying LINZ Protected Areas polygons. These indicate the presence of areas protected by the Conservation, Reserves, National Parks, Marine Mammal and Marine Reserves Act. 1 = present, 0 = absent |
| All | LUC1C | Y | Text | 1 | Field indicating the Land Use Capability Class Code. Derived from the NZLRI Land Use capability dataset. |
| All | LUC_HA | Y | Float | | The original, whole area in hectares of each individual and contiguous LUC1C class of land area. |
| All | Id_LUC | Y | Long/Text | 255 | Unique identifier for each area of contiguous LUC1C land. LUC1C field originates from the NZLRI Land Use Capability dataset. |
| All | ID | Y | Long | | The unique identifier (originally a Primary Key) for each parcel in the LINZ NZ Primary Parcel dataset . May also have the alias 'par_id'. |
| All | PARCEL_INTENT | Y | Text | 2002, 2008, 2012: 20 2019: 04 | A description of a right of interest intended to be assigned to each unique parcel in the LINZ NZ Primary Parcel dataset. e.g. Fee Simple Title, Road, Hydro, Maori, Railway. May also have the alias 'parcel_int'. |
| All | ISADDRESS | Y | Short | | Binary field identifying the presence of one or more LINZ NZ Street Address/NZ Street Address (Electoral) points within a whole parcel (multipart parcels grouped by unique parcel 'id') of the LINZ NZ Primary Parcel dataset. Used to identify polygon features for inclusion in the Level 3 output.1 = present, 0 = absent. |
| All | ISRESTRICTED | Y | Short | | Binary field identifying the presence of likely restrictions on the parcel_intent/land use of LINZ NZ Primary Parcels. Unrestricted parcels include those with parcel_intent: 'DCDB','Fee Simple Title','Maori','Statutory','Legalisation','Lease','Lease 20 years or More','Licence/Permit'. 1 = present, 0 = absent. |
| All | LINZ_HYDRO | Y | Short | | Binary field identifying the presence of LINZ Hydro parcels from the LINZ NZ Primary Parcel dataset, indicating a land cover of water. 1 = present, 0 = absent |
| All | LINZ_ROAD | Y | Short | | Binary field identifying the presence of LINZ Road parcels from the LINZ NZ Primary Parcel dataset, indicating roading related transport infrastructure. 1 = present, 0 = absent |

| Included in Deliverable | Feature Class & csv Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| All | LINZ_RAILWAY | Y | Short | | Binary field identifying the presence of LINZ Railway parcels from the LINZ NZ Primary Parcel dataset, indicating railway related transport infrastructure. 1 = present, 0 = absent |
| All | LINZ_STREAMBED | Y | Short | | Binary field identifying the presence of LINZ Streambed parcels from the LINZ NZ Primary Parcel dataset. 1 = present, 0 = absent |
| All | LINZ_RIVERBED | Y | Short | | Binary field identifying the presence of LINZ Riverbed parcels from the LINZ NZ Primary Parcel dataset. 1 = present, 0 = absent |
| All | PARCEL_HA | Y | Float | | The total original area in hectares associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset. One parcel id may have originally included multipart polygons in the NZ Primary Parcel dataset. |
| All | PARCEL_PRI | Y | Text | 10 | Field containing numerical range indicators associated with Table 11 in the technical report: Land parcel classification and sizes for primary production. Used to group PARCEL_HA records for analysis. |
| All | PARCEL_RES | Y | Text | 10 | Field containing numerical range indicators associated with Table 12 in the technical report: Parcel size classes partitioning residential land area. Used to group PARCEL_HA records for analysis. |
| All | FEATURE_HA | Y | Float | | Field containing the total area in hectares of each single part polygon feature present in Combinatorial_03. This is the smallest unit of areal measurement for features possible, as the datasets are not divided up further after Combinatorial_03 is created. Relevant to all outputs. |
| All | ISURBAN | Y | Short | | Binary field identifying the presence of polygone features flagged as urban land. Urban land is defined as including LCDB 'Urban Parkland/Open Space' and 'Built-up Area (settlement)' with features relevant to the time step being processed, Topo50 Airport, Cemetery, Golf Course, Rifle Range, Racetrack, Showgrounds, Sportfield, Building and Residential Area features. 1 = present, 0 = absent |
| All | ISRESIDENTIAL | Y | Short | | Binary field identifying the presence of polygone features flagged as residential land. Residential land is defined as whole parcels <= 2ha with one or more address point(s). 1 = present, 0 = absent |

| Included in Deliverable | Feature Class & csv Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| All | Shape_Length | Y | Double | | The length (perimeter) automatically recorded against each polygon feature in the dataset. Recorded in metres for the NZTM2000 projection used. |
| All | Shape_Area | Y | Double | | The area automatically recorded against each polygon feature in the dataset. Recorded in metres squared for the NZTM2000 projection used. |
| Combinatorial_03 | LEVEL1_LAND | Y | Short | | Field containing a flag indicating the inclusion of polygon features as available land, as per level 1 inclusion conditions. 1 = feature is included as availble land , 0 = feature is excluded as availble land. |
| Combinatorial_03 | LEVEL2_LAND | Y | Short | | Field containing a flag indicating the inclusion of polygon features as available land, as per level 2 inclusion conditions. 1 = feature is included as availble land , 0 = feature is excluded as availble land. |
| Combinatorial_03 | LEVEL3_LAND | Y | Short | | Field containing a flag indicating the inclusion of polygon features as available land, as per level 3 inclusion conditions. 1 = feature is included as availble land , 0 = feature is excluded as availble land. |
| Combinatorial_03 | LEVEL1_PARCEL | Y | Short | | Field containing a flag indicating the inclusion of polygon features as associated with parcels which contain any amount of available land, as per level 1 inclusion conditions. 1 = feature is included as (part of) a parcel associated with availble land , 0 = feature is excluded as (part of) a parcel associated with availble land. |
| Combinatorial_03 | LEVEL2_PARCEL | Y | Short | | Field containing a flag indicating the inclusion of polygon features as associated with parcels which contain any amount of available land, as per level 2 inclusion conditions. 1 = feature is included as (part of) a parcel associated with availble land , 0 = feature is excluded as (part of) a parcel associated with availble land. |
| Combinatorial_03 | LEVEL3_PARCEL | Y | Short | | Field containing a flag indicating the inclusion of polygon features as associated with parcels which contain any amount of available land, as per level 3 inclusion conditions. 1 = feature is included as (part of) a parcel associated with available land , 0 = feature is excluded as (part of) a parcel associated with availble land. |
| Combinatorial_Level1_parcel, | id_L1 | Y | Long | | Field containing all unique parcel 'id's from the LINZ NZ Primary Parcel dataset present after the removal of Level 1 exclusion features. A unique parcel 'id' join field for the Level1_parcel_sum join |

| Included in Deliverable | Feature Class & csv Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| Combinatorial_Level1_YYYY.csv | | | | | table, derived from the Combinatorial_Level1_land feature class output. Used to create the Combinatorial_Level1_parcel datasets and Combinatorial_03 LEVEL1_PARCEL flags. |
| Combinatorial_Level1_parcel, Combinatorial_Level1_YYYY.csv | sum_L1 | Y | Double | | The total area in hectares associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset after Level 1 sub-parcel exclusion features are removed. Derived from the Combinatorial_Level1_land feature class output. This field can be used in conjunction with the PARCEL_HA fields in the Combinatorial_03 and Combinatorial_Level1_parcel spatial datasets to determine percentages of available land per parcel, towards any necessary filtering of parcels associated with available land. |
| Combinatorial_Level2_parcel, Combinatorial_Level2_YYYY.csv | id_L2 | Y | Long | | Field containing all unique parcel 'id's from the LINZ NZ Primary Parcel dataset present after the removal of Level 2 exclusion features. A unique parcel 'id' join field for the Level2_parcel_sum join table, derived from the Combinatorial_Level2_land feature class output. Used to create the Combinatorial_Level2_parcel datasets and Combinatorial_03 LEVEL2_PARCEL flags. |
| Combinatorial_Level2_parcel, Combinatorial_Level2_YYYY.csv | sum_L2 | Y | Double | | The total area in hectares associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset after Level 2 sub-parcel exclusion features are removed. Derived from the Combinatorial_Level2_land feature class output. This field can be used in conjunction with the PARCEL_HA fields in the Combinatorial_03 and Combinatorial_Level2_parcel spatial datasets to determine percentages of available land per parcel, towards any necessary filtering of parcels associated with available land. |
| Combinatorial_Level3_parcel, Combinatorial_Level3_YYYY.csv | id_L3 | Y | Long | | Field containing all unique parcel 'id's from the LINZ NZ Primary Parcel dataset present after the removal of Level 3 exclusion parcels. A unique parcel 'id' join field for the Level3_parcel_sum join table, derived from the Combinatorial_Level3_land feature class output. Used to create the Combinatorial_Level3_parcel datasets and Combinatorial_03 LEVEL3_PARCEL flags. |

| Included in Deliverable | Feature Class & csv Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| Combinatorial_Level3_parcel, Combinatorial_Level3_YYYY.csv | sum_L3 | Y | Double | | The total area in hectares associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset after Level 3 exclusion parcels are removed. Derived from the Combinatorial_Level3_land feature class output. This field can be used in conjunction with the PARCEL_HA fields in the Combinatorial_03 and Combinatorial_Level3_parcel spatial datasets to determine percentages of available land per parcel, towards any necessary filtering of parcels associated with available land. |
| Combinatorial_Level(X)_parcel, Combinatorial_Level(X)_YYYY.csv | FREQUENCY | Y | Long | | The count of single part polygon features with identical parcel 'id' attributes. Combined to generate the sum_L(X) sums. Derived from the Combinatorial_Level(X)_land feature class output. |

**Table 17. Level parcel sum join tables**

| Included in Deliverable: | FGDB Table Field Name | Allow NULLS | Type | Definition |
|---|---|---|---|---|
| All | OBJECTID | N | Object ID | The unique, not null integer field used to uniquely identify rows in the table. |
| Level1_parcel_sum | id_L1 | Y | Long | Field containing all unique parcel 'id's from the LINZ NZ Primary Parcel dataset present after the removal of Level 1 exclusion features. A unique parcel 'id' join field for the Level1_parcel_sum join table, derived from the Combinatorial_Level1_land feature class output. Used to create the Combinatorial_Level1_parcel datasets and Combinatorial_03 LEVEL1_PARCEL flags. |
| Level1_parcel_sum | sum_L1 | Y | Double | The total area in hectares associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset after Level 1 sub-parcel exclusion features are removed. Derived from the Combinatorial_Level1_land feature class output. This field can be used in conjunction with the PARCEL_HA fields in the Combinatorial_03 and Combinatorial_Level1_parcel spatial datasets to determine percentages of available land per parcel, towards any necessary filtering of parcels associated with available land. |
| Level2_parcel_sum | id_L2 | Y | Long | Field containing all unique parcel 'id's from the LINZ NZ Primary Parcel dataset present after the removal of Level 2 exclusion features. A unique parcel 'id' join field for the Level2_parcel_sum join table, derived from the Combinatorial_Level2_land feature class output. Used to create the Combinatorial_Level2_parcel datasets and Combinatorial_03 LEVEL2_PARCEL flags. |
| Level2_parcel_sum | sum_L2 | Y | Double | The total area in hectares associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset after Level 2 sub-parcel exclusion features are removed. Derived from the Combinatorial_Level2_land feature class output. This field can be used in conjunction with the PARCEL_HA fields in the Combinatorial_03 and Combinatorial_Level2_parcel spatial datasets to determine percentages of available land per parcel, towards any necessary filtering of parcels associated with available land. |
| Level3_parcel_sum | id_L3 | Y | Long | Field containing all unique parcel 'id's from the LINZ NZ Primary Parcel dataset present after the removal of Level 3 exclusion parcels. A unique parcel 'id' join field for the Level3_parcel_sum join table, derived from the Combinatorial_Level3_land feature class output. Used to create the Combinatorial_Level3_parcel datasets and Combinatorial_03 LEVEL3_PARCEL flags. |
| Level3_parcel_sum | sum_L3 | Y | Double | The total area in hectares associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset after Level 3 exclusion parcels are removed. Derived from the Combinatorial_Level3_land feature class output. This field can be used in conjunction with the PARCEL_HA fields in the Combinatorial_03 and Combinatorial_Level3_parcel spatial datasets to determine percentages of available land per parcel, towards any necessary filtering of parcels associated with available land. |

| Included in Deliverable: | FGDB Table Field Name | Allow NULLS | Type | Definition |
|---|---|---|---|---|
| All | FREQUENCY | Y | Long | The count of single part polygon features with identical parcel 'id' attributes. Combined to generate the sum_L(X) sums. Derived from the Combinatorial_Level(X)_land feature class output. |

**Table 18. Region origin ID join table**

| Included In Deliverable: | FGDB Table Field Name | Allow NULLS | Type | Length | Definition |
|---|---|---|---|---|---|
| Region_Origin_ID | OBJECTID | N | Object ID | | The unique, not null integer field used to uniquely identify rows in the table |
| Region_Origin_ID | id_region | Y | Long | | Field containing all unique parcel 'id's from the LINZ NZ Primary Parcel dataset. A unique parcel 'id' join field for the Region_Origin_ID join table, derived from the Combinatorial_03 feature class output (pre feature removal). One unique parcel id may have more than one associated region_code. The field may be used to join to the Combinatorial outputs for regional whole parcel extraction. |
| Region_Origin_ID | region_code | Y | Text | 2 | Regional identifier (numeric code) |
| Region_Origin_ID | region_name | Y | Text | 200 | Regional identifier (name without macrons) |
| Region_Origin_ID | FREQUENCY | Y | Long | | The count of single part polygon features with identical parcel 'id' and 'region_code' attributes. Combined to generate the SUM_Shape_Area. |
| Region_Origin_ID | SUM_Shape_Area | Y | Double | | The total area in metres squared associated with each unique parcel 'id' from the LINZ NZ Primary Parcel dataset and its 'region_code'. |

## Appendix 5 – Histogram analysis of parcel size distribution

**Figure 2 Histogram showing the size distribution of land parcels in the Level 3 Likely Land Supply, relevant to the 2019 timestep. X axis labels identify groups A, B and C of the detailed parcel size classes used in the fragmentation analysis of this report (Table 5).**

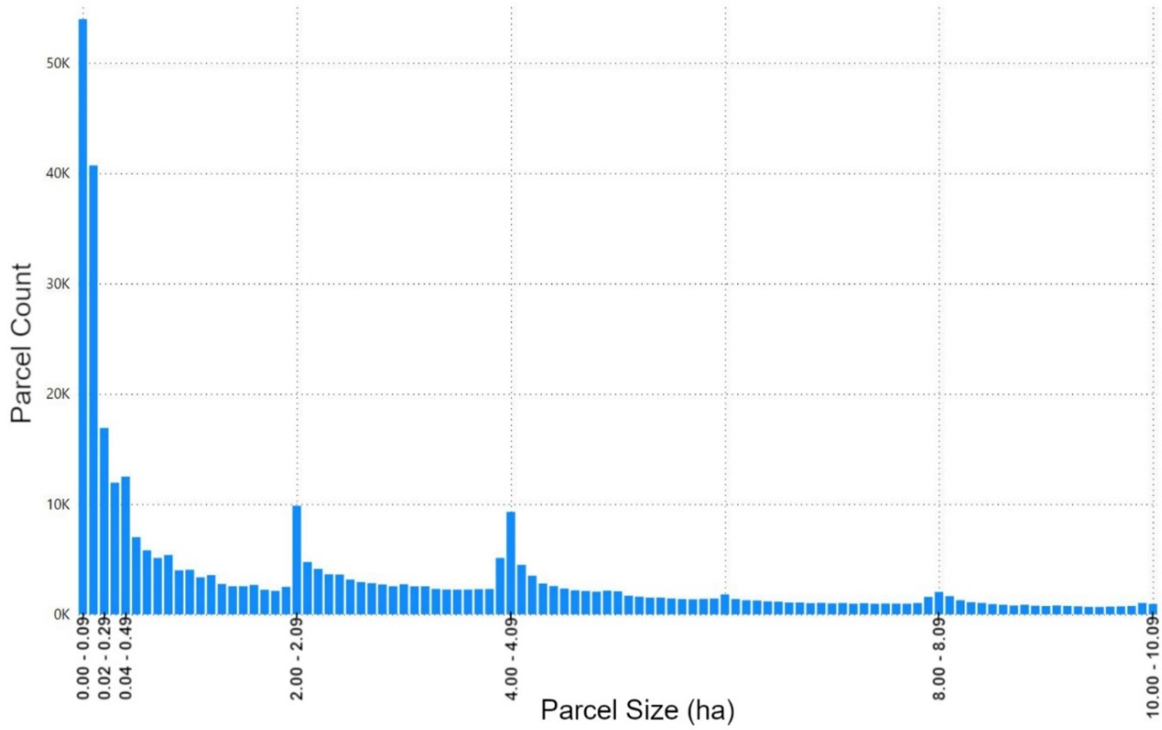


**Figure 3 Histogram of land parcel's classed as lifestyle land use in the Agribase® dataset (AsureQuality 2020). Blue lines identify groups A,B and C of the detailed parcel size classes used in the fragmentation analysis of this report (Table 5). They also highlight a distinction in parcel counts similar to that made between urban and rural residential broad parcel size classes (Table 6).**