Ministry for Primary Industries
Manatū Ahu Matua

Methodology for calculation of New Zealand's agricultural greenhouse gas emissions

Version 11

MPI Technical Paper

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Version and amendments

Version	Author(s)	Published	Changes
1.0	Andrea Pickering	May 2011	First detailed methodology report.
2.0	Simon Wear	August 2013	New methodologies, and inclusion of new crops to estimate emissions from nitrogen-fixing crops and from crop residue. Changes to the emission factors and methodology used to estimate emissions from prescribed burning of savannas and field burning of agricultural residues. Revised methodologies and emissions factors for minor species, goats, swine and poultry. Updated activity data appendix.
3.0	James M Fick	January 2016	Revised document to reflect the 2006 IPCC guidelines, changes in emission factors and methodology.
4.0	Joel Gibbs	December 2018	Revised introduction and title of document changed. New section detailing activity data sources. New section detailing the livestock population models for dairy cattle, beef cattle, sheep and deer. Updated methodology for sheep enteric methane. Revised and updated sections on: • energy requirements, • nitrogen excretion, • enteric methane, • manure management, • agricultural soils, • field burning, in order to improve completeness, transparency and readability. Revised and updated document in order to improve accuracy and completeness, following external review by Jiafa Luo, Surinder Saggar, Tony van der Weerden, Stuart Lindsey, Ronaldo Vibart, Arjan Jonker, David Pacheco, Steve Thomas, Stewart Ledgard, Cecile de Klein, Gary Waghorn, and Ryan Higgs. Re-formatted equations. Updated activity data appendix.
5.0	Hazelle Tomlin and Joel Gibbs	September 2019	Metabolisable energy (ME) required for gestation (ME_c) separated from production term (ME_p) in accordance with improvements made to the inventory model in 2019. Updated the methodology for emissions from nitrogen excretion based on methodology developed by Pacheco, Waghorn and Rollo (2018). Revisions to equations for methane and nitrous oxide from manure management to reflect review done by Rollo, Ledgard and Longhurst (2018) on the changing trends of manure management, specifically related to dairy cattle manure storage in anaerobic lagoons. Minor edits, corrections and amendments (to equations, appendices and text).

6.0	Joel Gibbs	June 2020	Included text on topography data in section 2. Minor edits and corrections to energy requirements section Addition of new text and methodology in section 5 on the allocation of nitrogen excreta to different hill slopes Revision of various sections discussing the calculation of emissions from goats Revision of text and equations in section 8.1.3 to account for the new emission factors (EF3) being used for livestock Minor corrections to equations in sections 5.1.4, 5.3.5, 8.2.2 and 8.3.2
7.0	Ben Morrow and Joel Gibbs	June 2021	Minor editorial changes and corrections throughout Updated HI value for wheat (from 0.46 to 0.41) Addition of new pasture quality data for Metabolisable Energy, Organic Matter Digestibility and Nitrogen Content in Appendix 3, 9, and 19 Addition of Appendix 27, providing total area of organic soils Update to population data in Appendixes, providing data for years 2017 - 19 Update to hill country data (from 2018 – 2019)
8.0	Catherine Sangster, Joel Gibbs and Ben Morrow	April 2022	Disaggregation of the $Frac_{LEACH}$ parameter. Updated parameter value for nitrogen leaching on cropland. Updated assumption used for purity of agricultural lime applied to farmland.
9.0	Catherine Sangster	May 2023	Disaggregation of the $Frac_{LEACH}$ parameter. Updated parameter value for nitrogen leaching on pasture and for synthetic nitrogen applied to all systems. Revised dairy population model Supplementary feed included in ME, N% and Digestibility
10.0	Catherine Sangster	April 2024	Update to the proportion of lambs held over to a second slaughter date Update to beef population methodology and liveweight calculation
11.0	Catherine Sangster	May 2025	Update to the estimated deer populations, mature hind liveweight, and velvet antler production. Update to emissions calculations for pigs Inclusion of emissions from non-manure organic amendments to soil Inclusion of a seasonal adjustment to wool growth Updated introduction

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1 Introduction

This document describes how New Zealand's agricultural greenhouse gas emissions are calculated

The methodology in this document is used to help calculate the official statistics for anthropogenic (human-induced) emissions of agricultural greenhouse gases (GHG) in New Zealand (referred to in this document as the agriculture inventory). This information is used for reporting, forecasting, and policy development purposes. New Zealand is required to report on its emissions every year under international agreements.

Emissions included under the agriculture sector are from processes in living things

Emissions from agriculture include sources such as:

- methane (CH_4) from livestock digestive systems (referred to as enteric CH_4);
- nitrous oxide (N_2O) from animal urine and dung; and
- N_2O from nitrogenous fertilisers added to the soil.

Emissions from fuel use or non-agricultural waste on farms are not covered here, instead they are included in the energy and the waste sectors.

The calculations of emissions are based on internationally-agreed rules and guidelines.

The guidelines provide standard methods to calculate emissions. The guidelines encourage countries to improve the accuracy of their estimates by developing methods optimal for their country's circumstances. A team of international experts reviews these calculations, both the standard and country-specific methods, to ensure that emissions estimates are of good quality.

New Zealand uses a model to calculate agricultural emissions

The model is based on the reporting guidelines as well as New Zealand and international scientific research. It draws on a range of different sources of information and data, for example animal population numbers, to calculate emissions.

This document is structured as follows:

The rest of Chapter 1 summarises the key international climate change agreements, provides an overview of emissions reporting, and briefly discusses New Zealand's particular circumstances for agricultural emissions reporting. At the end of the Chapter a high-level summary of the inventory model structure is outlined.

Chapter 2 discusses the sources of activity data used in the inventory.

Chapter 3 shows how monthly population numbers are calculated for the main livestock categories (dairy cattle, beef cattle, sheep and deer).

Chapter 4 outlines how the Inventory calculates energy and intake requirements for the major animal species.

Chapter 5 outlines how nitrogen intake, nitrogen retention and excretion are calculated. The distribution of nitrogen excretion on different hill slopes for beef cattle, sheep and deer are also covered.

Chapters 6 and 7 explain how emissions from enteric fermentation and manure management are calculated.

Chapter 8 explains direct and indirect N_2O emissions from agricultural soils.

Chapter 9 describes how relatively minor emissions from field burning are calculated.

Chapter 10 discusses emissions of carbon dioxide (CO_2) from carbon containing fertilisers.

Chapter 11 refers to prescribed burning of savannah.

Chapters 12 and 13 contain the references and appendices respectively.

1.1 International climate change agreements

New Zealand is a Party to the United Nations Framework Convention on Climate Change

The UNFCCC enables countries to collectively consider how to mitigate climate change and cope with its impacts. The UNFCCC became operational on 21 March 1994 and now has near-universal membership with 197 parties to the Convention.

The ultimate objective of the UNFCCC is to prevent dangerous anthropogenic (human) interference with the climate system. This requires stabilising the concentration of greenhouse gases in the atmosphere at an appropriate level. Article 2 states that such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure food production is not threatened, and to enable economic development to proceed in a sustainable manner. The treaty sets out responsibilities for three categories of states. These are developed countries, developed countries with special financial responsibilities, and developing countries. The developed countries are called Annex I countries. New Zealand is an Annex I party to the UNFCCC. Annex I countries are subject to additional obligations under the UNFCCC, obliging them to take the lead in combating climate change.

Previously New Zealand had obligations under the Kyoto Protocol

The Kyoto Protocol is a subsidiary agreement under the UNFCCC. It was developed to bring about more powerful and urgent action on climate change. The Kyoto Protocol shares and expands on the objectives, principles, and institutions of the UNFCCC. It committed developed countries (known as Annex 1 Parties) to reduction targets of GHG emissions for the first commitment period of the Kyoto Protocol (2008-2012). The Kyoto Protocol was adopted in 1997 and came into force in 2005. The first commitment period ran from 2008 to 2012.A second commitment period under the Kyoto Protocol ran from 2013 until 2020.

In 2009, New Zealand decided to take an emissions reduction commitment for the period 2013-2020 under the UNFCCC rather than under the Kyoto Protocol itself. New Zealand applied the Kyoto Protocol framework of rules to its unconditional 2020 target to ensure transparency.

The Paris Agreement took effect in 2020

The Paris Agreement is a legally binding international treaty on climate change. The Paris Agreement builds on the UNFCCC. Its overarching goal is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.”

The Paris Agreement works on a five-year cycle of increasingly ambitious climate action

Since 2020, countries have been submitting their national climate action plans, known as nationally determined contributions (NDCs). Each NDC is meant to reflect rising ambition. New Zealand’s first NDC aims to reduce net emissions by 50 per cent below our gross 2005 level by 2030. New Zealand’s second NDC aims to reduce net emissions by 51 to 55 per cent compared to 2005 levels by 2035.

With the Paris Agreement, countries established an enhanced transparency framework (ETF)

Under ETF countries report on actions taken and progress in climate change mitigation, adaptation measures and support provided or received. It also provides for international procedures for the review of the submitted reports. The agriculture inventory contributes to the following reports:

- National Communications
- Biennial Transparency Reports
- Annual GHG inventory

The inventory is submitted to the UNFCCC Secretariat in April each year. Each inventory is reviewed by a team of international experts to ensure emissions and removals are estimated accurately and transparently (UNFCCC, 2010).

The ETF specifies a standard reporting format. This ensures that estimates calculated at a detailed level can also be aggregated up to a common minimum level of detail for comparison with all other reporting countries

1.2 Guidelines for reporting emissions

New Zealand calculates its emissions following internationally-agreed rules and guidelines.

Methodological guidelines for reporting emissions and removals have been developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC is the international body for assessing the science relating to climate change. The reporting rules are decided in agreement by countries who are Parties to the Kyoto Protocol and the Paris Agreement. Standard guidelines allow the inventories of different countries to be compared.

Countries are required to calculate direct and indirect emissions and removals of the following gases:

- CO_2,
- N_2O,
- CH_4,
- carbon monoxide,
- hydrofluorocarbons,
- perfluorocarbons, and
- nitrogen trifluoride.

These are calculated across five sectors:

- Energy (e.g., emissions from transport and electricity generation)
- Industrial Processes and Product Use (IPPU) (e.g., cement production and refrigeration)
- Agriculture
- Land Use, Land-Use Change and Forestry (LULUCF)
- Waste.

Countries are required to use the 2006 IPCC Guidelines.

Since 2015, emissions are calculated using methodologies from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Countries may also use *the 2019 Refinement to the 2006 IPCC Guidelines* on a voluntary basis.

Prior to this, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, and the *Good Practice Guidance for Land Use, Land-Use Change and Forestry* were used to calculate emissions.

Emissions are calculated from activity data and emission factors.

An emission factor is defined as the average emission rate of a given GHG for a given source, relative to units of activity. They can be default values provided by the IPCC, or country-specific (i.e. emissions factors determined from in-country research). Activity data are data on the magnitude of a human activity resulting in emissions or removals taking place during a given period. Data on energy use, metal production, land areas, management systems, lime and fertilizer use and waste arisings are examples of activity data.

Countries choose which methods to use to estimate emissions.

The IPCC guidelines provide tiered reporting levels (described in section 1.3 of this chapter). Countries decide which method to follow based on:

- the size of a particular emissions source in their country,
- their capability and the availability of data, and
- the importance of a particular GHG source category in that inventory.

The Global Warming Potential allows comparison of the global warming impacts of different gasses.

Global warming potential (GWP) values are used to convert different greenhouse gases into a carbon dioxide equivalent metric. GWP measures how much a given GHG contributes to the Earth's radiative forcing over a specified time period. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) determines which GWP can be used. Currently reports must use the 100-year time-horizon GWP values from the IPCC Fifth Assessment Report (AR5).

1.3 Complexity of reporting – Tiers 1, 2, and 3

The most basic level of reporting complexity is the *Tier 1* level.

At this level, countries use activity data from their own country but can use equations and default parameters and emission factors provided by the IPCC. The methodology for Tier 1 uses data which are not broken down into subcategories, for example, total sheep population rather than the population of ewes, rams, lambs etc. The Tier 1 methodology accounts for country-specific livestock population demographics and production data through assumptions incorporated into default emission factors and related parameters. These default values are provided on a regional level, for example for Western Europe or Oceania.

A more complex methodology, *Tier 2*, can be used if disaggregated population data and production data for a country are available.

The guidelines encourage countries to improve the estimation of emissions by developing country-specific emission factors and related parameters. The basis of this Tier 2 methodology for livestock emissions is the estimation of the energy requirements for cattle and sheep, and the dry matter intake needed to meet these requirements. Dry matter intake is the weight of feed material consumed by an animal excluding the moisture the feed contains. CH_4 and N_2O emissions can then be calculated based on estimates of dry matter intake.

Tier 3 the most demanding in terms of complexity and data requirements.

Tier 3 methods require countries develop country-specific models and measurement systems that are tailored to address national circumstances, repeated over time and use high-resolution sub-national datasets.

1.4 New Zealand's agricultural emissions context

GHG emissions from pastoral agriculture make up around 50 percent of New Zealand's total emissions

Pastoral agriculture is a major component of the New Zealand agricultural sector, and pastoral agricultural products comprise around 44 percent of total merchandise exports (Free on board) in 2022 (Statistics New Zealand, 2024). As a result, GHG emissions from pastoral agriculture make up around 50 percent of New Zealand's total emissions (excluding LULUCF), the largest proportion of any Annex I party to the UNFCCC.

The Tier 2 methodology developed by the IPCC is unsuitable for New Zealand's farming systems

New Zealand has a favourable temperate climate, abundant agricultural land, and unique farming practices. Most livestock are born during July through to November (late winter to late spring). Farming practices are based on year-round outdoor grazing systems with a reliance on nitrogen fixation by legumes rather than nitrogen fertiliser as the main nitrogen source.

In New Zealand dairy cattle, beef cattle, sheep and deer are grazed outside year-round. Animal diet is composed primarily of pasture but also includes forage crops and supplementary feeds. In its original form the Tier 2 methodology developed by the IPCC for developed countries is not well suited for New Zealand's farming systems, as it is:

- based on feeding systems in Europe and the US, which use high levels of grain feed
- assumes that animals are housed for a significant portion of time.

New Zealand has developed its own Tier 2 methodology

New Zealand has developed its own Tier 2 methodology to determine the energy requirements of cattle, sheep, and deer, and subsequently the CH_4 and N_2O emissions from each species (Clark *et al*, 2003). This methodology was developed to conform to the IPCC good practice guidelines and considers the:

- unique characteristics and lifecycle of each species
- changing productivity of dairy, beef, sheep and deer industries.

This provides a more accurate estimate of emissions from New Zealand's key animal species compared with using fixed default emission factors. For example, New Zealand, like Australia, has a much lower proportion of agricultural emissions from manure management compared with other Annex 1 Parties to the UNFCCC, as intensive housing of major livestock species is rare in New Zealand. Research focused on improving the accuracy of the inventory is ongoing.

For further information of New Zealand's agriculture sector (in the context of greenhouse gas emissions) see chapters 1 and 2 (Executive summary and National Circumstances) of New Zealand's eighth national communication (https://environment.govt.nz/publications/new-zealands-eighth-national-communication/).

1.5 Sources of New Zealand's agricultural emissions

New Zealand estimates emissions using methods appropriate to the size of the different emission categories.

In 2023, 92.4 per cent of New Zealand's agriculture emissions were due to four grazed livestock categories: Dairy cattle, Non-dairy cattle, Sheep and Deer. New Zealand uses a detailed livestock population characterisation and a complex ruminant animal nutritional and energy model to support the calculation of emissions from these livestock. Livestock emissions from dairy and beef cattle, sheep and deer are calculated by using activity data to calculate the energy and intake requirements of these animals. Methodology specific to New Zealand is then used to calculate the resulting CH_4 and N_2O emissions from the calculated intake level.

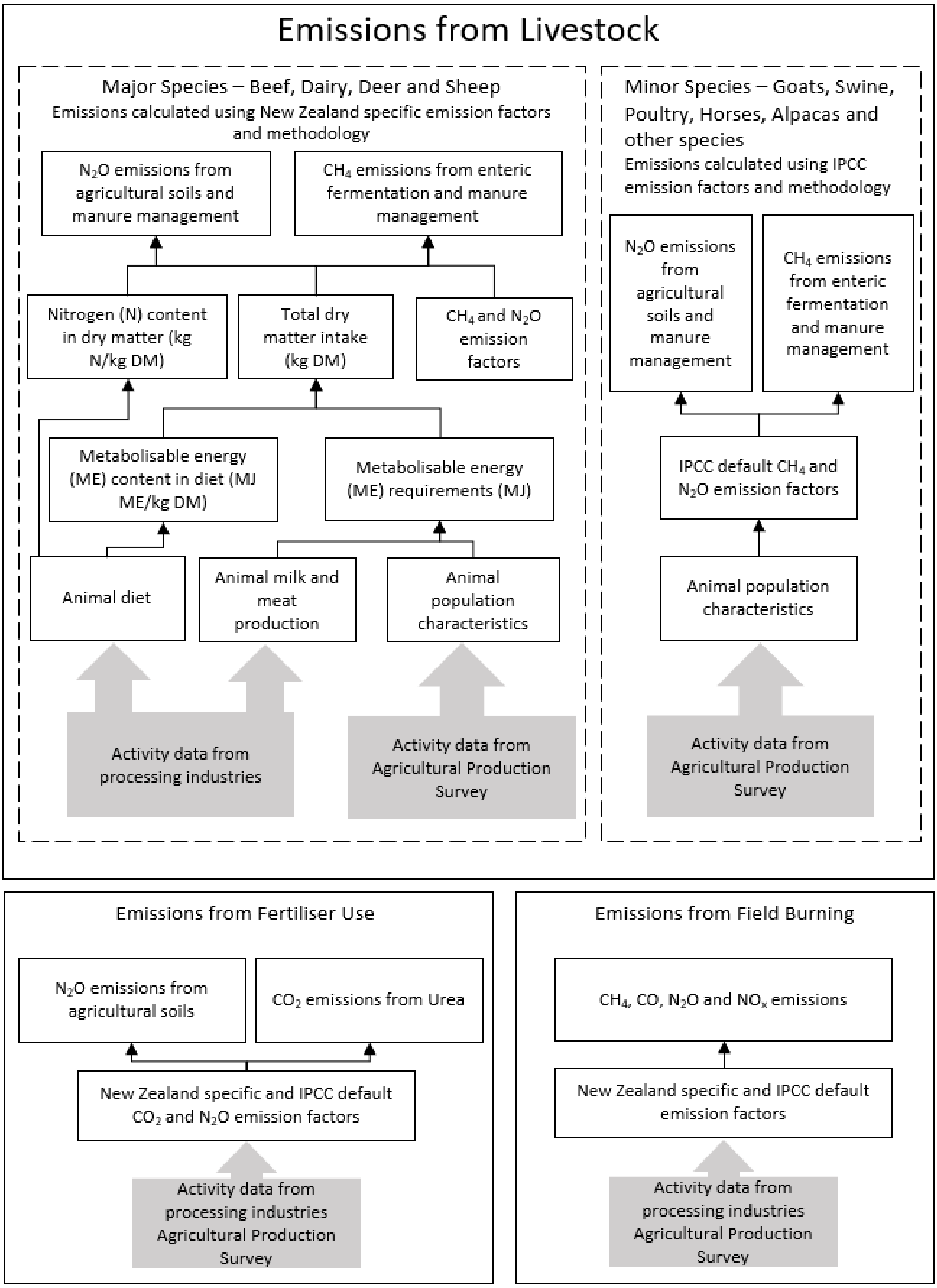
Other livestock species (Swine, Goats, Horses, Llama and alpacas, Mules and asses, and Poultry – referred to as 'minor' livestock categories) account for only 0.4 per cent of New Zealand's agriculture emissions and are estimated using Tier 1 methods. Where possible, New Zealand has used country-specific emission methods and emission factors to estimate emissions for these minor livestock species.

Direct and indirect N_2O emissions from synthetic fertiliser account for 3.3 per cent of New Zealand's agricultural emissions. Emissions associated with the use of fertiliser are calculated from activity data and a mixture of New Zealand and IPCC emission factors. CO_2 emissions from liming and urea contributed a combination of 1.72 per cent towards total agricultural emissions in 2023.

The remaining 2.1 per cent of New Zealand's agriculture emissions is due to organic fertiliser, crop residue returned to the soil, cropland cultivation (histosols and N mineralisation) and cropland burning. Emissions from crop residues and the burning of some agriculture residues are calculated by using a Tier 2 method.

The diagram below outlines how the inventory calculates different emission categories.

Figure 1.1: Schematic diagram of how New Zealand's agriculture emissions are calculated



2 Activity data – sources and assumptions

The inventory model uses information about agricultural activities to estimate emissions.

The inventory model uses activity data along with emission factors, equations and methodologies to estimate emissions. Activity data is defined as “data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time” (UNFCCC, 2014).

Data for the inventory is collected annually from the sources listed in Table 2.1.

A large amount of data for the inventory is collected by Statistics New Zealand, through a census held every five years (the Agricultural Production Census, (APC)) or through a survey (the Agricultural Production Survey APS)) held annually between census years. Activity data is also collected from industry organisations and the Ministry for Primary Industries (MPI).

Detailed data from the APS, DairyNZ, Beef and Lamb New Zealand, Deer Industry New Zealand, and slaughter statistics collected by MPI are all required for the Tier 2 part of the inventory model.

Most inventory data is collected on a June year-end basis.

Data collection in the year to June corresponds with the financial year for most New Zealand businesses and enables reporting of stable livestock populations at the end of June prior to the spring births that bulge the populations.

The Inventory is calculated for a calendar year.

January–December values are calculated from two years of data; the last six months of one June year and the first six months of the next. An underlying ‘population model’ of month-by-month demographic changes, including births and slaughters, has been developed using industry knowledge and assumptions as detailed in Chapter 3 and in Clark (2008). This provides population data for each subcategory of species for use in the model calculations.

Table 2.1: Sources of agricultural activity data used in the inventory

Description of data	Source
Animal population	Statistics New Zealand (APS and APC)
Dairy production	Livestock Improvement Corporation (LIC)
Dairy cow liveweight	Livestock Improvement Corporation (LIC)
Live cattle exports	Statistics New Zealand (Overseas merchandise trade statistics)
Wool production	Beef + Lamb New Zealand
Sheep, beef, and deer farm area by hill slope	Beef + Lamb New Zealand
Meat production and liveweight (sheep and beef)	Ministry for Primary Industries
Meat production (swine)	Ministry for Primary Industries
Deer liveweight	Ministry for Primary Industries
Synthetic fertiliser and urea	Fertiliser Association of New Zealand
Limestone and dolomite use	Statistics New Zealand (APS and APC)
Urease inhibitor use	Fertiliser Association of New Zealand
Soil organic matter loss	Ministry for the Environment
Pasture renewal	AsureQuality
Crop yield or area	Statistics New Zealand (APS and APC)
Pea production	Horticulture New Zealand
Potato production	Potatoes New Zealand
Burning of crop residue	Statistics New Zealand (APS and APC)
Seed production	AsureQuality

2.1 Animal population data - Dairy

For dairy, population data for the following subcategories of dairy cattle is required for the inventory:

- Milking cows and heifers
- Growing females < 1 year old
- Growing females 1-2 years old
- Breeding bulls

This data is collected by Statistics New Zealand. The inventory model uses regional dairy population data which is combined with regional production data to calculate dairy emissions at a regional level.

Under the IPCC Guidelines, it is recommended that emissions reported as “dairy” include only those emissions from dairy cows in commercial milk production, with emissions from the other cattle in the dairy herd reported along with beef cattle emissions under “other cattle”. However, for New Zealand’s inventory the definition of “dairy cattle” includes all heifers and growing females that will be used for milk production, and the breeding bulls specific to the dairy industry. The growing females are divided into two age classes. Therefore emissions are estimated for four sub-categories of dairy cattle: milking cows and heifers, growing females < 1 year old, growing females 1-2 years old, and breeding bulls. Consequently, emissions reported in the inventory under the dairy Section cover a broader range of animals than may be reported by other countries.

2.2 Animal population data - Beef

Population data for the following subcategories of beef cattle is required for the inventory:

- Growing cows 0 – 1 years
- Growing cows 1 – 2 years
- Breeding growing cows 2 – 3 years
- Breeding mature cows
- Breeding Bulls – mixed age
- Slaughter Heifers 0-1
- Slaughter Heifers 1-2
- Slaughter Heifers 2-3
- Slaughter Steers 0-1
- Slaughter Steers 1-2
- Slaughter Steers 2-3
- Slaughter Bulls 0-1
- Slaughter Bulls 1-2
- Slaughter Bulls 2-3

This data is collected by Statistics New Zealand. Data from Beef + Lamb NZ (see section 2.8) on the area of farm land and proportion of animals on different slopes is also needed to calculate nitrous oxide emissions.

2.3 Animal population data - Sheep

Population data on following subcategories of sheep is required for the inventory:

- Dry ewes
- Mature Breeding ewes
- Growing breeding sheep
- Growing non-breeding sheep
- Wethers
- Lambs
- Rams

This data is collected by Statistics New Zealand. Data from Beef + Lamb NZ (see section 2.8) on the area of farm land and proportion of animals on different slopes is also needed to calculate nitrous oxide emissions.

2.4 Animal population data - Deer

Population data on the following subcategories of deer is required for the inventory:

- Velvet hinds 0-1 years
- Velvet hinds 1-2
- Velvet hinds mature
- Velvet stags 0-1
- Velvet stags 1-2
- Velvet stags 2-3
- Velvet stags mature
- Venison hinds 0-1
- Venison hinds breeding 1-2
- Venison hinds mature
- Venison hinds non-breeding 1-2
- Venison stags 0-1
- Venison stags 1-2
- Venison stags 2-3
- Venison stags mature

This data is collected by Statistics New Zealand.

2.5 Animal population data – Minor Species

Population data on *goats*, *swine*, *poultry*, *emus*, *ostriches*, *horses*, and *alpacas* is collected annually by Statistics New Zealand and industry organisations. A Tier 1 methodology is used to calculate emissions from these animals.

2.6 Meat, wool and dairy production

In the inventory, production data refers to milk, meat and wool that is produced by the major livestock species (dairy cattle, beef cattle, sheep and deer). This information is collected by industry organisations and the Ministry for Primary Industries.

For the major livestock species, population data is combined with production data (e.g. milk, meat, wool) to calculate the energy requirements of these animals, which is discussed in the following chapter.

2.7 Fertiliser data

Data on the use of the following types of fertiliser is required for the inventory:

- Fertiliser nitrogen
- Urea
- Urea fertiliser coated with urease inhibitor
- Limestone
- Dolomite

This information is collected by industry organisations and Statistics New Zealand.

2.8 Topography data

Following changes made to the 2020 inventory, data on the topography of sheep, beef and deer farm land is required:

- Area of sheep, beef and deer farm land classed as flat, rolling or steep (split by region)
- Proportion of sheep, beef and deer on flat, rolling or steep land (split by region)

This information is compiled by Beef + Lamb New Zealand

2.9 Additional information

Further information on the following is collected for the inventory:

- Land undergoing pasture renewal
- Crop production
- Seed production

This is sourced from Statistics New Zealand and industry organisations, and is used to calculate emissions from pasture renewal, the decay of crop residue and the burning of crop residue. Emissions from these sources make up less than one per cent of New Zealand's total agricultural emissions.

3 Monthly population model

Population models are used to calculate monthly populations for the major livestock (Dairy cattle, beef cattle, sheep and deer) species. These models are outlined below, and in the paper by Clark (2008). Additional refinements to the population models were recommended by Thompson et.al. (2010) and Burggraaf et.al (2022).

The population models have been constructed to reflect the natural variation in livestock populations that occur throughout the year.

These models use APS data, Statistics NZ overseas merchandise trade statistics, and a set of fixed parameters and assumptions. To estimate monthly livestock populations for a full calendar year (January to December), data from three APS years is needed. This is because the inventory is reported by calendar year, while the model calculations and activity data follow the animals' physiological year, which typically runs from July to June. The APS provides livestock population data as at 30 June each year, for selected classes of animals.

The rest of this chapter explains the equations used to calculate monthly populations for the subcategories of livestock.

3.1 Dairy population model

3.1.1 Mature milking cows

Culling and losses from death occur throughout the year on New Zealand dairy farms.

The number and timing of culling of dairy cows can be affected by climate, milk price, timing of calving and many other factors. In dry years, or when milk prices are low, a portion of the herd may be culled in summer, before the end of lactation, so that more feed is available for remaining milkers. The methodology has been designed to capture the variation between years.

For the purposes of calculating the population the year begins on July 1st. Year t begins on the 1st of July and ends on 30th June in the following calendar year.

In the model, the mature milking cow numbers in July includes dry cows which are assumed to be sold to slaughter during the July calving period. The parameter $POPdnmc_t$, which counts the number of dry cows *and* heifers, is an annual number provided by the APS. It has been assumed (based on 1990-1996 data) that 53% of the animals making up $POPdnmc_t$ are dry cows (as opposed to heifers).

Equation 3.1 *Population of mature milking cows, on July 1st of year t*

$$POPmmc_{july1(t)} = POPdm_t + POPdnmc_t \times P_{dry}$$

Where:

$POPmmc_{july1(t)}$ = population of mature milking cows on 1st July (year *t*)

$POPdm_t$ = Total number of dairy cows and heifers, in milk or calf in year *t* (using data from APS)

$POPdnmc_t$ = Total number of dairy cows and heifers NOT in milk or calf in year *t* (using data from APS)

P_{dry} = proportion of dry cows compared to the total number of dairy cows and heifers NOT in milk or calf (currently assumed to be 53%)

For mature cows, the population in the model is set to peak in July. A total loss of 16.9% of the July 1st population is applied over the course of the year. This includes deaths and culls to slaughter of both empty and lactating cows.

In the model a long-term average monthly cull distribution (Appendix 11) to determine the proportion of the starting population of mature cows (including the 53% of the empty cows and heifers) still present each month.

Equation 3.2 *Survival rate of mature milking cows, at the end point of each month*

$$Survival\%_{month} = 1 - (TotalLoss\% \times \sum_{july-month} Slaughter\%_{month})$$

Where:

$Survival\%_{month}$ = percentage of the 1 July population remaining at the end of the month

TotalLoss% = 16.9%

$Slaughter\%_{month}$ = % of annual slaughter deaths (See Appendix 11)

Equation 3.3 *Population of mature milking cows, at the end point of each month*

$$POPmmc_{month\_end} = POPmmc_{july1(t)} \times Survival\%_{month}$$

Where:

$POPmmc_{month\_end(t)}$ = Population of mature milking cows, at the end point of each month (year *t*)

$POPmcc_{july1(t)}$ = population of mature milking cows on 1st July (year *t*)

$Survival\%_{month}$ = percentage of the 1 July population remaining at the end of the month

The final step is to calculate population values that characterise a whole month, not just the end point. The end month population data are adjusted to the mid-point of the month by averaging the end of the current and following month. The midpoint better characterised the whole month for monthly calculations.

3.1.2 Growing Heifers 0-1 years

For each physiological year (July to June), it is assumed that there is a 1% death rate for growing heifers 0-1 years. The August population is calculated by adding 1% to the next years June population. This 1% is decayed steadily over the year until the next July.

In July the population of growing heifers aged 0-1 is assumed to be zero as the June population of heifers in this age group move into the growing heifer 1-2 year category.

The following equation is used to calculate the August population of growing heifers aged between zero and one years. All of the required data are from the APS.

Equation 3.4 *August population of growing heifers aged between zero and one*

$$POPgh_{0-1Aug(t)} = (POPtotaldairy_t - POPdm_t - POPdnm_t - POPdbb_t) \times 1.01$$

Where:

$POPgh_{0\text{-}1month(t)}$ = population of growing heifers aged between zero and one in a particular month and year *t*

$POPtotaldairy_t$ = Total number of dairy cattle (using APS data)

$POPdm_t$ = Total number of dairy cows and heifers, in milk or calf year *t* (using data from the APS)

$POPdnm_t$ = Number of dairy cows and heifers *not* in milk or calf year *t* (using data from the APS)

$POPdbb_t$ = Number of dairy breeding bulls year *t* (using data from the APS)

Equation 3.5 *September to June population of growing heifers aged between zero and one*

$$POPgh_{0-1month(t)} = POPgh_{0-1Aug(t)} \times \sum_{August-month} (1 - 0.001month)$$

Where:

$POPgh_{0\text{-}1month(t)}$ = population of growing heifers aged between zero and one in particular month and year *t*

The final step is to calculate population values that characterise a whole month, not just the end point. The end month population data are adjusted to the mid-point of the month by averaging the end of the current and following month. The midpoint better characterised the whole month for monthly calculations.

3.1.3 Growing Heifers 1-2 years

In the model, the growing heifer 1-2 years numbers in July include dry heifers which are assumed to be sold to slaughter during the July calving period or exported through the year. The parameter $POPdnmc_t$, which counts the number of dry cows *and* heifers, is an annual number provided by the APS. It has been assumed (based on 1990-1996 data) that 47% of the animals making up $POPdnmc_t$ are heifers (as opposed to dry cows).

Equation 3.6 *July population of growing heifers aged between one and two*

$$POPgh_{1-2July} = POPgh_{0-1July(t)} + POPdnmc_t \times \left(1 - P_{dry}\right)$$

Where:

$POPgh_{1\text{-}2July}$ = population of growing heifers aged between one and two in July

$POPgh_{0\text{-}1July(t)}$ = population of growing heifers aged between zero and one in APS of same calendar year (just before 1 year old)

$POPdnmc_t$ = Total number of dairy cows and heifers, NOT in milk or calf in year t (using data from the APS)

P_{dry} = proportion of dry cows compared to the total number of dairy cows and heifers NOT in milk or calf (currently assumed to be 53%)

For the month of August, the method of calculation depends on the export volumes to ensure all the dry heifers are either exported or culled. If the annual export volume is less than the 47% of the not in-calf and not-lactating cows and heifers, the difference between 47% of the not in-calf and not-lactating cows and heifers and the annual heifer exports is removed from the august population. If the annual export volume is greater than the 47% of the not in-calf and not-lactating cows and heifers, no heifers are removed from the august population.

Data are not reported on the sex, breed, or age, however, more than 95% of the total prior to 2018 were dairy cattle, but beef-breed cattle exports have increased since then, possibly at around 10% of the total. Breeding bulls are a very small proportion of total exports.

Equation 3.7 *Heifer exports*

January 1990 to December 2018,

$$Exports_{month} = TotalExports_{month} \times 0.95$$

January 2019 onwards,

$$Exports_{month} = TotalExports_{month} \times 0.90$$

Where:

$Exports_{month}$ = heifer exports in month

$TotalExports_{month}$= total live cattle exports

Equation 3.8 *August population of growing heifers aged between one and two*

If $POPdnm_t \times \left(1 - P_{dry}\right) \leq Exports_{annual}$,

$$POPgh_{1-2Aug} = POPgh_{1-2July} - Exports_{July}$$

If $POPdnm_t \times \left(1 - P_{dry}\right) > Exports_{annual}$,

$$POPgh_{1-2Aug} = (POPgh_{1-2July} - Exports_{July}) - (POPdnm_t \times \left(1 - P_{dry}\right) - Exports_{annual})$$

Where:

$POPgh_{1\text{-}2July}$ = population of growing heifers aged between one and two in July

$POPgh_{0\text{-}1July(t)}$ = population of growing heifers aged between zero and one in APS of same calendar year (just before 1 year old)

$POPdnmc_t$ = Total number of dairy cows and heifers, NOT in milk or calf in year t (using data from the APS)

P_{dry} = proportion of dry cows compared to the total number of dairy cows and heifers NOT in milk or calf (currently assumed to be 53%)

$Exports_{July}$ = heifers exported in July

$Exports_{annual}$ = heifers exported in year t.

For the remaining months, a 1% death rate is applied, and monthly exports are subtracted.

Equation 3.9 *September – June population of growing heifers aged between one and two*

$$POPgh_{1-2month} = \left(POPgh_{1-2(month-1)} \times 0.999\right) - \ Exports_{month-1}$$

Where:

$POPgh_{1\text{-}2month}$ = population of growing heifers aged between one and two in a given month (September – June)

$POPgh_{1\text{-}2(month\text{-}1)}$ = population of growing heifers aged between one and two in the previous month

$Exports_{month\text{-}1}$ = heifer exports in previous month

3.1.4 Breeding Bulls

To calculate the population of breeding bulls for a particular month, data from two agricultural production surveys are required.

For the purposes of calculating the population the year now refers to the calendar year.

The July breeding bull population for any given year is equal to the dairy breeding population in the APS for that year. For the four months preceding July (March-June) the monthly populations are calculated by going backward month by month from the July value. The following equation is used to estimate the breeding bull population for June, May, April and March:

Equation 3.10 *Monthly population of breeding bulls, from March to June in year t*

$$POPbb_{(m)(t)} = POPbb_{(m+1)(t)} + \left(\frac{POPbb_{APS(t-1)} - POPbb_{APS(t)}}{nod_{year}}\right) \times nod_m$$

Where:

$POPbb_{(m)(t)}$ = population of breeding bulls in specific month *m* (year *t*)

$POPbb_{(m+1)(t)}$ = population of breeding bulls in next month *m+1* (year *t*)

$POPbb_{APS(t\text{-}1)}$ = population of dairy breeding bulls in previous year *t-1* (using data from the APS)

$POPbb_{APS(t)}$ = population of dairy breeding bulls from APS in current year *t* (using data from the APS)

nod_{year} = number of days in year

nod_m = number of days in month *m*

For the seven months after July (August-February) the monthly populations are calculated by going forward month by month from the July value.

Equation 3.11 *Monthly population of breeding bulls, from August in year t to February in year t+1*

$$POPbb_{(m)} = POPbb_{(m-1)} + \left(\frac{POPbb_{APS(t)} - POPbb_{APS(t+1)}}{nod_{year}}\right) \times nod_m$$

Where:

$POPbb_{(m)}$ = population of breeding bulls in specific month *m*

$POPbb_{(m-1)}$ = population of breeding bulls in previous month *m-1*

$POPbb_{APS(t)}$ = population of dairy breeding bulls from APS in year *t* (using data from the APS)

$POPbb_{APS(t+1)}$ = population of dairy breeding bulls from APS in year *t+1* (using data from the APS)

nod_{year} = number of days in year

nod_m = number of days in month *m*

The equations are designed to adjust the population of bulls gradually throughout the year, with a large change in from February to March as bulls are introduced into the herd or culled.

3.2 Beef population model

Eleven different classes of beef cattle are used in the model. These populations have strong links with each other as the cattle move from one age group to another:

The four classes of breeding cow are:

- Breeding Growing Cows 0-1
- Breeding Growing Cows 1-2
- Breeding Growing Cows 2-3
- Breeding Mature Cows

Breeding bulls have their own class:

- Breeding Bulls Mixed Age

The nine classes of slaughter animals are:

- Slaughter Heifers 0-1
- Slaughter Heifers 1-2
- Slaughter Heifers 2-3
- Slaughter Steers 0-1
- Slaughter Steers 1-2
- Slaughter Steers 2-3
- Slaughter Bulls 0-1
- Slaughter Bulls 1-2
- Slaughter Bulls 2-3

For all classes the average population for each month is calculated.

3.2.1 Breeding growing cows

The three classes of breeding growing cow are:

- Breeding Growing Cows 0-1
- Breeding Growing Cows 1-2
- Breeding Growing Cows 2-3

These populations are calculated using the same APS data (beef cows and heifers in calf, LC7057). The inventory assumes that the July 1st population of breeding growing cows aged 0-1, 1-2, and 2-3 are the same (all equal to LC7057). The inventory assumes these classes have the same annual death rate, which is currently assumed to be 2% per year.

Breeding growing cows aged 0-1 are used to demonstrate the calculations in the equations below. As the treatment of the three classes is identical, the equations outlined can also be used to calculate the population for breeding growing cows aged 1-2 and 2-3.

As the population change is linear, the average population in July is equal to the population at the midpoint of the month.

Equation 3.12 *Population of breeding growing cows aged between 0 and 1, for July*

$$POPbgc1_{jul} = POPbgc1_{jul\,1} \times \left(1 - \frac{DR_{bgc1}}{nod_{year}} \times \frac{nod_{jul}}{2}\right)$$

Where:

$POPbgc1_{jul}$ = population of breeding growing cows aged 0-1 in July

$POPbgc1_{jul1}$ = population of breeding growing cows aged 0-1 on July 1st

DR_{bgc1} = annual death rate of breeding growing cows aged 0-1

nod_{year} = number of days in year

nod_{july} = number of days in *July*

In August, the population of breeding growing cows is calculated forward from the July population using the following equation:

Equation 3.13 *Population of breeding growing cows aged between 0 and 1, for August*

$$POPbgc1_{aug} = POPbgc1_{jul} \times \left(1 - \frac{DR_{bgc1}}{nod_{year}} \times nod_{jul}\right)$$

Where:

$POPbgc1_{aug}$ = population of breeding growing cows aged 0-1 in August

$POPbgc1_{jul}$ = population of breeding growing cows aged 0-1 in July

DR_{bgc1} = annual death rate of breeding growing cows aged 0-1

nod_{year} = number of days in year

nod_{july} = number of days in *July*

For the four months preceding July (October-June) the monthly populations are calculated by going backward month by month from the July value:

Equation 3.14 *Monthly population of breeding growing cows aged 0 to 1, from October in year t to June in year t+1*

$$POPbgc1_{m} = POPbgc1_{(m+1)} \times \left(1 + \frac{DR_{bgc1}}{nod_{year}} \times nod_{m}\right)$$

Where:

$POPbgc1_{m}$ = population of breeding growing cows aged 0-1 in month *m*

$POPbgc1_{m+1}$ = population of breeding growing cows aged 0-1 in previous month *m-1*

DR_{bgc1} = annual death rate of breeding growing cows aged 0-1

nod_{year} = number of days in year

nod_{m} = number of days in month *m*

In September, breeding cows move into the next age group. Because of this there is an instantaneous change in the population on the 25th as breeding cows are either born or aged up. A weighted average of the population before and after the birthday is calculated as the representative population for September.

Populations for breeding growing cows are calculated forward from the midpoint of August and backwards from the midpoint of October. This determines the number of days the death rate must be applied to calculate the average population before and after the birthday.

Equation 3.15 *Population of breeding growing cows aged 0-1, for September, before and after cattle birth date*

$$POPbgc1_{sepAB} = POPbgc1_{oct(t)} \times \left(1 + \frac{DR_{bgc1}}{nod_{year}} \times \left(\frac{nod_{sep} - B_{day}}{2} + \frac{nod_{oct}}{2}\right)\right)$$

$$POPbgc1_{sepBB} = POPbgc1_{aug(t)} \times \left(1 - \frac{DR_{bgc1}}{nod_{year}} \times \left(\frac{nod_{aug} + B_{day}}{2}\right)\right)$$

Where:

$POPbgc1_{sepAB}$ = population of breeding growing cows aged 0-1 after birthday September in year *t*

$POPbgc1_{sepBB}$ = population of breeding growing cows aged 0-1 before birthday September in year *t*

$POPbgc1_{aug(t)}$ = population of breeding growing cows aged 0-1 in August in year t

$POPbgc1_{oct(t)}$ = population of breeding growing cows aged 0-1 in October in year t

DR_{bgc1} = annual death rate of breeding growing cows aged 0-1

nod_{year} = number of days in year

nod_{oct} = number of days in month *October*

nod_{sept} = number of days in month *September*

nod_{aug} = number of days in month *August*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

These populations are then combined as a weighted average (Equation 3.16).

Equation 3.16 *Population of breeding growing cows aged 0-1, for September*

$$POPbgc1_{sep} = \frac{POPbgc1_{sepBB} \times B_{day} + POPbgc1_{sepAB} \times (nod_{sep} - B_{day})}{nod_{sep}}$$

Where:

$POPbgc1_{sep}$ = population of breeding growing cows aged 0-1 in September

$POPbgc1_{sepAB}$ = population of breeding growing cows aged 0-1 in after birthday

$POPbgc1_{sepBB}$ = population of breeding growing cows aged 0-1 in before birthday

nod_{sept} = number of days in month *September*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

3.2.2 **Breeding mature cows**

The calculation of monthly mature breeding cow populations is more complicated than the calculation of younger breeding cow populations, and follows a three-step process detailed below.

Step 1

An initial population of breeding mature cows is calculated for each month.

The July 1st population is equal to the number of beef cows and heifers in calf 2 years and over (LC7056) less July 1st population of breeding growing cows aged 2-3 (LC7057). The average value for July is calculated using Equation 3.12.

The August population is calculate using Equation 3.13. The annual death rate for breeding mature cows is currently assumed to be 2.7% per year.

On September 25th the breeding growing cows 2-3 age up into the breeding mature cows. An averaging process is applied. This differs slightly from the process described in 3.2.1 as both the breeding mature cow and the incoming breeding growing cow populations are being calculated forward from the August value.

Equation 3.17 *Population of breeding mature cows, for September in year t, before and after cattle birth date*

$$POPbmc_{sepAB} = POPbmc_{aug} \times \left(1 - \frac{DR_{bmc}}{nod_{year}} \times \left(\frac{nod_{sep} + B_{day}}{2} + \frac{nod_{aug}}{2}\right)\right) +$$
$$POPbgc3_{aug} \times \left(1 - \frac{DR_{bgc3}}{nod_{year}} \times \left(\frac{nod_{sep} + B_{day}}{2} + \frac{nod_{aug}}{2}\right)\right)$$
$$POPbmc_{sepBB} = POPbgc1_{aug} \times \left(1 - \frac{DR_{bmc}}{nod_{year}} \times \left(\frac{nod_{aug} + B_{day}}{2}\right)\right)$$

Where:

$POPbmc_{sepAB}$ = population of breeding mature cows in after birthday September

$POPbmc_{sepBB}$ = population of breeding mature cows in before birthday September

$POPbmc_{aug}$ = population of breeding mature cows in August

$POPbgc3_{aug}$ = population of breeding growing cows aged 2-3 in August

DR_{bgc3} = annual death rate of breeding growing cows aged 2-3

DR_{bmc} = annual death rate of breeding mature cows

nod_{year} = number of days in year

nod_{sept} = number of days in month *September*

nod_{aug} = number of days in month *August*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

These populations are then combined as a weighted average.

Equation 3.18 *Population of breeding mature cows, for September*

$$POPbmc_{sep} = \frac{POPbmc_{sepBB} \times B_{day} + POPbmc_{sepAB} \times (nod_{sep} - B_{day})}{nod_{sep}}$$

Where:

$POPbmc_{sep}$ = population of breeding mature cows in September

$POPbmc_{sepAB}$ = population of breeding mature cows after birthday in September

$POPbmc_{sep(t)BB}$ = population of breeding mature cows before birthday in September

nod_{sept} = number of days in month *September*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

The populations from October to February are calculated forwards from September. However, it is important not to use the average value calculated above as the starting point as this would artificially lower the result. Therefore, the next step is to calculate the value on the 15th of October, after the breeding growing cows 2-3 have entered the breeding mature cow population. The August populations for breeding mature cows and breeding growing cows 2-3 are decayed from the midpoint of August to the first of October using their respective death rates. From this value the breeding mature cow population is calculated at midpoint of October.

Equation 3.19 *Population of breeding mature cows for October 1*

$$POPbmc_{oct1} = POPbmc_{aug} \times \left(1 - \frac{DR_{bmc}}{nod_{year}} \times \left(\frac{nod_{aug}}{2} + nod_{sep}\right)\right) + POPbgc3_{aug} \times \left(1 - \frac{DR_{bgc3}}{nod_{year}} \times \left(\frac{nod_{aug}}{2} + nod_{sep}\right)\right)$$

Where:

$POPbmc_{oct1}$ = population of breeding mature cows on 1st October

$POPbmc_{aug}$ = population of breeding mature cows in August

$POPbgc3_{aug}$ = population of breeding growing cows aged 2-3 in August

DR_{bgc3} = annual death rate of breeding growing cows aged 2-3

DR_{bmc} = annual death rate of breeding mature cows

nod_{year} = number of days in year

nod_{sept} = number of days in month *September*

nod_{aug} = number of days in month *August*

Equation 3.20 *Population of breeding mature cows, for October*

$$POPbmc_{Oct} = POPbmc_{oct1} \times \left(1 - \frac{DR_{bmc}}{nod_{year}} \times \left(\frac{nod_{oct}}{2}\right)\right)$$

Where:

$POPbmc_{oct1}$ = population of breeding mature cows on 1st October

$POPbmc_{oct}$ = population of breeding mature cows in October

DR_{bmc} = annual death rate of breeding mature cows

nod_{year} = number of days in year

nod_{oct} = number of days in month *October*

From November to February the population of mature breeding cows is calculated forward from the previous month.

Equation 3.21 *Population of breeding mature cows, for November to February*

$$POPbmc_m = POPbmc_{m-1} \times \left(1 - \frac{DR_{bmc}}{nod_{year}} \times nod_{m-1}\right)$$

Where:

$POPbmc_m$ = population of breeding mature cows in month *m*

$POPbmc_{m-1}$ = population of breeding mature cows in previous month *m-1*

DR_{bmc} = annual death rate of breeding mature cows

nod_{year} = number of days in year

nod_{m-1} = number of days in month *m -1*

For the four months preceding July (April-June) the monthly populations are calculated by going backward month by month from the July value:

Equation 3.22 *Monthly population of breeding mature cows, from April to June*

$$POPbmc_m = POPbmc_{(m+1)} \times \left(1 + \frac{DR_{bmc}}{nod_{year}} \times nod_m\right)$$

Where:

$POPbmc_m$ = population of breeding mature cows in month *m*

$POPbmc_{m+1}$ = population of breeding mature cows in previous month *m+1*

DR_{bmc} = annual death rate of breeding mature cows

nod_{year} = number of days in year

nod_m = number of days in month *m*

Breeding mature cows are slaughtered on the 31st of March (Thompson, Clark, Davison, & Muir, 2010). This date may change in the future so March uses an averaging procedure despite the step change occurring at the end of the month.

Equation 3.23 *Population of breeding mature cows, for March, before and after slaughter date*

$$POPbmc_{marAS} = POPbmc_{Apr} \times \left(1 + \frac{DR_{bmc}}{nod_{year}} \times \left(\frac{nod_{mar} - S_{day}}{2} + \frac{nod_{apr}}{2}\right)\right)$$

$$POPbmc_{marBS} = POPbmc_{Feb} \times \left(1 - \frac{DR_{bmc}}{nod_{year}} \times \left(\frac{nod_{Feb} + S_{day}}{2}\right)\right)$$

Where:

$POPbmc_{mar(t)AS}$ = population of breeding mature cows in after slaughter in March

$POPbmc_{mar(t)BS}$ = population of breeding mature cows in before slaughter in March

$POPbmc_{Feb(t)}$ = population of breeding mature cows in February

$POPbmc_{Apr(t)}$ = population of breeding mature cows in April

DR_{bmc} = annual death rate of breeding mature cows

nod_{year} = number of days in year

nod_{mar} = number of days in month *March*

nod_{Feb} = number of days in month *February*

nod_{apr} = number of days in month *April*

S_{day} = number of days from start of the month until slaughter, currently 31th March.

These populations are then combined as a weighted average.

Equation 3.24 *Population of breeding mature cows, for March*

$$POPbmc_{mar} = \frac{POPbmc_{marBS} \times S_{day} + POPbmc_{marAS} * (nod_{mar} - S_{day})}{nod_{mar}}$$

Where:

$POPbmc_{mar(t)}$ = population of breeding mature cows in March

$POPbmc_{mar(t)AS}$ = population of breeding mature cows in after slaughter in March

$POPbmc_{mar(t)BS}$ = population of breeding mature cows in before slaughter in

nod_{mar} = number of days in month *March*

S_{day} = number of days from start of the month until slaughter, currently 31th March.

Step 2

Using the population figures from step 1, an *interim* number of deaths for breeding mature cows for each month is calculated using the following formula:

Equation 3.25 *Number of deaths of breeding mature cows in month m*

$$Dbmc_m = POPbmc_m \times \left(\frac{DR_{bmc}}{nod_{year}} \times nod_m\right)$$

Where:

$Dbmc_{m(t)}$ = calculated number of deaths of mature breeding cows in month *m*

$POPbmc_{m(t)}$ = population of breeding mature cows in month *m*

DR_{bmc} = annual death rate of breeding growing cows aged 1-2

nod_{year} = number of days in year

nod_m = number of days in month *m*

These monthly death numbers are aggregated to give an annual death figure (from July to June).

Equation 3.26 *Annual number of deaths of breeding mature cows from July to June*

$$Dbmc_{AT} = \sum_{m=jul}^{jun} Dbmc_m$$

Where:

$Dbmc_{AT}$ = Annual number of deaths of mature breeding cows

$Dbmc_m$ = calculated number of deaths of mature breeding cows in month m

These calculated death numbers are reallocated, based on the assumption that half of the annual mature breeding cow deaths will occur in September. The remaining death numbers are spread evenly throughout the year.

Equation 3.27 *Number of deaths of breeding mature cows in September*

$$Dbmc_{sep(t)} = Dbmc_{AT} \times Pdeath_{bmc(sep)}$$

Where:

$Dbmc_{sep(t)}$ = calculated number of deaths of mature breeding cows in September

$Dbmc_{AT}$ = Annual number of deaths of mature breeding cows

$Pdeath_{bmc(sep)}$ = proportion of annual mature breeding cow deaths assumed to occur in September. Currently set at 50%

Equation 3.28 *Annual number of deaths of breeding mature cows, excluding September*

$$Dbmc_{exl.sep} = Dbmc_{AT} - Dbmc_{sep(t)}$$

Where:

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

$Dbmc_{AT}$ = Annual number of deaths of mature breeding cows

$Dbmc_{sep}$ = calculated number of deaths of mature breeding cows in September

Step 3

The population of mature breeding cows is re-calculated based on the annual number of deaths for mature breeding cows calculated in step two. It is assumed that half of the total annual deaths will occur in September, with the remaining amount distributed evenly throughout the rest of the year.

On July 1st it is assumed the breeding mature cow population is equal to the number of beef cows and heifers in calf 2 years and over (LC7056) less July 1st population of breeding growing cows aged 2-3 (LC7057). The equations below are used to calculate the monthly populations of mature breeding cows for the remaining months.

Equation 3.29 *Population of breeding mature cows, for July*

$$POPbmc_{jul} = POPbmc_{jul1} - \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times \frac{nod_{july}}{2}$$

Where:

$POPbmc_{jul}$ = population of breeding mature cows in July

$POPbmc_{jul1}$ = population of breeding mature cows on July 1st

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod_{year} = number of days in year

nod_{sep} = number of days in September

nod_{july} = number of days in July

Equation 3.30 *Population of breeding mature cows, for August*

$$POPbmc_{aug} = POPbmc_{jul} - \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times nod_{july}$$

Where:

$POPbmc_{aug(t)}$ = population of breeding mature cows in August

$POPbmc_{jul(t)}$ = population of breeding mature cows in July (see Equation 3.26)

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod_{year} = number of days in year

nod_{sep} = number of days in September

nod_{july} = number of days in July

On the 25th of September there is an instantaneous increase in the mature breeding cow population when the breeding growing cows age up. The inventory assumes that 50% of the annual breeding mature cow deaths occur in September. Some of these occur through the month as breeding mature cows die at the same rate as they do in other months. To reach 50% there are additional deaths that are assumed to occur suddenly at calving. Because of this a weighted average is calculated.

The first step is to calculate how many additional deaths there are in September.

Equation 3.31 *Additional deaths of breeding mature cows, for September*

$$ADbmc_{sep} = Dbmc_{sept} - \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times nod_{sep}$$

Where:

$ADbmc_{sept(t)}$ = Additional deaths in September

$Dbmc_{sep(t)}$ = calculated number of deaths of mature breeding cows in September

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod_{year} = number of days in year

nod_{sep} = number of days in September

Equation 3.32 *Population of breeding mature cows, for September, before and after cattle birth date*

$$POPbmc_{sepAB} = POPbmc_{aug} - \left(\frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times \left(\frac{nod_{sep} + B_{day}}{2} + \frac{nod_{aug}}{2}\right)\right) + POPbgc3_{aug} \times \left(1 - \frac{DR_{bgc3}}{nod_{year}} \times \left(\frac{nod_{sep} + B_{day}}{2} + \frac{nod_{aug}}{2}\right)\right) - ADbmc_{sep(t)}$$

$$POPbmc_{sepBB} = POPbmc_{aug} - \left(\frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times \left(\frac{nod_{aug} + B_{day}}{2}\right)\right)$$

Where:

$POPbmc_{sepAB}$ = population of breeding mature cows in after birthday September

$POPbmc_{sepBB}$ = population of breeding mature cows in before birthday September

$POPbmc_{aug}$ = population of breeding mature cows in August

$POPbgc3_{aug}$ = population of breeding growing cows aged 2-3 in August

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

DR_{bgc3} = annual death rate of breeding growing cows aged 2-3

$ADbmc_{sept}$ = Additional deaths in September

nod_{year} = number of days in year

nod_{sept} = number of days in month *September*

nod_{aug} = number of days in month *August*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

These populations are then combined as a weighted average (Equation 3.33).

Equation 3.33 *Population of breeding mature cows, for September*

$$POPbmc_{sep} = \frac{POPbmc_{sepBB} \times B_{day} + POPbmc_{sepAB} * (nod_{sep} - B_{day})}{nod_{sep}}$$

Where:

$POPbmc_{sep}$ = population of breeding growing cows aged 0-1 in September

$POPbmc_{sepAB}$ = population of breeding mature cows after birthday in September

$POPbmc_{sepBB}$ = population of breeding mature cows before birthday in September

nod_{sept} = number of days in month *September*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

The populations from October to February are calculated forwards from September. However, it is important not to use the average value calculated above as the starting point as this would artificially lower the result. Therefore, the next step is to calculate the value on the 15th of October, after the breeding growing cows 2-3 have entered the breeding mature cow population. The August populations for breeding mature cows and breeding growing cows 2-3 are calculated from the midpoint of August to the first of October using their respective death rates or number of deaths. From this value the breeding mature cow population is calculated at midpoint of October.

Equation 3.34 *Population of breeding mature cows, for October 1st, before and after cattle birth date*

$$POPbmc_{Oct1} = POPbmc_{aug} - \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times \left(\frac{nod_{aug}}{2} + nod_{sep}\right) + POPbgc3_{aug} \times \left(1 - \frac{DR_{bgc3}}{nod_{year}} \times \left(\frac{nod_{aug}}{2} + nod_{sep}\right)\right) - ADbmc_{sep}$$

Where:

$POPbmc_{oct1}$ = population of breeding mature cows on 1st October in year *t*

$POPbmc_{aug}$ = population of breeding mature cows in August in year *t*

$POPbgc3_{aug}$ = population of breeding growing cows aged 2-3 in August in year *t*

DR_{bgc3} = annual death rate of breeding growing cows aged 2-3

$ADbmc_{sept}$ = Additional deaths in September

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod_{year} = number of days in year

nod_{sept} = number of days in month *September*

nod_{aug} = number of days in month *August*

Equation 3.35 *Population of breeding mature cows, for October*

$$POPbmc_{oct} = POPbmc_{oct1} - \left(\frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times \left(\frac{nod_{oct}}{2}\right)\right)$$

Where:

$POPbmc_{oct1}$ = population of breeding mature cows on 1st October in year *t*

$POPbmc_{oct}$ = population of breeding mature cows in October in year *t*

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod_{year} = number of days in year

nod_{oct} = number of days in month *October*

Equation 3.36 *Population of breeding mature cows, for November in year t to February in year t+1 (* **(DairyNZ Economics Group, 2019)***)*

$$POPbmc_m = POPbmc_{m-1} - \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times nod_{m-1}$$

Where:

$POPbmc_m$ = population of breeding mature cows in month *m*

$POPbmc_{m-1}$ = population of breeding mature cows in previous month *m-1*

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod_{year} = number of days in year

nod_{sep} = number of days in September

nod_{m-1} = number of days in previous month *m*

The April to June populations of breeding mature cows is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

Equation 3.37 *Monthly population of breeding mature cows, from April to June*

$$POPbmc_m = POPbmc_{m+1} + \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times nod_m$$

Where:

$POPbmc_m$ = population of breeding mature cows in month m

$POPbmc_{m-1}$ = population of breeding mature cows in next month m+1

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September (see Equation 3.28).

nod_{year} = number of days in year

nod_{sep} = number of days in *September*

nod_m = number of days in month *m*

In March mature cows are slaughtered on the 31st (Thompson, Clark, Davison, & Muir, 2010). This date may change in the future so March uses an averaging procedure despite the step change occurring at the end of the month.

Equation 3.38 *Population of breeding mature cows, for March, before and after slaughter date*

$$POPbmc_{marAS} = POPbmc_{apr} + \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times \left(\frac{nod_{mar} - S_{day}}{2} + \frac{nod_{apr}}{2}\right)$$
$$POPbmc_{marBS} = POPbmc_{feb} - \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times \left(\frac{nod_{feb} + S_{day}}{2}\right)$$

Where:

$POPbmc_{marAS}$ = population of breeding mature cows in after slaughter in March

$POPbmc_{marBS}$ = population of breeding mature cows in before slaughter in March

$POPbmc_{feb}$ = population of breeding mature cows in February

$POPbmc_{apr}$ = population of breeding mature cows in April

$Dbmc_{exl.sep}$ = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod_{year} = number of days in year

nod_{mar} = number of days in month *March*

nod_{feb} = number of days in month *February*

nod_{apr} = number of days in month *April*

S_{day} = number of days from start of the month until slaughter, currently 31th March.

These populations are then combined as a weighted average.

Equation 3.39 *Population of breeding mature cows, for March*

$$POPbmc_{mar} = \frac{POPbmc_{marBS} \times S_{day} + POPbmc_{marAS} \times (nod_{mar} - S_{day})}{nod_{mar}}$$

Where:

$POPbmc_{mar}$ = population of breeding mature cows in March

$POPbmc_{marAS}$ = population of breeding mature cows in after slaughter in March

$POPbmc_{marBS}$ = population of breeding mature cows in before slaughter in March

nod_{mar} = number of days in month *March*

S_{day} = number of days from start of the month until slaughter, currently 31st March.

3.2.3 Slaughter classes

There are nine separate classes for non-breeding animals in the beef population model. These are Slaughter Heifers, Steers, and bulls aged 0-1,1-2, and 2-3 years. The July 1st values are taken from the APS. The linecodes for each class are listed below.

July 1st values

- Slaughter Heifers 1-2 = LC7059 Beef cows and heifers (not in calf) 1-2yrs old
- Slaughter Heifers 2-3 = Lc7058 Beef cows and heifers (not in calf) 2yrs and over
- Slaughter Steers 0-1 = Lc7067 Steer Calves, under 1 year
- Slaughter Steers 1-2 = Lc7066 Steers, 1-2 years old
- Slaughter Steers 2-3 = Lc7065 Steers, 2 years old and over
- Slaughter Bulls 0-1 = Lc7073 Beef non-breeding bulls (under 1 year)
- Slaughter Bulls 1-2 = Lc7072 Beef non-breeding bulls 1-2yrs old
- Slaughter Bulls 2-3 = Lc7071 Beef non-breeding bulls 2yrs and over

Slaughter Heifers 0-1 are calculated by subtracting the population of breeding growing cows 0-1 (LC7057) from total beef heifer and calves under 1 year old (LC7064).

These classes all share the same birth date but have different slaughter dates.

Table 3.1: Details on beef slaughter classes population parameters

Class	Birth date	Slaughter date	Slaughter percent	Death rate per year excluding slaughter
Slaughter Heifers 0-1	25th September	NA	NA	2%
Slaughter Heifers 1-2	NA	19th March	30% of slaughtered heifers	2%
Slaughter Heifers 2-3	NA	6th January	70% of slaughtered heifers	2%
Slaughter Steers 0-1	25th September	NA	NA	2%
Slaughter Steers 1-2	NA	21st March	14% of slaughtered steers	2%
Slaughter Steers 2-3	NA	14th January	86% of slaughtered steers	2%
Slaughter Bulls 0-1	25th September	NA	NA	2%
Slaughter Bulls 1-2	NA	NA	NA	2%
Slaughter Bulls 2-3	NA	3rd February	100% of slaughtered bulls	2%

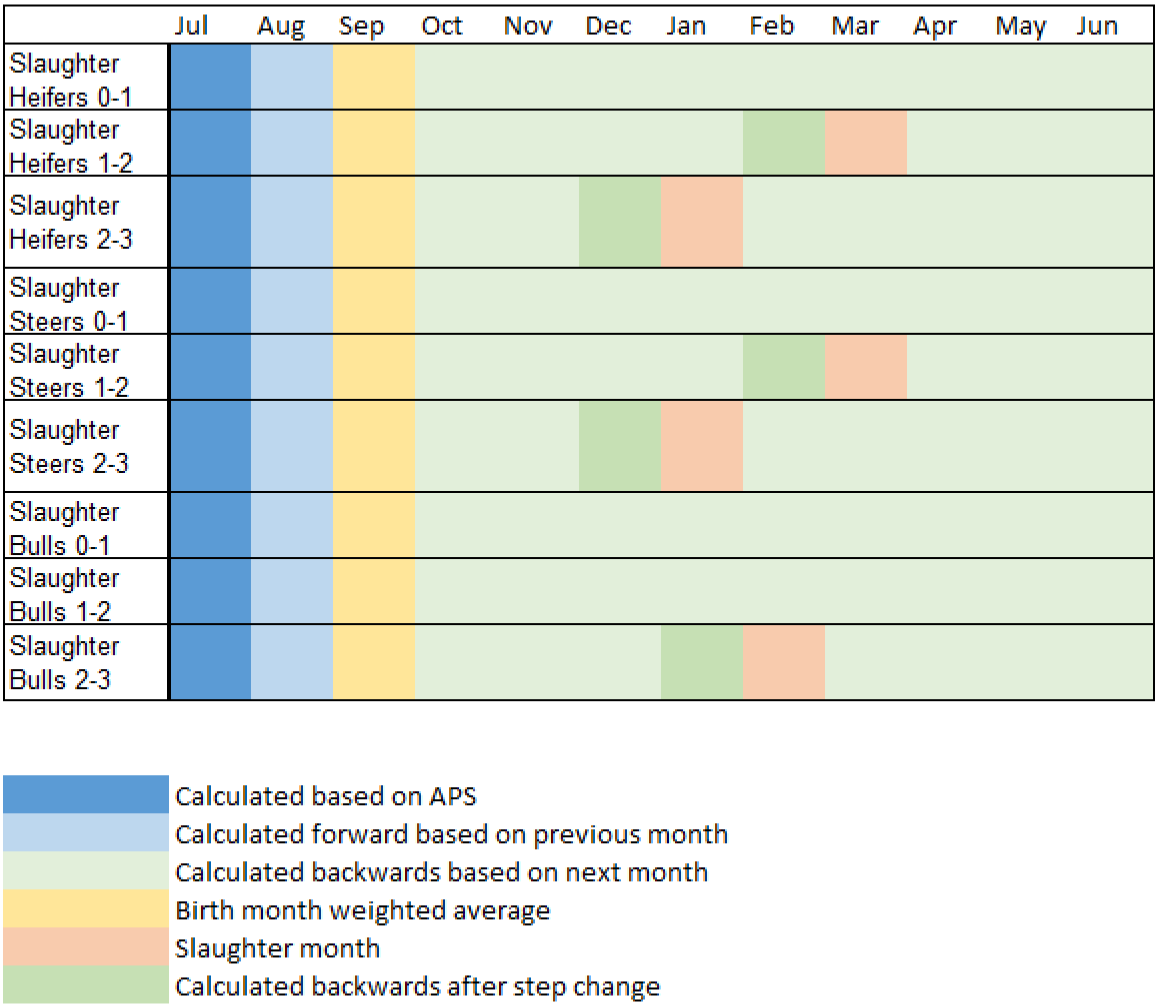
The number of animals slaughtered is based on the Livestock Slaughter Statistics. The Livestock Slaughter Statistics provide annual total kill for Heifers, Steers, and Bulls. These are divided into the age classes using the percentages in Table 3.1.

To accommodate the within year population dynamics there are six different cases, each with a set of equations used to calculate the monthly population:

- In July the population for all classes is calculated based on information in the APS
- The August population for all classes is calculated based on the July population.
- The September population is a weighted average of the population calculated before and after the birth and age up of the animals.
- The remaining months are calculated backwards from the next month.
- Months where slaughter occurs are calculated as a weighted average of the population before and after the slaughter date. Slaughtered animals are removed from the population on the slaughter date.
- The months preceding slaughter are calculated by increasing from a value before the slaughter date. It is important not to use the average value calculated above as the starting point as this would artificially lower the result.

Figure 3.1 shows for each class which case each month is calculated using. The only difference in the calculations between classes is when each case is applied. Below Slaughter Heifers 2-3 are used to demonstrate the equations for each case. The equations outlined can also be used to calculate the population for the remaining slaughter classes by changing the months each equation is applied in.

Figure 3.1: diagram showing when different equations are used to calculate slaughter class populations.



As the population change is linear the average population in July is equal to the population at the midpoint of the month.

Equation 3.40 *Population of Slaughter Heifers 2-3, for July*

$$POPsh3_{jul} = POPsh3_{jul\,1} \times \left(1 - \frac{DR_{sh3}}{nod_{year}} \times \frac{nod_{jul}}{2}\right)$$

Where:

$POPsh3_{jul1}$ = population of Slaughter Heifers aged 2-3 on July 1st

$POPbgc1_{jul}$ = population of Slaughter Heifers aged 2-3 in July

DR_{sh3} = annual death rate of Slaughter Heifers aged 2-3

nod_{year} = number of days in year

nod_{july} = number of days in July

In August, the population of slaughter animals is calculated using the following equation:

Equation 3.41 *Population of Slaughter Heifers aged between 2 and 3, for August*

$$POPsh3_{aug} = POPsh3_{jul} \times \left(1 - \frac{DR_{sh3}}{nod_{year}} \times nod_{jul}\right)$$

Where:

$POPsh3_{aug}$ = population of Slaughter Heifers aged 2-3 in August

$POPbgc1_{jul}$ = population of Slaughter Heifers aged 2-3 in July

DR_{sh3} = annual death rate of Slaughter Heifers aged 2-3

nod_{year} = number of days in year

nod_{july} = number of days in July

For months shaded light green in Figure 3.1 the population of slaughter animals is calculated backwards from the next month using the following equation:

Equation 3.42 *Monthly population of Slaughter Heifers aged between 2 and 3, from February to June*

$$POPsh3_{m} = POPsh3_{(m+1)} \times \left(1 + \frac{DR_{sh3}}{nod_{year}} \times nod_{m}\right)$$

Where:

$POPsh3_{m}$ = population of Slaughter Heifers aged 2-3 in month *m*

$POPsh3_{m+1}$ = population of Slaughter Heifers aged 2-3 in previous month *m+1*

DR_{sh3} = annual death rate of Slaughter Heifers aged 2-3

nod_{year} = number of days in year

nod_{m} = number of days in month *m*

For months where slaughter occurs (shaded orange in Figure 3.1) the population of slaughter animals is calculated from the next month using the following equation:

Equation 3.43 *Average population of Slaughter Heifers aged between 2 and 3, before and after slaughter in month m*

$$POPsh3_{AS(m)} = POPsh3_{m+1} \times \left(1 + \frac{DR_{sh3}}{nod_{year}} \times \left(\frac{nod_{m} - S_{day}}{2} + \frac{nod_{m+1}}{2}\right)\right)$$

$$POPsh3_{BS(m)} = POPsh3_{m+1} \times \left(1 - \frac{DR_{sh3}}{nod_{year}} \times \left(\left(nod_{m} - \frac{S_{day}}{2}\right) + \frac{nod_{m+1}}{2}\right)\right) + \left(Sltr_{H} \times P_{sh3} \times \left(1 + \left(\frac{DR_{sh3}}{nod_{year}} \times \frac{S_{day}}{2}\right)\right)\right)$$

Where:

$POPsh3_{AS(m)}$ = population of Slaughter Heifers aged 2-3 after slaughter in month *m*

$POPsh3_{BS(m)}$ = population of Slaughter Heifers aged 2-3 before slaughter in month *m*

$POPsh3_{m+1}$ = population of Slaughter Heifers aged 2-3 in next month

DR_{sh3} = annual death rate of Slaughter Heifers aged 2-3

nod_{year} = number of days in year

nod_m = number of days in month *m*

nod_{m+1} = number of days in month *m+1*

S_{day} = number of days from start of the month until slaughter

$Sltr_h$ = number of heifers slaughtered in year *t*

P_{sh3} = proportion of heifers slaughtered as 2-3 year olds (currently 86%)

These populations are then combined as a weighted average.

Equation 3.44 *Population of Slaughter Heifers aged 2-3, for January*

$$POPsh3_{Jan} = \frac{POPsh3_{BS(m)} \times S_{day} + POPsh3_{AS(m)} \times (nod_m - S_{day})}{nod_m}$$

Where:

$POPsh3_{jan}$ = population of Slaughter Heifers aged 2-3 in January

$POPsh3_{AS(m)}$ = population of Slaughter Heifers aged 2-3 after slaughter in month *m*

$POPsh3_{BS(m)}$ = population of Slaughter Heifers aged 2-3 before slaughter in month *m*

nod_m = number of days in month *m*

S_{day} = number of days from start of the month until slaughter

For the month preceding slaughter, it is important not to use the average value calculated above as the starting point because this would artificially lower the result. Therefore, the population value on the first of the slaughter month is calculated, then the mid-month values is calculated from this. Months that are calculated in this manner are shaded dark green in Figure 3.1.

Equation 3.45 *Population of Slaughter Heifers aged 2-3 for January 1*

$$POPsh3_{Jan1} = POPsh3_{m+1} \times \left(1 + \frac{DR_{sh3}}{nod_{year}} \times \left(\frac{nod_{m+1}}{2} + nod_m\right)\right) + Sltr_H \times P_{sh3} \times (1 + \frac{DR_{sh3}}{nod_{year}} \times S_{day})$$

Where:

$POPsh3_{jan1}$= population of Slaughter Heifers aged 2-3 on 1st January

$POPsh3_{m+1}$ = population of Slaughter Heifers aged 2-3 in month m+1

DR_{sh3} = annual death rate of Slaughter Heifers aged 2-3

S_{day} = number of days from start of the month until slaughter

$Sltr_h$ = number of heifers slaughtered in current year

P_{sh3} = proportion of heifers slaughtered as 2-3 year olds (currently 86%)

nod_{year} = of days in year

nod_m = number of days in month *m*

nod_{m+1} = number of days in month *m+1*

Equation 3.46 *Population of Slaughter Heifers aged 2-3, for December*

$$POPsh3_{dec} = POPsh3_{Jan1(t)} \times \left(1 + \frac{DR_{sh3}}{nod_{year}} \times \left(\frac{nod_m}{2}\right)\right)$$

Where:

$POPsh3_{dec}$ = population of Slaughter Heifers aged 2-3 in December

$POPsh3_{jan1}$= population of Slaughter Heifers aged 2-3 on 1st January

DR_{sh3} = annual death rate of Slaughter Heifers aged 2-3

nod_{year} = of days in year

nod_m = number of days in month *m*

In September, slaughter animals move into the next age group and are born. Because of this there is a discontinuity on the 25th as animals are either born or aged up. A weighted average of the population before and after the discontinuity is calculated as the representative population for September.

The population is calculated forward from the midpoint of August and backwards from the midpoint of October. This determines the number of days the death rate must be applied to calculate the average population before and after the birthday.

Equation 3.47 *Population of Slaughter Heifers aged 2-3, for September, before and after cattle birth date*

$$POPsh3_{sepAB} = POPsh3_{oct} \times (1 + \frac{DR_{sh3}}{nod_{year}} \times \left(\frac{nod_{sep} - B_{day}}{2} + \frac{nod_{oct}}{2}\right))$$

$$POPsh3_{sepBB} = POPsh3_{aug} \times (1 - \frac{DR_{sh3}}{nod_{year}} \times \left(\frac{nod_{aug} + B_{day}}{2}\right))$$

Where:

$POPsh3_{sepAB}$ = population of Slaughter Heifers aged 2-3 at midpoint after birthday

$POPsh3_{sepBB}$ = population of Slaughter Heifers aged 2-3 at midpoint before birthday

$POPbgc1_{aug}$ = population of Slaughter Heifers aged 2-3 in August

$POPbgc1_{oct}$ = population of Slaughter Heifers aged 2-3 in October

DR_{bgc1} = annual death rate of Slaughter Heifers aged 2-3

nod_{year} = number of days in year

nod_{oct} = number of days in month *October*

nod_{sept} = number of days in month *September*

nod_{aug} = number of days in month *August*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

These populations are then combined as a weighted average.

Equation 3.48 *Population of breeding growing cows aged 0-1, for September*

$$POPsh3_{sep} = \frac{POPsh3_{sepBB} \times B_{day} + POPsh3_{sepAB} * (nod_{sep} - B_{day})}{nod_{sep}}$$

Where:

$POPsh3_{sep}$ = population of Slaughter Heifers aged 2-3 in September

$POPsh3_{sepAB}$ = population of Slaughter Heifers aged 2-3 at midpoint after birthday

$POPsh3_{sepBB}$ = population of Slaughter Heifers aged 2-3 at the midpoint before birthday

nod_{sept} = number of days in month *September*

B_{day} = number of days from start of the month until birth date of beef cattle, currently 25th September.

3.2.4 Breeding Bulls Mixed age

The population of mixed age breeding bulls is assumed to change steadily over the course of a year. The July population is equal to the breeding bull population in the APS (line code 7068). From August to June of the following year, the equation below is used to calculate monthly populations of breeding bulls.

Equation 3.49 *Monthly population of mixed age breeding bulls, from August in year t to June in year t+1*

$$POPbbma_m = POPbbma_{m-1} + \left(\frac{POPbbma_{Jul,t+1} - POPbbma_{Jul,t}}{nod_{year}} \times nod_{m-1}\right)$$

Where:

$POPbbma_m$ = population of mixed age breeding bulls in month m

$POPbbma_{m-1}$ = population of mixed age breeding bulls in previous month m

$POPbbma_{Jul,t+1}$ = population of mixed age breeding bulls in July of next year t+1

$POPbbma_{Jul,t}$ = population of mixed age breeding bulls in July of current year t

nod_{year} = number of days in year

nod_{m-1} = number of days in previous month m-1

3.3 Sheep population model

Eight different classes of sheep are used in the model. These populations have strong links with each other as they move from one age group to another.

- Dry Ewes
- Mature Breeding Ewes
- Growing Breeding Sheep
- Growing Non-Breeding Sheep
- Wethers
- Lambs
- Rams

3.3.1 Dry ewes

In the inventory model the 'dry ewes' population class only exists in July. This population is equal to the dry ewes sheep population recorded annually in the agricultural production census (using line code 6722).

From August to June (inclusive) the population of dry ewes is assumed to be zero.

3.3.2 Mature breeding ewes

The population of mature breeding ewes varies throughout the year. The July population is equal to the mature breeding ewe population in the APS (line code 6721).

In the inventory model it is assumed that the annual death rate of mature breeding ewes is 5.6%, with 40% of these deaths occurring in the months of August and September.

Equation 3.50 *Annual number of deaths of mature breeding ewes from July to June*

$$Dmbe_{AT(t)} = DR_{mbe} \times POPmbe_{jul(t)}$$

Where:

$Dmbe_{AT(t)}$ = Annual number of deaths of mature breeding ewes in year *t*

DR_{mbe} = Annual death rate of mature breeding ewes (currently assumed to be 5.6%)

$POPmbe_{jul(t)}$ = population of mature breeding ewes in July of year *t* (from APS)

Equation 3.51: *Number of mature breeding ewe deaths that occur in August and September*

$$Dmbe_{Aug+Sep(t)} = Dmbe_{AT(t)} \times PDmbe_{Aug+Sep}$$

Where:

$Dmbe_{Aug+Sep(t)}$ = Number of mature breeding ewe deaths that occur in August and September in year *t*

$Dmbe_{AT(t)}$ = Annual number of deaths of mature breeding ewes in year *t*

$PDmbe_{Aug+Sep}$ = Proportion of annual mature breeding ewe deaths that occur in August or September (currently assumed to be 40%)

The August population of mature breeding ewes is calculated using the following formula:

Equation 3.52 *Population of mature breeding ewes in August*

$$POPmbe_{aug(t)} = POPmbe_{jul(t)} - \left(\frac{Dmbe_{AT(t)} - Dmbe_{Aug+Sep(t)}}{nod_{year} - nod_{Aug} - nod_{Sep}} \times nod_{Jul}\right)$$

Where:

$POPmbe_{aug(t)}$ = population of mature breeding ewes in August in year *t*

$POPmbe_{jul(t)}$ = population of mature breeding ewes in July in year *t* (from APS)

$Dmbe_{AT(t)}$ = Annual number of deaths of mature breeding ewes in year *t* (Equation 3.50)

$Dmbe_{Aug+Sep(t)}$ = Number of mature breeding ewe deaths that occur in August and September in year *t* (see Equation 3.51)

nod_{year} = number of days in year

nod_{Aug} = number of days in August

nod_{Sep} = number of days in September

nod_{Jul} = number of days in July

The September and October populations of mature breeding ewes are calculated using the following formula:

Equation 3.53 *Population of mature breeding ewes in September and October*

$$POPmbe_{m(t)} = POPmbe_{m-1(t)} - \left(\frac{Dmbe_{Aug+Sep(t)}}{nod_{Aug} + nod_{Sep}} \times nod_{Aug}\right)$$

Where:

$POPmbe_{m(t)}$ = population of mature breeding ewes in month *m* in year *t*

$POPmbe_{m-1(t)}$ = population of mature breeding ewes in previous month *m-1* in year *t*

$Dmbe_{Aug+Sep(t)}$ = Number of mature breeding ewe deaths that occur in August and September in year *t* (see Equation 3.51)

nod_{Aug} = number of days in August

nod_{Sep} = number of days in September

The November to March populations of mature breeding ewes are calculated using the following formula:

Equation 3.54 *Population of mature breeding ewes between November and March*

$$POPmbe_{m} = POPmbe_{m-1} - \left(\frac{Dmbe_{AT} - Dmbe_{Aug+Sep}}{nod_{year} - nod_{Aug} - nod_{Sep}} \times nod_{m-1}\right)$$

Where:

$POPmbe_{m}$ = population of mature breeding ewes in month *m*

$POPmbe_{m-1}$ = population of mature breeding ewes in previous month *m-1*

$Dmbe_{AT}$ = Annual number of deaths of mature breeding ewes (see Equation 3.50)

$Dmbe_{Aug+Sep}$ = Number of mature breeding ewe deaths that occur in August and September (see Equation 3.51)

nod_{year} = number of days in year

nod_{Aug} = number of days in August

nod_{Sep} = number of days in September

nod_{m-1} = number of days in previous month *m-1*

The April to June populations mature breeding ewes is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

Equation 3.55 *Population of mature breeding ewes in June*

$$POPmbe_{Jun(t)} = POPmbe_{jul(t)} - \left(\frac{Dmbe_{AT(t)} - Dmbe_{Aug+Sep(t)}}{nod_{year} - nod_{Aug} - nod_{Sep}} \times nod_{Jun}\right)$$

Where:

$POPmbe_{Jun(t)}$ = population of mature breeding ewes in June in year *t*

$POPmbe_{jul(t)}$ = population of mature breeding ewes in July in year *t* (from APS)

$Dmbe_{AT(t)}$ = Annual number of deaths of mature breeding ewes in year *t* (see Equation 3.50)

$Dmbe_{Aug+Sep(t)}$ = Number of mature breeding ewe deaths that occur in August and September in year *t* (see Equation 3.51)

nod_{year} = number of days in year

nod_{Aug} = number of days in August

nod_{Sep} = number of days in September

nod_{Jun} = number of days in June

Equation 3.56 *Population of mature breeding ewes in April and May*

$$POPmbe_{m(t)} = POPmbe_{m+1(t)} - \left(\frac{Dmbe_{AT(t)} - Dmbe_{Aug+Sep(t)}}{nod_{year} - nod_{Aug} - nod_{Sep}} \times nod_{m}\right)$$

Where:

$POPmbe_{m(t)}$ = population of mature breeding ewes in month *m* in year *t*

$POPmbe_{m+1(t)}$ = population of mature breeding ewes in next month *m+1* in year *t*

$Dmbe_{AT(t)}$ = Annual number of deaths of mature breeding ewes in year *t* (see Equation 3.50)

$Dmbe_{Aug+Sep(t)}$ = Number of mature breeding ewe deaths that occur in August and September in year *t* (see Equation 3.51)

nod_{year} = number of days in year

nod_{Aug} = number of days in August

nod_{Sep} = number of days in September

nod_{Jun} = number of days in month m

3.3.3 Growing breeding sheep

The population of growing breeding sheep varies throughout the year. The July population is equal to the breeding ewe hogget population in the APS (line code 6723).

The August population of growing breeding sheep is calculated using the following formula:

Equation 3.57 *Population of growing breeding sheep in August*

$$POPgbs_{aug(t)} = POPgbs_{jul(t)} \times \left(1 - \frac{DR_{gbs} \times nod_{Jul}}{nod_{year}}\right)$$

Where:

$POPgbs_{aug(t)}$ = population of growing breeding sheep in August in year *t*

$POPgbs_{jul(t)}$ = population of growing breeding sheep in July in year *t* (from APS)

DR_{gbs} = Annual death rate of growing breeding sheep (currently assumed to be 3.6%)

nod_{year} = number of days in year

nod_{Jul} = number of days in July

Equation 3.58 *Population of growing breeding sheep between September and March*

$$POPgbs_m = POPgbs_{m-1} \times \left(1 - \frac{DR_{ttdh} \times nod_{m-1}}{nod_{year}}\right)$$

Where:

$POPgbs_m$ = population of growing breeding sheep in month m

$POPgbs_{m-1}$ = population of growing breeding sheep in previous month m

DR_{ttdh} = Annual death rate of two-tooth dry hoggets (currently assumed to be 4.71%)

nod_{year} = number of days in year

nod_{m-1} = number of days in previous month m

The April to June populations growing breeding sheep is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

Equation 3.59 *Population of growing breeding sheep in June*

$$POPgbs_{Jun(t)} = POPgbs_{jul(t)} \times \left(1 + \frac{DR_{gbs} \times nod_{Jun}}{nod_{year}}\right)$$

Where:

$POPgbs_{Jun(t)}$ = population of growing breeding sheep in June in year *t*

$POPgbs_{jul(t)}$ = population of growing breeding sheep in July in year *t* (from APS)

DR_{gbs} = Annual death rate of growing breeding sheep (currently assumed to be 3.6%)

nod_{year} = number of days in year

nod_{Jul} = number of days in June

Equation 3.60 *Population of growing breeding sheep in April and May*

$$POPgbs_{m(t)} = POPgbs_{m+1(t)} \times \left(1 + \frac{DR_{gbs} \times nod_m}{nod_{year}}\right)$$

Where:

$POPgbs_{m(t)}$ = population of growing breeding sheep in month m in year *t*

$POPgbs_{m+1(t)}$ = population of growing breeding sheep in next month m+1 in year *t*

DR_{gbs} = Annual death rate of growing breeding sheep (currently assumed to be 3.6%)

nod_{year} = number of days in year

nod_{Jul} = number of days in June

3.3.4 Growing non-breeding sheep

The population of growing non-breeding sheep varies throughout the year. The July population is equal to the sum of the:

- Dry ewe hogget

- Ram hogget
- Wether hogget

populations found from the APS.

The August population of growing non-breeding sheep is calculated using the following formula:

Equation 3.61 *Population of growing non-breeding sheep in August*

$$POPgnbs_{aug(t)} = POPgnbs_{jul(t)} \times \left(1 - \frac{DR_{gnbs} \times nod_{Jul}}{nod_{year}}\right)$$

Where:

$POPgnbs_{aug(t)}$ = population of growing non-breeding sheep in August in year *t*

$POPgnbs_{jul(t)}$ = population of growing non-breeding sheep in July year *t* (from APS)

DR_{gnbs} = Annual death rate of growing non-breeding sheep (currently assumed to be 3.6%)

nod_{year} = number of days in year

nod_{Jul} = number of days in July

In September the population of growing non-breeding sheep changes significantly as populations move into different age classes. The September population of growing non-breeding sheep is calculated using the following formula:

Equation 3.62 *Population of growing non-breeding sheep in September*

$$POPgnbs_{Sep(t)} = POPdeh_{jul(t)} \times \left(1 - \frac{DR_{gnbs} \times nod_{Jul}}{nod_{year}}\right)$$

Where:

$POPgnbs_{Sep(t)}$ = population of growing non-breeding sheep in September of year *t*

$POPdeh_{jul(t)}$ = population of dry ewe hoggets in July of year *t* (from APS; line code 6724)

DR_{gnbs} = Annual death rate of growing non-breeding sheep (currently assumed to be 3.6%)

nod_{year} = number of days in year

nod_{Jul} = number of days in July

From October to March the populations of growing non-breeding sheep are calculated using the following formula:

Equation 3.63 *Population of growing non-breeding sheep between October and March*

$$POPgnbs_{m} = POPgnbs_{m-1} \times \left(1 - \frac{DR_{gnbs} \times nod_{m-1}}{nod_{year}}\right)$$

Where:

$POPgnbs_{m}$ = population of growing non-breeding sheep in month m

$POPgnbs_{jul}$ = population of growing non-breeding sheep in previous month m-1

DR_{gnbs} = Annual death rate of growing non-breeding sheep (currently assumed to be 3.6%)

nod_{year} = number of days in year

nod_{m-1} = number of days in previous month m-1

The April to June populations of growing non-breeding sheep is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on). In June, a more complex formula is used to account for the different death rates that are assumed for dry ewe hoggets, ram hoggets and whether hoggets.

Equation 3.64 *Population of growing non-breeding sheep in June*

$$POPgnbs_{Jun(t)} = POPdeh_{jul(t)} \times \left(1 + \frac{DR_{deh} \times nod_{Jun}}{nod_{year}}\right) + POPrh_{jul(t)} \times \left(1 + \frac{DR_{rh} \times nod_{Jun}}{nod_{year}}\right) + POPwh_{jul(t)} \times \left(1 + \frac{DR_{wh} \times nod_{Jun}}{nod_{year}}\right)$$

Where:

$POPgnbs_{Jun(t)}$ = population of growing non-breeding sheep in June of year *t*

$POPdeh_{jul(t)}$ = population of dry ewe hoggets in July of year *t* (from APS; line code 6724)

$POPrh_{jul(t)}$ = population of ram hoggets in July of year *t* (from APS)

$POPwh_{jul(t)}$ = population of whether hoggets in July of year *t* (from APS)

DR_{deh} = Annual death rate of dry ewe hoggets (currently assumed to be 3.6%)

DR_{rh} = Annual death rate of ram hoggets (currently assumed to be 4.71%)

DR_{wh} = Annual death rate of whether hoggets (currently assumed to be 4.71%)

nod_{year} = number of days in year

nod_{Jun} = number of days in June

Equation 3.65 *Population of growing non-breeding sheep in April and May*

$$POPgnbs_{m(t)} = POPgnbs_{m+1(t)} \times \left(1 + \frac{DR_{gnbs} \times nod_{m}}{nod_{year}}\right)$$

Where:

$POPgnbs_{m}$ = population of growing non-breeding sheep in month *m* of year *t*

$POPgnbs_{m+1}$ = population of growing non-breeding sheep in next month *m+1* in year *t*

DR_{gnbs} = Annual death rate of growing non-breeding sheep (currently assumed to be 3.6%)

nod_{year} = number of days in year

nod_{Jul} = number of days in June

3.3.5 Wethers

The population of wethers varies throughout the year, and is assumed to change linearly from the July of one year to the July of the next year. The July population is equal to the wether population in the APS (line code 6727).

Equation 3.66 *Monthly population of wethers from August to June*

$$POPws_m = POPws_{m-1} + \left(\frac{POPws_{Jul,p} - POPws_{Jul,n}}{nod_{year}} \times nod_{m-1}\right)$$

Where:

$POPws_m$ = population of wethers in month *m*

$POPws_{m-1}$ = population of wethers in previous month *m-1*

$POPws_{jul,p}$ = population of wethers in the July *before* month *m*

$POPws_{jul,p}$ = population of wethers in the next July *after* month *m*

nod_{year} = number of days in year

nod_{m-1} = number of days in previous month *m-1*

3.3.6 Lambs

The population of lambs varies throughout the year. Data on the annual population of lambs is collected and published by Statistics New Zealand, and it is assumed that the September population of lambs is equal to the annual value published by SNZ using line codes 6700 and 6701.

After September the population of lambs falls as they are slaughtered or moved to different sheep classes. Between October and February, and between May and August, the lamb population is calculated using the following formula:

Equation 3.67 *Monthly population of lambs for October, November, December, January, February, May, June, July and August*

$$POPls_m = POPls_{m-1} \times \left(1 - \frac{DR_{ls} \times nod_{m-1}}{nod_{year}}\right)$$

Where:

$POPls_m$ = population of lambs in month *m*

$POPls_{jul}$ = population of lambs in previous month *m-1*

DR_{ls} = Annual natural death rate of lambs (currently assumed to be 4.5%)

nod_{year} = number of days in year

nod_{m-1} = number of days in previous month *m-1*

In March, it is assumed that the lamb population is equal to the sum of the July population of the four growing non-breeding sheep categories (breeding ewe hoggets, dry ewe hoggets, ram hoggets, and wether hoggets). An adjustment is made to account for the deaths that are assumed to have occurred between March and July

Equation 3.68 *Population of lambs in March*

$$POPls_{Mar(t)} = \frac{POPbeh_{Jul(t)} + POPdeh_{Jul(t)} + POPrwh_{Jul(t)}}{\omega_{ls}}$$

Where:

$POPls_{Mar(t)}$ = population of lambs in March of year *t*

$POPbeh_{Jul(t)}$ = population of breeding ewe hoggets in July of year *t* (from APS, line code 6723)

$POPdeh_{Jul(t)}$ = population of dry ewe hoggets in July of year *t* (from APS, line code 6724)

$POPrh_{Jul(t)}$ = population of ram and wether hoggets in July of year *t* (from APS, line code 6738)

ω_{ls} = adjustment factor to account for the deaths that are assumed to have occurred between March and July (currently set to 0.987)

During March the model assumes that some lambs are sent to slaughter. The fraction of lambs that are slaughtered in March is used to calculate the April population of lambs. For the years 1990 to 2010 this fraction is determined using a linear trend starting at 86% in 1990 and ending at 79% in 2010. This trend is based on a sample of industry data. For the years after 2010 the 2011-2019 average of 78% is used (Stevens, et al., 2022).

Equation 3.69 *Population of lambs in April*

$$POPls_{Apr(t)} = POPls_{Mar(t)} \times (1 - DPls_{Mar})$$

Where:

$POPls_{Apr(t)}$ = population of lambs in April of year *t*

$POPls_{Mar(t)}$ = population of lambs in March of year *t*

$DPls_{Apr}$ = Proportion of lambs sent to slaughter during March

The lamb populations for May, June, July and August are calculated using the same formula used to calculate the lamb populations between October and February (Equation 3.65).

3.3.7 Rams

The population of rams varies throughout the year, and is assumed to change linearly from the July of one year to the July of the next year. The July population is equal to the ram population in the APS (line code 6720).

Equation 3.70 *Monthly population of rams from August to June*

$$POPrs_m = POPrs_{m-1} + \left(\frac{POPrs_{Jul,p} - POPrs_{Jul,n}}{nod_{year}} \times nod_{m-1}\right)$$

Where:

$POPrs_m$ = population of rams in month m

$POPrs_{m-1}$ = population of rams in previous month m-1

$POPrs_{jul,p}$ = population of rams in the July *before* month m

$POPrs_{jul,p}$ = population of rams in the next July *after* month m

nod_{year} = number of days in year

nod_{m-1} = number of days in previous month m-1

3.4 Deer population model

Fifteen different classes of deer are used in the model. Animals are divided based on age, sex, breeding status, and value chain (venison or velvet). These populations have strong links with each other as they move from one age group to another.

Table 3.2 Deer classes used in the model.

	Velvet	Venison
Hinds	Velvet Hinds 0-1 Velvet Hinds 1-2 Velvet Hinds Mature	Venison Hinds 0-1 Venison Hinds Breeding 1-2 Venison Hinds Non Breeding 1-2 Venison Hinds Mature
Stags	Velvet Stags 0-1 Velvet Stags 1-2 Velvet Stags 2-3 Velvet Stags Mature	Venison Stags 0-1 Venison Stags 1-2 Venison Stags 2-3 Venison Stags Mature

3.4.1 July population values

The total deer population supplied by Statistics NZ is divided among the classes in Table 3.2 using a method created by (Stevens & Ward, 2023). The methodology for calculating the July populations is outlined below.

A complete set of APS linecodes is available from 2012 to present. For years 1990 to 2023 Infoshare has a more aggregated data set that can be mapped onto the more detailed APS linecodes (Table 3.3). The populations in the aggregated classes were allocated to the appropriate linecodes for the years 1990 - 2011 based on the average proportions 2012 – 2014. Missing values were interpolated.

Table 3.3 APS Linecodes and Infoshare categories

APS linecode		Infoshare category
lc7600	Deer females mated 2 years and over	Female deer mated since 30 June last year
lc7605	Deer females mated over 1 year but under 2 years	
lc7610	Deer females NOT mated 2 years and over	Other female deer
lc7615	Deer females NOT mated over 1 year but under 2 years	
lc7618	Deer females under 1 year old (include fawns still on the farm)	
lc7620	Deer non-breeding males 2 years and over	Male deer (2 yrs and over)
lc7645	Deer breeding males 2 years old and over	
lc7630	Deer males under 1 year old (include fawns still on the farm)	Male deer (under 2 yrs)
lc7625	Deer non-breeding males over 1 year but under 2 years	
lc7648	Deer breeding males over 1 year but under 2 years	
lc7696	Fawns born on farm and alive at four months	

3.4.1.1 Young stags

Stags destined for the venison value chain are slaughtered under 20 months of age, and normally at months 10-14 (Stevens & Ward, 2023). Assuming a birth date of November 19th , any stags reported as being in the 1–2 year-old non breeding category (LC7625) at 30 June are 20 months of age. Thus, these stags can be classified as entering the velvet antler selection process. The death rate of the 1–

2-year-old stags is then used to back calculate the number of velvet stags 0-1 required. The residual deer males under 1 year old (LC7630) are therefore part of the venison value chain The equations are as follows:

Equation 3.71 *Population of velvet stags aged 1-2 in July*

$$Velvet\ Stags\ 1-2\ = lc7625$$

Where:

Lc7625 = Deer non-breeding males over 1 year but under 2 years

Velvet Stags 1-2 = Population of stags aged 1-2 in July

Equation 3.72 *Population of velvet stags aged 0-1 in July*

$$Velvet\ Stags\ 0-1 = \frac{lc7625}{1-\ DR_{ds2}}$$

Where:

Lc7625 = Deer non-breeding males over 1 year but under 2 years

DR_{ds2} = Annual death rate of stags aged 1-2 (assumed to be 2%)

Velvet Stags 0-1 = Population of velvet stags aged 0-1 in July

Equation 3.73 *Population of venison stags aged 0-1 in July*

$$Venison\ Stags\ 0-1 = lc7630 - Velvet\ Stags\ 0-1$$

Where:

LC7630 = Deer males under 1 year old (include fawns still on the farm)

Venison Stags 0-1 = Population of venison stags aged 0-1 in July

3.4.1.2 Velvet Hinds

The number of hinds required to produce velvet antler stags is divided into several parts. Firstly, the number of hinds to directly provide stags is calculated, then the number of hinds required to produce replacement hinds is calculated. These numbers are adjusted to include the future death rates of fawns as they age through the process.

The number of hinds is also adjusted for the current reproductive success of the national herd. Hinds in class lc7610, deer females not mated 2 years and over, are considered part of the breeding herd and therefore included in calculation of reproductive success and breeding stag requirements. This allows that class to be equally represented in allocation to venison or velvet antler enterprises.

Equation 3.74 *Population of breeding hinds required to produce stag replacements*

$$Hinds\ for\ velvet\ stag\ replacements = \frac{lc7625}{RS \times (1 - DR_{ds2})}$$

Where:

Hinds for velvet stag replacements = Population of breeding hinds required to produce stag replacements in July

Lc7625 = Deer non-breeding males over 1 year but under 2 years

RS = reproductive success

DR_{ds2} = Annual death rate of stags aged 1-2 (assumed to be 2%)

Note that reproductive success, by using the number of hinds mated and the number of fawns recorded at June 30 (lc7696), already includes death rate in the first 8 months of life. Therefore, no adjustment is made for death rate of stags or hinds in the first year of life.

Equation 3.75 *Reproductive success of hinds in year n*

$$RS = \frac{lc7696_n}{lc7600_{n-1} + lc7610_{n-1} + lc7605_{n-1}}$$

Where:

RS = Reproductive success of hinds in year n

$Lc7696_n$ = Fawns born on farm and alive at four months in year n

$Lc7600_{n-1}$ = Deer females mated 2 years and over in year n -1

$Lc7610_{n-1}$ = Deer females NOT mated 2 years and over in year n -1

$Lc7605_{n-1}$ = Deer females mated over 1 year but under 2 years in year n-1

The hinds population required to breed replacement hinds can be grouped into two sub populations:

a. Hinds required to breed replacements for the hinds that breed velvet stags

b. Hinds required to breed replacements for the above group of hinds

A replacement rate of 20% is used for mixed age hinds (Stevens & Ward, 2023). This results in a combined replacement rate of 24% when both groups are taken into consideration.

Equation 3.76 *Population of breeding hinds required to service the velvet hind population.*

$$Hinds\ to\ replace\ velvet\ hinds = \frac{Hinds\ for\ velvet\ stag\ replacements\ \times HRR}{RS \times (1 - DR_{dh2})}$$

Where:

Hinds to replace velvet hinds = Population of breeding hinds required to service the velvet hind population in July

Hinds for velvet stag replacements = Population of breeding hinds required to produce stag replacements in July

DR_{dh2} = Annual death rate of hinds aged 1-2 (assumed to be 2%)

HRR = combined hind replacement rate (assumed to be 24%)

RS = reproductive success

The velvet hinds required to replace both stags and hinds are added together. The total velvet hinds required are then reallocated to age categories.

Equation 3.77 *Ratio of hinds over 2 to total hinds*

$$R_{h2+} = \frac{lc7600 + lc7610}{lc7600 + lc7605 + lc7610}$$

Where:

R_{h2+} = the ratio of hinds over 2 to total hinds

Lc7600 = Deer females mated 2 years and over

Lc7610 = Deer females NOT mated 2 years and over

Lc7605 = Deer females mated over 1 year but under 2 years

Equation 3.78 *Population of mature velvet hinds in July*

$$Velvet\ hinds\ mature = Total\ velvet\ hinds\ \times R_{h2+}$$

Where:

Velvet hinds mature = Population of mature velvet hinds in July

Total velvet hinds = Hinds for velvet stag replacements + Hinds to replace velvet hinds

R_{h2+} = the ratio of hinds over 2 to total hinds

Equation 3.79 *Population of velvet hinds aged 1-2 in July*

$$Velvet\ hinds\ 1-2 = Total\ velvet\ hinds\ \times (1 - R_{h2+})$$

Where:

Velvet hinds 1-2 = Population of velvet hinds aged 1-2 in July

Total velvet hinds = Hinds for velvet stag replacements + Hinds to replace velvet hinds

R_{h2+} = the ratio of hinds over 2 to total hinds

Hind fawns also need to be allocated as future replacements for the velvet antler hind herd, from the Hinds aged 0-1 category. This sets aside an appropriate number of hind fawns (as 8-month-olds at June 30; lc7618) to enter the velvet antler hind herd as rising 2-year-olds.

Equation 3.80 *Population of velvet hinds aged 0-1 in July*

$$Velvet\ hinds\ 0-1=\frac{Velvet\ hinds\ 1-2}{1-\ DR_{dh2}}$$

Where:

Velvet hinds 0-1 = Population of velvet hinds aged 0-1 in July

Velvet hinds 1-2 = Population of velvet hinds aged 1-2 in July

DR_{dh2} = Annual death rate of hinds aged 1-2 (assumed to be 2%)

3.4.1.3 Venison hinds

Venison hinds make up the remainder of the total hinds so are calculated by subtracting the velvet hinds from the total hinds for each age group. As per the velvet antler herd, hind fawns need to be allocated as replacements for the venison hind herd. The rest are available for slaughter

Equation 3.81 *Population of mature venison hinds in July*

$$Venison\ hinds\ mature=\ (lc7600+lc7610)-Velvet\ hinds\ mature$$

Where:

Venison hinds mature = Population of mature venison hinds in July

Velvet hinds mature = Population of mature velvet hinds in July

Lc7600 = Deer females mated 2 years and over

Lc7610 = Deer females NOT mated 2 years and over

Equation 3.82 *Population of venison hinds mated (breeding) aged 1-2 in July*

$$Venison\ hinds\ mated\ 1-2=lc605-\ Velvet\ hinds\ 1-2$$

Where:

Venison hinds mated 1-2 = Population of breeding venison hinds aged 1-2 in July

Velvet hinds 1-2 = Population of velvet hinds aged 1-2 in July

Lc7605 = deer females mated over 1 year but under 2 years

Equation 3.83 *Population of venison hinds not mated (non-breeding) aged 1-2 in July*

$$Venison\ hinds\ not\ mated\ 1-2 = lc7615$$

Where:

Lc7615 = Deer females NOT mated over 1 year but under 2 years

Venison hinds not mated 1-2 = Population of non-breeding venison hinds aged 1-2 in July

Equation 3.84 *Population of venison hinds aged 0-1 in July to be used as replacements.*

$$Venison\ replacement\ hinds\ 0-1 = \frac{Venison\ hinds\ mated\ 1-2}{1-\ DR_{dh2}}$$

Where:

Venison replacement hinds 0-1 = Population of venison hinds aged 0-1 in July to be used as replacements.

Venison hinds mated 1-2 = Population of breeding venison hinds aged 1-2 in July

DR_{dh2} = Annual death rate of hinds aged 1-2 (assumed to be 2%)

Equation 3.85 *Population of venison hinds aged 0-1 in July that do not replace breeding hinds*

$$\begin{aligned} &Venison\ slaughter\ hinds\ 0-1 \\ &\quad = lc7618 -\ (Venison\ replacement\ hinds\ 0-1 +\ Velvet\ hinds\ 0-1) \end{aligned}$$

Where:

Venison slaughter hinds 0-1 = Population of venison hinds aged 0-1 in July that do not replace breeding hinds

Venison replacement hinds 0-1 = Population of venison hinds aged 0-1 in July to be used as replacements

Velvet hinds 0-1 = Population of velvet hinds aged 0-1 in July

Lc7618 = Deer females under 1 year old (include fawns still on the farm)

3.4.1.4 Stags for breeding

Breeding stags are allocated based on the relative populations of breeding hinds. It is common industry practice to mate older males to older females, and to mate younger males to younger females. Therefore, deer breeding males over 1 and under 2 years (lc7648) are allocated to deer females over 1 and under 2 years (lc7605). Deer breeding males 2 years old and older (lc7645) are allocated to the deer females 2 years and older (both mated lc7600, and non-mated lc7610). Stags aging up from the 1-2 to 2-3 age categories have a 40% culling rate (Stevens & Ward, 2023).

Equation 3.86 *Population of velvet stages mated aged 1-2 in July*

$$Velvet\ stags\ breeding\ 1-2 = \frac{lc7648\ \times\ Velvet\ hinds\ 1-2}{lc7605}$$

Where:

Velvet stags breeding 1-2 = Population of velvet stages mated aged 1-2 in July

Velvet hinds 1-2 = Population of velvet hinds aged 1-2 in July

Lc7605 = Deer females mated over 1 year but under 2 years

Lc7648 = Deer breeding males over 1 year but under 2 years

Equation 3.87 *Population of velvet stags mated aged 2 and older in July*

$$Velvet\ stags\ breeding\ 2+ = \frac{lc7645\ \times\ Velvet\ hinds\ mature}{lc7600 + lc7610}$$

Where:

Velvet stags breeding 2+ = Population of velvet stags mated aged 2 and older in July

Venison hinds mature = Population of mature venison hinds in July

Lc7600 = Deer females mated 2 years and over

Lc7610 = Deer females NOT mated 2 years and over

Lc7645 = Deer breeding males 2 years old and over

Equation 3.88 *Population of velvet stags mated aged 2-3 in July*

$$Velvet\ stags\ breeding\ 2-3 =\ Velvet\ stags\ breeding\ 1-2\ \times (1 - CR)$$

Where:

Velvet stags breeding 2-3 = Population of velvet stags mated aged 2-3 in July

Velvet stags breeding 1-2 = Population of velvet stages mated aged 1-2 in July

CR = cull rate of stags between 1-2 and 2-3 year old cohorts (assumed to be 40%)

Equation 3.89 *Population of mature breeding velvet stags in July*

$$Velvet\ stags\ breeding\ mature =\ Velvet\ stags\ breeding\ 2+\ - Velvet\ stags\ breeding\ 2-3$$

Where:

Velvet stags breeding mature = Population of mature breeding velvet stags in July

Velvet stags breeding 2+ = Population of velvet stags mated aged 2 and older in July

Velvet stags breeding 2-3 = Population of velvet stags mated aged 2-3 in July

The same equations are repeated for venison stags, using classes from the venison value chain where appropriate.

3.4.1.5 Stags retained for velvet antler production

Equation 3.90 *Population of velvet stages not mated aged 2-3 in July*

$$Velvet\ stags\ non\ breeding\ 2-3 = lc7625\ \times\ (1-CR)$$

Where:

Velvet stags non breeding 2-3 = Population of velvet stages not mated aged 2-3 in July

Lc7625 = Deer non-breeding males over 1 year but under 2 years

CR = cull rate of stags between 1-2 and 2-3 year old cohorts (assumed 40%)

Equation 3.91 *Population of mature not mated velvet stags in July*

$$Velvet\ stags\ non\ breeding\ mature = lc7620 -\ Velvet\ stags\ non\ breeding\ 2-3$$

Where:

Velvet stags non breeding mature = Population of mature not mated velvet stags in July

Velvet stags non breeding 2-3 = Population of velvet stages not mated aged 2-3 in July

Lc7620 = Deer non-breeding males 2 years and over

As there is no metabolic difference between breeding and non-breeding stags these populations are combined to simplify the model.

3.4.2 Hinds aged 0-1

The population of hinds aged 0-1 varies throughout the year. Venison replacement and slaughter hinds 0-1 are combined after the population calculation to simplify the subsequent modelling.

Equation 3.92 *Population of hinds aged 0 to 1 in August*

$$POPdh1_{aug(t)} = POPdh_{jul(t)} - \left(\frac{POPdh_{jul(t)} \times DR_{dh1}}{nod_{mar-jul}} \times PDdh1_{mar-jul}\right) \times nod_{jul}$$

Where:

$POPdh1_{aug(t)}$ = population of hinds aged 0-1 in August in year *t*

$POPdh1_{jul(t)}$ = population of hinds aged 0-1 in July in year *t*

DR_{dh1} = Annual death rate of hinds aged 0-1 (assumed to be 5%)

$nod_{mar-jul}$ = number of days between March and July (inclusive)

$PDdh1_{mar-jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod_{july} = number of days in July

The second part of this equation (from the first bracket onwards) is used to calculate the number of deaths that are estimated to occur in a specific month.

Between September and November the monthly population of 0-1 hinds is calculated using the following formula:

Equation 3.93 *Monthly population of hinds aged 0 to 1, for September, October and November*

$$POPdh1_{m(t)} = POPdh_{m-1(t)} - \left(\frac{POPdh_{jul(t)} \times DR_{dh1}}{nod_{aug-feb}} \times \left(1 - PDdh1_{mar-jul}\right)\right) \times nod_{m-1}$$

Where:

$POPdh1_{m(t)}$ = population of hinds aged 0-1 in month *m* of year *t*

$POPdh1_{m-1(t)}$ = population of hinds aged 0-1 in previous month *m-1* of year *t*

$POPdh1_{jul(t)}$ = population of hinds aged 0-1 in July of year *t*

DR_{dh1} = Annual death rate of hinds aged 0-1 (assumed to be 5%)

$nod_{aug-feb}$ = number of days between August and February (inclusive)

$PDdh1_{mar-jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod_{m-1} = number of days in previous month *m-1*

In December it is assumed that new deer calves are born, while 12 month old hinds are moved into the next age class. These changes are seen in the December population figure.

The December to June populations of hinds aged between 0 and 1 is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

Equation 3.94 *June population of hinds aged 0 to 1*

$$POPdh1_{jun(t)} = POPdeer_{(t)} \times Pdh1_{(t-1)} + \left(\frac{POPdh_{jul(t)} \times DR_{dh1}}{nod_{mar-jul}} \times PDdh1_{mar-jul}\right) \times nod_{jun}$$

Where:

$POPdh1_{jun(t)}$ = population of hinds aged 0-1 in June of year *t*

$POPdeer_{(t)}$ = Total number of deer in year *t* (from APS)

$Pdht_{t-1}$ = proportion of total deer population in July of year *t-1* assumed to be 0-1 year old hinds (using table in Appendix 19)

$POPdh1_{jul(t)}$ = population of hinds aged 0-1 in July of year *t*

DR_{dh1} = Annual death rate of hinds aged 0-1 (assumed to be 5%)

$nod_{mar-jul}$ = number of days between March and July (inclusive)

$PDdh1_{mar-jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod_{jun} = number of days in June

Equation 3.95 *Monthly population of hinds aged 0 to 1, for May, April and March*

$$POPdh1_{m(t)} = POPdh_{m+1(t)} + \left(\frac{POPdh_{jul(t)} \times DR_{dh1}}{nod_{mar-jul}} \times PDdh1_{mar-jul}\right) \times nod_m$$

Where:

$POPdh1_{m(t)}$ = population of hinds aged 0-1 in month m of year *t*

$POPdh1_{m+1(t)}$ = population of hinds aged 0-1 in next month m+1 of year *t*

$POPdh1_{jul(t)}$ = population of hinds aged 0-1 in July of year *t*

DR_{dh1} = Annual death rate of hinds aged 0-1 (assumed to be 5%)

$nod_{mar-jul}$ = number of days between March and July (inclusive)

$PDdh1_{mar-jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod_m = number of days in month m

Equation 3.96 *Monthly population of hinds aged 0 to 1, for February, January and December*

$$POPdh1_m = POPdh_{m+1} + \left(\frac{POPdh_{jul} \times DR_{dh1}}{nod_{aug-feb}} \times \left(1 - PDdh1_{mar-jul}\right)\right) \times nod_m$$

Where:

$POPdh1_m$ = population of hinds aged 0-1 in month *m*

$POPdh1_{m+1}$ = population of hinds aged 0-1 in next month *m+1*

$POPdh1_{jul}$ = population of hinds aged 0-1 in subsequent July

DR_{dh1} = Annual death rate of hinds aged 0-1 (assumed to be 5%)

$nod_{aug-feb}$ = number of days between August and February (inclusive)

$PDdh1_{mar-jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod_m = number of days in month *m*

3.4.3 Hinds aged 1-2

The population of hinds aged 1-2 varies throughout the year.

The August to November populations are calculated using the following formula:

Equation 3.97 *Population of Hinds aged 1-2 in August to November*

$$POPdh2_{m(t)} = POPdh2_{m-1(t)} - \left(\frac{POPdh2_{jul(t)} \times DR_{dh2} \times PDdh2_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{m-1}\right)$$

Where:

$POPdh2_{m(t)}$ = population of hinds aged 1-2 in month *m* of year *t*

$POPdh2_{m-1(t)}$ = population of hinds aged 1-2 in previous month *m-1* of year *t*

$POPdh2_{jul(t)}$ = population of hinds aged 1-2 in July of year *t*

DR_{dh2} = Annual death rate of hinds aged 1-2 (assumed to be 2%)

$PDdh2_{Jun\text{-}Oct}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

$nod_{Jun\text{-}Oct}$ = number of days between June and October (inclusive, i.e. 153)

nod_{m-1} = number of days in previous month *m-1*

In December the hind populations move into a new age class (i.e. the 0-1 hind population becomes the 1-2 hind population).

Equation 3.98 *Population of Hinds aged 1-2 in December*

$$POPdh2_{dec(t)} = POPdh1_{nov(t)} - \left(\frac{POPdh2_{jul(t)} \times DR_{dh2} \times PDdh2_{nov}}{nod_{nov}} \times nod_{nov}\right)$$

Where:

$POPdh2_{dec(t)}$ = population of hinds aged 1-2 in December of year *t*

$POPdh1_{nov(t)}$ = population of hinds aged 0-1 in November of year *t*

$POPdh2_{jul(t)}$ = population of hinds aged 1-2 in July of year *t*

DR_{dh2} = Annual death rate of hinds aged 1-2 (assumed to be 2%)

$PDdh2_{nov}$= proportion of annual deaths assumed to occur in November Currently assumed to be 30%

nod_{Nov} = number of days in November

The January to June populations of hinds aged 1-2 are calculated in backwards order using the July population.

Equation 3.99 *Population of Hinds aged 1-2 in June*

$$POPdh2_{Jun(t)} = POPdh2_{Jul(t)} + \left(\frac{POPdh2_{Jul(t)} \times DR_{dh2} \times PDdh2_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{Jun}\right)$$

Where:

$POPdh2_{Jun(t)}$ = population of hinds aged 1-2 in June of year *t*

$POPdh2_{Jul(t)}$ = population of hinds aged 1-2 in July of year *t*

$DR_{dh2(t)}$ = Annual death rate of hinds aged 1-2 (assumed to be 2%)

$PDdh2_{Jun\text{-}Oct}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

$nod_{Jun\text{-}Oct}$ = number of days between June and October (inclusive, i.e. 153)

nod_{Jun} = number of days in June

Equation 3.100 *Monthly Population of Hinds aged 1-2, from January to May*

$$POPdh2_{m(t)} = POPdh2_{m+1(t)} + \left(\frac{POPdh2_{Jul(t)} \times DR_{dh2} \times PDdh2_{Dec-May}}{nod_{Dec-May}} \times nod_{m}\right)$$

Where:

$POPdh2_{m(t)}$ = population of hinds aged 1-2 in month m of year *t*

$POPdh2_{m+1(t)}$ = population of hinds aged 1-2 in next month *m+1* of year *t*

$POPdh2_{Jul(t)}$ = population of hinds aged 1-2 in July of year *t*

DR_{dh2} = Annual death rate of hinds aged 1-2 (assumed to be 2%)

$PDdh2_{December\text{-}May}$ = proportion of annual deaths assumed to occur between December and May (inclusive). Currently assumed to be 10%

$nod_{Dec\text{-}May}$ = number of days between December and May (inclusive, i.e. 182)

nod_m = number of days in month *m*

3.4.4 Mature Hinds

The population of mature hinds aged varies throughout the year. The model assumes that the annual death rate of mature hinds is 2%. Most (60%) of these deaths occur between June and October (inclusive), and another 30% occur in November. These assumptions are used to calculate the monthly populations.

The August to November populations are calculated using the following formula:

Equation 3.101 *Monthly population of mature hinds from August to November*

$$POPdbh_{m(t)} = POPdbh_{m-1(t)} - \left(\frac{POPdbh_{jul(t)} \times DR_{dbh} \times PDdbh_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{m-1}\right)$$

Where:

$POPdbh_m$ = population of mature hinds in month *m* of year *t*

$POPdbh_{m-1}$ = population of mature hinds in previous month *m-1* of year *t*

$POPdbh_{jul}$ = population of mature hinds in July of year *t*

DR_{dbh} = Annual death rate of mature hinds (assumed to be 2%)

$PDdbh_{Jun\text{-}Oct}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

$nod_{Jun\text{-}Oct}$ = number of days between June and October (inclusive, i.e. 153)

nod_{m-1} = number of days in previous month *m-1*

In December the breeding hind population is boosted by the movement of the 1-2 hind population into the breeding hind population.

Equation 3.102 *Population of mature hinds in December*

$$POPdbh_{Dec(t)} = POPdbh_{Nov(t)} - \left(POPdbh_{jul(t)} \times DR_{dbh} \times PDdbh_{Nov}\right) + POPdh2_{Nov(t)}$$

Where:

$POPdbh_{Dec(t)}$ = population of mature hinds in December of year *t*

$POPdbh_{Nov(t)}$ = population of mature hinds in November of year *t*

$POPdbh_{jul(t)}$ = population of mature hinds in July of year *t*

DR_{dbh} = Annual death rate of mature hinds (assumed to be 2%)

$PDdbh_{Nov}$ = proportion of annual deaths assumed to occur in November. Currently assumed to be 60%

$POPdh2_{Nov(t)}$ = population of hinds aged 1-2 in November of year *t*

The January and February mature hind population is calculated by using the following equation

Equation 3.103 *Monthly population of mature hinds from for January and February*

$$POPdbh_m = POPdbh_{m-1} - \left(\frac{POPdbh_{jul} \times DR_{dbh} \times PDdbh_{Dec-May}}{nod_{Dec-May}} \times nod_{m-1}\right)$$

Where:

$POPdbh_m$ = population of mature hinds in month m

$POPdbh_{m-1}$ = population of mature hinds in previous month m-1

$POPdbh_{jul}$ = population of mature hinds in the July immediately prior

DR_{dbh} = Annual death rate of mature hinds (assumed to be 2%)

$PDdbh_{Dec-May}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 10%

$nod_{Dec-May}$ = number of days between June and October (inclusive, i.e. 182)

nod_{m-1} = number of days in previous month m-1

The March to June populations of mature hinds are calculated in backwards order using the July population.

Equation 3.104 *Population of mature hinds in June*

$$POPdbh_{Jun(t)} = POPdbh_{Jul(t)} + \left(\frac{POPdbh_{Jul(t)} \times DR_{dbh} \times PDdbh_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{Jun}\right)$$

Where:

$POPdbh_{Jun(t)}$ = population of mature hinds in June of year *t*

$POPdbh_{Jul(t)}$ = population of mature hinds in July of year *t*

DR_{dbh} = Annual death rate of mature hinds (assumed to be 2%)

$PDdbh_{Jun-Oct}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

$nod_{Jun-Oct}$ = number of days between June and October (inclusive, i.e. 153)

nod_{Jun} = number of days in June

Equation 3.105 *Monthly Population of mature hinds, from March to May*

$$POPdbh_{m(t)} = POPdbh_{m+1(t)} + \left(\frac{POPdbh_{Jul(t)} \times DR_{dbh} \times PDdbh_{Dec-May}}{nod_{Dec-May}} \times nod_m\right)$$

Where:

$POPdbh_{m(t)}$ = population of mature hinds in month *m* of year *t*

$POPdbh_{m+1(t)}$ = population of mature hinds in next month *m+1* of year *t*

DR_{dbh} = Annual death rate of mature hinds (assumed to be 2%)

$PDdbh_{Dec-May}$ = proportion of annual deaths assumed to occur between December and May (inclusive). Currently assumed to be 10%

$nod_{Dec-May}$ = number of days between December and May (inclusive, i.e. 182)

nod_m = number of days in month *m*

3.4.5 Stags aged 0-1

The population of stags aged 0-1 varies throughout the year. The Inventory model assumes that 65% of annual stag 0-1 deaths occur in the months between March and July (inclusive). This higher death rate is reflected in the August population of stags aged 0-1.

Equation 3.106 *Population of stags aged 0-1 in August*

$$POPds1_{Aug(t)} = POPds1_{Jul(t)} - \left(\frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1}\right)$$

Where:

$POPds1_{Aug(t)}$ = population of stags aged 0-1 in August of year *t*

$POPds1_{Jul(t)}$ = population of stags aged 0-1 in July of year *t*

DR_{ds1} = Annual death rate of stags aged 0-1 (assumed to be 5%)

$PDds1_{Mar-Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

$nod_{Mar-Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{m-1} = number of days in previous month m-1

Equation 3.107 *Population of stags aged 0-1 in September and October*

$$POPds1_{m(t)} = POPds1_{m-1(t)} - \left(\frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1}\right)$$

Where:

$POPds1_{Aug(t)}$ = population of stags aged 0-1 in month *m* of year *t*

$POPds1_{Jul(t)}$ = population of stags aged 0-1 in previous month *m-1* of year *t*

DR_{ds1} = Annual death rate of stags aged 0-1 (assumed to be 5%)

$PDds1_{Aug-Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 35%

$nod_{Aug-Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_{m-1} = number of days in previous month *m-1*

In November it is assumed that new stag calves are born, while 12 month old stags are moved into the next age class. These changes are seen in the December population figure.

The November to June populations of hinds aged between 0 and 1 is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

Equation 3.108 *Population of stags aged 0-1 in June*

$$POPds1_{Jun(t)} = POPds1_{Jul(t)} + \left(\frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun}\right)$$

Where:

$POPds1_{Jun(t)}$ = population of stags aged 0-1 in June of year *t*

$POPds1_{Jul(t)}$ = population of stags aged 0-1 in July of year *t*

DR_{ds1} = Annual death rate of stags aged 0-1 (assumed to be 5%)

$PDds1_{Mar\text{-}Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

$nod_{Mar\text{-}Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{Jun} = number of days in June

Equation 3.109 *Population of stags aged 0-1 between March and May*

$$POPds1_{m(t)} = POPds1_{m+1(t)} + \left(\frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_m\right)$$

Where:

$POPds1_{m+1(t)}$ = population of stags aged 0-1 in month *m* of year *t*

$POPds1_{m+1(t)}$ = population of stags aged 0-1 in next month *m+1* of year *t*

$POPds1_{Jul(t)}$ = population of stags aged 0-1 in July of year *t*

DR_{ds1} = Annual death rate of stags aged 0-1 (assumed to be 5%)

$PDds1_{Mar\text{-}Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

$nod_{Mar\text{-}Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_m = number of days in month m

Equation 3.110 *Population of stags aged 0-1 between November and February*

$$POPds1_m = POPds1_{m+1} + \left(\frac{POPds1_{Jul} \times DR_{ds1} \times PDds1_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_m\right)$$

Where:

$POPds1_{m+1}$ = population of stags aged 0-1 in month m

$POPds1_{m+1}$ = population of stags aged 0-1 in next month m+1

$POPds1_{Jul}$ = population of stags aged 0-1 in next July

DR_{ds1} = Annual death rate of stags aged 0-1 (assumed to be 5%)

$PDds1_{Aug\text{-}Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 35%

$nod_{Aug\text{-}Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_m = number of days in month m

3.4.6 Stags aged 1-2

The population of stags aged 1-2 varies throughout the year.

Equation 3.111 *Population of stags aged 1-2 in August*

$$POPds2_{Aug(t)} = POPds2_{Jul(t)} - \left(\frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1}\right)$$

Where:

$POPds2_{Aug(t)}$ = population of stags aged 1-2 in August of year *t*

$POPds2_{Jul(t)}$ = population of stags aged 1-2 in July of year *t*

DR_{ds2} = Annual death rate of stags aged 1-2 (assumed to be 2%)

$PDds2_{Mar-Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar-Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{m-1} = number of days in previous month m-1

Equation 3.112 *Population of stags aged 1-2 in September, October, November, January and February*

$$POPds2_m = POPds2_{m-1} - \left(\frac{POPds2_{Jul} \times DR_{ds2} \times PDds2_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1}\right)$$

Where:

$POPds2_m$ = population of stags aged 1-2 in month *m*

$POPds2_{m-1}$ = population of stags aged 1-2 in previous month *m-1*

$POPds2_{Jul}$ = population of stags aged 1-2 in previous July

DR_{ds2} = Annual death rate of stags aged 1-2 (assumed to be 2%)

$PDds2_{Aug-Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 20%

$nod_{Aug-Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_{m-1} = number of days in previous month m-1

The December 1-2 stag population is calculated differently, as it is assumed that the 0-1 population move into the higher age bracket during this month.

Equation 3.113 *Population of stags aged 1-2 in December*

$$POPds2_{Dec(t)} = POPds1_{Nov(t)} - \left(\frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1}\right)$$

Where:

$POPds2_{Dec(t)}$ = population of stags aged 1-2 in December of year *t*

$POPds2_{Nov(t)}$ = population of stags aged 1-2 in November of year *t*

$POPds2_{Jul(t)}$ = population of stags aged 1-2 in July of year *t*

DR_{ds2} = Annual death rate of stags aged 1-2 (assumed to be 2%)

$PDds2_{Aug-Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 20%

$nod_{Aug-Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_{m-1} = number of days in previous month m-1

The March to June populations of stags aged between 1 and 2 is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

Equation 3.114 *Population of stags aged 1-2 in June*

$$POPds2_{Jun(t)} = POPds2_{Jul(t)} + \left(\frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun}\right)$$

Where:

$POPds2_{Jun(t)}$ = population of stags aged 1-2 in June of year *t*

$POPds2_{Jul(t)}$ = population of stags aged 1-2 in July of year *t*

DR_{ds2} = Annual death rate of stags aged 1-2 (assumed to be 2%)

$PDds2_{Mar\text{-}Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar\text{-}Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{Jun} = number of days in June

Equation 3.115 *Population of stags aged 1-2 between March and May*

$$POPds2_{m(t)} = POPds2_{m+1(t)} + \left(\frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_m\right)$$

Where:

$POPds2_{m+1(t)}$ = population of stags aged 1-2 in month *m* of year *t*

$POPds2_{m+1(t)}$ = population of stags aged 1-2 in next month *m+1* of year *t*

$POPds2_{Jul(t)}$ = population of stags aged 1-2 in July of year *t*

DR_{ds2} = Annual death rate of stags aged 1-2 (assumed to be 2%)

$PDds2_{Mar\text{-}Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar\text{-}Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_m = number of days in month *m*

3.4.7 Stags aged 2-3

The population of stags aged 2-3 varies throughout the year. The Inventory model assumes that 80% of annual stag 2-3 deaths occur in the months between March and July (inclusive). This higher death rate is reflected in the August population of hinds aged 2-3.

Equation 3.116 *Population of stags aged 2-3 in August*

$$POPds3_{Aug(t)} = POPds3_{Jul(t)} - \left(\frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1}\right)$$

Where:

$POPds3_{Aug(t)}$ = population of stags aged 2-3 in August of year *t*

$POPds3_{Jul(t)}$ = population of stags aged 2-3 in July of year *t*

DR_{ds3} = Annual death rate of stags aged 2-3 (assumed to be 2%)

$PDds3_{Mar\text{-}Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar\text{-}Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{m-1} = number of days in previous month m-1

Equation 3.117 *Population of stags aged 2-3 in September, October, and November*

$$POPds3_{m(t)} = POPds3_{m-1(t)} - \left(\frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1}\right)$$

Where:

$POPds3_{m(t)}$ = population of stags aged 2-3 in month *m* of year *t*

$POPds3_{m-1(t)}$ = population of stags aged 2-3 in previous month *m-1* of year *t*

$POPds3_{Jul(t)}$ = population of stags aged 2-3 in July of year *t*

DR_{ds3} = Annual death rate of stags aged 2-3 (assumed to be 2%)

$PDds3_{Aug-Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 20%

$nod_{Aug-Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_{m-1} = number of days in previous month m-1

The December to June populations of stags aged between 2 and 3 is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on). Approximately 40% of stags evaluated for velvet production are slaughtered at about 25 months of age with a mean slaughter date of mid-December.

Equation 3.118 *Population of stags aged 2-3 in June*

$$POPds3_{Jun(t)} = POPds3_{Jul(t)} + \left(\frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun}\right)$$

Where:

$POPds3_{Jun(t)}$ = population of stags aged 2-3 in June of year *t*

$POPds3_{Jul(t)}$ = population of stags aged 2-3 in July of year *t*

DR_{ds3} = Annual death rate of stags aged 2-3 (assumed to be 2%)

$PDds3_{Mar-Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar-Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{Jun} = number of days in June

Equation 3.119 *Population of stags aged 2-3 between March and May*

$$POPds3_{m(t)} = POPds3_{m+1(t)} + \left(\frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m}\right)$$

Where:

$POPds3_{m+1(t)}$ = population of stags aged 2-3 in month *m* of year *t*

$POPds3_{m+1(t)}$ = population of stags aged 2-3 in next month *m+1* of year *t*

$POPds3_{Jul(t)}$ = population of stags aged 2-3 in July of year *t*

DR_{ds3} = Annual death rate of stags aged 2-3 (assumed to be 2%)

$PDds3_{Mar-Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar-Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{m} = number of days in month m

Equation 3.120 *Population of stags aged 2-3 in December*

$$POPds3_{m} = POPds2_{Nov(t)} + \left(\frac{POPds3_{Jul} \times DR_{ds3} \times PDds3_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m}\right)$$

Where:

$POPds3_m$ = population of stags aged 2-3 in month *m*

$POPds2_{Nov(t)}$ = population of stags aged 1-2 in November of year t

$POPds3_{Jul}$ = population of stags aged 2-3 in next July

DR_{ds3} = Annual death rate of stags aged 2-3 (assumed to be 2%)

$PDds3_{Aug-Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 20%

$nod_{Aug-Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_m = number of days in month *m*

Equation 3.121 *Population of stags aged 2-3 between January and February*

$$POPds3_{m} = POPds3_{m+1} + \left(\frac{POPds3_{Jul} \times DR_{ds3} \times PDds3_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m}\right)$$

Where:

$POPds3_m$ = population of stags aged 2-3 in month *m*

$POPds3_{m+1}$ = population of stags aged 2-3 in next month *m+1*

$POPds3_{Jul}$ = population of stags aged 2-3 in next July

DR_{ds3} = Annual death rate of stags aged 2-3 (assumed to be 2%)

$PDds3_{Aug-Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 20%

$nod_{Aug-Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_m = number of days in month *m*

3.4.8 Mature stags

The population of mature stags varies throughout the year. Between August and June, the population of mature stags is calculated in the same way as the population of stags aged 2-3, using the same assumptions on death rates and the proportion of deaths occurring in a particular month.

Equation 3.122 *Population of mature stags in August*

$$POPdsma_{Aug(t)} = POPdsma_{Jul(t)} - \left(\frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1}\right)$$

Where:

$POPdsma_{Aug(t)}$ = population of mature stags in August of year *t*

$POPdsma_{Jul(t)}$ = population of mature stags in July of year *t*

DR_{dsma} = Annual death rate of mature stags (assumed to be 2%)

$PDdsma_{Mar-Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar\text{-}Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{m-1} = number of days in previous month *m-1*

Equation 3.123 *Population of mature stags in September, October, and November*

$$POPdsma_{m(t)} = POPdsma_{m-1(t)} - \left(\frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1}\right)$$

Where:

$POPdsma_{m(t)}$ = population of mature stags in month *m* of year *t*

$POPdsma_{m-1(t)}$ = population of mature stags in previous month *m-1* of year *t*

$POPdsma_{Jul(t)}$ = population of mature stags in July of year *t*

DR_{ds3} = Annual death rate of mature stags (assumed to be 2%)

$PDds3_{Aug\text{-}Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 20%

$nod_{Aug\text{-}Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_{m-1} = number of days in previous month m-1

The December to June populations of mature stags is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

Equation 3.124 *Population of mature stags in June*

$$POPdsma_{Jun(t)} = POPdsma_{Jul(t)} + \left(\frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun}\right)$$

Where:

$POPds3_{Jun(t)}$ = population of mature stags in June of year *t*

$POPds3_{Jul(t)}$ = population of mature stags in July of year *t*

DR_{ds3} = Annual death rate of mature stags (assumed to be 2%)

$PDds3_{Mar\text{-}Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar\text{-}Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_{Jun} = number of days in June

Equation 3.125 *Population of mature stags between March and May*

$$POPdsma_{m(t)} = POPdsma_{m+1(t)} + \left(\frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m}\right)$$

Where:

$POPdsma_{m(t)}$ = population of mature stags in month *m* of year *t*

$POPdsma_{m+1(t)}$ = population of mature stags in next month *m+1* of year *t*

$POPds3_{Jul(t)}$ = population of mature stags in July of year *t*

DR_{dsma} = Annual death rate of mature stags (assumed to be 2%)

$PDdsma_{Mar-Jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 80%

$nod_{Mar-Jul}$ = number of days between March and July (inclusive, i.e. 153)

nod_m = number of days in month m

Equation 3.126 *Population of mature stags between December and February*

$$POPdsma_m = POPdsma_{m+1} + \left(\frac{POPdsma_{Jul} \times DR_{dsma} \times PDdsma_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_m\right)$$

Where:

$POPdsma_{m+1}$ = population of mature stags in month *m*

$POPdsma_{m+1}$ = population of mature stags in next month *m+1*

$POPds3_{Jul}$ = population of mature stags in next July

DR_{dsma} = Annual death rate of mature stags (assumed to be 2%)

$PDdsma_{Aug-Feb}$ = proportion of annual deaths assumed to occur between August and February (inclusive). Currently assumed to be 20%

$nod_{Aug-Feb}$ = number of days between August and February (inclusive, i.e. 212)

nod_m = number of days in month m

The next chapter discusses how population and production data for the major livestock species is used to calculate energy requirements.

4 Estimation of energy requirements and dry matter intake

Calculated energy requirements are combined with data on the energy content of animals' diets to estimate dry matter intake (DMI).

In the inventory, *Energy requirements* refers to the amount of energy that is needed for an animal to survive and produce animal products such as milk, meat, fibre, velvet and conceptus (pregnancy). *DMI* refers to the amount of feed consumed, excluding water content.

An animal requires energy for production, maintenance, pregnancy, lactation and activity (e.g. grazing and walking). The Inventory model estimates the total ME required by an average animal for an average day for a given month. This value (ME_{total}) is combined with information on the estimated ME content of total diet (ME_{diet}) to estimate the amount of dry matter eaten by a single animal in a single day.

Energy requirements are calculated for dairy and beef cattle, sheep and deer, but not for minor species (i.e. goats, alpacas, horses, other). The calculation of energy requirements forms part of the tier 2 methodology used to calculate emissions for cattle, sheep and deer. Specific details relating to each livestock category are outlined in sections 4.4, 4.5, 4.6 and 4.7.

New Zealand's energy requirement calculations are based on the Australian Feeding Standard's algorithms for cattle and sheep (CSIRO, 1990).

Nearly all animals in New Zealand graze 'improved' sown pastures. However, the default IPCC algorithms used for estimating energy requirements are based on either grain-fed cattle or sheep husbandry under very different circumstances from that in New Zealand. As a result, New Zealand's Inventory model is instead based on the Australian Feeding Standard's algorithms for cattle and sheep (CSIRO, 1990). These have been developed from freely grazing ruminants and better reflect the New Zealand feeding situation[a]. Figure 4.1 summarises how energy requirements are calculated.

New Zealand uses 'metabolisible energy' (ME) to estimate DMI.

ME represents the energy that is available to an animal (CSIRO, 1990) through absorption of nutrients, and is different to the concept of 'net energy' (NE), which represents the energy that is actually able to be used by the animal for maintenance, and incorporated in product, as described in CSIRO (1990). The inventory model assumes livestock are fed both pasture and non-pasture feed.

The agricultural inventory model uses data from a range of sources[b] to estimate the ME requirements of New Zealand's livestock population. Although the equations used here and in feeding standards (e.g. CSIRO, 2007) have a sound physiological basis and are based on measurements from several animal species in a range of physiological states (growing, lactating, pregnant, etc.) it is important to appreciate that variation (associated with diet, breed, species and their interactions) exists within species. The results of any ME calculations therefore should be regarded as estimates.

Feed intake estimates are used to calculate enteric methane emissions and nitrogen excretion for each livestock category.

The calculated DMI and N intake provide the basis for estimating enteric methane emissions and nitrogen excretion (and hence nitrous oxide emissions) by each livestock category, by day, month and then by year. By aggregating across days, livestock numbers, and livestock categories, the annual inventories of methane and nitrous oxide emissions can be estimated.

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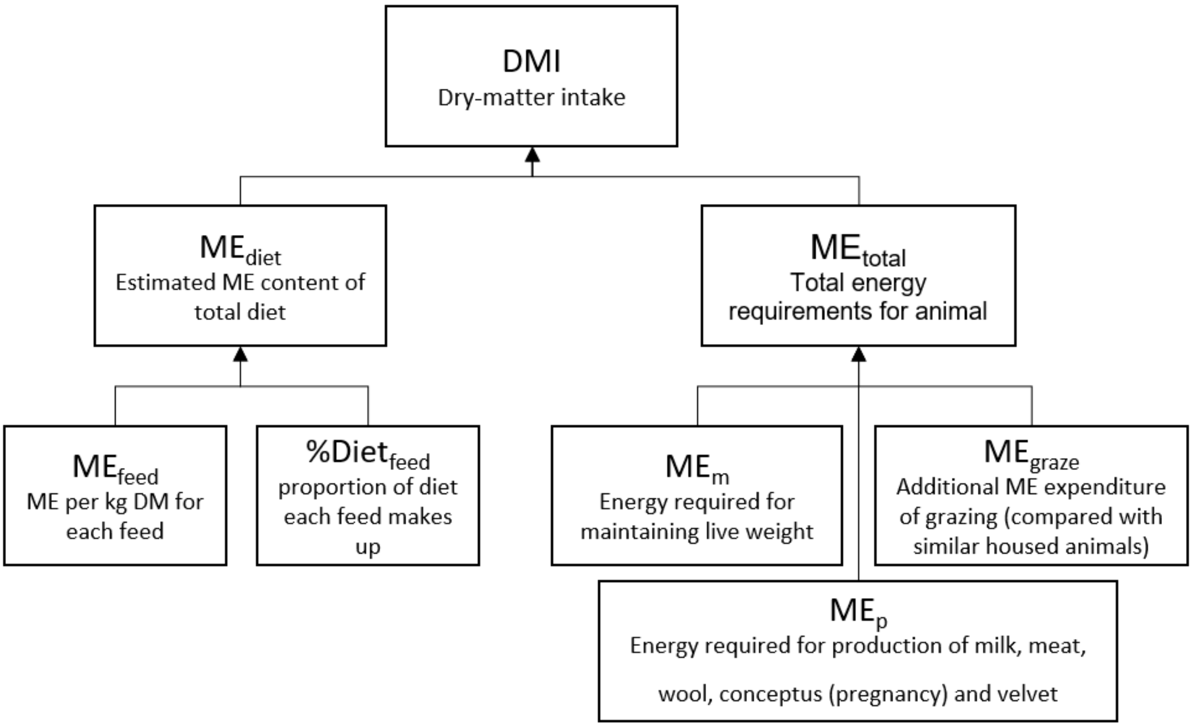
[a] The IPCC Tier 2 energy requirements model is based on 'net energy, NE' whereas the New Zealand approach (using the Australian Feeding Standards algorithms) uses 'metabolisable energy, ME'. Net energy relates to metabolisable energy as follows: NE = ME – energy lost by the animal as heat (Lassey, 2007, figure 2).

Statistics New Zealand's annual Agricultural Production Survey (APS) and census, New Zealand Dairy Statistics, Beef and Lamb New Zealand, Deer Industry New Zealand, and slaughter statistics collected by the Ministry for Primary Industries (MPI)

Figure 4.1: How energy requirements and dry-matter intake are calculated



4.1.1 Calculation of dry matter intake

Dry matter intake of an average animal is determined by taking the total energy requirement as outlined in Figure 4.1, and dividing this by the energy content of the total diet (ME_{diet}).

Equation 4.1 *Calculation of dry matter intake*

$$DMI = \frac{ME_{total}}{ME_{diet}}$$

Where:

DMI = dry matter intake per day for an average animal (kg/d)

ME_{total} = total metabolisible energy required per day for an average animal representing specified categories (MJ/d)

ME_{diet} = energy content of feed intake or the metabolisible energy per kilogram of dry matter for total diet (MJ/kg)

For grazing ruminants, the ME content the total diet ($Diet_{ME}$) represents the energy available to the animal for maintenance, production and activity (grazing, walking, etc.) (Waghorn, 2007).

4.2 Calculation of total diet quality

Pasture quality varies seasonally for dairy, sheep, beef, and deer. Different quantities and types of non-pasture are fed through the year. Present data supports the including annual variation in non-pasture feed for dairy cattle and seasonal variation for beef cattle and sheep.

The energy content of the total diet consumed by livestock is calculated using a weighted average based on the usage of different feeds.

4.2.1 Calculation of total diet metabolisable energy

Equation 4.2 *Calculation of total diet ME*

$$ME_{diet} = \sum_{feed} ME_{feed} \times \%Diet_{feed}$$

Where:

ME_{diet} = metabolisible energy per kilogram of dry matter for total diet (MJ/kg).

ME_{feed}= metabolisible energy per kilogram of dry matter for each feed (MJ/kg). The ME_{feed} values used in these inventory calculations for different months and animal categories are given in Appendix 3 (pasture) and Appendix 5 (non-pasture).

$\%Diet_{feed}$ = proportion of the livestock diet each feed makes up. The dietary proportions used in these calculations are given in Appendix 6 (dairy) and Appendix 7 (sheep and beef). Deer are assumed to be entirely pasture fed.

4.2.2 Calculation of total diet digestibility

Equation 4.3 *Calculation of total diet digestibility*

$$DMD = \sum_{feed} DMD_{feed} \times \%Diet_{feed}$$

Where:

DMD = dry matter digestibility of total diet consumed

DMD_{feed}= dry matter digestibility of feed. The DMD_{feed} values used in these inventory calculations for different months and animal categories are given in Appendix 3 (pasture) and Appendix 5 (non-pasture).

$\%Diet_{feed}$ = proportion of the livestock diet of each feed makes up. The dietary proportions used in these calculations are given in Appendix 6 (dairy) and Appendix 7 (sheep and beef). Deer are assumed to be entirely pasture fed.

4.3 Components of metabolisable energy

The total daily metabolisible energy requirements of an animal (ME_{total}) is the sum of four components:

- ME_m: ME for maintenance (MJ/d).
- ME_p: ME required for production, in the form of wool, meat (live weight gain), milk or velvet (MJ/d)
- ME_{graze}: additional ME expenditure associated with outdoor production systems (walking and grazing) compared with similar animals in confined conditions (MJ/d).
- ME_c: ME required for gestation or growth of the conceptus at any given time during pregnancy (MJ/d)

Equation 4.4 *Total metabolisible energy requirements, ME_{total}*

$$ME_{total} = ME_m + ME_p + ME_{graze} + ME_c$$

Where:

ME_{total} = Total ME requirements of animal (MJ/d)

ME_m = metabolisable energy required to maintain animal weight (MJ/d).

ME_p = metabolisable energy required for production (MJ/d)

ME_{graze} = additional metabolisable energy expenditure of grazing (MJ/d).

ME_c = Metabolisible energy required for gestation or growth of the conceptus (MJ/d)

ME_m is the amount of energy required to maintain the animal[c]. ME_p is the amount of energy that is required by an animal for the production of milk, wool, velvet, and live weight gain. ME_{graze} is the additional ME expenditure associated with outdoor production systems (walking and grazing) compared with similar animals in confined conditions (CSIRO, 1990). Additional energy requirements associated with cold conditions (CSIRO, 2007) have not been implemented in this model.

The ME_m requirement for an animal of a defined weight is not constant, and will vary with energy costs of production. Increased productivity requires higher feed intakes and this affects the proportion of viscera and costs associated with respiration, cardiac output, etc. The inventory model accounts for this by adding 10 percent of the dietary ME allocated to production (ME_p) to ME_m (CSIRO, 1990). The addition of the term $0.1 \times ME_p$ in Equation 4.5 is used to account for this.

The inventory uses a generic equation to calculate ME_m for dairy and beef cattle, sheep and deer, but equations used to calculate ME_p and ME_{graze} differ for each animal category, and are outlined in sections 4.4, 4.5, 4.6 and 4.7. All of the equations in this section are expressed on a per-animal per day basis, unless otherwise stated.

Equation 4.5 *Metabolisable energy required for maintenance, ME_m :*

$$ME_m = K \times S \times \frac{0.28LW^{0.75} \times e^{-0.03A}}{k_m} + 0.1 \times ME_p$$

Where:

ME_m = metabolisable energy required to maintain animal weight (MJ/d).

K = Coefficient that accounts for differences in fasting heat production across species (CSIRO, 1990, pg 22). This value is 1.0 for sheep, and 1.4 for cattle and deer (CSIRO, 2007)

S = Coefficient that accounts for differences in basal metabolic rate between males and females. This value is 1.0 for mature females and castrates or 1.15 for entire mature males (CSIRO, 2007).

LW = Live weight of animal (kg)

A = Age in years, up to a maximum value of 6

k_m = Efficiency of utilisation of ME for maintenance, or the factor used to convert ME to NE for maintenance

ME_p = ME required for production (MJ/d)

The parameter k_m is the efficiency of the use of ME, and is calculated by using the following equations (CSIRO, 2007):

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[c] The current code in the inventory, as well as previous versions of the methodology document, also refer to ME_m as BASAL.

Equation 4.6 *Efficiency of utilisation for maintenance, k_m*

$$k_m = 0.35 \times Q_m + 0.503$$

Where:

k_m = Efficiency of utilisation of ME for maintenance.

Q_m = ratio of diet ME to gross energy (GE) concentration of diet

Equation 4.7 *Ratio of metabolisible to gross energy for feed, Q_m*

$$Q_m = \frac{ME_{diet}}{GE_{diet}}$$

Where:

Qm = ratio of feed ME to GE concentration of diet.

ME_{diet} = ME content of diet (Equation 4.2) (MJ/kg)

GE_{diet} = gross energy per kilogram of dry matter, assumed to be 18.45 mega joules per kilogram of dry matter (MJ/kg)

Q_m represents the ratio of diet ME concentration to the gross energy concentration of diet. The value of Q_m will typically range from 0.5 to 0.7 (9.0 to 12.5 MJ ME/kg DM relative to 18.45 MJ GE/kg DM) depending on the animal species and time of year.

GE_{diet} is set at 18.45 MJ/kg for dairy cattle beef cattle, sheep and deer, which is consistent with the IPCC default value (IPCC, 2006).

The next sections in chapter 4 go into more specific detail of how energy requirements are calculated for the major livestock species.

4.4 Energy requirements for dairy cattle

Dairy farming takes place in many regions of New Zealand. Regional data on dairy cattle populations are collected by Statistics New Zealand, and regional productivity data (milk yield and composition) is collected by the Livestock Improvement Corporation. To improve accuracy in the inventory, regional differences can be taken into account by carrying out dairy calculations at a regional scale.

The regions used in the dairy inventory are Northland, Auckland, Waikato, Bay of Plenty, Gisborne, Hawke's Bay, Taranaki, Wanganui-Manawatu, Wellington, Tasman, Nelson, Marlborough, West Coast, Canterbury, Otago and Southland.

For the dairy part of the inventory, emissions are estimated for four sub-categories of dairy cattle:

- milking cows and milking heifers,
- growing females < 1 year old,
- growing females 1-2 years old, and
- breeding bulls

4.4.1 Total energy requirements

The total energy requirements for each subcategory of dairy cattle is outlined in the table below, which are based on Equation 4.4 outlined in Section 4.3.

Table 4.1: Equations for the total ME requirements for each subcategory of dairy cattle

Dairy subcategories	Equation

Milking cows and heifers	$ME_{total} = ME_m + ME_l + ME_c + ME_g + ME_{graze}$
Growing females less than one year of age	$ME_{total} = ME_m + ME_g + ME_{graze} - Z_1$
Growing females between one and two years	$ME_{total} = ME_m + ME_g + ME_{graze}$
Breeding bulls	$ME_{total} = ME_m + ME_g + ME_{graze}$

Where:

ME_{total} = Total ME requirements of animal (MJ/d)

ME_m = ME required for maintenance (MJ/d)

ME_l =ME required for milk production (MJ/d)

ME_c =ME required for gestation or growth of the conceptus (MJ/d)

ME_g =ME required for live weight gain (growth) (MJ/d)

ME_{graze} = Additional ME expenditure of grazing (MJ/d)

Z_1 = Energy contained in the milk diet of young animals (MJ/d)

The equations in Table 4.1 detail the components of ME required by different subcategory of dairy cattle. In addition to requirements for maintenance and grazing activities, it is assumed that growing females and breeding bulls only *produce* live weight gain (ME_g), while milking cows produce milk (ME_l) and calves (gestation – ME_c).

Dairy animals are assumed not to graze until their third month of life. Until that time they are milk fed, which supports their ME requirement during those months. This reduction in the energy requirements from dry matter is accounted for by subtracting a term, z_1, in the calculation of total ME requirements. This term z_1 represents the energy contained in the milk diet. Milk-fed calves (that is, calves less than two months old) do not generate or emit methane.

The following section details the calculations for each component of ME for dairy.

4.4.2 Energy required for maintenance

As stated in Section 4.3, the inventory uses a generic equation to calculate ME_m for the main animal species, including dairy cattle (Equation 4.5). For dairy, the value for K is set to 1.4.

Live weights for cows are updated annually using data from MPI. It is assumed that dairy bulls have a live weight of 500kg. Calves at birth are assumed to be 9% of an average cow's weight with linear weight gain reaching 90% of an average cow's weight at the first calving (2 yr old). For the purposes of variable A (age) in Equation 4.5, Dairy cattle in the four subcategories are assumed to be the following ages:

- 4 years old for milking cows and heifers
- 0.5 years old for growing females less than 1 year old
- 1.5 years old for growing females between one and two years of age
- 4 years old for breeding bulls

Additional data on live weights is provided in appendix 1.

4.4.3 Metabolisable energy requirements of production

The ME_p component for dairy cattle is made up of the following components, which are also specified in Equation 4.8 to Equation 4.20:

- ME_l: ME required for milk production (MJ/d)
- ME_g: ME required for live weight gain (growth) (MJ/d)

Equation 4.8 *Metabolisible energy requirements for dairy cattle production*

$$ME_p = ME_l + ME_g$$

As stated earlier the inventory model assumes that growing females and breeding bulls only *produce* live weight gain (ME_g), while milking cows produce milk (ME_l) and calves (gestation – ME_c)

4.4.3.1 Metabolisable energy requirements for milk production

The energy requirements for milk production (ME_l) are calculated using methodology developed the United Kingdom's Energy & Protein Requirements of Ruminants Agricultural and Food Research Council (AFRC; 1993). The following equation is used to calculate ME_l:

Equation 4.9 *Metabolisible energy requirements for milk production*

$$ME_l = \frac{Y \times MILK_{GE}}{k_l}$$

Where:

ME_l = Metabolisible energy required for milk production (MJ/d)

Y = Daily milk yield per milking cow (kg/d)

$MILK_{GE}$ = Gross energy content of milk (MJ/kg)

k_l = Efficiency of use of ME for milk production, or the factor used to measure how efficiently ME is used by a dairy cow to produce milk (see Equation 4.12)

In the model, litres of milk is converted into kilograms of milk using a factor of 1.03 (that is, number of litres multiplied by 1.03 = kilograms of milk) (www.ifcndairy.org). Over the course of a year, the amount of milk produced by a cow varies, and is assumed to vary from a low in June to a high in October. The current proportions used in the inventory are outlined in Appendix 8. This information is inserted into the following equation to calculate the daily milk yield (Y) per milking cow in a given month.

Equation 4.10 *Calculation of daily per cow milk yield for dairy cattle*

$$Y = \frac{N_m \times mp_{month}}{P_{milkingcow} \times D_{month}}$$

Where:

Y = Daily milk yield per milking cow (kg/d)

N_m = National aggregate annual milk yield (kg)

mp_{month} = Milk produced in a given month as a proportion of total annual milk produced (Appendix 8)

$P_{milkingcow}$ = population of mature milking cows in a given month

D_{month} = number of days in given month

To determine the gross energy content of milk ($MILK_{GE}$), the average fat and protein concentrations of this milk are required, along with the following AFRC (1993) equation:

Equation 4.11 *Gross energy content of milk*

$$MILK_{GE} = 0.376 \times F + 0.209 \times P + 0.948$$

Where:

$MILK_{GE}$ = Gross energy content of milk (MJ/kg)

F = fat content of milk, measured as a percentage (data collected from LIC)

P = protein content of milk, measured as a percentage (data collected from LIC)

Activity data on the fat and protein content of milk is displayed in Appendix 1.

k_l is calculated by using the following equation from ARC (1980).

Equation 4.12 *Efficiency of utilisation for milk production*

$$k_l = 0.35 \times Q_m + 0.42$$

Where:

k_l = Efficiency of use of ME for milk production, or the factor used to measure how efficiently ME is used by a dairy cow to produce milk

Q_m = the ratio of total diet ME concentration to the gross energy concentration of total diet. (see Equation 4.7, Section 4.3)

The suitability of these equations for the New Zealand situation has been demonstrated using New Zealand specific studies. Grainger *et al*. (1983) has shown that the relationship between the gross energy content of milk ($MILK_{GE}$) and the concentration of fat and protein has different parameter values for Holstein-Friesian and Jersey breeds. However, due to a lack of suitable data on disaggregation by breed (from 1990 onwards) it is not possible to use these New Zealand specific relationships in calculating emissions for the inventory.

4.4.3.2 Metabolisible energy requirements for change in live weight

In order to predict the energy required for a change in live weight of a dairy cow, a set of equations taken from the ARC (1980) are utilized for:

- non-lactating animals (Breeding bulls and growing females less than two years);
- milking cows and heifers

4.4.3.2.1 Live weight gain for non-lactating animals

Equation 4.13 *Metabolisable energy requirements for live weight gain in non-lactating animals :*

Where:

$$ME_g = \frac{(6.7 + R) + \frac{20.3 - R}{1 + e^{-6(P_{lw} - 0.4)}}}{k_{gnl}} \times LWG \times 0.92$$

ME_g = Energy required for live weight gain (MJ/d)

R =An adjustment for rate of change in live weight

LWG = Live weight gain in kg/day

P_{lw} = ratio of current live weight (LW) to a standard reference weight (SRW) of a mature animal

k_{gnl} = Net efficiency of dietary metabolisable energy conversion to live weight gain for non-lactating animals

A number of variables in this equation require additional calculations, which are set out below. The variable R is used to adjust for the rate of gain or loss of live weight. The calculation of R requires information on the change in empty body weight (EBC) or the body weight minus weight of gut contents, and standard reference weight (SRW) of a mature animal. SRW values are fixed at values determined by the CSIRO (1990):

- 550 kg for females
- 770 kg for bulls

LWG measures the daily live weight gain of an animal. P_{lw} is the ratio of current live weight (C_{lw}) to a standard reference weight (SRW) of a mature animal. Annual information on current live weight is provided in appendix 1.

k_{gnl} is a conversion factor that used to measure how efficiently ME is used by a dairy cow for weight gain (see Equation 4.20).

Equation 4.14 *Calculating rate of gain or loss in live weight:*

$$R = \frac{EBC}{4 \times SRW^{0.75}} - 1$$

Equation 4.15 *Calculating ratio between current live weight and standard reference:*

$$P_{lw} = max\left(\frac{LW_x}{SRW}, 1\right)$$

Equation 4.16 *Change in empty body weight (Equation 4.16):*

$$EBC = 0.92 \times LWG$$

Equation 4.17 *Efficiency of utilisation for live weight gain for non-lactating animals*

$$k_{gnl} = 0.042 \times ME_{diet} + 0.006$$

Where:

R =An adjustment for rate of change in live weight

EBC = change in empty body weight (kg/d)

SRW = Standard reference weight of a mature animal of a specific dairy cow breed (kg), either 550kg for females or 770kg for bulls

LWG = Live weight gain (kg/d)

LW_x = current live weight of animal *x* (kg)

ME_{diet} = Metabolisible energy content of feed (MJ/kg)

The calculation of live weight and live weight gain (LWG) for the different animal species is outlined in section 4.8. LWG is assumed to be zero for mature milking cows.

4.4.3.2.2 Live weight gain for growing lactating animals

The equation below outlines the variables and parameters that are used to calculate ME_g for growing lactating animals.

Equation 4.18 *Metabolisable energy requirements for live weight gain in growing lactating animals:*

$$ME_g = \frac{neclw \times LWG}{k_g}$$

Where:

Neclw = net energy content of liveweight (MJ)

LWG = Live weight gain (kg/day)

k_g = Net efficiency of dietary metabolisable energy conversion to live weight gain

The variables neclw and kg require additional calculations and inputs such as body condition score (cs) and kl. The body condition score is a visual assessment of an animal's body fat reserves and is assumed to be 6 for dairy cattle. k_l measures how efficiently ME is used by a dairy cow to produce milk and is also discussed in Section 4.4.3.1 (see Equation 4.12)

Equation 4.19 *Calculation of neclw:*

$$neclw = 10.1 + 2.47 \times cs$$

Equation 4.20 *Efficiency of utilisation for live weight gain:*

$$k_g = 0.95 \times k_l$$

Where:

Neclw = net energy content of liveweight (MJ)

cs = condition score, assumed to be 6

k_g = Net efficiency of dietary metabolisable energy conversion to live weight gain

k_l = Net efficiency of dietary metabolisable energy conversion for milk production (see Section 4.4.3.1)

4.4.4 Metabolisable energy requirements for gestation

In order to determine the metabolisable energy required for gestation, an equation taken from ARC (1980) is used to determine the total energy retention at any given time during pregnancy using the Gompertz model. These values can then be used to calculate the daily metabolisable energy required during the gestation period. Thus, daily metabolisable energy values are determined by the following equation:

Equation 4.21 *Metabolisable energy requirements for gestation:*

$$ME_c = 0.025 \times LW_c \times \frac{0.0201E_t \times e^{-0.0000576prg}}{k_c}$$

Where:

ME_c = Metabolisible energy required for gestation or growth of the conceptus (MJ/d)

LW_C = Calf birth weight (kg).

E_t = Energy required for the gravid uterus in utero (MJ/d)

prg = Number of days the cow has been pregnant (see Appendix 9)

k_c = Efficiency of use of ME for conceptus energy gain (0.133)

The calf birth weight (W_c) is estimated as 9% of the adult cow's live weight (AFRC, 1993). This liveweight information is updated each year (see Appendices 1 and 13). Analysis of this from 1990 to 2009 determines calf birth weight over the time series to be between 39.9 to 41.4 kg.

k_c is a conversion factor that used to measure how efficiently ME is used by a dairy cow for gestation. A value of k_c = 0.133 is currently used (ARC, 1980).

E_t measures the amount of energy required growth of the uterus as well as the foetus, and is calculated below:

Equation 4.22 *Energy requirement for the gravid uterus:*

$$E_t = 10^{151.665 - 151.64e^{-0.0000576prg}}$$

Values for coefficients used in the calculation of the term E_t are adopted from ARC (1980) where they were determined for a calf whose birth weight was 40.0kg at 281 days of gestation.

A summary of the net requirements for gestation can be found in report from CSIRO, 1990.

4.4.5 Metabolisable energy requirement for grazing

The following equation from CSIRO (1990) is used determine the metabolisable energy required for grazing:

Equation 4.23 *Metabolisable energy required for grazing*

$$ME_{graze} = \frac{\left(\left(C \times (0.9 - DMD) \times \left(ME_m + ME_p + ME_c - Z_1\right)\right) + 0.05 \times \left(\frac{T}{GF + 3}\right) \times Feed_{ME}\right)W}{k_m \times ME_{diet} - C \times W \times (0.9 - DMD)}$$

Where:

C =additional energy for eating that grazing animals require compared with confined animals (0.006)

DMD = Dry matter digestibility required for gestation

ME_m = metabolisable energy required to maintain animal weight (MJ/d).

ME_c = metabolisable energy

Z_1 = the amount of energy received from milk (MJ/d)

ME_p = metabolisable energy required for production (MJ/d)

T = Terrain factor. Value of 1 currently used for dairy (flat land) (see CSIRO 1990 for details)

GF = Availability of green forage (tonnes/ha).

W = Animal live weight (kg)

k_m =Efficiency of utilisation for maintenance, or the factor used to convert net energy (used for maintenance) to metabolisable energy

ME_{diet} = energy content of feed intake or the metabolisible energy per kilogram of dry matter (MJ/kg)

The coefficient C is used to help determine the additional energy for eating that grazing animals require compared to housed animals. A value of 0.006 is used for cattle (CSIRO, 1990).

Information on the dry matter digestibility (DMD) is contained in Appendix 3 (pasture) and Appendix 5 (non-pasture).

The parameter T represents how the energy used for walking varies with terrain (e.g. flat or steep land). A value of T = 1 is used for dairy.

GF represents the availability of forage. A higher value means that animals will spend less energy searching for forage. A GF value of 3.5 tonnes of dry matter per hectare is used in the inventory for cattle.

Information on animal liveweight (W) is provided in appendix one.

The variable k_m is used to account for the energy lost by the body tissues as heat. It can also be thought as the efficiency of the use of ME. The equation specified in section 4.2 (Equation 4.4) is used to calculate k_m.

4.4.6 Adjustment to total metabolisable energy requirements for cattle up to 1 year old

In New Zealand farming practice, animals less than one year of age are only fed milk for the first 2-3 months of their life (August – October). These milk-fed calves do not produce any methane and the inventory takes this into account through the use of the term Z_1 in Equation 4.24). Z_l represents the amount of energy received from milk and is determined as follows:

Equation 4.24 *Energy received from milk:*

$$Z_1 = \frac{Z_{mp}}{d} \times \frac{MILK_{GE}}{k_l}$$

Where:

Z_1 = the amount of energy received from milk (MJ/d)

Z_{mp} = Milk fed to calves (kg).

d = Number of days of receiving milk (61 days)

$MILK_{GE}$ = Gross energy content of milk (MJ/kg)

k_l = Net efficiency of ME utilisation for milk production (Equation 4.12)

The term Z_{mp} is the amount of milk fed to a calf during the first two months of life. For the dairy industry in New Zealand, this generally comes from milk powder and is assumed to total 200 kilograms/animal (Financial Budget Manual, 2002). The inventory assumes that calves receive milk for 61 days. After this period (two months) Z_1 is set to zero.

The calculation of $MILK_{GE}$ is outlined in Section 4.4.3.1 (Equation 4.11). As discussed in Section 4.4.3.1, k_l represents the factor that measures how efficiently ME is used by a dairy cow to produce milk (see Equation 4.12).

4.4.7 Summary of metabolisible energy requirements for dairy

The equations outlined in Section 4.4 are used to determine the total metabolisible energy (ME_{total}) requirements for each class of dairy cattle. This figure can then be used to calculate Dry Matter Intake (DMI) using the equation in Section 4.1.1 (Equation 4.1), which is ultimately used to calculate emissions.

4.5 Energy requirements for beef cattle

4.5.1 Total maintenance energy requirements

The total energy requirements for beef cattle is made up of the components and equations outlined in section 3.2. The components used in the calculations of ME requirements for dairy cattle are also used for beef cattle (i.e. ME_m, ME_l, ME_c ME_g, ME_{graze} and Z_1).

Beef calves do not begin grazing until their sixth month of life. Until that time they are milk fed. As with dairy calves they therefore do not require the same amount of energy for grazing in that year and the total ME requirement needs to be adjusted for the reduced ME_{graze}. This is again done by including a further term, z_1, in the calculations for the total ME requirements.

Each subcategory of beef animal and the high-level equations used to calculate their total ME requirements are outlined in Table 4.2.

Table 4.2: Beef animal subcategories and equations used to calculate ME requirements

Beef cattle subcategories	Equation used to calculate total ME requirements
1. Growing cows 0 – 1 years	$ME_{total} = ME_m + ME_g + ME_{graze} - Z_l$
2. Growing cows 1 – 2 years	$ME_{total} = ME_m + ME_g + ME_{graze}$
3. Breeding growing cows 2 – 3 years	$ME_{total} = ME_m + ME_g + ME_l + ME_c + ME_{graze}$
4. Breeding mature cows	$ME_{total} = ME_m + ME_g + ME_l + ME_c + ME_{graze}$
5. Breeding Bulls – mixed age	$ME_{total} = ME_m + ME_g + ME_{graze}$
6. Slaughter Heifers 0 – 1 years	$ME_{total} = ME_m + ME_g + ME_{graze} - Z_l$
7. Slaughter Heifers 1 - 3 years	$ME_{total} = ME_m + ME_g + ME_{graze}$

8. Slaughter steers 0 – 1 years	$ME_{total} = ME_m + ME_g + ME_{graze} - Z_l$
9. Slaughter steers 1 - 3 years	$ME_{total} = ME_m + ME_g + ME_{graze}$
10. Slaughter Bulls 0 - 1 years	$ME_{total} = ME_m + ME_g + ME_{graze} - Z_l$
11. Slaughter Bulls 1 – 3 years	$ME_{total} = ME_m + ME_g + ME_{graze}$

Where:

ME_{total} = Total metabolisible energy requirements of animal (MJ/d)

ME_m = Metabolisible energy required for maintenance (MJ/d)

ME_l =Metabolisible energy required for milk production (MJ/d)

ME_c =Metabolisible energy required for gestation (MJ/d)

ME_g =Metabolisible energy required for live weight gain (growth) (MJ/d)

ME_{graze} = Additional metabolisable energy expenditure of grazing (MJ/d)

Z_1 = Energy contained in the milk diet of young animals (MJ/d)

4.5.2 Metabolisible energy required for maintenance

As for dairy cattle, Equation 4.3 is used to determine maintenance energy requirements for beef cattle. Information on live weight (W) and age (A) used in this equation are contained in appendix 8 and 2, respectively. Values of 1.4 for *K* and 1.15 for S are used for beef cattle, which is the same as dairy cattle. Information on feed ME content for beef cattle is contained in Appendices 3 & 5 and calculated by Equation 4.2.

4.5.3 Metabolisable energy requirements of production

4.5.3.1 Metabolisable energy requirements of milk production

Of the beef cattle subcategories, only *breeding growing cows 2 – 3 years* and *breeding mature cows* produce milk. Equations 4.9, 4.11, 4.12 (in Section 4.4.3.1) and 4.26 (see below) are also used to determine milk production energy requirements for these beef cattle. Some of the parameters used in these equations have identical values to those used in the calculation of ME_l for dairy cattle, which are:

- Fat content of milk (F)
- Protein content of milk (P)
- Gross energy content of milk ($MILK_{GE}$)
- Efficiency of metabolisible energy used for milk production (k_l)
- Number of days in a given month (D_{month})

The remaining parameters (listed below) use different values (compared to dairy cattle) to calculate milk production energy requirements for beef cattle:

- Daily milk yield per breeding beef cow (Y)
- Proportion of total annual milk produced by beef cattle in a given month (mp_{month})
- Ratio of diet ME concentration to the gross energy concentration of diet (Q_m). The inventory assumes that beef cattle consume pasture with a different metabolisible energy content ($PAST_{ME}$). $PAST_{ME}$ values are provided in appendix 3. Non pasture feed values are provided in appendix 5. Total diet ME (ME_{diet}) is calculated using Equation 4.2.
- Population of breeding beef cows in a given month ($P_{milkingcow}$)

The inventory model assumes that a breeding beef cow produces 824 kilograms of milk per year (appendix 8). This can be used to calculate the daily milk yield per breeding beef cow (Y).

Equation 4.25 *Calculation of daily per cow milk yield for beef cattle*

$$Y = \frac{A_m \times mp_{month} \times Calf\%}{D_{month}}$$

Where:

Y = Daily milk yield per milking cow (kg/d)

A_m = Annual milk yield per breeding beef cow (assumed to be 824 kg)

mp_{month} = Milk produced in a given month as a proportion of total annual milk produced (see Appendix 8)

Calf% = calving percentage, assumed to be 85%

D_{month} = number of days in given month

Information on milk fat (F) and milk protein (P) in these equations is provided in appendix 8. Information on the fraction of total annual milk produced in a given month (mp_{month}) is contained in Appendix 8.

4.5.3.2 Energy requirements for change in live weight

The equations used to calculate ME_g (energy required for live weight gain) for beef cattle are identical to those used to calculate ME_g for dairy cattle (Equation 4.13 – Equation 4.20 in Section 4.4.3.2).

The equations in Section 4.4.3.2.1 *live weight gain for non-lactating animals* are used to calculate ME_g for the following classes of beef cattle:

- Growing cows 0 – 1 years
- Growing cows 1 – 2 years
- Breeding Bulls – mixed age
- Slaughter Heifers 0 – 1 years
- Slaughter Heifers 1 - 2 years
- Slaughter steers 0 – 1 years
- Slaughter steers 1 - 2 years
- Slaughter Bulls 0 - 1 years
- Slaughter Bulls 1 – 2 years

The equations in Section 4.4.3.2.1 *live weight gain for growing lactating animals* are used to calculate MEg for the following classes of beef cattle:

- Breeding growing cows 2 – 3 years
- Breeding mature cows

Data on live weight is calculated using data provided by MPI. A linear trend is used to estimate live weight for growing beef cattle. Calf birth weight is assumed to be 7% of final liveweight for all beef animal classes. However, since bulls and steers have the same birthweight, their birthweights are calculated based on 7% of final bull liveweight. Data on beef live weights are provided in appendix 15. No weight gain is assumed for adult beef cows.

4.5.4 Metabolisable energy requirements for gestation

Equation (4.21) in Section 4.4.4 is used to determine the energy requirements for beef cattle conception and gestation. Calf weight (W_c) is assumed to be 7% of final liveweight for all beef animal classes. However, since bulls and steers have the same birthweight, their birthweights are calculated based on 7% of final bull liveweight. For calculating the energy required for gestation we use an average of the male and female birth weights. The energy required for gestation is multiplied by the calving percentage (assumed to be 85%) to account for the empty beef cows each year. Values for the number of days the cow has been pregnant (prg) are found in Appendix 9.

4.5.5 Additional metabolisable energy expenditure of grazing at pasture

Section 4.4.5 is used to determine the additional energy beef cattle require for grazing, relative to confined animals of similar live weight.

Some of the parameters used in this equation have identical values to those used in the calculation of ME_{graze} for dairy cattle, which are:

- Additional energy for eating that grazing animals require compared to housed animals (C)
- Availability of green forage (GF)
- Efficiency of utilisation for maintenance (km)

The remaining parameters (listed below) use different values (compared to dairy cattle) to calculate grazing energy requirements for beef cattle:

- Terrain factor (T) A value of 1.5 is used, reflecting undulating pasturelands
- Dry matter intake (DMI). Different values of DMI are calculated for beef cattle, using the iteration methodology outlined in Section 4.4.4.
- Dry matter digestibility (DMD). Monthly values of DMD for beef cattle are calculated using Equation 4.3.
- Live weight (LW)

Live weight (LW) for beef cattle is calculated by the model for each subcategory assuming a linear weight gain described in Section 4.5.3.

4.5.6 Adjustment to total energy requirements for beef cattle aged up to 1 year

All beef animals up to one year of age receive some of their energy requirements from milk. For the first 8 months of life it is assumed that they are fed either suckled milk or milk derived from powder, which is used to supplement suckled milk.

For the first two months of life, the Inventory model assumes that a calf bred as beef livestock does not produce any methane as they are fed strictly milk. Equation 4.24, outlined in Section 4.4.5 is used to calculate the amount of energy received from milk for these beef calves.

For the third to eighth months (3–8) of a beef calf's life, the equations below are used to calculate the amount of energy received from milk.

Equation 4.26 *Energy received from milk for beef calves 3-8 months:*

$$Z_{1bc} = \frac{Z}{d} \times \frac{MILK_{GE}}{k_l}$$

Where:

Z_{1bc} = the daily amount of energy received from milk for each beef calf 3-8 months of age (MJ/d)

Z = the total amount of milk fed to each calf over the 3-8 month period (kg)

$MILK_{GE}$ = Gross energy content of milk (MJ/kg)

k_l = Efficiency of use of metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a dairy cow to produce milk (see Equation 4.12)

d = Number of days receiving milk (assumed to be 182 days)

Equation 4.27 *Amount of milk fed to beef calves 3-8 months:*

$$Z = Y_{bc} + Z_{mp}$$

Where:

Z = the total amount of milk fed to each calf over the 3-8 month period (kg)

Y_{bc} = total milk yield for beef cattle (kg/year) (from appendix 8, assumed to be 824 kg per year for all years)

Z_{mp}= Milk fed to each calf from milk powder over the 3-8 month period (200kg)

Information on milk yields is provided in appendix 8. For month 9 onwards, z_1 is set to 0.

4.5.7 Determination of Dry Matter Intake

The equations outlined in Section 4.5 are used to determine the total metabolisible energy (ME_{total}) requirements for each class of beef cattle. This figure can then be used to calculate Dry Matter Intake (DMI) using the equation in Section 4.1.1 (Equation 4.1) which is ultimately used to calculate emissions. It is important to note that the ME content of total diet ME_{diet} for beef cattle is different to dairy cattle.

4.6 Energy requirements for sheep

The total energy requirement for sheep comprises several components which are affected by age and physiological state. The basic calculation was outlined in Equation 4.4. The same components that make up ME_p for cattle also make up the ME_p for sheep, with the added component of ME_{wool} to account for the ME requirement for the growth of wool. This means that for sheep, $ME_p = ME_l + ME_g + ME_{wool}$.

Immediately after birth lambs obtain most of their energy from milk, therefore an energy discount is required to cover the months when the lamb obtains some of its energy from milk. Again, this is achieved by subtracting a term, Z_1, in the calculations for the total ME requirements.

Each subcategory of sheep animal and the specific ME components used in the calculation of total ME requirements for each subcategory are outlined in Table 4.3.

Table 4.3: Equations for the total ME requirements for each subcategory of sheep

Sheep subcategories	Equation
1. Dry ewes	$ME_{total} = ME_m + ME_{wool} + ME_{graze}$
2. Mature Breeding ewes	$ME_{total} = ME_m + ME_l + ME_c + ME_{wool} + ME_{graze}$
3. Growing breeding sheep	$ME_{total} = ME_m + ME_l + ME_c + ME_g + ME_{wool} + ME_{graze}$
4. Growing non-breeding sheep	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze}$
5. Wethers	$ME_{total} = ME_m + ME_{wool} + ME_{graze}$
6. Lambs	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze} - z_l$
7. Rams	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze}$

4.6.1 Metabolisable energy requirements for maintenance

Equation 4.5 in Section 4.3 is used to determine maintenance energy requirements for sheep, with K (the coefficient that accounts for differences in fasting heat production across species) equalling 1 for sheep (CSIRO, 1990). The live weight associated with each subcategory of sheep for a particular month is determined by the model based on live weight data in Appendix 16 and the methodology outlined in section 4.8.3. The age (A) in Equation 4.5 is detailed for each subcategory in Appendix 2. Feed properties are calculated in Equation 4.2 and Equation 4.3.

4.6.2 Metabolisable energy requirements for gestation

For the purpose of determining energy requirements of gestation and milk production the model assumes that if a ewe is pregnant in a month, she is not lactating. Therefore the energy requirements for gestation are only calculated for the months when the number of days pregnant for that month is > 0. In the inventory model calculations it is assumed that all lambs are born on 1 September. Thus, conception would have happened 147 days earlier on 6 April. It is also assumed in the inventory model that all lambs intended for meat production are weaned on 1 December and slaughtered on 1 March the following year. Therefore, the ewes are assumed to be pregnant from 6 April to 1 September (147 days) and to lactate from 1 September to 10 January (122 days).

While the equations for determining the ME requirements for gestation in sheep have a similar basis to that of cattle, the coefficients used are different for sheep and are displayed below.

Equation 4.28 *Metabolisable energy requirements for gestation for ewes:*

$$ME_c = 0.25 \times W_l \times L\% \times \frac{0.07372E_t \times e^{-0.00643prg}}{k_c}$$

Where:

ME_c = ME required for gestation (MJ/d)

W_l = lamb birth weight (kg)

L% = lambing percent

E_t = Energy required for the "gravid foetus" in utero (MJ)

prg = Number of days the ewe has been pregnant (see Appendix 9)

k_c = Net efficiency of dietary ME conversion to energy needed for gestation. Currently assumed to be 0.13 (ARC, 1980).

Equation 4.29 *Energy requirement for gravid fetus in utero:*

$$E_t = 10\text{^}(3.322 - 4.979 \times e^{-0.00643prg})$$

Values for coefficients used in the calculation of the term E_t are adopted from the ARC (ARC, 1980) where they were determined for a lamb with a birth weight of 4.0 kg at 147 days of gestation. A summary of the net requirements for gestation can be found in the CSIRO report (CSIRO, 1990). For the calculation of the New Zealand Inventory, lamb birth weight is assumed to be 9% of ewe live weight (see Appendix 16).

4.6.3 Metabolisable energy requirements of milk production

The ME requirement for milk production in sheep is taken from the Australian Feeding Standards (CSIRO, 1990). This equation requires data on milk fat and the number of days of lactation (or receiving milk). The milk fat value of 8 percent for lactating ewes has been suggested as a suitable value by CSIRO (1990) for use when experimental data is not available and is based on earlier measurements.

The first set of brackets in the equation below represents the gross energy content of sheep and the second set of brackets represents the amount of milk produced by sheep.

Equation 4.30 *Metabolisible energy requirements of milk production for sheep*

$$ME_l = \frac{(0.328F + 0.0028d_{srm} + 2.2033) \times y}{k_l}$$

Where:

ME_l = Metabolisible energy required for milk production (MJ/d)

F = Milk fat percentage (currently set at 8%, see Appendix 16)

d_{srm} = Number of days since lactation began (see Table 4.4)

y = Daily milk yield (kg/day)

k_l = Efficiency of use of metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk (see Equation 4.12)

Equation 4.31 *Calculation of daily sheep milk yield*

$$y = \frac{Y_{sheepm} \times mp_{month}}{d_{month}} \times L\%$$

Where:

y = Daily milk yield, for a particular day and month (kg/day)

Y_{sheepm} = annual milk yield per sheep (kilograms per sheep per year) (see Appendix 16)

MP_{month} = proportion of total annual milk produced in a given month (see Appendix 8)

$L_{\%}$ = lambing percent

d_{month} = number of days in a given month

Table 4.4: Monthly d_{srm} values used in calculation of ME_l

Month	Days Lactating in Month	Day of Lactation *(d_{srm})*
7	0	0
8	0	0
9	20	5
10	31	35
11	30	66
12	31	96
1	10	122
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0

4.6.4 **Energy requirements for change in live weight**

The equation used to calculate the ME requirements for changes in live weight in sheep is the same as that used for cattle (Equation 4.13 in Section 4.4.3.2). Sheep standard reference weights are 92 kg, 66 kg and 80 kg for rams, ewes and wethers (taken from CSIRO, 1990; Clark, 2008). The current live weight is determined by the model for all subcategories based on live weight inputs at birth and maturity (see Appendix 16). Live weight change for rams is detailed in the Appendix (see Appendix 16). A negligible weight change is assumed for adult ewes (to keep the weight change a non-zero number for purposes of the model calculations, only). For all other sheep subcategories weight changes are determined by the model as a linear change from initial and final weight.

There are different values for the terms k_g for various subclasses of sheep (see Table 4.3). For ewes and growing breeding sheep (subcategories 1, 2 and 3 in Table 4.3) k_g can be calculated using Equation 4.32, while for the remaining sheep categories k_g can be calculated using Equation 4.33.

Equation 4.32 *Calculation of sheep live weight gain efficiency for dry ewes, mature breeding ewes and growing breeding sheep*

$$k_g = 0.950 \times k_l$$

Where:

k_g = Net efficiency of dietary ME conversion to live weight gain

k_l = Efficiency of use of metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk (see Equation 4.12**Error! Reference source not found.**)

For subcategories 4, 5, 6 and 7:

Equation 4.33 *Calculation of sheep live weight gain efficiency for non-breeding sheep, wethers, lambs and rams*

$$k_g = 0.042 \times ME_{diet} + 0.006$$

Where:

k_g = Net efficiency of dietary ME conversion to live weight gain

ME_{diet}= energy content of feed (MJ/kg) (see Equation 4.2)

4.6.5 Metabolisable energy requirements for wool growth

The following equations are used to calculate ME required for wool growth in adult sheep and lambs, using the assumption that a lambs fleece weight is half an adult's fleece weight (CSIRO, 1990). The amount of wool produced by all sheep and lambs in a year is assumed to be equal to the national annual greasy wool production value published by Beef + Lamb New Zealand

To help calculate the distribution of annual wool yield distributed to month and class we have developed a new concept described here as the *average sheep growth day.* One hypothetical sheep alive for one day generates one average sheep growth day. If you have five sheep alive for one day these generate five average sheep growth days. As lambs are assumed to grow wool at half the rate of adult sheep, three lambs alive for one day generate 1.5 average sheep growth days.

The methodology is as follows:

1. Calculate the seasonal adjustment for each month, using *FVGrel*
2. Calculate how many average sheep growth days each class has for each month
3. Sum the average sheep growth days to get the total annual growth days
4. Divide the national annual wool yield by the total annual average sheep growth days to calculate the wool grown per average sheep growth day
5. Multiply the wool grown per average sheep growth day by the sheep growth days in each month and class to get monthly wool growth

This is done using the following equations. Further information on these equations is available in Sangster (2023).

4.6.5.1 Calculating the amount of wool produced

The following equations show how daily wool production per sheep is calculated. In these equations the population of sheep. These equations are necessary to account for the monthly variability in sheep populations and the seasonal cycle of wool growth.

Equation 4.34 *Monthly seasonal adjustment to wool growth*

$$FVGrel_m = A * \sin(f * month\ number + \varphi) + 1$$

Where:

$FVGrel_m$= Adjustment to wool growth to apply in month m

A = amplitude (currently set to 0.32 or 0.5)

f = frequency (set to 0.52)

$Month\ number$ = Month number (January = 1, December = 12)

φ = phase shift (set to 1.66)

Equation 4.35 *Average sheep growth days produced*

$$AverageGD_{m,c} = POPsheep_{m,c} \times FVGrel_m \times Days_m$$

Where:

$AverageGD_{m,c}$ = Average sheep growth days from adult sheep in month m and class c

$POPsheep_{m,c}$ = Adult sheep population in month m and class c

$Days_m$ = number of days in month m

Equation 4.36 *Average sheep growth days produced by lambs*

$$AverageGD_{m,c} = POPls_{m,c} \times FVGrel_m \times Days_m \times Awool_{lamb}$$

Where:

$AverageGD_{m,c}$ = Average sheep growth days from lambs in month m and class c

$POPls_{m,c}$ = lamb population in month m and class c

$Days_m$ = number of days in month m

$Awool_{lamb}$ = factor used to adjust for the slower wool growth of lambs compared to adult sheep (currently equal to 0.5)

Equation 4.37 *Total average sheep growth days in a year*

$$Total\ Annual\ GD = \sum_{c,m} AverageGD_{m,c}$$

Where:

$Total\ Annual\ GD$ = Total average sheep growth days in a year

$AverageGD_{m,c}$ = Average sheep growth days in month m and class c. This includes both lambs and adult sheep.

Equation 4.38 *Wool grown per average sheep growth day*

$$Daily\ average\ wool\ growth = \frac{natWool_{greasy}}{Total\ Annual\ GD}$$

Where:

$Total\ Annual\ GD$ = Total average sheep growth days in a year

natWoolgreasy = annual greasy wool production (kg) from Beef + Lamb statistics (see Appendix 16)

Equation 4.39 *Total wool grown by class c in month m*

$$totWool_{c,m} = AverageGD_{c,m} \times Daily\ average\ wool\ growth$$

Where:

$totWool_{c,m}$ = total wool grown by class c in month m (kg)

$AverageGD_{m,c}$ = Average sheep growth days in month m and class c. This includes both lambs and adult sheep.

4.6.5.2 Calculating the metabolisable energy required for wool growth.

Sheep continue to grow wool even when chronically undernourished, and because of the inevitability of this production its energy cost is often accepted as an integral part of the energy requirements for maintenance. From information in ARC (1980) it appears that many of the determinations of efficiency of utilisation for maintenance (km) and net efficiency of dietary ME conversion to live weight gain (kg) have been made with sheep that grew 6 g dry greasy wool per day (CSIRO, .2007, page 45-46). Therefore, the ME required for wool growth is only for wool grown beyond the base rate of 6 g per day. This is reflected by subtracting 6 from the daily grams of wool grown. If less than 6 g of wool is grown the ME required for wool growth is set to zero, rather than taking on a negative value.

The following equations are used to calculate ME required for wool growth in adult sheep and lambs, using the assumption that a lambs fleece weight is half an adult’s fleece weight (CSIRO, 1990).

Equation 4.40 *Metabolisible energy required for wool growth*

$$ME_w = 0.13 \times \left(\frac{totWool_{c,m} \times 1000}{Pop_{m,c} \times Days_m} - 6 \right)$$

Where:

ME_w = ME required for wool growth (MJ/d)

$totWool_{c,m}$ = total wool grown by class c in month m (kg)

$POP_{m,c}$ = sheep population in month m and class c

$Days_m$ = number of days in month m

4.6.6 Additional metabolisable energy expenditure of grazing relative to confined animals of similar live weight

The calculation used to estimate additional ME expenditure for grazing for cattle (see Equation 4.23) is the same as that used for sheep. However, the term C has a value of 0.05, and terrain factor (T) has the value of 1.5, reflecting undulating terrain as for beef cattle (Clark *et al.*, 2003). Total diet ME content and dry matter digestibility (DMD) are calculated by Equation 4.2 and Equation 4.3. The current live weight (W) is determined by the model for all classes based on live weight inputs (Appendix 16). GF represents the availability of forage. A higher value means that animals will spend less energy searching for forage. A GF value of 2.5 tonnes of dry matter per hectare is used in the inventory for sheep.

4.6.7 Adjustment to total energy requirements for lambs

Rising 1 year old lambs are fed either suckled milk or milk derived from powder, which is produced to supplement suckled milk in their first 122 days. The total energy requirements for lambs need to take this into account for this period.

Also, for the first two months of life, a lamb is assumed not to produce any methane, as they are fed only milk. The adjustment for methane is applied directly to the DMI value.

The total ME requirement is adjusted for the energy received from milk by a value of z_1. For September to January the daily energy received from milk is calculated using the following equation:

Equation 4.41 *Energy received from milk for young lambs*

$$z_1 = \frac{Y_{sheepm}}{d_{srm} \times P_{lamb}} \times \frac{0.328F + 0.0028d_{srm} + 2.2033}{k_l}$$

Where:

z_1 = energy received from milk per lamb (MJ/d)

Y_{sheepm} = annual milk yield per sheep (kilograms per sheep per year)

P_{lamb} = annual lambing percentage rate (see Appendix 16)

d_{srm} = number of days young lambs receive milk (assumed to be 122)

F = Milk fat percentage (assumed to be 8%, see Appendix 16)

k_l = Efficiency of use of ME for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk (see Equation 4.12**Error! Reference source not found.**)

For other months of the year z_l is assumed to be zero.

4.6.8 Determination of Dry Matter Intake

The equations outlined in Section 4.6 are used to determine the total metabolisable energy (ME_{total}) requirements for each class of sheep. This figure can then be used to calculate dry Matter Intake (DMI) using the equation in Section 4.1.1 (Equation 4.1), which is ultimately used to calculate emissions.

4.7 Energy requirements for deer

Total ME requirements for deer by subcategory are set out in the table below and are made up of the following components.

ME_m = the ME requirement for maintenance including grazing

ME_l = ME required for milk production

ME_c = ME required for conception/gestation

ME_g = ME requirements for live weight gain

ME_{velvet} = the ME required for the growth of velvet.

The energy requirements of the Velvet and Venison subcategories are the same, so only the age and sex breakdown is shown.

Table 4.5: Equations for the total ME requirement for each livestock subcategory of deer

Deer subcategories	Equation
Hinds 0-1 years old	$ME_{total} = ME_m + ME_g - z_l$
Hinds 1-2 years old	$ME_{total} = ME_m + ME_c + ME_g$
Hinds Mature	$ME_{total} = ME_m + ME_l + ME_c + ME_g$
Stags 0-1 years old	$ME_{total} = ME_m + ME_g - z_l$
Stags 1 – 2 years old	$ME_{total} = ME_m + ME_g + ME_{velvet}$
Stags 2 – 3 years old	$ME_{total} = ME_m + ME_g + ME_{velvet}$
Stags Mature	$ME_{total} = ME_m + ME_g + ME_{velvet}$

4.7.1 Maintenance energy requirements

Equation 4.5 (Section 4.3) is also used to determine maintenance energy requirements for Deer. Different deer-specific values for live weight (LW) and age (A) are used.

A slightly different method is used to calculate k_m:

Equation 4.42 *Efficiency of utilisation for maintenance, k_m*

$$k_m = 0.2 \times Q_m + 0.503$$

Where:

k_m = Efficiency of utilisation of ME for maintenance.

Q_m = ratio of diet ME to gross energy (GE) concentration of diet

The maintenance energy requirements and the energy requirements for live weight gain were taken from Bown *et al.* (2012) who recommended adopting the CSIRO (1990) equations for deer.

A value of 1.4 is used for K (the variation in basal metabolic rate for different species), which is the same value used for dairy and beef cattle. (Nicol & Brookes, 2007; Bown *et al.*, 2012)

For the parameter S (the variation in basal metabolic rate for males and females), the same values of 1.00 for females and 1.15 for males are used (Nicol & Brookes, 2007).

Live weight (LW) for each class of deer is determined by the model using slaughter data (see Appendix 18).

The parameter value for age (A) in this equation is detailed for each class in Appendix 2

4.7.2 Additional metabolisable energy expenditure of grazing

The ME requirement equations for deer have no ME_{graze} component. It is assumed that the grazing component of energy expenditure is contained within ME_m.

4.7.3 Energy requirements for live weight gain (ME_g)

Bown *et al*. (2012) recommended that the energy requirements for live weight gain estimates use the CSIRO (1990) equation for ME_g in deer as applied by Nicol & Brookes (2007). The equation used for calculating ME required for live weight gain in deer is identical to the equation used in Section 4.4.3.2.

Equation 4.43 *Metabolisable energy requirements for live weight gain in deer :*

$$ME_g = \frac{(6.7 + R) + \frac{20.3 - R}{1 + e^{-6(P_{lw} - 0.4)}}}{k_{gnl}} \times LWG \times 0.92$$

Where:

ME_g = Energy required for live weight gain (MJ/d)

R =An adjustment for rate of change in live weight (see Equation 4.14, Section 4.4.3.2)

LWG = Live weight gain in kg/day

P_{lw} = ratio of current live weight (C_{lw}) to a standard reference weight (SRW) of a mature animal (see Equation 4.15, Section 4.4.3.2.1)

k_{gnl} = Net efficiency of dietary metabolisable energy conversion to live weight gain for non-lactating animals (see Equation 4.19, Section 4.4.3.2.1)

4.7.4 Metabolisable energy requirements for lactation

The inventory assumes that young deer are born on the 19th of November. For the next 120 days, it is assumed that breeding hinds produce milk for these young deer. The daily energy required to do this (ME_l) is calculated using the equation below.

Equation 4.44 *Metabolisible energy requirements of milk production for deer*

$$ME_l = \frac{Y_{deerm} \times mp_{month}}{d_{month}} \times \frac{evl}{k_{ldeer}} \times W$$

Where:

ME_l = Metabolisible energy required for milk production (MJ/d)

Y_{deerm} = annual milk yield per breeding hind (assumed to be 204 kilograms per deer per year) (see Appendix 18)

MP_{month} = Milk produced in a given month as a proportion of total annual milk produced (see Appendix 8)

d_{month} = Number of days in month m

evl = energy content of deer milk, currently set at 5.9 MJ/kg milk (Bown *et al.,* 2012)

k_{ldeer} = Efficiency of use of metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a breeding hind to produce milk. Currently set to 0.64 (Moe *et al.,* 1971)

W = Weaning rate, currently set at 0.85 for mature hinds and 0.7 for hinds 1-2 (Suttie, 2012)

For the other months of the year (April to October), ME_l is set to zero.

4.7.5 Adjustment to total energy requirements deer less than one year old

Rising 1 year old stags and hinds receive some of their energy requirements from milk. For the first 4 months (120 days) of life (from November 19 to March 18) they are fed suckled milk and are assumed not to produce any methane.

The ME requirements for these young deer are calculated by subtracting the energy received from milk (z_l) from the other components of ME (such as maintenance – see Table 4.5).

Equation 4.45 *Energy received from milk for young deer*

$$z_1 = \frac{Y_{deerm}}{d_{drm}} \times evl_{deer} \times k_{ldeer}$$

Where:

z_1 = energy received from milk (MJ/d)

Y_{deerm} = annual milk yield per deer (assumed to be 204 kilograms per deer per year, see Appendix 18)

d_{drm} = number of days young hinds and stags receive milk (assumed to be 120)

evl_{deer} = energy content of deer milk (5.9 MJ/kg milk (Bown *et al*., 2012))

k_{ldeer} = Efficiency of use of metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a breeding hind to produce milk. Currently set to 0.64 (Moe *et al.,* 1971)

For other months of the year z_1 is assumed to be zero.

4.7.6 Metabolisable energy requirements for conception/gestation

The amount of energy required for gestation is calculated on a monthly basis. For the breeding and rising two-year old hinds subcategories of deer, the energy requirements for pregnancy is determined through adapting equations of Fennessy *et al.* (1981) and adjusting this equation by applying a 'trimester factor' to hind live weight, based on the recommendations of Mulley & Flesch (2001):

Equation 4.46 *Energy required for gestation in breeding hinds*

$$ME_c = 0.7 \times TF \times LW^{0.75} \times W$$

Where:

ME_c = energy required for gestation (MJ/d)

TF = trimester factor (see table 6)

LW = hind live weight

W = Weaning rate, currently. Currently set at 70% Hinds 1-2 and 85% Mature Hinds (Suttie, 2012).

Table 4.6: Trimester factor used in the determination of ME requirement for conception/gestation for deer

Month	Trimester factor (TF)
July	0.1
August	0.3
September	0.3
October	0.6
November	0.6
December	0.0
January	0.0
February	0.0
March	0.0
April	0.0
May	0.0
June	0.1

4.7.7 Metabolisable energy requirements for velvet production

The inventory model assumes that stags over one year of age produce velvet. This is assumed to happen each year over a 65 days, from the 1st of September to the 4th of November. During this period 0.5 mejajoules of ME is required each day to produce velvet (Suttie, 2012).

Equation 4.47 *Energy required for velvet production in stags*

$$ME_{velvet} = 0.5$$

Where:

ME_{velvet} = energy required for velvet production (MJ/d)

For other months of the year ME_{velvet} is assumed to be zero.

4.7.8 Determination of Dry Matter Intake

The equations outlined in Section 4.7, Table 4.5 are used to determine the ME_{total} requirements for each class of deer. These figures can then be used to calculate DMI using the equation in Section 4.1.1 (Equation 4.1), which is ultimately used to calculate emissions. It is important to note that the energy content of total diet ME_{diet} for deer is different to the other animal categories and is calculated using a different methodology.

It is assumed deer are entirely pasture fed. The ME content of deer pasture is calculated as a weighted average of ME_{feed} for pasture on dairy and beef-sheep land (Suttie 2012). In 1990, 46 percent of the deer herd was grazed on land use classes used for dairy, and the remaining 54 percent of the deer herd were grazed on land classes used for sheep and beef grazing. Over time the deer herd has grazed less on dairy land and more on land used for sheep and beef. From 2010 onwards, it is assumed only 10 percent of the deer herd remains on dairy land, and 90 percent on sheep and beef land (Suttie 2012).

4.8 Calculation of live weight and live weight gain

The equations and parameters used to calculate live weight and live weight gain are outlined in this section. Additional details on the calculation of live weight and live weight gain can also be found in the publication by Rollo (2018).

As discussed earlier, each species is split into several classes, and the inventory model calculates an average live weight and live weight gain value for each month and year for each of these classes.

Animals classed as mature have a fixed live weight which does not change. Animals classed as growing (either for slaughter or as breeding replacements) have a live weight which increases linearly from their assigned birth date, to the date at which the model deems that they have reached maturity or are slaughtered.

To calculate live weight, information on mature and slaughter weights are required, along with information or assumptions on the animal birth weight.

Live weight gain is calculated on a per day basis, and requires information on the change in weight over the growing period and the number of days required to reach maturity of slaughter.

Monthly live weight and live weight gain values are only calculated for dairy cattle, beef cattle, sheep and deer. For swine annual weight values from Statistics New Zealand is used to calculate nitrogen excretion (see Section 5.7.5). For the remaining animal categories (horses, mules and asses, alpacas, poultry and goats) weights are not used to calculate emissions.

The table below summarises the parameters, assumptions and activity data that is used to calculate live weight and live weight gain for the animal classes in the tier 2 inventory model

Table 4.7: Parameters used to calculate live weight and live weight gain

Species	Class	Class type and purpose	Birth date	days of growth from birth to maturity/ slaughter	Slaughter date	Killing out %age	live weight	live weight gain (kg/day)	Birth weight as a percentage of adult weight
Dairy	Growing females < 1 year old	Breeding replacements	13-Aug	687	NA	50%	Calculated monthly	Calculated	9%
	Growing females 1-2 years old	Breeding replacements	NA	687	NA		Calculated monthly	Calculated	NA
	Milking cows and heifers	Breeding	NA	NA	NA		Annual AD	0	NA
	Breeding bulls	Male	NA	NA	NA		500kg	0.5	NA
Beef	Growing cows 0 – 1 years	Breeding replacements	25-Sep	1095	NA	50%	Calculated monthly	Calculated	7%
	Growing cows 1 – 2 years	Breeding replacements	NA	1095	NA		Calculated monthly	Calculated	NA
	Growing cows 2 – 3 years	Breeding replacements	NA	1095	NA		Calculated monthly	Calculated	NA
	Breeding mature cows	Breeding	NA	NA	NA		Annual AD	0	NA
	Slaughter Heifers 0 – 1 years	Slaughter	25-Sep	544/837	NA		Calculated monthly	Calculated	7%
	Slaughter Heifers 1 - 2 years	Slaughter	NA	544/837	19-Mar		Calculated monthly	Calculated	NA
	Slaughter Heifers 2 - 3 years	Slaughter	NA	837	6-Jan				
	Slaughter steers 0 – 1 years	Slaughter	25-Sep	546/845	NA		Calculated monthly	Calculated	7%

	Slaughter steers 1 - 2 years	Slaughter	NA	546/845	21-Mar		Calculated monthly	Calculated	NA
	Slaughter steers 2 - 3 years	Slaughter	NA	845	14-Jan		Calculated monthly	Calculated	NA
	Slaughter Bulls 0 - 1 years	Slaughter	25-Sep	865	NA		Calculated monthly	Calculated	7%
	Slaughter Bulls 1 – 2 years	Slaughter	NA	865	NA		Calculated monthly	Calculated	NA
	Slaughter Bulls 2 - 3 years	Slaughter	NA	865	3-Feb		Calculated monthly	Calculated	NA
	Breeding Bulls – mixed age	Male	NA	NA	NA		600kg	0.5	NA
Sheep	Mature Breeding ewes	Breeding	NA	NA	NA	40%	Annual AD	0	NA
	Dry ewes	Slaughter	NA	NA	NA	40%	Annual AD	0	NA
	Growing breeding sheep	Breeding replacements	NA	396	NA	40%	Calculated monthly	0	NA
	Growing non-breeding sheep	Slaughter	NA	396	NA	40%	Calculated monthly	0	NA
	Wethers	Slaughter	NA	NA	NA	40%	equals adult breeding ewe	0	NA
	Lambs for 1st slaughter	Slaughter	11-Sep	171	28-Feb	45%	Annual AD	Calculated	9%
	Lambs for 2nd slaughter	Slaughter	11-Sep	171+184	31-Aug	45%	Annual AD	Calculated	9%
	Rams	Male	NA	NA	NA	40%	Calculated	0.05	NA
Deer	Breeding Hinds	Breeding	NA	NA	NA	55%	uses data in report by Suttie (2012)	0	9%
	Hinds 0-1	Slaughter	19-Nov	NA	NA		Calculated monthly	Calculated	NA
	Hinds 1-2	Slaughter	NA	466	28-Feb		Calculated monthly	Calculated	NA
	Stags 0-1	Slaughter	19-Nov	466 or 629	NA		Calculated monthly	Calculated	10%
	Stags 1-2	Slaughter	NA	466 or 629	28-Feb		Calculated monthly	Calculated	NA
	Stags 2-3	Slaughter	NA	629	NA		Calculated monthly	Calculated	NA
	Mature stags	Male	NA	NA	NA		uses data in report by Suttie (2012)	0	NA

4.8.1 Live weight and live weight gain – dairy

4.8.1.1 Growing heifers 0-1 and 1-2 years old

For growing dairy heifers, the average live weight in a particular month is calculated using the formula below. The month-to-month change in these average values is also used to calculate live weight gain.

Equation 4.48 *Monthly live weight for growing heifers*

$$LWgh_{m,y} = Birth\ weight_{gh,y} + Adult\ weight_{mmc,y}(100\% - 9\%) \times \left(\frac{AgeMM_{gh,m}}{days\ to\ maturity_{gh}}\right)$$

Where:

$LWgh_{m,y}$ = live weight of growing heifers in month *m*, year *y* (kg)

Birth $weight_{gh,y}$ = birth weight of growing heifers in year *y* (equal to 9% of adult weight of mature milking cows)

Adult $weight_{mmc,y}$ = mature weight of milking cows in year y (from activity data – see Section 4.8.2.2)

100% : weight of animal at two years of age (as a proportion of adult weight)

9%: Birth weight as a proportion of adult weight for dairy calves (as a proportion of adult weight)

$AgeMM_{gh,m}$ = age (in days) of growing heifers at mid-month m

Days to maturity = days required growing heifers to reach maturity (currently set at 687)

The inventory assumes that all dairy calves (growing heifers 0-1) are born on the 13th of August and have a birth weight equal to 9% of an adult dairy cow weight. The weight of these animals increases linearly until they are 687 days old, at which point their weight is assumed to be 100% of an adult dairy cow's weight (described in the next section). After 687 days, they join the class of mature milking cows.

The table below further outlines how the parameters used in the calculation of liveweight for growing heifers in Equation 4.48 changes in the months following birth, and shows the growing heifer weights over time as a percentage of the mature milking cow weight.

Table 4.8: Monthly values used to calculate live weight and live weight gain for growing heifers

				live weight as a proportion of adult weight		
Month	Class	days since birth (start of month)	days since birth (end of month)	start of month	month average	end of month
August (birth)	Growing heifers 0-1	0	19	N/A	10.2%	11.4%
September	Growing heifers 0-1	19	49	11.4%	13.2%	15.1%
October	Growing heifers 0-1	49	80	15.1%	17.0%	19.0%
November	Growing heifers 0-1	80	110	19.0%	20.8%	22.7%
December	Growing heifers 0-1	110	141	22.7%	24.6%	26.6%
January	Growing heifers 0-1	141	172	26.6%	28.5%	30.4%
February	Growing heifers 0-1	172	200	30.4%	32.2%	33.9%
March	Growing heifers 0-1	200	231	33.9%	35.9%	37.8%
April	Growing heifers 0-1	231	261	37.8%	39.7%	41.5%
May	Growing heifers 0-1	261	292	41.5%	43.5%	45.4%
June	Growing heifers 0-1	292	322	45.4%	47.3%	49.1%
July	Growing heifers 1-2	322	353	49.1%	51.1%	53.0%
August	Growing heifers 1-2	353	384	53.0%	54.9%	56.9%
September	Growing heifers 1-2	384	414	56.9%	58.7%	60.6%
October	Growing heifers 1-2	414	445	60.6%	62.5%	64.5%
November	Growing heifers 1-2	445	475	64.5%	66.3%	68.2%
December	Growing heifers 1-2	475	506	68.2%	70.1%	72.1%
January	Growing heifers 1-2	506	537	72.1%	74.0%	75.9%
February	Growing heifers 1-2	537	565	75.9%	77.7%	79.4%
March	Growing heifers 1-2	565	596	79.4%	81.4%	83.3%

April	Growing heifers 1-2	596	626	83.3%	85.2%	87.0%
May	Growing heifers 1-2	626	657	87.0%	89.0%	90.9%
June	Growing heifers 1-2	657	687	90.9%	92.8%	94.6%
July	Milking cows mature				100%	

Live weight gain for growing heifers (in terms of kilograms per day) can be calculated using the formula below:

Equation 4.49 *Live weight gain for growing heifers*

$$LWG_{gh,m,y} = \frac{Adult\ weight_{mmc,y}(100\% - 9\%)}{days\ to\ maturity_{gh}}$$

Where:

$LWG_{gh,m,y}$ = live weight gain of growing heifers in year *y* and month *m* (kg per day)

100% : weight of animal at first calving (as a proportion of adult weight)

9%: Birth weight as a proportion of adult weight for dairy calves (as a proportion of adult weight)

Adult $weight_{mmc,y}$ = mature weight of milking cows in year *y* (from activity data – see Section 4.8.1.2)

Days to $maturity_{gh}$ = days required growing heifers to reach maturity (currently set at 687)

4.8.1.2 Mature milking cows

The live weight of mature milking cows is calculated using data from LIC. The inventory model calculates weights separately for each region based on the breed composition (e.g. Jersey, Friesian…) in these regions. National average cow weights since 1990 are shown in appendix 1.

The live weight gain for mature milking cows is assumed to be zero.

4.8.1.3 Breeding bulls

The inventory model currently assumes that the live weight for breeding bulls is fixed at 500kg for all years.

It is assumed that breeding bulls have a live weight gain of 0.5 kg per day.

4.8.2 Live weight and live weight gain – beef

4.8.2.1 Mixed age breeding bulls

The inventory model currently assumes that the live weight for mixed age breeding beef bulls is fixed at 600kg for all years.

It is assumed that breeding bulls have a live weight gain of 0.5 kg per day.

4.8.2.2 Breeding mature cows

The live weight of breeding mature cows in the beef sector is assumed to be stable, with a live weight gain of zero. This weight is calculated using the following equation.

Equation 4.50 *Live weight for breeding mature beef cows*

$$LWbbmc_y = \left(\frac{\left(TOTcarcwgt_{cattle,y} - (LWmmc_y \times KO_{DC}) \times \left(Ncow_{slaughtered,y} - (RR_{Beef} \times Nbeef_{Bcow,y})\right)\right)}{Nbeef_{cow} \times RR_{Beef}}\right) \Big/ KO_{DC}$$

Where:

$LWbbmc_y$= live weight of breeding mature beef cows, for a particular year *y* ending in June (kg)

$TOTcarcwgt_{cattle,y}$ = total carcass weight of all dairy and beef cattle sent to slaughter, for a particular year *y* ending in June (kg). Data provided by Statistics New Zealand

$LWmmc_y$ = live weight of mature milking dairy cows in year *y*, in kilograms (see Section 4.8.1.2)

KO_{DC} = killing out percentage for dairy cows (currently set at 42%)

$Ncow_{slaughtered,y}$ = Number of dairy and beef cows slaughtered, for a particular year ending in June (data provided by Statistics New Zealand)

RR_{Beef} = beef cow replacement rate, currently set at 17%

$Nbeef_{Bcow,y}$ = number of beef breeding cows, for a particular year ending in June. Data provided by Statistics New Zealand (line codes 7056 and 7057)

4.8.2.3 Breeding growing cows

Breeding replacements for the beef industry are grown over a period of three years. It is assumed that these animals are born on the 25th of September each year. Because the period of growth occurs over three years, in any given period there will be three age groups of breeding growing cows (with different weights) growing at the same time with the same rate of live weight gain (one group will be aged between zero and one, another group will be aged between one and two and the other group will be aged between two and three).

Equation 4.51 *Monthly live weight for breeding growing cows*

$$LWbbgc_{m,y} = Birth\ weight_{bbgc,y} + \left(\frac{AgeMOM_{bbgc,m}}{days\ to\ maturity_{bbgc}}\right) \times \left(LWbbmc_y - Birth\ weight_{bbgc,y}\right)$$

Where:

$LWbbgc_{m,y}$ = live weight of breeding growing cows in month *m*, year *y* (kg)

$Birth\ weight_{bbgc,y}$ = birth weight of breeding growing cows in year *y* (equal to 7% of breeding mature cow live weight) (kg)

$AgeMOM_{bbgc,m}$ = age (in days) of breeding growing cows at the middle of month *m*

Days to $maturity_{bbgc}$ = number of days from birth to slaughter for breeding growing cows (currently set at 1095)

$LWbbmc_y$= live weight of breeding mature beef cows, for a particular year ending in June (kg)

Equation 4.52 *Live weight gain for breeding growing cows*

$$LWGbbgc_y = \frac{LWbbmc_y - Birth\ weight_{bbgc,y}}{days\ to\ maturity_{bbgc}}$$

Where:

$LWGbbgc_{m,y}$ = live weight gain of breeding growing cows in year y (kg)

$LWbbmc_y$= live weight of breeding mature beef cows, for a particular year ending in June (kg)

$Birth\ weight_{bbgc,y}$ = birth weight of breeding growing cows in year y (equal to 7% of breeding mature cow live weight) (kg)

Days to $maturity_{bbgc}$ = number of days from birth to slaughter for breeding growing cows (currently set at 1095)

4.8.2.4 Slaughter Bulls, Slaughter Heifers and Slaughter Steers

Slaughter Bulls, Slaughter Heifers and Slaughter Steers are from birth (25th September each year) to slaughter (see Table 4.7 for exact ages and dates). The live weight of these animals at slaughter is calculated by dividing the carcass weight by the killing out percentage (set at 50%)

Because the period of growth occurs over three years, in any given period there will be three age groups for each of the three slaughter animals (with different weights) growing at the same time with the same rate of live weight gain.

If there are residual animals in the 2-3 year old age groups after the slaughter date it is assumed that these animals have constant liveweight and no live weight change.

Equation 4.53 *Monthly live weight for Slaughter Bulls, Slaughter Heifers and Slaughter Steers*

$$\begin{aligned} LWbslaugher_{x,m,y} &= Birth\ weight_{bslaughter,x,y} \\ &+ \left(\frac{AgeMOM_{bslaughter,m}}{days\ to\ slaughter_{bslaughter,x}}\right) \\ &\times \left(LWbslaughter_{at\ slaughter,x,y} - Birth\ weight_{bslaughter,x,y}\right) \end{aligned}$$

Where:

$LWbslaughter_{x,m,y}$ = live weight in kilograms of beef slaughter animals in year *y*, for animal type *x* (either slaughter bulls, Slaughter Heifers and slaughter steers)

$Birth\ weight_{bslaughter,x,y}$ = birth weight in kilograms of beef slaughter animals in year *y*, for animal type *x*. Equal to 7% of live weight at slaughter for Slaughter Heifers, and 7% of bull live weight at slaughter for slaughter bulls and steers.

$AgeMOM_{bslaughter,x,m}$ = age (in days) of beef slaughter animals at the middle of month *m*, for animal type *x*

$Days\ to\ slaughter_{bslaughter}$ = number of days from birth to slaughter for (see Table 4.7, the longest growth period is used where multiple are stated)

$LWbslaughter_{at\ slaughter,x,y}$ = live weight in kilograms of beef slaughter animals at slaughter in year *y*, for animal type *x* (see Equation 4.54)

Equation 4.54 *Live weight at slaughter for slaughter bulls, Slaughter Heifers and slaughter steers*

$$LWbslaughter_{at\ slaughter,x,y} = \frac{Carcass\ weight_{bslaughter,x,y}}{KO_{beef}}$$

Where:

$LWbslaughter_{at\ slaughter,x,y}$ = live weight in kilograms of beef slaughter animals at slaughter in year *y*, for animal type *x*

$Carcass\ weight_{bslaughter,y}$ = average carcass weight in kilograms of beef slaughter animals for year *y* ending in June , for animal type *x*. Data from Statistics New Zealand

KO_{beef} = killing out percentage for beef animals (currently set at 50%)

Equation 4.55 *Live weight gain for slaughter bulls, Slaughter Heifers and slaughter steers*

$$LWGbslaugher_{x,y} = \frac{LWbslaughter_{at\ slaughter,x,,y} - Birth\ weight_{bslaughter,x,y}}{days\ to\ slaughter_{bslaughter,x}}$$

Where:

$LWGbslaughter_{x,y}$ = live weight gain in kilograms per day, of beef slaughter animals in year *y*, for animal type *x*

$LWbslaughter_{at\ slaughter,x,y}$ = live weight in kilograms of beef slaughter animals at slaughter (see Table 4.7, the longest growth period is used where multiple are stated) in year *y*, for animal type *x* (see Equation 4.54)

$Birth\ weight_{bslaughter,x,y}$ = birth weight in kilograms of beef slaughter animals in year y, for animal type x. Equal to 7% of live weight at slaughter.

$Days\ to\ slaughter_{bslaughter}$ = number of days from birth to (see Table 4.7, the longest growth period is used where multiple are stated)

4.8.3 Live weight and live weight gain – sheep

4.8.3.1 Wethers, Dry Ewes, and Mature Breeding Ewes

The live weight for wethers, dry ewes, and mature breeding ewes for a particular year is calculated by dividing the average carcass weight of adult sheep (for each year ending in June) by the killing out percentage for adult sheep (40%).

Equation 4.56 *Monthly live weight for wethers, dry ewes, and mature breeding ewes*

$$LWas_y = \frac{Carcass\ weight_{as,y}}{KO_{as}}$$

Where:

$LWas_y$= live weight of wethers, dry ewes, and mature breeding ewes, for a particular year *y* ending in June (kg)

$Carcass\ weight_{as,y}$ = average carcass weight of adult sheep for year *y* ending in June (kg). data from Statistics New Zealand

KO_{as} = killing out percentage for adult sheep. Currently set at 40%

It is assumed that there is no live weight gain for these animal classes.

4.8.3.2 Rams

The live weight for rams (for each year ending in June) is assumed to be 40% greater than the live weight for wethers, dry ewes, and mature breeding ewes.

Equation 4.57 *Monthly live weight for rams*

$$LWram_y = LWas_y \times 1.4$$

Where:

$LWram_y$= live weight of whethers, dry ewes, and mature breeding ewes, for a particular year *y* ending in June (kg)

$LWas_y$ = live weight of whethers, dry ewes, and mature breeding ewes, for a particular year *y* ending in June (kg). Calculated from Equation 4.56.

It is assumed that rams have a live weight gain of 0.05 kg per day

4.8.3.3 Lambs

The inventory model assumes that lambs are born on the 11th of September each year and are grown for two slaughter dates (28th February after 171 days, and 31 August after a further 184 days). 84% of lambs are slaughtered at the first slaughter date.

Average lamb slaughter weight data (for each year ending June) is gathered from Statistics New Zealand and this is used (along with an assumed killing out percentage of 45%) to calculate the lamb live weight at the date of first slaughter (see Equation 4.60). The birth weight is set at 9% of the whethers, dry ewes, and mature breeding ewe live weight.

The lamb live weight increases linearly from birth (Equation 4.58). Following the first slaughter date, the rate of live weight gain for the remaining lambs from the 1st of March to the 31st of August is halved (Equation 4.61). The middle of the month is used for the estimate of lamb age to calculate the weight for each month.

Equation 4.58 *Monthly live weight for lambs between September and February inclusive*

$$\begin{aligned} LWlamb_{m,y} &= Birth\ weight_{lamb,y} \\ &+ \left(\frac{AgeMOM_{lamb,m}}{days\ to\ 1st\ Slaughter_{lamb}}\right) \\ &\times \left(LW1stSlaughter_{lamb,y} - Birth\ weight_{lamb,y}\right) \end{aligned}$$

Where:

$LWlamb_{m,y}$ = live weight of lambs in month *m*, year *y*, from September to February (kg)

$Birth\ weight_{lamb,y}$ = birth weight of lambs in year *y* (equal to 9% of whethers, dry ewes, and mature breeding ewe live weight) (kg)

$AgeMOM_{lamb,m}$ = age (in days) of lambs at the middle of month *m*

Days to 1st $Slaughter_{lamb}$ = number of days from birth to slaughter for lambs (currently set at 171)

$LW1stSlaughter_{lamb,y}$ = live weight of lambs at first slaughter in year *y* (kg) (Equation 4.60)

Equation 4.59 *Monthly live weight for lambs between March and August inclusive*

$$LWlamb_{m,y} = LWlamb_{m-1,y} + nod_m \times LWG_{lamb,2nd,y}$$

Where:

$LWlamb_{m,y}$ = live weight of lambs in month *m*, year *y*, from March to August (kg)

$LWlamb_{m,y}$ = live weight of lambs in previous month *m* and year *y* (kg)

nod_m = number of days in month *m*

$LWG_{lamb,2nd,y}$ = live weight gain of lambs between March and August following first slaughter in year *y*

Equation 4.60 *Lamb live weight at first slaughter*

$$LW1stSlaughter_{lamb,y} = \frac{Carcass\ weight_{lamb,y}}{KO_{lamb}}$$

Where:

$LW1stSlaughter_{lamb,y}$ = live weight of lambs at first slaughter (28 February) in year *y* (kg)

$Carcass\ weight_{lamb,y}$ = average carcass weight of lambs for year *y* ending in June (kg). Data from Statistics New Zealand

KO_{lamb} = killing out percentage for lambs. Currently set at 45%

Equation 4.61 *Live weight gain for lambs between September and February inclusive*

$$LWG_{lamb,1st,y} = \frac{LW1stSlaughter_{lamb,y} - Birth\ weight_{lamb,y}}{days\ to\ 1st\ Slaughter_{lamb}}$$

Where:

$LWG_{lamb,1st,y}$ = live weight gain of lambs in period before first slaughter in year *y* (kg per day)

$LW1stSlaughter_{lamb,y}$ = live weight of lambs at first slaughter (28 February) in year *y* (kg) (Equation 4.60)

$Birth\ weight_{lamb,y}$ = birth weight of lambs in year *y* (equal to 9% of wethers, dry ewes, and mature breeding ewe live weight) (kg)

Days to 1^{st} $Slaughter_{lamb}$ = number of days from birth to slaughter for lambs (currently set at 171)

Equation 4.62 *Live weight gain for lambs between March and August inclusive*

$$LWG_{lamb,2st,y} = LWG_{lamb,1st,y} \times 0.5$$

Where:

$LWG_{lamb,2st,y}$ = live weight gain of lambs in period before after first slaughter in year *y* (kg per day)

$LWG_{lamb,1st,y}$ = live weight gain of lambs in period before first slaughter in year *y* (kg per day)

4.8.3.4 Growing breeding sheep and growing non-breeding sheep

The class of animals designated as growing breeding sheep and growing non-breeding sheep gain weight linearly over a 12 month period from September (before this they are in the lambs category, and have weight characteristics as designated in Section 4.8.4.3) to September (after which they become wethers, dry ewes, or mature breeding ewes and have a stable weight).

The following equations are used to calculate monthly live weights and live weight gain.

Equation 4.63 *Monthly live weight for growing breeding sheep and growing non-breeding sheep*

$$LWsg_{m,y} = LWlamb_{12m,y} + \left(\frac{\left(LWas_y - LWlamb_{12m,y}\right)}{365} \times nod_{m,since\ Sept}\right)$$

Where:

$LWsg_{m,y}$ = live weight of growing sheep (growing breeding sheep and growing non-breeding sheep) in month *m*, year *y* (kg)

$LWlamb_{12m,y}$ = live weight of lambs at 12 months old of year *y* (kg) (Equation 4.59)

$nod_{m,since\ Sept}$ = number of days since September at the end of month *m*

$LWas_y$= live weight of whethers, dry ewes, and mature breeding ewes, for a particular year *y* ending in June (kg)

Equation 4.64 *Live weight gain for growing breeding sheep and growing non-breeding sheep*

$$LWGsg_y = \frac{LWas_y - LWlamb_{12m,y}}{365}$$

Where:

$LWGsg_y$ = live weight gain of growing sheep (growing breeding sheep and growing non-breeding sheep) in year *y* (kg per day)

$LWas_y$= live weight of whethers, dry ewes, and mature breeding ewes, for a particular year *y* ending in June (kg)

$LWlamb_{12m,y}$ = live weight of lambs at 12 months old in year *y* (kg) (Equation 4.59)

4.8.4 Live weight and live weight gain – deer

The equations and parameters used to calculate live weights for deer follow the methodology developed by Suttie (2012), which was approved for inclusion in the inventory by the Agriculture Inventory Advisory Panel.

The inventory assumes that both hinds and stags are born on the 19th of November each year, and have a weight that increases linearly according to Equation 4.69 and Equation 4.75. A portion of these animals are slaughtered after 466 days at the end of February. Following this, the rate of weight gain decreases (Equation 4.71 and Equation 4.78). At two years of age, the hinds are deemed to have reached a stable weight and are classified as breeding hinds. At three years of age the stags are deemed to have reached a stable weight and are classified as breeding stags

4.8.4.1 Mature hinds

The inventory model assumes that mature hinds have a stable weight. Instead of using killing out percentages, data and methodology from Suttie (2012) is used to calculate live weight. Average live weight of mature hinds is approximately 110 kg (Stevens & Ward, 2023). Therefore a cap of 110 kg is applied to breeding hinds.

Equation 4.65 *Monthly live weight for mature hinds*

$$LWbh_y = \max\left[110,\ \left(Carcass\ weight_{hind,y} \times \frac{baselineLW_{hind,y}}{Carcass\ weight_{hind,1989}}\right)\right]$$

Where:

$LWbh_y$= live weight of breeding hinds for a particular year *y* ending in June (kg)

Carcass $weight_{hind,y}$ = average carcass weight of hinds for year *y* ending in June (kg). Data supplied by Deer Industry New Zealand

$baselineLW_{hind,y}$ = baseline live weight of hinds in year *y*, using data from Suttie (2012). See Table 4.9 for values

Carcass $weight_{hind,1989}$ = average carcass weight of hinds in 1989 for the year ending in June (42.43 kg). Data supplied by Deer Industry New Zealand

4.8.4.2 Hinds from birth to first slaughter

The monthly live weight for hinds in the first 466 days of their life can be calculated using the equations below. Because this period of growth is longer than 365 days, the months of November, December, January and February will have two age groups of young hinds (with different weights) growing at the same rate (one group will have been recently born and the other group will have recently turned one).

Equation 4.66 *Monthly live weight for growing hinds, from birth to first slaughter*

$$LWhind_{birth\ to\ 1st\ slaughter,m,y} = \left(\frac{AgeMOM_{hind,m,y}}{days\ to\ 1st\ Slaughter_{hind}} \times \left(LWhind_{at\ 1st\ slaughter,m,y} - Birth\ weight_{hind,y}\right)\right)$$

Where:

$LWhind_{birth\ to\ 1st\ slaughter,m,y}$ = live weight of growing hinds for a particular year *y* and month m, for the first 466 days of their life

$AgeMOM_{hind,m,y}$ = age (in days) of growing hinds at the middle of month *m* in year *y*

days to 1st $slaughter_{hind}$ = number of days between birth and first slaughter for growing hinds (466)

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg) (Equation 4.67)

Birth $weight_{hind,y}$ = live weight of hinds at birth in year *y* (kg) (Equation 4.68)

Equation 4.67 *Live weight for growing hinds at first slaughter*

$$LWhind_{at\ 1st\ slaughter,y} = \frac{Carcass\ weight_{hind,y}}{KO_{hind}}$$

Where:

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg).

Carcass $weight_{hind,y}$ = average carcass weight of hinds for year *y* ending in June (kg). Data supplied by Deer Industry New Zealand

KO_{hind} = killing out percentage for hinds. Currently set at 55%

The live weight of hinds at birth is assumed to be 9% of the mature breeding hind weight.

Equation 4.68 *Live weight of hinds at birth*

$$Birth\ weight_{hind,y} = 9\% \times LWbh_y$$

Where:

Birth $weight_{hind,y}$ = live weight of hinds at birth in year *y* (kg)

$LWbh_y$= live weight of breeding hinds for a particular year *y* ending in June (kg) (Equation 4.65)

Equation 4.69 *Live weight gain for growing hinds from birth to first slaughter*

$$LWGhind_{birth\ to\ first\ slaughter,y} = \frac{LWhind_{at\ 1st\ slaughter,y} - Birth\ weight_{hind,y}}{days\ to\ 1st\ Slaughter_{hind}}$$

Where:

$LWGhind_{birth\ to\ first\ slaughter,y}$ = live weight gain of growing hinds from birth to first slaughter in year y (kg per day)

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg) (Equation 4.67)

$Birth\ weight_{hind,y}$ = live weight of hinds at birth in year *y* (kg) (Equation 4.68)

days to 1st $slaughter_{hind}$ = number of days between birth and first slaughter for growing hinds (466)

4.8.4.3 Hinds from first slaughter to maturity

From the 28th of February, the live weight of hinds older than the age of one but younger than two (when they become mature breeding hinds) can be calculated using the formula below.

Equation 4.70 *Monthly live weight for growing hinds, from first slaughter to maturity*

$$LWhind_{1st\ slaughter\ to\ mature,m,y} = \left(\frac{AgeMOM_{hind,m,y} - days\ to\ 1st\ Slaughter_{hind}}{days\ to\ maturity_{hind}} \times \left(LWbh_y - LWhind_{at\ 1st\ slaughter,m,y}\right)\right)$$

Where:

$LWhind_{1st\ slaughter\ to\ maturity,m,y}$ = live weight of growing hinds for a particular year *y* and month *m*, from 466 days of age to maturity

$AgeMOM_{hind,m,y}$ = age (in days) of growing hinds at the middle of month *m* in year *y*

days to 1st $slaughter_{hind}$ = number of days between birth and first slaughter for growing hinds (466)

days to $maturity_{hind}$ = number of days between first slaughter and maturity for growing hinds (306)

$LWbh_y$= live weight of mature hinds for a particular year *y* ending in June (kg) (Equation 4.65)

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg) (equation 4.63)

Equation 4.71 *Live weight gain for growing hinds from first slaughter to maturity*

$$LWGhind_{1st\ slaughter\ to\ maturity,y} = \frac{LWbh_y - LWhind_{at\ 1st\ slaughter,m,y}}{days\ to\ maturity_{hind}}$$

Where:

$LWGhind_{slaughter\ to\ maturity,y}$ = live weight gain of growing hinds from first slaughter to maturity in year *y* (kg per day)

$LWbh_y$= live weight of mature hinds for a particular year *y* ending in June (kg) (Equation 4.65)

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg) (Equation 4.67)

days to $maturity_{hind}$ = number of days between first slaughter and maturity for growing hinds (306)

4.8.4.4 Stags from birth to first slaughter

The monthly live weight for stags in the first 466 days of their life can be calculated using the equations below. Because this period of growth is longer than 365 days, the months of November, December, January and February will have two age groups of young stags (with different weights) growing at the same rate (one group will have been recently born and the other group will have recently turned one).

Equation 4.72 *Monthly live weight for growing stags, from birth to first slaughter*

$$LWstag_{birth\ to\ 1st\ slaughter,m,y} = \left(\frac{AgeMOM_{stag,m,y}}{days\ to\ 1st\ Slaughter_{stag}} \times \left(LWstag_{at\ 1st\ slaughter,m,y} - Birth\ weight_{stag,y}\right)\right)$$

Where:

$LWstag_{birth\ to\ 1st\ slaughter,m,y}$ = live weight of growing stags for a particular year *y* and month m, for the first 466 days of their life

$AgeMOM_{stag,m,y}$ = age (in days) of growing stags at the middle of month *m* in year *y*

days to 1^{st} $slaughter_{stag}$ = number of days between birth and first slaughter for growing stag (466)

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year *y* at slaughter after 466 days (kg) (Equation 4.73)

Birth $weight_{stag,y}$ = live weight of stags at birth in year *y* (kg) (Equation 4.74)

Equation 4.73 *Live weight for growing stags at first slaughter*

$$LWstag_{at\ 1st\ slaughter,y} = \frac{Carcass\ weight_{stag,y}}{KO_{stag}}$$

Where:

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year *y* at slaughter after 466 days (kg).

Carcass $weight_{stag,y}$ = average carcass weight of stags for year *y* ending in June (kg). Data supplied by Deer Industry New Zealand

KO_{stag} = killing out percentage for stags. Currently set at 55%

The live weight of stags at birth is assumed to be 10% of the mature breeding hind weight.

Equation 4.74 *Live weight of stags at birth*

$$Birth\ weight_{stag,y} = 10\% \times LWbh_y$$

Where:

Birth $weight_{stag,y}$ = live weight of stags at birth in year *y* (kg)

$LWbh_y$= live weight of breeding hinds for a particular year *y* ending in June (kg) (

Equation 4.63)

Equation 4.75 *Live weight gain for growing stags from birth to first slaughter*

$$LWGstag_{birth\ to\ first\ slaughter,y} = \frac{LWstag_{at\ 1st\ slaughter,y} - Birth\ weight_{stag,y}}{days\ to\ 1st\ Slaughter_{stag}}$$

Where:

$LWGstag_{birth\ to\ first\ slaughter,y}$ = live weight gain of growing stags from birth to first slaughter in year *y* (kg per day)

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year *y* at slaughter after 466 days (kg) (Equation 4.73)

$Birth\ weight_{stag,y}$ = live weight of stags at birth in year *y* (kg) (Equation 4.74)

days to 1st $slaughter_{stag}$ = number of days between birth and first slaughter for growing stags (466)

4.8.4.5 Stags from first slaughter to maturity

From the 28th of February, the live weight of stags between the age of one (including mature stags) and three can be calculated using the formulas below. Because this period of growth is longer than 365 days, there will be two age groups of young stags (with different weights) growing at the same rate (one group will be aged between one and two and the other group will be aged between two and three).

Equation 4.76 *Monthly live weight for growing stags, from first slaughter to maturity*

$$LWstag_{1st\ slaughter\ to\ three,m,y} = \left(\frac{AgeMOM_{stag,m,y} - days\ to\ 1st\ Slaughter_{stag}}{days\ to\ maturity_{stag}} \times \left(LWstag_{age\ three,y} - LWstag_{at\ 1st\ slaughter,m,y}\right)\right)$$

Where:

$LWstag_{1st\ slaughter\ to\ three,m,y}$ = live weight of stags for a particular year *y* and month *m*, from 466 days of age to three years of age

$AgeMOM_{stag,m,y}$ = age (in days) of stags at the middle of month *m* in year *y*

days to 1st $slaughter_{stag}$ = number of days between birth and first slaughter for stags (466)

days to $maturity_{stag}$ = number of days between first slaughter and age three for stags (671)

$LWstag_{age\ three,y}$= live weight of stags at age three for a particular year *y* ending in June (kg) (Equation 4.77)

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year *y* at slaughter after 466 days (kg) (Equation 4.73)

The inventory model assumes that breeding stags are aged between two and three and are still gaining weight. The final weight of these animals when they turn three can be calculated using the formula below.

Equation 4.77 *Monthly live weight for stags at three years of age*

$$LWstag_{age\ three,y} = Carcass\ weight_{stag,y} \times \frac{baselineLW_{stag,y}}{Carcass\ weight_{stag,1989}}$$

Where:

$LWstag_{age\ three,y}$= live weight of stags at age three for a particular year *y* ending in June (kg)

$Carcass\ weight_{stag,y}$ = average carcass weight of stags for year *y* ending in June (kg). Data supplied by Deer Industry New Zealand

$baselineLW_{stag,y}$ = baseline live weight of stags in year *y*, using data from Suttie (2012). See Table 4.9 for values

$Carcass\ weight_{stag,1989}$ = average carcass weight of stags in 1989 for the year ending in June (53.59 kg). Data supplied by Deer Industry New Zealand

Equation 4.78 *Live weight gain for stags from first slaughter to age three*

$$LWGstag_{1st\ slaughter\ to\ age\ three,y} = \frac{LWstag_{age\ three,y} - LWstag_{at\ 1st\ slaughter,m,y}}{days\ to\ maturity_{stag}}$$

Where:

$LWGstag_{slaughter\ to\ age\ three,y}$ = live weight gain of growing stags from first slaughter to three years of age in year *y* (kg per day)

$LWstag_{age\ three,y}$= live weight of stags at age three for a particular year y ending in June (kg) (Equation 4.77)

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year y at slaughter after 466 days (kg) (Equation 4.73)

$days\ to\ maturity_{stag}$ = number of days between first slaughter and age three for stags (671)

4.8.4.6 Baseline live weights for stags and hinds

The values for $baselineLW_{hind,y}$ and $baselineLW_{stag,y}$ for a particular year can be found in the table below.

Table 4.9: values for $baselineLW_{hind,y}$ and $baselineLW_{stag,y}$, by year (kg)

Year	$baselineLW_{hind,y}$	$baselineLW_{stag,y}$,
1990	100.000	133.000
1991	100.619	135.500
1992	101.238	138.000
1993	101.857	139.167
1994	102.476	140.333
1995	103.095	141.500
1996	103.714	142.667
1997	104.333	143.833
1998	104.952	145.000
1999	105.571	139.000
2000	106.190	147.000
2001	106.810	147.500
2002	107.429	148.000
2003	108.048	145.000
2004	108.667	145.000

2005	109.286	150.000
2006	109.905	150.000
2007	110.524	150.000
2008	111.143	150.000
2009	111.762	150.000
2010	112.381	150.000
2011-present	113.000	150.000

4.8.5 live weight and live weight gain – swine

Swine weight data compiled by Statistics New Zealand is used to calculate nitrous oxide emissions (see Section 5.7.5). However, this weight data is not used to calculate energy requirements or methane emissions.

4.8.6 live weight and live weight gain – other animals

As mentioned earlier, live weights are not used to calculate emissions for horses, mules and asses, alpacas, poultry and goats.

5 Nitrogen excretion

This chapter outlines the equations and parameters that are used to calculate nitrogen excretion (N_{ex}) for New Zealand's four major livestock species dairy, beef, sheep, and deer, as well as all other livestock species which are classified as 'minor'.

In order to calculate nitrous oxide emissions from livestock manure and agricultural soils, the amount of nitrogen excreted needs to be determined for each livestock subcategory. N_{ex} is calculated by subtracting the nitrogen (N) retained by the animal (for example for live weight change, growth of new born, milk production, wool and velvet) from the N consumed by an animal (N intake).

Nitrous oxide (N_2O) emissions can then be estimated from the total amounts of nitrogen (N) excreted in urine (N_u) and faeces (N_f), and emission factors specific to the characteristics of each livestock class' manure management systems (MMS). Calculations are made for a given year on a monthly time step basis and then summed to estimate total N_2O emitted from all such systems.

For the purpose of this methodology document;

- Partitioning refers to the proportion of total N_{ex} divided between the two manure forms, urine and dung.
- Allocation refers to the proportion of N_{ex} (partitioned already to both manure types, dung and urine), that is allocated to different slope types.

Partitioning of nitrogen excreta between dung and urine

The partitioning of N between urine and faeces is calculated as a percentage of total N_{ex}. Prior to the 2019 inventory submission, the urine component (N_u) of N_{ex} was calculated based on the methodology developed by Luo and Kelliher (2010) and N_f was then calculated by subtracting N_u from N_{ex}. A review by Pacheco, Waghorn and Rollo, commissioned by the Ministry for Primary Industries as part of inventory improvement efforts, determined that equations used to predict faecal N (N_f) are more precise and accurate than the urinary N equations (2018). The review compiled a dataset from peer reviewed literature of 448 mean N balances from ruminants fed a forage diet. Using this dataset, the authors evaluated the predictive performance of the inventory methodology equation in usage as developed by Luo and Kelliher (2010) and an alternative equation proposed by Thomson and Muir (2016) which were derived from 33 and 72 data values respectively.

It was concluded that neither of the equations performed consistently, in terms of accuracy and precision, across all livestock categories and recommended that equations predict absolute N_f because it is less prone to measurement errors than N_u in N balance studies. Therefore, from the 2019 inventory submission two equations are now incorporated into the inventory methodology. This addresses the identified issues with consistency of performance of the previous equations across livestock classes.

Allocation of nitrogen excreta to different hill slopes

In 2020 MPI adopted a revised methodology and set of emission factors to calculate direct N2O emissions from cattle, sheep and deer. These revised emission factors are disaggregated by slope (as well as livestock type), and a methodology is used to calculate the amount of nitrogen (in the form of urine or dung) deposited on these different slopes.

Under this new methodology, pastoral land in New Zealand is split into four slope categories based on topography:

- Flatland is classified as *flat pastoral land or plains* with a gradient lower than 12 degrees.
- Low slopes are classified as *hill country pastoral land* with a gradient lower than 12 degrees.
- Medium slopes are classified as *hill country pastoral land* with a gradient between 12 degrees and 24 degrees.
- Steep slopes are classified as *hill country pastoral land* with a gradient greater than 24 degrees.

The emission factors used to calculate direct N_2O emissions from cattle, sheep and deer are described in detail in chapter 8, Section 8.1.3.

A 'nutrient transfer model' developed by Saggar et al. (2015) is used to calculate the amount of dung and urine deposited onto different hill slope categories. Approximately 80 per cent of land on sheep, beef and deer farms is classed as medium (12–24 degrees) or steep (greater than 24 degrees) sloped land (see figure A3.1.3). The nutrient transfer model uses data on the area of farm land under different slope types, and accounts for animals spending relatively more time on lower slopes.

For cattle, sheep and deer, the estimated nitrogen excretion (Nex) values are separated into urine and dung components using the methodology outlined by Pacheco et al. (unpublished).Urinary N from beef cattle, sheep and deer is allocated to the different slope types, $Nex_{URINE,LOW}$ (i.e. urine deposited on low slopes), $Nex_{URINE,MED}$ (urine deposited on medium slopes) and $Nex_{URINE,STEEP}$. (urine deposited on steep slopes). For dairy cattle, it is assumed that all urine is deposited on flatland, ($Nex_{URINE,FLAT}$). The flatland/low slope emission factor for cattle urine ($EF_{3(PRP\ FLAT)}$ = 0.0098) is applied to all dairy cattle urine.

Dung N from dairy cattle, beef cattle, sheep and deer is not allocated to different slope types as the same emission factor for dung (0.12%) is used across all slope types.

5.1 Calculation of nitrogen content of total diet

The nitrogen content of the total diet consumed by livestock is calculated using a weighted average based on the usage of different feeds.

Equation 5.1 *Calculation of total diet nitrogen content*

$$N_{diet} = \sum_{feed} N_{feed} \times \%Diet_{feed}$$

Where:

N_{diet} = Nitrogen content of total diet consumed, expressed as a proportion of DMI

N_{feed} = Nitrogen content of feed expressed as a proportion of DMI The N_{feed} values used in these inventory calculations for different months and animal categories are given in Appendix 3 (pasture) and Appendix 5 (non-pasture).

$\%Diet_{feed}$ = proportion of the livestock diet of each feed makes up. The dietary proportions used in these calculations are given in Appendix 6 (dairy) and Appendix 7 (sheep and beef). Deer are assumed to be entirely pasture fed.

Pasture quality varies seasonally. Different quantities and types of non-pasture are fed through the year. Present data supports the including annual variation for dairy cattle and seasonal variation for beef cattle and sheep.

5.2 Dairy

This section describes the calculations used to determine nitrogen excretion in dairy cattle. To calculate N_{ex}, the amount of N used in milk production and live weight gain (including growth of new born during pregnancy) is subtracted from the N intake of an animal.

Each class of dairy cattle (as set out in Table 4.1 in Section 4.4.1) will have different levels of nitrogen intake, retention and excretion, and these levels will change over the course of the year as energy requirements and milk production changes.

Equation 5.2 *Nitrogen excretion for dairy cattle:*

$$N_{ex} = N_i - (N_m + N_{lwg})$$

Where:

N_{ex} = Nitrogen excretion per animal (kilograms of nitrogen per day)

N_i = Nitrogen intake per animal (kg N/day)

N_{rm} = nitrogen secreted in milk per animal (kg N/day)

N_{lwg} = nitrogen retained in live weight gain per animal (kg N/day)

5.2.1 **Nitrogen intake**

5.2.1.1 Dairy cattle greater than one year old

For cattle greater than 1 year old nitrogen intake (N_i) is determined by:

Equation 5.3 *Nitrogen intake for dairy cattle more than 1 year old:*

$$N_i = DMI \times N_{diet}$$

Where:

N_i = Nitrogen intake per animal (kg of nitrogen per day)

DMI = dry matter intake per animal (kg/day see Section 4.1.1)

N_{diet} = Nitrogen content of total diet consumed by dairy cattle, expressed as a proportion of DMI (see Equation 5.1)

5.2.1.2 Dairy cattle less than one year old

Intakes are calculated separately for the period when milk forms part of the diet (first 61 days of life) and for the remainder of the year. During the first 61 days of life, dairy calves are fed milk as all or part of their diet. The following equations are used to calculate N intake for young dairy cattle.

Equation 5.4 *Nitrogen intake through milk by young dairy cattle:*

$$z_3 = \frac{Z_{mp}}{d} \times \frac{P_{mp}}{6.25}$$

Where:

Z_3 = nitrogen intake through milk powder per animal (kg N per day)

Z_{mp} = total milk (derived from milk powder) fed to a calf between birth and weaning (200 kg)

d = number of days per year that N is consumed through milk (currently set at 61)

P_{mp} = protein content of milk powder fed to dairy calves (value currently used is 0.0366 grams of protein per gram of milk powder)

The first fraction in the above equation is used to calculate the daily milk intake for calves, while the second fraction calculates the nitrogen content of this milk. The value of 6.25 is used because of the assumption that 6.25 tonnes of protein contains 1 tonne of nitrogen (Pierce & Haenisch, 1947).

During the first 61 days of life, Equation 5.5 (below) is used to calculate N intake for young cattle. For other months, Equation 5.3 (above) is used.

Equation 5.5 *Nitrogen intake for cattle less than 1 year old in in the first 61 days:*

$$N_i = (DMI \times N_{diet}) + z_3$$

Where:

N_i = Nitrogen intake per animal (kg N per day)

DMI = dry matter intake per animal (kg/day see Section 4.1.1)

N_{diet} = Nitrogen content of total diet consumed by dairy cattle, expressed as a proportion of DMI (i.e. grams of N per gram of DMI, see Equation 5.1)

Z_3 = nitrogen intake through milk powder per animal (kg N per day)

5.2.2 Nitrogen retained in milk

The N secreted as milk production for lactating dairy cows is determined by the following equation:

Equation 5.6 *Nitrogen secreted in milk for mature milking cows:*

$$N_{rm} = Y \times \frac{P}{6.25}$$

Where:

N_{rm} = Amount of nitrogen secreted in milk per animal (kg N per day)

Y = Daily milk yield per milking cow (kg/d) (see Equation 4.10, Section 4.4.3.1)

P = Protein content of milk, expressed as a proportion (i.e. grams of N per gram of milk, see appendix 1 for values)

5.2.3 Nitrogen retained in live weight gain

Growing animals retain N in animal tissues through live weight gain. The amount of N retained will depend on the subcategory of animal and the amount and composition of gain. The N retained in the growing foetus is realised in that animals' birth month, rather than over the course of the pregnancy.

Equation 5.7 *Nitrogen retained in animal tissues through live weight gain:*

$$N_{lwg} = LWG \times \frac{N_{bt}}{100}$$

Where:

N_{lwg} = Amount of nitrogen retained in animal tissues through liveweight gain per animal (kg of nitrogen per day)

LWG = live weight gain per animal (kg per day) (see Section 4.8.1)

N_{bt} = nitrogen content of body tissue, currently set at 3.26% (see appendix 1)

5.2.4 Nitrogen in urine and faeces

N_{ex} is comprised of nitrogen from urine (N_u) and faeces (N_f). Once N_{ex} is calculated from Equation 5.2, the proportion and amount of N in both urine (N_u) and faeces (N_f) can then be determined with the following equations, which were developed by Pacheco, Waghorn and Rollo (2018).

Equation 5.8 *Nitrogen excreted in faeces:*

$$N_f = (-4.623 + (N_{diet} \times 100 \times 1.970) + (DMI \times 7.890)) \times 0.001$$

Where:

N_f = Amount of nitrogen excreted in faeces per animal (kilograms of nitrogen per day)

N_{diet} = Nitrogen content of total diet consumed by dairy cattle, expressed as a proportion of DMI (i.e. grams of N per gram of DMI, see Equation 5.1)

DMI = the dry matter intake (kilograms per day)

Equation 5.9 *Nitrogen excretion in urine:*

$$N_u = N_{ex} - N_f$$

Where:

N_u = Amount of nitrogen excreted in urine per animal (kg N per day)

N_f = Amount of nitrogen excreted in faeces per animal (kg N per day)

N_{ex} = Nitrogen excretion per animal calculated from Equation 5.2 (kilograms N per day)

5.2.5 Nitrogen excretion on sloped land

As stated at the start of section 5, it is assumed that all dairy urine and is deposited on flatland. Dairy excreta is not allocated to different slope types because the Inventory assumes that all dairy cattle graze on flatland. The flatland/low slope emission factor for cattle urine ($EF_{3(PRP\ FLAT)}$ = 0.0098) is applied to all dairy cattle urine, and a $EF_{3(PRP\text{-}DUNG)}$ value of 0.0012 is applied to all dairy dung.

5.3 Beef

This section describes the calculations used to determine nitrogen excretion in beef cattle (using the categories set out in Table 4.2 in Section 4.5.1). To do this, estimates of nitrogen intake, nitrogen retention (through live weight gain) and secretion in milk need to be calculated. Daily estimates of N_{ex} for a particular subcategory of beef cattle can be calculated using Equation 5.2 in Section 5.2.

5.3.1 Nitrogen intake

5.3.1.1 Nitrogen intake by beef cattle older than one year old

Equation 5.3 (Section 5.2.1.1) is used to calculate N intake by beef cattle greater than one year old.

5.3.1.2 Nitrogen intake by rising 1-year olds

For cattle less than 1 year old the nitrogen intake needs to account for the amount of nitrogen that they consume from milk during their first eight months of life.

Equation 5.10 *Nitrogen intake through milk by young beef cattle:*

$$z_{3beef} = Z \times \frac{P_{mp}}{6.25}$$

Where:

Z_{3beef} = nitrogen intake through milk per animal (kg of nitrogen per day)

Z = the milk fed to each calf per day over the 1-8 month period (kg)

d = number of days per year N is consumed through milk (currently set at 243)

P_{mp} = protein content of milk powder fed to calves (value currently used is 0.0366 grams of protein per gram of milk powder)

The first fraction in the above equation is used to calculate the daily milk intake for calves, while the second fraction calculates the nitrogen content of this milk. The value of 6.25 is used because of the assumption that 6.25 tonnes of protein contains 1 tonne of nitrogen (Pierce & Haenisch, 1947).

For the first six months of life, Equation 5.11 (below) is used to calculate N intake for young cattle. For other months (when there is no intake of milk), Equation 5.3 (Section 5.2.1.1) is used.

Equation 5.11 *Nitrogen intake for beef cattle less than 1 year old in in first six months of life*

$$N_i = (DMI \times N_{diet}) + z_{3beef}$$

Where:

N_i = Nitrogen intake per animal (kg of nitrogen per day)

DMI = dry matter intake per animal (kg/day see Section 4.1.1)

N_{diet} = Nitrogen content of total diet consumed by beef cattle, expressed as a proportion of DMI (see Equation 5.1)

Z_{3beef} = nitrogen intake through milk per animal (kg of nitrogen per day)

5.3.2 Nitrogen secreted in milk

For six months of the year from September to February, cows that have calves produce milk and the nitrogen in this milk is calculated according to Equation 5.12

Equation 5.12 *Nitrogen secreted in milk of cows rearing their calves:*

$$N_{rm} = Y \times \frac{P}{6.25}$$

Where:

N_{rm} = Amount of nitrogen in milk (kg N per animal per day)

Y = Daily milk yield per milking cow (kg/d) (see Equation 4.25, Section 4.5.3.1)

P = Protein content of milk (see Appendix 13)

For the other months of the year (March-August) N_{rm} is set to zero.

The other subcategories of beef cattle (growing cows up to two years, bulls, heifers and steers) produce no milk so N_{rm} is always zero.

5.3.3 Nitrogen retained in live weight gain

Growing animals retain N in animal tissues through live weight gain. The amount of N retained (N_{lwg}) through this will depend on the subcategory of animal and the rate at which they gain weight.

Equation 5.7 (Section 5.2.3) can be used to calculate N_{lwg} for different subcategories of beef cattle.

5.3.4 Nitrogen in urine and faeces

For beef cattle, the amount of N excreted in urine (N_u) and faeces (N_f) per animal per day can be determined using Equation 5.8 and Equation 5.9 in Section 5.2.4.

5.3.5 Nitrogen excretion on sloped land

The total N excreted in urine (N_u) for beef cattle is allocated to low, medium and steep slopes using the method described in Section 5.6.

A single dung emission factor ($EF_{3(PRP\text{-}DUNG)}$ = 0.0012) is used across all slope categories for cattle, sheep and deer, and therefore dung excreta does not need to be allocated to different slopes.

5.4 Sheep

This section describes the calculations used to determine nitrogen excretion in sheep. To calculate N excreted (N_{ex}), the N retained in liveweight gain and wool and secreted in milk is subtracted from the N intake (N_i) of an animal.

The N intake value takes feed intake into account, as well as milk consumed by young sheep. The N retention value accounts for N secreted in milk production, and retained in body tissue for live weight gain and wool.

Each class of sheep (as described in Section 4.6, Table 4.3) will have different levels of nitrogen intake, retention and excretion, and these levels will change over the course of the year as intake and production levels change.

Equation 5.13 *Nitrogen excretion for sheep:*

$$N_{ex} = N_i - (N_m + N_{lwg} + N_{wool})$$

Where:

N_{ex} = Nitrogen excretion per animal (kilograms of nitrogen per day)

N_i = Nitrogen intake per animal (kg N/day)

N_{rm} = nitrogen secreted in milk per animal (kg N/day)

N_{lwg} = nitrogen retained in live weight gain per animal (kg N/day)

N_{wool} = nitrogen retained in wool growth per animal (kg N/day)

5.4.1 Nitrogen intake

N intake is calculated separately for sheep under 1-year old and over 1-year old, to account for the intake of milk by lambs.

5.4.1.1 *Sheep older than one year*

Equation 5.3 (Section 5.2.1.1) can be used to calculate N intake by sheep greater than one year old. The sheep-specific values for the nitrogen content of total diet are calculated using Equation 5.1.

5.4.1.2 *Sheep younger than one year*

For sheep less than 1-year old the N intake needs to account for the amount of N consumed in milk in the first 122 days of life using the term z_3 (the N from milk).

Equation 5.14 *Nitrogen intake through milk by lambs:*

$$z_{3lamb} = \frac{Y_{sheepm}}{d_{srm} \times P_{lamb}} \times \frac{P_{mp}}{6.25}$$

Where:

Z_{3lamb} = nitrogen intake through milk per animal (kg of nitrogen per day)

Y_{sheepm} = annual milk yield per sheep (kilograms per sheep per year)

P_{lamb} = annual lambing percentage rate (see Appendix 16)

d_{srm} = number of days young lambs receive milk (assumed to be 122)

P_{mp} = protein content of sheep milk (value currently used is 0.06 grams of protein per gram of milk)

The first fraction in the above equation is used to calculate the daily milk intake for lambs, while the second fraction calculates the nitrogen content of this milk. The value of 6.25 is used because of the assumption that 6.25 tonnes of protein contains 1 tonne of nitrogen (Pierce & Haenisch, 1947).

For September to January, Equation 5.15 (below) is used to calculate N intake for lambs. For other months (when the inventory assumes no intake of milk), Equation 5.3 (Section 5.2.1.1) is used.

Equation 5.15 *Nitrogen intake for sheep less than 1 year old for September to December:*

$$N_i = (DMI \times N_{diet}) + z_{3lamb}$$

Where:

N_i = Nitrogen intake per animal (kg of nitrogen per day)

DMI = dry matter intake per animal (kg/day see Section 4.1.1)

N_{diet} = Nitrogen content of total diet consumed by sheep, expressed as a proportion of DMI (see Equation 5.1)

Z_{3lamb} = nitrogen intake through milk per animal (kg of nitrogen per day)

5.4.2 Nitrogen secreted in milk

For four months of the year from September to December, mature breeding ewes and growing breeding sheep produce milk for young lambs. The amount of nitrogen used for this milk production is calculated using the formula below

Equation 5.16 *Nitrogen secreted in milk for mature breeding ewes and growing breeding sheep:*

$$N_{rm} = y \times \frac{P}{6.25}$$

Where:

N_{rm} = Amount of nitrogen secreted in milk per animal that produces milk (kg of nitrogen per day)

y = Daily milk yield per sheep, for a particular day and month (kg/day)

P = Protein content of milk ((value currently used is 0.06 grams of protein per gram of milk)

For the other months of the year (January-August) N_{rm} is set to zero for mature breeding ewes and growing breeding sheep.

The other subcategories of sheep (dry ewes, growing non breeding sheep, whethers, lambs and rams) produce no milk so N_{rm} is assumed to be zero for all 12 months of the year for these sheep subcategories.

5.4.3 Nitrogen retained in wool

Part of the nitrogen taken in by sheep is retained for the growth of wool.

The daily amount of nitrogen retained through wool production can be calculated using the equation below.

Equation 5.17 *Nitrogen retained in wool produced by sheep:*

$$N_{wool} = \frac{totWool_{c,m}}{Pop_{m,c} \times Days_m} \times wool_{Ncontent}$$

Where:

N_{wool} = Amount of nitrogen retained in wool per animal (kg of nitrogen per day)

$totWool_{c,m}$ = total wool grown by class c in month m (kg) (See Equation 4.39)

$POP_{m,c}$ = sheep population in month m and class c

$Days_m$ = number of days in month m

$Wool_{Ncontent}$ = Proportion of nitrogen content of wool (assumed to be 0.134)

5.4.4 Nitrogen retained in live weight gain

Growing animals retain N in animal tissues through live weight gain. The amount of N retained (N_{lwg}) through this will depend on the subcategory of animal and the rate at which they gain weight.

To determine the amount of nitrogen retained through live weight gain for sheep, the following equation is used.

Equation 5.18 *Nitrogen retained in tissues of individual sheep through liveweight gain:*

$$N_{lwg} = LWG \times \frac{N_{bt,sheep}}{100}$$

Where:

N_{lwg} = Amount of nitrogen retained in animal tissues through liveweight gain per animal (kg N per day)

LWG = live weight gain per animal (kilograms/day, see Section 4.8 for detailed calculations)

$N_{bt,sheep}$ = proportion of nitrogen content of body tissue for sheep, currently set at 0.026% (see Appendix 16)

5.4.5 Nitrogen in urine and faeces

For sheep, a separate equation to Equation 5.8 is required to calculate the amount of N excreted in faeces (N_f) per animal per day to address issues with the consistency of performance across the livestock species. As with the other three major livestock species, for sheep, the amount of N excreted in urine (N_u) can be determined using Equation 5.9 in Section 5.2.4.

For sheep, N excreted in faeces can be calculated using the following equation developed by Pacheco, Waghorn and Rollo (2018):

Equation 5.19 *Nitrogen excreted in faeces:*

$$N_f = \left(2.230 + (N_i \times 0.299) + ([N_{diet} \times 100]^2 \times -0.237)\right) \times 0.001$$

Where:

N_f = Amount of nitrogen excreted in faeces per animal (kilograms of nitrogen per day)

N_{diet} = Nitrogen content of total diet consumed by dairy cattle, expressed as a proportion of DMI (i.e. grams of N per gram of DMI, see Equation 5.1)

N_i = the nitrogen intake per animal (grams nitrogen per day)

5.4.6 Nitrogen excretion on sloped land

The total N excreted in urine (N_u) for sheep is allocated to low, medium and steep slopes using the method described in Section 5.6.

Because a single dung emission factor ($EF_{3(PRP\text{-}DUNG)}$ = 0.0012) is used across all slope categories for cattle, sheep and deer, dung excreta does not need to be allocated to different slopes.

5.5 Deer

This section describes the calculations used to determine nitrogen excretion in deer. To calculate N excreted (N_{ex}), the N retained and secreted in milk, is subtracted from the N intake (N_i) of an animal.

The N intake value is based on forages, as well as milk consumed by young deer. The N retention accounts for N in milk produced after fawning, retained in body tissue for growth (liveweight gain), and in velvet production by stags.

Each subcategory of deer (as outlined in Section 4.7, Table 4.5) will have different levels of nitrogen intake, retention and excretion, and these levels will change over the course of the year as intake and production levels change.

Equation 5.20 *Nitrogen excretion for deer:*

$$N_{ex} = N_i - (N_m + N_{lwg} + N_{velvet})$$

Where:

N_{ex} = Nitrogen excretion per animal (kilograms of nitrogen per day)

N_i = Nitrogen intake per animal (kg N/day)

N_{rm} = nitrogen retained in milk per animal (kg N/day)

N_{lwg} = nitrogen retained in live weight gain per animal (kg N/day)

N_{velvet} = nitrogen retained in velvet per animal (kg N/day)

5.5.1 Nitrogen intake

N intake is calculated separately for deer under 1-year old and over 1-year old, to account for the intake of milk by young hinds and stags

5.5.1.1 Deer older than one year

Equation 5.3 (Section 5.2.1.1) can be used to calculate N intake by deer older than one year old. The deer-specific values for the nitrogen content of feed (N_{diet}) are calculated using the pasture values in Appendix 3 and the proportions in Appendix 4.

It is assumed deer are entirely pasture fed. The N content of deer pasture is calculated as a weighted average of N_{feed} for pasture on dairy and beef-sheep land (Suttie 2012). In 1990, 46 percent of the deer herd was grazed on land use classes used for dairy, and the remaining 54 percent of the deer herd were grazed on land classes used for sheep and beef grazing. Over time the deer herd has grazed less on dairy land and more on land used for sheep and beef. From 2010 onwards, it is assumed only 10 percent of the deer herd remains on dairy land, and 90 percent on sheep and beef land (Suttie 2012).

5.5.1.2 Deer younger than one year

The nitrogen intake from deer in the first year of life needs to account for consumption of milk during the first four months of their life using the term z_3 (the amount of nitrogen received from milk).

Equation 5.21 *Nitrogen intake through milk by deer:*

$$z_{3deer} = \frac{Y_{deerm}}{d_{drm}} \times \frac{P_{m,deer}}{6.25}$$

Where:

Z_{3deer} = nitrogen intake through milk per animal (kg N per day)

Y_{deerm} = annual milk yield per deer (kilograms per sheep per year) (assumed to be 204 kilograms per deer per year, see Appendix 18)

d_{drm} = number of days young hinds and stags receive milk (assumed to be 120)

$P_{m,deer}$ = protein content of deer milk (assumed to be 0.0366 grams of protein per gram of milk)

The first fraction in the above equation is used to calculate the daily milk intake for young deer, while the second fraction calculates the nitrogen content of this milk.

For the first four months of a young deer's life, Equation 5.22 (below) is used to calculate N intake for deer. For deer older than four months (when there is no intake of milk), Equation 5.3 (Section 5.2.1.1) is used.

Equation 5.22 *Nitrogen intake for deer less than four months old:*

$$N_i = (DMI \times N_{diet}) + z_{3deer}$$

Where:

N_i = Nitrogen intake per animal (kg N per day)

DMI = dry matter intake per animal (kg/day see Section 4.1.1)

N_{diet} = Nitrogen content of total diet consumed by deer, expressed as a proportion of DMI (see appendices 3 & 4)

Z_{3deer} = nitrogen intake through milk per animal (kg of nitrogen per day)

5.5.2 Nitrogen secreted in milk

The inventory assumes that for 120 days from 19 November, breeding hinds produce milk for young deer. The nitrogen secreted in milk production is calculated using the formula below.

Equation 5.23 *Nitrogen secreted in milk for breeding hinds:*

$$N_{rm} = \frac{Y_{deerm}}{d_{drm}} \times \frac{P_{m,deer}}{6.25}$$

Where:

N_{rm} = Amount of nitrogen secreted in milk per animal that produces milk (kg N per day)

Y_{deerm} = annual milk yield per deer (kilograms per year) (assumed to be 204 kilograms per deer per year, see Appendix 18)

d_{drm} = number of days young hinds and stags receive milk (assumed to be 120)

$P_{m,deer}$ = protein content of deer milk (assumed to be 0.0366 grams of protein per gram of milk)

For the other months of the year N_{rm} is set to zero for breeding hinds.

The other subcategories of deer (Hinds aged less than 2, and all stags) produce no milk so N_{rm} is assumed to be zero for all 12 months of the year for these deer subcategories.

In the above equation the protein content of milk is divided by 6.25 because of the assumption that 6.25 tonnes of protein contains 1 tonne of nitrogen (Pierce & Haenisch, 1947).

5.5.3 Nitrogen retained in velvet

Stags over one year of age produce velvet over a 65 day period from the 1st of September to the 4th of November. The nitrogen retained through the production of this velvet is accounted for with the following calculation. It is assumed that in this period velvet growth occurs at a constant rate.

Equation 5.24 *Nitrogen retained in velvet production:*

$$N_{velvet} = \frac{Prod_{velvet}}{d_{velvet}} \times Velvet_{Ncontent}$$

Where:

N_{velvet} = Amount of nitrogen retained in velvet production per animal (kg N per day)

$Prod_{velvet}$ = annual velvet production per animal (kilograms per stag per year) (see Appendix 18 for annual values)

d_{velvet} = number of days stags produce velvet (assumed to be 65)

$Velvet_{Ncontent}$ = amount of nitrogen contained in velvet (assumed to be 0.09 grams of protein per gram of velvet)

For the rest of the year (5 November-August), N_{velvet} is set to zero for stags over one year of age.

The other subcategories of deer (stags aged less than 1 year, and all hinds) produce no velvet so N_{velvet} is assumed to be zero for all 12 months of the year for these deer subcategories.

5.5.4 Nitrogen retained in live weight gain

Growing deer retain N in animal tissues through live weight gain. The amount of N retained (N_{lwg}) through this will depend on the subcategory of animal and the rate at which they gain weight.

To determine the amount of nitrogen retained through live weight gain for deer, the following equation is used.

Equation 5.25 *Nitrogen retained in deer tissues through liveweight gain:*

$$N_{lwg} = LWG \times \frac{N_{bt,deer}}{100}$$

Where:

N_{lwg} = Amount of nitrogen retained in tissues through live weight gain per animal (kg N per day)

LWG = live weight gain per animal (kg/day)

$N_{bt,deer}$ = nitrogen content of body tissue for deer, currently set at 3.71% (see Appendix 18)

5.5.5 Nitrogen in urine and faeces

For deer, the amount of N excreted in urine (N_u) and faeces (N_f) per animal per day can be determined using Equation 5.8 and Equation 5.9 in Section 5.2.4. Values on the nitrogen content of forages for deer (N_{diet}) are calculated from the pasture values in Appendix 3 and the proportions in Appendix 4.

5.5.6 Nitrogen excretion on sloped land

The total N excreted in urine (N_u) for deer is allocated to low, medium and steep slopes using the method described in Section 5.6.

Because a single dung emission factor ($EF_{3(PRP\text{-}DUNG)}$ = 0.0012) is used across all slope categories for cattle, sheep and deer, dung excreta does not need to be allocated to different slopes.

5.6 Allocation of urine and dung to different hill slopes

The nutrient transfer model outlined by Saggar et al. (2015) is used to allocate total dung and urine between low, medium and steep slopes following the partitioning of excreta to dung and urine by livestock type.. Beef + Lamb New Zealand provides data (on the topography and number of animals on different farm types) used in the nutrient transfer model.

The following steps describe excreta and nutrient allocation across livestock and slope types.

Step 1: Calculations of total nitrogen excretion (N_{ex}) rates for each animal category

Total N_{ex} for sheep, beef cattle and deer are calculated using the methods described in sections 5.2, 5.3, and 5.4.

Step 2: Partitioning of N_{ex} between urine and dung

The total N_{ex} calculated in step 1 is partitioned into urine and dung using the method described by Pacheco et al. (unpublished), and Section 5.2.4 (beef cattle), Section 5.3.5 (sheep) and Section 5.4.5 (deer).

Step 3: Allocation of dung and urinary excreta to different hill slope types

For dung excreta, a single emission factor ($EF_{3(PRP-DUNG)}$ = 0.0012, less than half the previous emission factor used of 0.0025) is used across all slope categories for cattle, sheep and deer. Therefore dung excreta does not need to be allocated to different slope types.

For urinary excreta, the Nutrient Transfer Model described by Saggar et al. (2015), uses Beef + Lamb New Zealand data on livestock populations combined with the proportion of sheep and beef farmland on different hill slopes to allocate total urinary excreta to the different hill slope categories. This is essentially to account for the preference of livestock to spend more time on flatter slopes. Using the Nutrient Transfer Model, the proportion of urinary excreta deposited on low slopes is therefore higher than would be expected by simply using the proportion of low slope land area, as shown graphically in Figure 5.3.

The equations and variables needed to allocate excreta to the different slope types are outlined in Table 5.1, and figures 5.1 and 5.2. The following is an example intended to illustrate the process of determining the proportion of urinary excreta to be accounted for under each slope and livestock type for all major livestock types (except dairy cattle, where the entire herd is assumed to be farmed on flat land).

A farming area with 0 per cent flat land, 50 per cent low sloped land and 50 per cent steep sloped land will result in the following allocation of urinary excreta:

- 67.5 per cent of urinary excreta will be allocated to low sloped land, and will use the corresponding emission factor *for flat or low sloped land* (since the percentage of low sloped land area is between 35 to 85 per cent, we use 0.45 × 0.5 + 0.45 = 0.675),
- 21 per cent of urinary excreta will be allocated to steep sloped land, and will use the corresponding emission factor for steep sloped land (where the percentage of steep land area is between 40 – 60 per cent, 0.21 is used), and
- the remaining proportion, 11.5 per cent, is then assumed to be deposited onto medium sloped land and will use the corresponding emission factor.

Corresponding emission factors are dependent on the livestock type being accounted for, either sheep, beef cattle or deer. It is possible as more data becomes available and more research is conducted, there may be a small proportion of the dairy herd that have emissions from excreta deposited on sloped land.

As mentioned, in the new methodology, medium (12 to 24 degrees gradient) and steep (greater than 24 degrees gradient) slopes use the same emission factor. Direct N_2O emissions in the agricultural soils category can then be calculated using these emission factors, which are explained in Section 8.1.3 table 8.1.

Because a single dung emission factor ($EF_{3(PRP-DUNG)}$ = 0.0012) is used across all slope categories for cattle, sheep and deer, dung excreta does not need to be allocated to different slopes.

Table 5.1: Allocation of urine deposition to flat and low sloped land (0–12 degrees) and steep sloped land (more than 24 degrees) where x is the percentage of each category, split by the percentage of low slope and steep slope land available. Note that Table 5.1 allocates urine to the slope categories used in New Zealand's agriculture Inventory, based on Beef + Lamb New Zealand data.

Allocation to flat or low slope land	
Percentage of flat to low sloped land area (<12º)	**Fraction urine deposition**
Less than 1%	27x
1–5%	0.27
5–9%	0.405
9–35%	0.55

Allocation to flat or low slope land	
Percentage of flat to low sloped land area (<12º)	**Fraction urine deposition**
35–85%	(0.45x + 0.45)
Greater than 85%	(0.5x + 0.5)
Allocation to steep land	
Percentage of steep land area (>24º)	**Fraction urine deposition**
Less than 1%	10x
1–20%	0.10
20–40%	0.14
40–60%	0.21
60–85%	0.28
Greater than 85%	4.8x – 3.8

Figure 5.1: Proportion of urine nitrogen (N) applied to low slopes (of up to 12 degrees gradient) using the nutrient transfer model. The equal proportion line is shown in grey to illustrate where urine deposited would be assumed to be proportionate to slope type of land area).

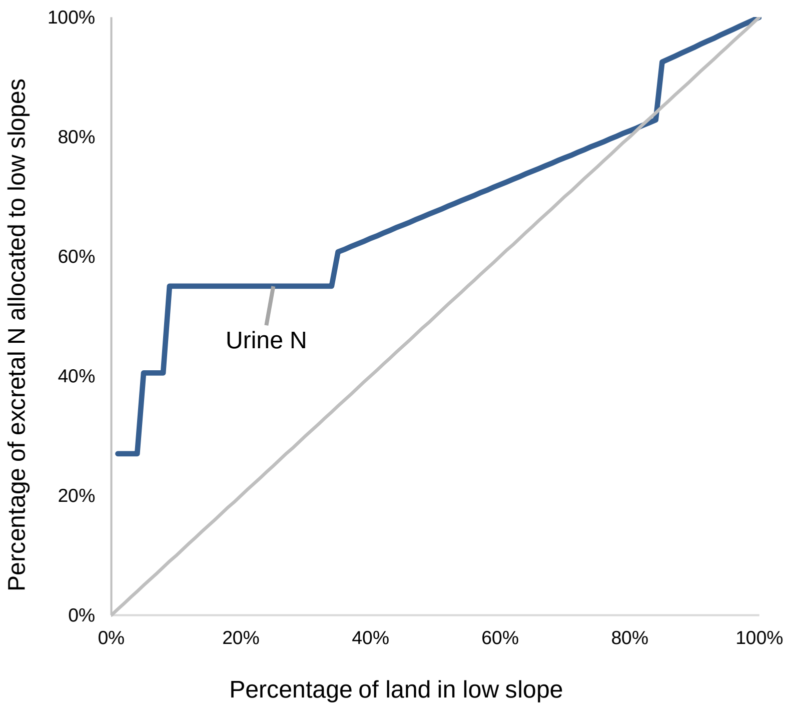
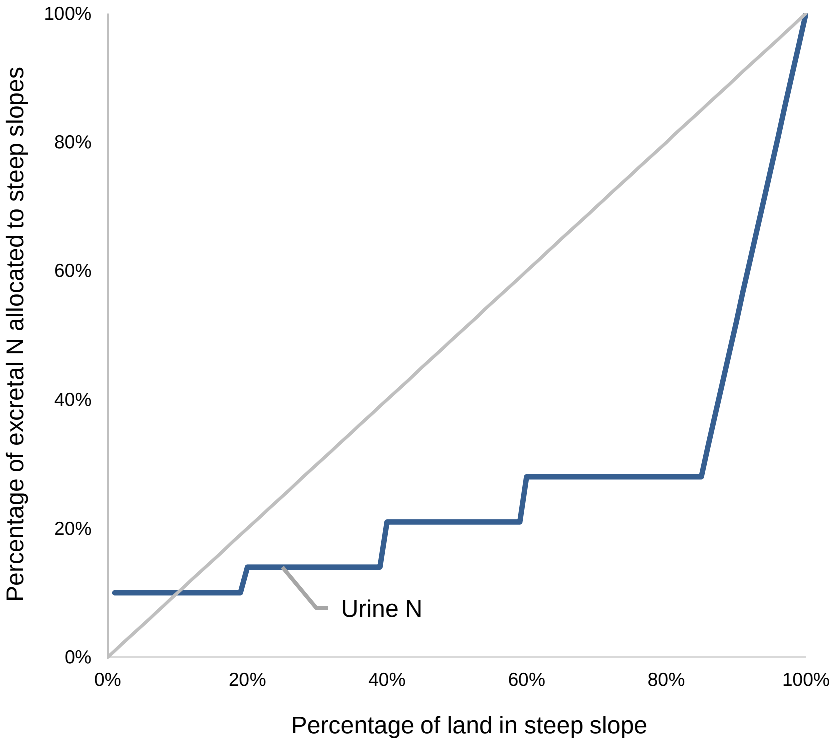


Figure 5.2: Proportion of urine nitrogen (N) applied to steep slopes (of greater than 24 degrees) using the nutrient transfer model The equal proportion line is shown in grey to illustrate where

urine deposited would be assumed to be proportionate to slope type of land area.



Tables 5.2, 5.3, 5.4 and Figure 5.2 provide examples of how nutrient allocation using the nutrient transfer model methodology uses Beef + Lamb New Zealand data to allocate urine nitrogen (N) to different hill slopes. First, data on the number of sheep, beef cattle and deer in each farm class are used to allocate total urine N to these different farm classes (tables 5.2 and 5.3).

Table 5.2: Share of livestock population, and amount of urine nitrogen (N) deposition in 2018, by Beef + Lamb New Zealand farm class in 2019

Farm class	Percentage of sheep population on farm class (%)	Amount of sheep urine N on farm class (kg N)	Percentage of beef cattle population on farm class (%)	Amount of beef cattle urine N on farm class (kg N)	Percentage of deer population on farm class (%)	Amount of deer urine N on farm class (kg N)
1. South Island High Country	7.4	26,550,296	3.5	8,048,380	14.3	2,831,091
2. South Island Hill Country	12.1	43,132,632	6.7	15,618,726	7.8	1,544,421
3. North Island Hard Hill Country	17.2	61,282,608	15.7	36,654,059	7.7	1,534,984
4. North Island Hill Country	25.4	90,627,947	41.3	96,240,410	32.0	6,338,045
5. North Island Intensive Finishing	6.8	24,437,161	11.1	25,806,893	2.2	437,992
6. South Island Finishing Breeding	19.1	68,037,424	14.0	32,686,935	27.5	5,457,651
7. South Island Intensive Finishing	10.1	36,093,050	3.4	7,980,935	8.5	1,685,597
8. South Island Mixed Finishing	1.9	6,933,601	4.2	9,858,498	0.0	0
Total		**357,094,719**		**232,894,836**		**19,829,780**

Each farm class has a different proportion of land in low, medium and steep slopes, as shown in Table 5.3. The data are combined with the nutrient transfer methodology to calculate total urinary excreta by hill slope and livestock type. From this point, direct N_2O emissions can be calculated using the emission factors in section 8.

Table 5.3: Proportion of total sheep, beef and deer land on different hill slopes, by Beef + Lamb New Zealand farm class, for 2018/19 year

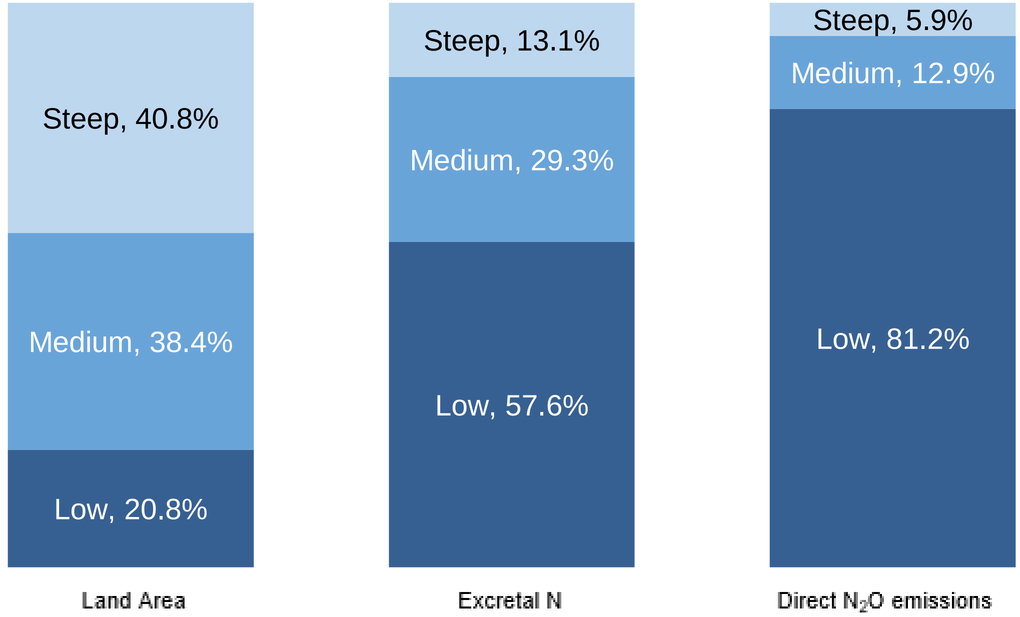
	Land type by slope

Farm class	Flat/low (0–12° slope) (%)	Rolling/medium (12–24° slope) (%)	Steep (>24° slope) (%)
1. South Island High Country	8.3	26.4	65.2
2. South Island Hill Country	16.2	25.8	58.0
3. North Island Hard Hill Country	8.1	35.7	56.1
4. North Island Hill Country	15.1	54.4	30.5
5. North Island Intensive Finishing	44.2	50.7	5.1
6. South Island Finishing Breeding	36.3	47.3	16.4
7. South Island Intensive Finishing	58.7	41.3	0.0
8. South Island Mixed Finishing	87.1	12.9	0.0
Total sheep, beef and deer land	**20.1**	**38.1**	**41.8%**

Table 5.4: Proportion of total sheep, beef and deer urine nitrogen deposited on different hill slopes, by Beef + Lamb New Zealand farm class, for 2019

Farm class	Flat/low	Rolling/medium	Steep
1. South Island High Country	0.41	0.32	0.28
2. South Island Hill Country	0.55	0.24	0.21
3. North Island Hard Hill Country	0.41	0.39	0.21
4. North Island Hill Country	0.55	0.31	0.14
5. North Island Intensive Finishing	0.65	0.25	0.10
6. South Island Finishing Breeding	0.61	0.29	0.10
7. South Island Intensive Finishing	0.71	0.29	0.00
8. South Island Mixed Finishing	0.94	0.06	0.00
Total sheep urine	**0.56**	**0.30**	**0.14**
Total beef urine	**0.56**	**0.30**	**0.14**
Total deer urine	**0.55**	**0.30**	**0.15**
Total sheep, beef and deer urine	**0.56**	**0.30**	**0.14**

Figure 5.3: Proportion of sheep, beef and deer land area, excretal nitrogen (N) and nitrous oxide (N_2O) emissions by hill slope category for sheep, beef cattle and deer farms in 2019



5.7 Other livestock

Annual nitrogen excretion amounts for the minor animal categories (goats, swine, horses, mules and asses, broilers, layers, other poultry, and alpaca) are calculated by multiplying population data from Statistics New Zealand by annual nitrogen excretion (N_{ex}) factor values (Table 5.5).

Table 5.5: Default values for nitrogen excreted (N_{ex})

Species	N_{ex} (kg/head/year)	Reference
Goats	10.6 for 1990 12.1 for 2009 12.7 for 2018	Lassey, 2011
Swine	10.8 for 2009 11.05 for 2013	Hill, 2012
Horses	25.0	2006 IPCC default - Table 10.19
Mules and asses	25.0	2006 IPCC default – Table 10.19
Poultry - broilers	0.39	Fick *et al.*, 2011
Poultry - layers	0.42	Fick *et al.*, 2011
Other Poultry (including ducks, turkeys, emus, and ostriches)	0.60	2006 IPCC –Table 10.19
Alpaca	12.6	2006 IPCC –Table 10.19

5.7.1 Goats

For goats, country-specific annual nitrogen excretion rates ($N_{ex,goats}$) are calculated for each year using the methodology developed by Lassey (2011). Fixed values are used for 1990 (10.6 kg N head^{-1} yr^{-1})) and 2009 (12.1 kg N $^{head-1\ yr-}$), which were recommended based on estimates of the number of goats being used for dairy production. Annual excretion rates for the years between 1990 and 2009, as well as after 2009 are calculated based on the estimated proportion of dairy goats in the total goat population, using research from Burggraaf et al. (unpublished). Table 5.6 shows how the estimated proportion of dairy goats in the total farmed goat population ($Pgoat_{milk,y}$) has changed over time, increasing from 3% in 1990 to 67% in 2018.

Table 5.6: Total farmed goats, and estimated dairy goat population 1990-2018

Year	Total farmed goat population (Statistics New Zealand)	Estimated dairy goat population (Burggraaf et al.)	Proportion of dairy goats in overall farmed goat population (Burggraaf et al.)
1990	1,062,900	31,887	3%
1991	792,580	42,564	5%
1992	532,800	41,243	8%
1993	352,860	35,678	10%
1994	283,500	35,385	12%
1995	336,800	50,021	15%
1996	227,900	39,249	17%
1997	228,000	44,671	20%
1998	228,000	50,076	22%
1999	186,400	45,357	24%
2000	175,295	46,810	27%
2001	164,189	47,737	29%
2002	153,084	48,136	31%
2003	179,435	60,676	34%
2004	141,206	51,096	36%
2005	136,120	52,482	39%
2006	131,033	53,626	41%
2007	111,981	48,484	43%
2008	95,731	43,717	46%
2009	82,229	39,500	48%
2010	95,281	48,029	50%
2011	85,970	45,373	53%
2012	90,096	49,686	55%
2013	79,977	46,002	58%
2014	97,370	58,314	60%
2015	74,718	46,519	62%
2016	112,385	72,634	65%
2017	101,076	67,721	67%
2018	88,785	59,486	67%

Equation 5.26 *Annual nitrogen excretion for goats:*

$$N_{ex,goat,y} = N_{ex,goat,y-1} + \left(\frac{Pgoat_{milk,y} - Pgoat_{milk,y-1}}{Pgoat_{milk,2009} - Pgoat_{milk,1990}}\right) \times \left(N_{ex,goat,2009} - N_{ex,goat,1990}\right)$$

Where:

$N_{ex,goat,y}$ = Annual nitrogen excretion per goat in year *y* (kg N per year)

$N_{ex,goat,y-1}$ = Annual nitrogen excretion per goat in previous year *y-1* (kg N per year)

$Pgoat_{milk,y}$ = Proportion of milking goats in total goat population in year *y* (see Table 5.6 for values)

$Pgoat_{milk,y-1}$ = Proportion of milking goats in total goat population in previous year *y* (see Table 5.6 for values)

$Pgoat_{milk,2009}$ = Proportion of milking goats in total goat population in 2009 (see Table 5.6 for values)

$Pgoat_{milk,1990}$ = Proportion of milking goats in total goat population in 1990 (see Table 5.6 for values)

$N_{ex,goat,2009}$ = Annual nitrogen excretion per goat in 2009 (set at 12.1 kilograms of nitrogen per year)

$N_{ex,goat,1990}$ = Annual nitrogen excretion per goat in 1990 (set at 10.6 kilograms of nitrogen per year)

For goats, country-specific nitrogen excretion rates of 10.6 kg N/head/year for 1990 and 12.1 kg N/head/year for 2009 are used to estimate nitrous oxide emissions. These values are based on the differing population characteristics for those 2 years (Lassey, 2011).

5.7.2 Poultry

Country specific and IPCC (2006) default nitrogen excretion rates are used for poultry (Fick *et al.,* 2011). The country-specific values are 0.39 kg N/head/year for broiler birds and 0.42 kg N/head/year for layer hens. Ducks, turkeys, emus and ostriches make up approximately 1 per cent of New Zealand's poultry population and flock sizes are unclear as they are reported by Statistics New Zealand under 'other Poultry'. Therefore, the IPCC default value of 0.6 kg N/head/year for 'other Poultry' is retained.

5.7.3 Horses, mules and asses

New Zealand uses IPCC (2006) default N_{ex} values (listed in Table 8) for horses, mules and asses.

5.7.4 Alpacas

There is no IPCC default value available for N_{ex} for alpacas. The current inventory assumes that the annual N_{ex} value for alpacas is equivalent to the average annual N_{ex} amount for sheep in 1990 (i.e., total nitrogen excretion from sheep in 1990 divided by the total sheep population in 1990). This was done for the following reasons:

- alpacas and sheep have similar live weights
- there are no data demonstrating that alpacas had the same level of productivity increases that have occurred in sheep, so the alpaca N_{ex} factor is fixed at the 1990 sheep value, and is not indexed to changes in sheep over time
- the literature indicates that alpacas have a nitrogen intake close to that of sheep, and no significant difference in the partitioning of nitrogen (Pinares-Patino *et al.*, 2003).

Equation 5.27 *Annual nitrogen excretion for alpaca:*

$$N_{ex,alpaca} = \frac{\sum_{class}\sum_{month}\left(N_{ex,sheep,c,1990} \times nod_m \times POPs_{c,m,1990}\right)}{POPsheep_{1990}}$$

Where:

$N_{ex,alpaca}$ = Annual nitrogen excretion per alpaca (kilograms of nitrogen per year)

$N_{ex,sheep,c,1990}$ = Nitrogen excretion per sheep in subcategory c in 1990, calculated using Equation 5.13, Section 5.4 (kilograms of nitrogen per day)

nod_m = number of days in month m

$POPs_{c,m,1990}$ = population of sheep subcategory c in month m in 1990, calculated using equations in section 3.3

$POPsheep_{1990}$ = total sheep population in 1990 (from Statistics New Zealand)

class refers to the different categories of sheep used in the inventory

month refers to the twelve months of the calendar year.

5.7.5 Swine

Swine in the New Zealand Inventory use and enhanced Tier 1 methodology. The population is divided into breeding pigs and growing pigs. Breeding sows (being sows in gestation and sows which have farrowed), make up approximately 97 percent of the breeding herd, with the other 3 percent being boars. Boars are similar to gestating sows in terms of volatile solids (VS) production, excreted nitrogen (N_{ex}) production, gross energy intake (GEI) etc.

A New Zealand-specific Nex rate for breeding pigs and growing pigs is calculated for each year based on the 2022 value of 24.25 kg nitrogen (N) head^{-1} year^{-1} for breeding pigs and 5.89 kg nitrogen (N) head^{-1} year^{-1} for growing pigs (Ritchie, 2024). The 2022 values are based on the weighted average of the distribution of animal weights by swine category. Estimates of Nex rates for all other years are indexed relative to 2022 for the average pig carcass weights for each year.

Average pig weights have increased since 1990 due to improvements in productivity. Data on pig carcass weights are collected by MPI from meat processors.

Equation 5.28 *Annual nitrogen excretion for swine:*

$$N_{ex,swine,y,c} = \frac{Aveslauweight_{swine,y,c}}{Aveslauweight_{swine,c,2022}} \times N_{ex,swine,c,2022}$$

Where:

$N_{ex,swine,y}$ = Annual nitrogen excretion per pig in class c and year *y* (kilograms of nitrogen per year)

$Aveslauweight_{swine,y}$ = average slaughter weight per pig in class c and year y, in kilograms (from Statistics New Zealand)

$Aveslauweight_{swine,2010}$ = average slaughter weight per pig in 2022 in kilograms (set at 231.97 kg for breeding pigs and 42.87 kg for growing pigs)

$N_{ex,swine,2010}$ = Annual nitrogen excretion per pig in 2022 (kilograms of nitrogen set at 24.25 for breeding pigs and 5.89 for growing pigs)

Equation 5.29 *Average swine slaughter weight:*

$$Aveslauweight_{swine,y} = \frac{totslauweight_{swine,y,c}}{SlauNum_{swine,y,c}}$$

Where:

$Aveslauweight_{swine,y,c}$ = average slaughter weight per pig in class c and year y, in kilograms (from Statistics New Zealand)

$totslauweight_{swine,y,c}$ = total aggregate slaughter weight of swine in class c and year y, in kilograms (from Statistics New Zealand)

$SlauNum_{swine,y,c}$ = number of pigs slaughtered in class c and year y

6 Methane emissions from enteric fermentation

Methane (CH_4) is a by-product of fermentation in ruminants and some non-ruminant animals such as swine and horses. Within the agricultural sector, ruminants are the largest source of the enteric release of CH_4, which accompanies feed degradation in the rumen. The amount of CH_4 released depends largely on total DMI, which itself depends on the type, age and weight of the animal, the quality, composition and quantity of feed, and the energy expenditure of the animal.

Enteric methane (EM) production from cattle (dairy and beef), sheep and deer was identified as a key source of greenhouse gas emissions for New Zealand through Intergovernmental Panel on Climate Change (IPCC) Tier 1 calculations. Therefore, a New Zealand-specific Tier 2 methodology developed by Clark *et al.* (2003) is used to calculate these CH_4 sources. This country-specific tier 2 methodology takes into account the unique characteristics of New Zealand livestock farming (see section 1.3)

For cattle and deer, enteric CH_4 emissions for a single animal per day is calculated by multiplying estimated daily DMI (calculated using the methods described in chapter 4 of this document) by a CH_4 yield factor. Population estimates (calculated using the methods described in chapter 3 of this document) are used to get an aggregate annual estimate of enteric CH_4 emissions for dairy cattle, beef cattle and deer. A more complex methodology is used to estimate enteric CH_4 emissions for sheep, which is described in Section 6.3.

Figure 6.1: Schematic diagram of how New Zealand's emissions from enteric fermentation for cattle and deer are calculated

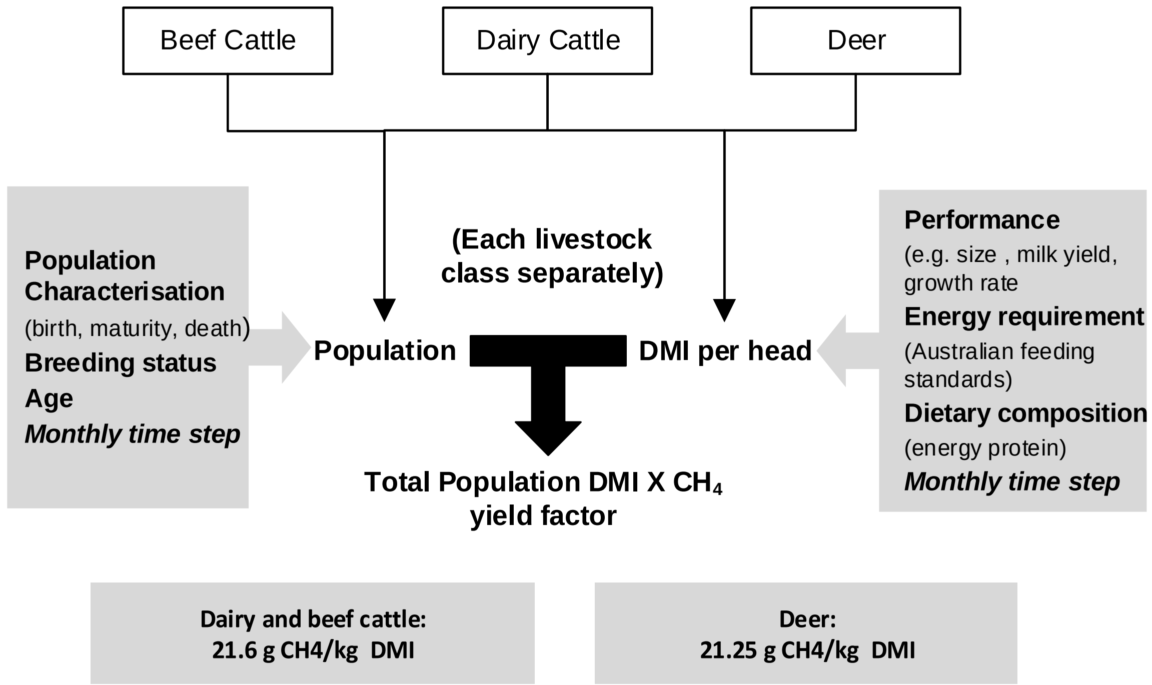
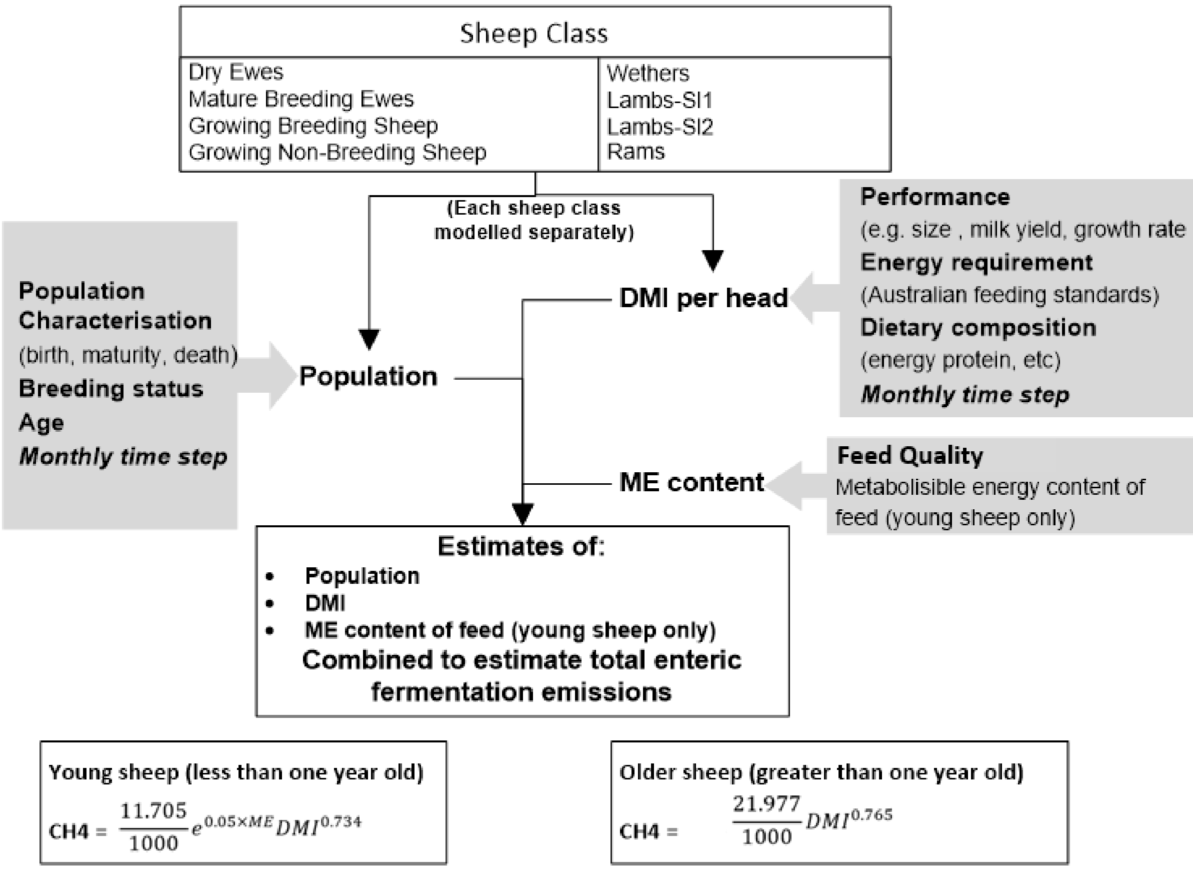


Figure 6.2: Schematic diagram of how New Zealand's emissions from enteric fermentation for sheep are calculated (ME is refers to metabolisable energy and DMI refers to dry matter intake).



Since 1996 CH_4 has been measured in New Zealand from grazing cattle and sheep using the SF_6 tracer technique (Lassey *et al.*, 1997; Ulyatt *et al.*, 1999, 2002a, 2002b, 2005). Since 2008 CH_4 has been measured from cattle and sheep fed cut pasture in respiration chambers (Swainson *et al*., 2016; Jonker *et al*., 2017). New Zealand now has one of the largest datasets in the world of CH_4 emissions determined using the SF_6 technique and respiration chambers on ruminants fed fresh pasture.

Published and unpublished data were used to derive New Zealand-specific enteric methane yield values and equations for cattle (Clark *et al.,* 2003) and sheep (Swainson, Muetzel and Clark, 2016). Assumptions have been made for beef cattle (assumed to have the same yield value as dairy cattle) and deer (explained in Section 6.4) (Clark *et al.,* 2003).

6.1 Dairy

The daily production of enteric methane ($CH_{4\text{-enteric-cattle}}$ in Equation 6.1) by a particular subcategory of dairy cattle can be determined using the following equation:

Equation 6.1 *Daily enteric methane emissions per animal – dairy and beef cattle*

$$CH_{4-enteric-cattle} = DMI \times \frac{MCR}{1000}$$

Where:

$CH_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg), for a particular subcategory of cattle (subcategories as defined in Table 4.1 in Section 4.4.1)

DMI = dry matter intake (kg per animal per day) (see Section 4.1.1)

MCR = Methane conversion rate (21.6 grams of methane per kg of DMI)

The value of 21.6 (methane conversion rate) is the methane emitted (g CH_4/kg intake) per unit of intake and is derived from experiments on New Zealand dairy cows. It equates to a loss of 6.5% of gross energy assuming that the feed has a gross energy concentration of 18.45 MJ/kg DM and gross energy of methane (enthalpy of combustion) is 55.6 MJ/kg CH_4[d].

Dairy calves are fed on milk for the first two months of their life (August and September) and it is assumed that they produce no methane during this period. $CH_{4\text{-enteric-cattle}}$ is set to zero for dairy calves during these months.

As stated in Section 4.4, Regional data on dairy cattle populations and productivity (milk yield and composition) is used to improve accuracy in the inventory.

The annual enteric methane emissions for dairy cattle for all regions and subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for each month and region, and each subcategory of dairy cattle (see appendix 2).

Equation 6.2 *Annual enteric methane emissions in the dairy sector*

$$dairyCH_{4-enteric} = \sum_{region}\sum_{month}\sum_{class} POPdairy_{c,m,r} \times nod_m \times CH_{4-enteric-cattle}$$

Where:

$dairyCH_{4\text{-enteric}}$ = annual enteric methane emissions for all dairy cattle (kg)

$POPdairy_{c,m,r}$ = population of dairy animals in subcategory *c*, month *m* and region *r*

nod_m = number of days in month *m*

$CH_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of dairy cattle (e.g. mature milking cows, breeding bulls…) in a particular month and region (Equation 6.1)

class refers to the different categories of dairy cattle used in the inventory (as defined in Table 4.1 in Section 4.4.1)

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

6.2 Beef

The per-animal production of enteric methane for beef cattle is calculated using the same equation (Equation 6.1, in Section 6.1) used for dairy cattle, with the same value for MCR. DMI is calculated using beef-specific energy requirement values (set out in Section 4.5) and the equation in Section 4.1.1, for the different subcategories of beef cattle (as defined in Table 4.2 in Section 4.5.1).

Beef calves are fed on milk for the first two months (61 days) of their life and produce no methane during this period. $CH_{4\text{-enteric-cattle}}$ is set to zero for beef calves during these months.

The annual enteric methane emissions for beef cattle for all subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for each month and subcategory of beef cattle (see appendix 2).

Equation 6.3 *Annual enteric methane emissions in the beef sector*

$$beefCH_{4-enteric} = \sum_{month}\sum_{class} POPbeef_{c,m} \times nod_m \times CH_{4-enteric-cattle}$$

Where:

[d] That is, the methane loss (as a percentage of gross energy) = 21.6/18.45 x 0.0556 x 100% = 6.5%

beef$CH_{4\text{-enteric}}$ = annual enteric methane emissions for all beef cattle (kg)

POPbeef$_{c,m,r}$ = population of beef animals in subcategory *c*, in month *m*

nod$_m$ = number of days in month *m*

$CH_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of beef cattle (e.g. Slaughter Heifers 0-1, breeding mature cows…) in a particular month (Equation 6.1)

class refers to the different categories of beef cattle used in the inventory (as defined in Table 4.2 in Section 4.5.1)

month refers to the twelve months of the calendar year.

6.3 Sheep

The per-animal production of enteric methane for sheep is calculated using the equations below. For sheep younger than one year of age, Equation 6.4 and Equation 6.6 are used, while for sheep older than one year of age, Equation 6.5 and Equation 6.7 are used.

Lambs are fed on milk for the first two months of their life (September and October) and it is assumed they produce no methane during this period. $CH_{4\text{-enteric-sheep}<1}$ is set to zero for lambs during these months.

Equation 6.4 *Daily enteric methane emissions per animal – sheep younger than one year of age* [e]

$$CH_{4-enteric,sheep<1} = \frac{11.705}{1000} \times e^{0.05 \times ME_{diet}} \times DMI^{0.734}$$

Where:

$CH_{4\text{-enteric,sheep}<1}$ = enteric methane emissions per animal per day (kg), for sheep less than one year of age (e.g. lambs), but older than 2 months

ME_{diet} = metabolisible energy per kilogram of dry matter for total diet (MJ/kg)(see Equation 4.2)

DMI = dry matter intake (kg per animal per day) (see Section 4.1.1)

Equation 6.5 *Daily enteric methane emissions per animal – sheep older than one year of age* [f]

$$CH_{4-enteric,sheep>1} = \frac{21.977}{1000} \times DMI^{0.765}$$

Where:

$CH_{4\text{-enteric,sheep}>1}$ = enteric methane emissions per animal per day (kg), for a particular subcategory sheep greater than one year of age (e.g. dry ewes, mature breeding ewes, growing breeding sheep, growing non-breeding sheep, wethers, lambs, rams)

DMI = dry matter intake (kg per animal per day) (see Section 4.1.1)

The above equations are based on Swainson, Muetzel and Clark (2016). This paper analysed a large dataset of recent experiments in New Zealand where methane emissions from sheep, fed cut pasture of varying amounts and quality, were measured in respiration chambers. The meta-analysis confirmed that DMI has the largest influence on CH4 emissions, and also found that pasture quality (as measured

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[e] The equation displayed here is a re-arranged form of the equation displayed in Swainson, Muetzel and Clark (2016):

$Ln(CH_4) = 0.734 \times ln(DMI) + 0.05 \times ME + 2.46$

[f] The equation displayed here is a re-arranged form of the equation displayed in Swainson, Muetzel and Clark (2016):

$Ln(CH_4) = 0.765 \times ln(DMI) + 3.09$

by metabolisable energy content) had a small but statistically significant effect on emissions from sheep younger than one year of age.

The paper concluded that two log-transformed equations (one for sheep younger than one year of age, and one for sheep older than one year of age) provided the best fit for the data and recommended that these equations be used in the national inventory (Swainson, Muetzel and Clark, 2016).

The annual methane emissions from all sheep (kt/yr) can be calculated using Equation 6.6, Equation 6.7, and Equation 6.8.

Equation 6.6 *Annual enteric methane emissions for lambs*

$$totalCH_{4-enteric,sheep<1} = \sum_{month} POPlamb_m \times nod_m \times CH_{4-enteric-sheep<1}$$

Where:

$totalCH_{4\text{-enteric,sheep}<1}$ = annual enteric methane emissions for all sheep less than one year old (kg)

$POPlamb_m$ = population of lambs in month *m*

nod_m = number of days in month *m*

$CH_{4\text{-enteric-sheep}<1}$ = enteric methane emissions per lamb per day (kg) in a particular month *m* (Equation 6.4)

month refers to the twelve months of the calendar year.

Equation 6.7 *Annual enteric methane emissions for sheep greater than one year old*

$$totalCH_{4-enteric,sheep>1} = \sum_{month}\sum_{class} POPsheep_{c,m} \times nod_m \times CH_{4-enteric-sheep>1}$$

Where:

$totalCH_{4\text{-enteric,sheep}>1}$ = annual enteric methane emissions for all sheep greater than one year old (kg)

$POPsheep_{c,m}$ = population of sheep (greater than one year old) in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4\text{-enteric-sheep}>1}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of sheep (e.g. dry ewes, mature breeding ewes…) in a particular month *m* (Equation 6.5)

class refers to the different subcategories of sheep used in the inventory

month refers to the twelve months of the calendar year.

Equation 6.8 *Annual enteric methane emissions for all sheep*

$$totalsheepCH_{4-enteric} = totalCH_{4-enteric,sheep>1} + totalCH_{4-enteric,sheep<1}$$

Where:

$totalsheepCH_{4\text{-enteric}}$ = annual enteric methane emissions for all sheep (kg)

$totalCH_{4\text{-enteric,sheep}>1}$ = annual enteric methane emissions for all sheep greater than one year old (kg) (Equation 6.6)

$totalCH_{4\text{-enteric,sheep}<1}$ = annual enteric methane emissions for all sheep less than one year old (kg) (Equation 6.7)

6.4 Deer

The per-animal production of enteric methane for deer is calculated using the same equation (x, in Section 6.1) used for dairy cattle. However, the methane conversion rate (MCR) is set to 21.25 grams of methane per kg of DMI. The MCR value for deer is the average of the MCR value currently used for cattle (21.6 grams of CH_4 per kg of DMI) and the (now defunct) MCR value used for adult sheep until 2016 (20.9) (Clark, 2003).

DMI is calculated using deer-specific energy requirement values (set out in Section 4.7) and the DMI equation in Section 4.1.1.

Equation 6.9 *Daily enteric methane emissions per animal – deer*

$$CH_{4-enteric-deer} = DMI \times \frac{MCR}{1000}$$

Where:

$CH_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg), for a particular subcategory of deer

DMI = dry matter intake (kg per animal per day) (see Section 4.1.1)

MCR = Methane conversion rate (21.25 grams of methane per kg of DMI)

Young hinds and stags are fed on milk for the first 120 days of their life (November to March) and it is assumed that they produce no methane during this period. $CH_{4\text{-enteric-deer}}$ is set to zero for newborn hinds and stags during these months

The annual enteric methane emissions for the deer population for all subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for each month and subcategory of deer (see appendix 2).

Equation 6.10 *Annual enteric methane emissions in the deer sector*

$$deerCH_{4-enteric} = \sum_{month}\sum_{class} POPdeer_{c,m} \times nod_m \times CH_{4-enteric-deer}$$

Where:

$deerCH_{4\text{-enteric}}$ = annual enteric methane emissions for all deer (kg)

$POPdeer_{c,m}$ = population of deer animals in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4\text{-enteric-deer}}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of deer in a particular month *m* (Equation 6.9)

class refers to the different categories of deer used in the inventory

month refers to the twelve months of the calendar year.

6.5 Other livestock sources

Methane produced from enteric fermentation from all other livestock is calculated using the Tier 1 method documented in the 2006 IPCC guidelines. Table 9 shows the other livestock categories which are calculated in New Zealand and their emission factors and the reference for background information on the emission factors.

Table 6.1: Enteric fermentation methane emission factors used for all other species

Species	Methane (kg CH_4/head/year)	Reference
Goats	7.4 (for 1990) 8.5 (for 2009)	Lassey (2011) Lassey (2011)
Swine	1.06	Hill (2012)
Horses	18.0	IPCC default - Table 10.10 *2006 IPCC guidelines*
Mules and asses	10.0	IPCC default - Table 10.10 *2006 IPCC guidelines*
Poultry (eg geese, guinea fowl, emus, ostriches etc)	Not estimated	IPCC default - *Table 10.10* *2006 IPCC guidelines*
Alpaca	8.0	IPCC default - *Table 10.10* *2006 IPCC guidelines*

IPCC default emission factors are used for horses, mules and asses and alpaca while New Zealand-derived values are used for goats and swine. These minor species comprised 0.15 per cent of total enteric CH_4 emissions in 2015. For each minor livestock species, the emission factors are multiplied by the species population (Appendix 20) to obtain the total methane emissions.

6.5.1 Goats

New Zealand uses specific enteric fermentation emission factors of:

- 7.4 kg CH_4/head/year for 1990
- 8.5 kg CH_4/ head/year for 2009

These emission factors are used based on the changing population characteristics over this period (Lassey, 2011). From 1990 to 2015 the population declined from 1.06 million goats to 0.08 million goats. Most of the decline in the herd was in the non-milking goat population (i.e. farmed goats raised for meat or fur).

For intermediate years between 1990 and 2009, and for 2010 onwards, the emission factor is calculated based on the estimated proportion of dairy goats in the overall farmed goat population as shown in Table 5.6.

These factors are multiplied by goat population data to obtain the total CH_4 emissions produced by goats from enteric fermentation for a given inventory year. This calculation is similar to the equation used to calculate nitrogen excretion for goats (Equation 5.26, Section 5.7.1).

Equation 6.11 *Annual enteric fermentation for goats:*

$$CH_{4,goat,y} = CH_{4,goat,y-1} + \left(\frac{Pgoat_{milk,y} - Pgoat_{milk,y-1}}{Pgoat_{milk,2009} - Pgoat_{milk,1990}}\right) \times \left(CH_{4,goat,2009} - CH_{4,goat,1990}\right)$$

Where:

$CH_{4,goat,y}$ = Annual enteric fermentation per goat in year *y* (kilograms of methane per year)

$CH_{4,goat,y-1}$ = Annual enteric fermentation per goat in previous year *y-1* (kilograms of methane per year)

$Pgoat_{milk,y}$ = Proportion of milking goats in total goat population in year y (see Table 5.6, Section 5.7.1)

$Pgoat_{milk,y-1}$ = Proportion of milking goats in total goat population in previous year *y* (see Table 5.6, Section 5.7.1)

$Pgoat_{milk,2009}$ = Proportion of milking goats in total goat population in 2009 (see Table 5.6)

$Pgoat_{milk,1990}$ = Proportion of milking goats in total goat population in 1990 (see Table 5.6)

$CH_{4,goat,2009}$ = Annual enteric fermentation per goat in 2009 (set at 7.4 kilograms of methane per year)

$CH_{4,goat,1990}$ = Annual enteric fermentation per goat in 1990 (set at 8.5 kilograms of methane per year)

6.5.2 Swine

New Zealand uses a Tier 1 approach with country-specific emission factors to determine enteric fermentation emissions from swine. Gross energy data from swine diets were used in the Tier 2 IPCC equation (equation 10.21, IPCC, 2006) to determine the country-specific enteric fermentation emission factors for breeding pigs and growing pigs (see Table 6.2). Surveys of commercial pig diet were conducted in 2009 (Hill, 2012) and 2022 (Ritchie, 2024). For years between the surveys the EFs are interpolated. These factors are then multiplied by population data to obtain the total CH4 emissions produced by swine from enteric fermentation for a given inventory year.

Table 6.2 Enteric fermentation emissions factors (kg CH_4 $head^{-1}$ $year^{-1}$) for pig classes

Year	Breeding pigs (kg CH4 per animal per annum)	Growing pigs (kg CH4 per animal per annum)
1990	2.21	0.89
1995	2.21	0.89
2000	2.21	0.89
2005	2.21	0.89
2010	2.19	0.89
2015	2.10	0.85
2020	2.01	0.82
2022+	1.97	0.81

The country-specific emission factors were developed from industry data on gross energy intake (GEI) (Hill, 2012) (Ritchie, 2024) in which data on the composition of swine diets and industry practices in place to manage waste from production systems were obtained from representative surveys of swine farms in 2009 and 2022. Nutritional information was available for different swine age classes and categories. Additionally, the average value of GEI was adjusted for population and further verified against national animal welfare standards.

The New Zealand emission factors for swine are lower than the IPCC (2006) default for developed countries.g The IPCC (2006) default value for swine is based on average values derived from 1980s Western German swine production and population statistics, and is not representative of New Zealand swine systems. In particular, the default value does not reflect changes in production due to improvements in genetic selection, reproductive cycle performance, housing and feed, animal husbandry and herd management. Further information on these factors is provided in the report by Hill (2012) and Ritchie (2024).

6.5.3 Horses

In the absence of data to develop New Zealand emissions' factors, the IPCC default value is used to determine emissions from enteric fermentation from horses (Table 9). This value is multiplied by population data on horses to obtain the total CH_4 emissions produced by horses from enteric fermentation for a given inventory year.

g The IPCC (2006) default emission factor for swine is identical to the IPCC (1996) emission factor.

6.5.4 Mules and asses

In the absence of data to develop New Zealand emissions' factors, the IPCC default value is used to determine emissions from enteric fermentation from mules and asses (Table 9). This value is multiplied by population data to obtain the total CH_4 emissions produced by mules and asses from enteric fermentation for a given inventory year.

6.5.5 Poultry

New Zealand does not estimate emissions from enteric fermentation of poultry because there is no IPCC 2006 methodology to estimate emissions from this category (Table 9).

6.5.6 Alpacas

The IPCC default value from the IPCC 2006 guidelines (IPCC, 2006) is based on a study carried out in New Zealand (Table 9). In the absence of further work carried out on alpacas in New Zealand this value has been used but is yet to be taken on as a country specific value.

This value is multiplied by population data to obtain the total CH_4 emissions produced by alpacas from enteric fermentation for a given inventory year.

7 Methane and nitrous oxide from manure management

This chapter discusses how emissions from manure management are estimated. The manure management component of the inventory includes methane and nitrous oxide emissions related to the handling and decomposition of livestock manure.

Manure management methane emissions from major livestock species (dairy and beef cattle, sheep and deer) are estimated using tier 2 methods, while manure management methane emissions from minor livestock species (goats, swine, horses, mules and asses, poultry, alpacas) are estimated using tier 1 methods. All manure management nitrous oxide emissions are estimated using tier 1 methods.

7.1 Methane

Livestock manure is composed principally of organic material and water. When manure decomposes in the absence of oxygen, methanogens produce CH_4. The amount of CH_4 emissions depends on:

- the amount of manure produced
- the amount of faecal dry matter (FDM) contained in the manure
- the amount of manure that decomposes anaerobically (i.e., how the manure is stored).

Sections 7.1.1 to 7.1.4 describe how CH4 manure management emissions are estimated for the four major livestock species. For this tier 2 methodology, calculations of faecal dry matter (FDM) are used.

Based on research performed by Ulyatt (2002a, 2002b), faecal dry matter output (FDM, kg DM/head/day) is calculated for each of the four major livestock categories (dairy cattle, non-dairy cattle, sheep and deer) and subcategory (as described in Chapter 4 in tables 4.1, 4.1 4.3, and 4.4) from the following equation:

Equation 7.1 *Production of daily faecal dry matter per animal*

$$FDM = DMI \times (1 - DMD)$$

Where:

FDM = kilograms of faecal dry matter per animal per day

DMI = dry matter intake (kg per animal per day) (see Section 4.1.1)

DMD = dry matter digestibility (see Equation 4.3)

7.1.1 Dairy

Prior to the 2019 inventory submission, the inventory assumed that 6 per cent of the manure produced by lactating cattle is deposited onto pads prior to and during milking and stored in anaerobic lagoons (Ledgard & Brier, 2004). With changing trends in dairy cattle effluent management, the inventory now assumes that after 2015, 8.5 per cent of the manure produced by lactating cattle is apportioned to manure management systems (Rollo, Ledgard and Longhurst, 2017) (see Table 7.1).

A Tier 2 equation derived from 2006 IPCC guidelines (equations 10.23 and 10.24) linking volatile solids to FDM is used for calculating methane emissions from anaerobic lagoons (CH_{4AL}). This equation only applies to mature milking cows.

Equation 7.2 *Calculation of methane from anaerobic lagoons for dairy cattle*

$$CH_{4AL-dairy} = FDM \times (1 - ASH) \times B_0 \times 0.67 \times MCF \times MS_{AL,CH4,y}$$

Where:

$CH_{4AL\text{-}dairy}$ = amount of methane produced per dairy animal from anaerobic lagoons per day (kg)

FDM = kilograms of faecal dry matter per animal per day

ASH = Ash content of manure, assumed to be 0.08 (IPCC default value)

B_0 = Maximum methane-producing capacity of manure, 0.24 (IPCC, 2006)

MCF = Methane conversion factor, 0.74 (IPCC, 2006)

$MS_{AL,CH4,y}$ = fraction of total annual dairy manure excreted in anaerobic lagoons in year *y*. Table 7.1 shows the value for each year for mature milking cows which for 2017 was equal to 8.5%. For all other animal classes, this is set to 0%.

The 0.67 value in this equation represents the conversion factor used to convert cubic metres of CH_4 to kilograms of CH_4[h]. The value used for B_0 is the IPCC Oceania default value which was verified by Pratt *et al.,* 2012). The value for MCF is the IPCC default value for uncovered anaerobic lagoon at an annual temperature of 15ºC which was also verified by Pratt *et al.,* 2012).

Table 7.1 shows the annual proportion of mature milking cattle manure distributed between managed manure systems i.e. anaerobic lagoons, and directly onto pasture. The second column, $MS_{AL,CH4}$ presents the proportion of mature milking cattle excreta that is deposited specifically to anaerobic lagoons. The third column presents the remaining proportion of mature milking cattle manure that is not deposited in anaerobic lagoons, i.e. the proportion which is deposited directly on pasture (MS_{PRP}).

Table 7.1: Annual proportion of mature milking cattle manure between management systems

Year	$MS_{AL,CH4}$	MS_{PRP}
1990	5.779%	94.221%
1991	5.779%	94.221%
1992	5.779%	94.221%
1993	5.779%	94.221%
1994	5.779%	94.221%
1995	5.779%	94.221%
1996	5.779%	94.221%
1997	5.779%	94.221%
1998	5.779%	94.221%
1999	5.779%	94.221%
2000	5.779%	94.221%
2001	5.779%	94.221%
2002	5.779%	94.221%
2003	5.779%	94.221%
2004	5.779%	94.221%
2005	5.838%	94.162%
2006	5.906%	94.094%
2007	5.993%	94.007%
2008	6.109%	93.891%
2009	6.264%	93.736%
2010	6.466%	93.534%
2011	6.726%	93.274%
2012	7.052%	92.948%
2013	7.455%	92.545%
2014	7.942%	92.058%
2015	8.525%	91.475%

[h] 1mol of CH4 at NTP = 24.0548L and 16.044g. Thus 1m3 CH4 =0.66697 or 0.67.

2016	8.525%	91.475%
2017	8.525%	91.475%
2018	8.525%	91.475%
2019	8.525%	91.475%
2020	8.525%	91.475%
2021	8.525%	91.475%
2022	8.525%	91.475%
2023	8.525%	91.475%

Most FDM (e.g. 91.5% for 2017 as shown in Table 7.1 from mature milking cows, and 100% from growing heifers and breeding bulls) from the New Zealand dairy herd is deposited onto pasture (Ledgard & Brier, 2004). The following equation is used to calculate methane emissions from FDM deposited on pasture (CH_{4PRP} in kg (CH_4)/head/day):

Equation 7.3 *Calculation of methane from FDM deposited onto pasture*

$$CH_{4PRP-dairy} = FDM \times MS_{PRP} \times Y_m$$

Where:

$CH_{4PRP\text{-}dairy}$ = amount of methane produced per animal per day from FDM deposited on pasture (kg)

FDM = kilograms of faecal dry matter per animal per day

MS_{PRP} = proportion of manure excreted on pasture, by mature milking cows, as shown in Table 7.1, column 3 from Section 7.1.1. For other classes it is assumed all manure is excreted on pasture.

Y_m = Methane yield value, currently set at 0.00098198 kg CH_4/kg FDM (Sherlock *et al.,* 2003; Saggar *et al.,* 2003)

The methane yield value of 0.00098198 kg CH_4/kg FDM was determined from studies by Sherlock *et al* (2003) and Saggar *et al.* (2003). For more details on this calculation see Table 7.3 in Section 7.1.4.

The total annual manure management methane emissions for dairy cattle for all subcategories can be calculated using the formulae below. These formulae aggregate the daily methane emissions for the twelve months of the year and for all subcategories of dairy cattle (see appendix 2).

Equation 7.4 *Total annual manure management methane emissions from anaerobic lagoons in the dairy sector*

$$dairyCH_{4-AL} = \sum_{region} \sum_{month} \sum_{class} \left(POPmmc_{m,r} \times nod_m \times CH_{4AL-dairy,m,r}\right)$$

Where:

$dairyCH_{4\text{-}AL}$ = annual manure management methane emissions from anaerobic lagoons for all dairy cattle (kg)

$POPmmc_{m,r}$ = population of mature milking cows in month *m* and region *r*

nod_m = number of days in month *m*

$CH_{4AL\text{-}dairy,m}$ = amount of methane produced per dairy animal per day from anaerobic lagoons per day in month *m* and region *r* (kg)

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

Equation 7.5 *Total annual manure management methane emissions from FDM deposited onto pasture for dairy cattle*

$$dairyCH_{4-PRP} = \sum_{region} \sum_{month} \sum_{class} \left(POPdairy_{c,m,r} \times nod_m \times CH_{4PRP-dairy,m,r}\right)$$

Where:

$dairyCH_{4\text{-}PRP}$ = annual manure management methane emissions from pasture range and paddock for all dairy cattle (kg)

$POPdairyc_{c,m,r}$ = population of dairy animals in subcategory *c*, month *m* and region *r*

nod_m = number of days in month *m*

$CH_{4PRP\text{-}dairy}$ = amount of methane produced per dairy animal per day from FDM deposited onto pasture in month *m* and region *r* (kg)

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

Equation 7.6 *Annual manure management methane emissions in the dairy sector*

$$dairyCH_{4-mm} = dairyCH_{4-AL} + dairyCH_{4-PRP}$$

Where:

$dairyCH_{4\text{-}mm}$ = annual manure management methane emissions for all dairy cattle (kg)

$dairyCH_{4\text{-}AL}$ = annual manure management methane emissions from anaerobic lagoons for all dairy cattle (kg)

$dairyCH_{4\text{-}PRP}$ = annual manure management methane emissions from pasture range and paddock for all dairy cattle (kg)

7.1.2 Beef

For beef cattle, 100% of FDM is spread onto pasture. Methane emissions from manure management are calculated for all subcategories of beef cattle using the following equation.

Equation 7.7 *Calculation of methane emissions from FDM deposited onto pasture for beef cattle*

$$CH_{4PRP-beef} = FDM \times Y_m$$

Where:

$CH_{4PRP\text{-}beef}$ = amount of methane produced per beef animal per day from FDM deposited on pasture (kg/day)

FDM = kilograms of faecal dry matter per animal per day

Y_m = Methane yield value, currently set at 0.00098198 kg CH_4/kg FDM

The methane yield value of 0.00098198 kg CH_4/kg FDM was determined from trials by Sherlock *et al* (2003) and Saggar *et al* (2003). For more details on this calculation see Table 7.3 in Section 7.1.4.

The total annual manure management methane emissions for beef cattle for all subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for the twelve months of the year and for all subcategories of beef cattle (see appendix 2).

Equation 7.8 *Annual manure management methane emissions in the beef sector*

$$beefCH_{4-mm} = \sum_{month}\sum_{class}\left(POPbeef_{c,m} \times nod_m \times CH_{4PRP-beef}\right)$$

Where:

$beefCH_{4\text{-}mm}$ = annual manure management methane emissions for all beef cattle (kg)

$POPbeef_{c,m}$ = population of beef animals in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4PRP\text{-}beef}$ = manure management methane emissions per animal per day (kg) for a particular subcategory of beef cattle (e.g. Slaughter Heifers 0-1, breeding mature cows…) in a particular month *m* (see Equation 7.7)

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

7.1.3 Sheep

For sheep, 100% of FDM is spread onto pasture. Methane emissions from manure management are calculated for all subcategories of sheep using the following equation.

Equation 7.9 *Calculation of methane from FDM deposited onto pasture*

$$CH_{4PRP-sheep} = FDM \times Y_{msheep}$$

Where:

$CH_{4PRP\text{-}sheep}$ = amount of methane produced per animal per day from FDM deposited on pasture (kilograms)

FDM = kilograms of faecal dry matter per animal per day (Equation 7.1)

Y_{msheep} = Methane yield value, currently set at 0.000691 kilograms of methane per kilogram of FDM

The methane yield value of 0.000691 kg CH_4/kg FDM was determined from a study by Carran *et al* (2003). FDM is calculated using Equation 7.1 (Section 7.1), using sheep-specific values for DMI (calculated in Equation 4.1, Section 4.1.1) and DMD (calculated using Equation 4.3).

The total annual manure management methane emissions for sheep for all subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for the twelve months of the year and for all subcategories of sheep (see appendix 2).

Equation 7.10 *Annual manure management methane emissions in the sheep sector*

$$sheepCH_{4-mm} = \sum_{month}\sum_{class}\left(POPsheep_{c,m} \times nod_m \times CH_{4PRP-sheep}\right)$$

Where:

$sheepCH_{4-mm}$ = annual manure management methane emissions for all sheep (kg)

$POPsheep_{c,m}$ = population of sheep in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4PRP-sheep}$ = manure management methane emissions per animal per day (kg) for a particular subcategory of sheep (e.g. mature breeding ewes, lambs…) in a particular month *m* (see Equation 7.9)

class refers to the different categories of sheep used in the inventory

month refers to the twelve months of the calendar year.

7.1.4 Deer

For deer, 100% of FDM is spread onto pasture. Methane emissions from manure management are calculated for all subcategories of deer using the following equation.

Equation 7.11 *Calculation of methane from FDM deposited onto pasture*

$$CH_{4PRP-deer} = FDM \times Y_{mdeer}$$

Where:

$CH_{4PRP-deer}$ = amount of methane produced per animal per day from FDM deposited on pasture (kilograms)

FDM = kilograms of faecal dry matter per animal per day (Equation 7.1)

Y_{mdeer} = Methane yield value, currently set at 0.000914788 kilograms of methane per kilogram of FDM

The methane yield value of 0.000914788 kg CH_4/kg FDM was determined by calculating the average of a set of studies by Carran *et al* (2003), Sherlock *et al* (2003) and Saggar *et al* (2003). The information separated by green and blue curly bracketed rows in the following table explains how this value (as well as the Y_m value for cattle) was calculated.

Figure 7.1: calculation of manure management methane emission factors for cattle and deer

Average of three measures used for cattle

Animal measured	Study name/description	CH4 emitted per kilogram of dung-carbon	CH4 emitted per kilogram of dung
Cattle	Massey D3 (Saggar et al (2003))	2.6613	1.059204
Cattle	Massey D1 (Saggar et al (2003))	2.4721	0.983907
Cattle	Sherlock et al (2003)	2.2684	0.902829
Sheep	High value of Carran et al 2003)	3.2610	1.288000
Sheep	Low value of Carran et al 2003)	0.9390	0.340000

Average of all five measures used for deer

Average of first three measurements (cattle emission factor)	2.4672667	0.98198
Average of all five measurements (deer emission factor)	2.32036	0.914788

The average of five measurements from three studies were used to calculate Y_{mdeer}, and the average of the measurements by the Saggar and Sherlock studies were used to calculate Ym for cattle. The last two rows in the above figure represent the high and low measurement values from the study by Carran *et al* (2003)[i].

FDM is calculated using Equation 7.1 (Section 7.1), using deer-specific values for DMI (calculated in Equation 4.1, Section 4.1.1) and DMD (calculated using Equation 4.3).

The total annual manure management methane emissions for deer for all subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for the twelve months of the year and for all subcategories of deer (see appendix 2).

Equation 7.12 *Total annual manure management methane emissions in the deer sector*

$$deerCH_{4-mm} = \sum_{month}\sum_{class}\left(POPdeer_{c,m} \times nod_m \times CH_{4PRP-deer}\right)$$

Where:

$deerCH_{4\text{-}mm}$ = annual manure management methane emissions for all deer (kg)

$POPdeer_{c,m}$ = population of deer in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4PRP\text{-}deer}$ = manure management methane emissions per animal per day (kg) for a particular subcategory of deer in a particular month *m* (see Equation 7.11)

class refers to the different categories of deer used in the inventory

month refers to the twelve months of the calendar year.

7.1.5 Other livestock sources

Calculations for methane from manure management for all other livestock sources follow the IPCC tier 1 default calculations.

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[i] Data from the full set of measurements by Carran are on table 1, page 8 of Carran et al. (2003). The average of these five values are used as the Y_{msheep} (manure management methane sheep yield) value

Equation 7.13 *Calculation of total annual methane from manure management for minor livestock species*

$$minorCH_{4-mm-c} = MEF_c \times POPminor_c$$

Where:

$minorCH_{4\text{-mm-c}}$ = annual amount of methane produced per animal per day from manure management, for minor animal species *c* (kilograms)

MEF_c = Manure management emission factor for minor animal species *c* (kilograms of methane per animal per year) (see Table 7.3)

$POPminor_c$ = population of minor livestock species *c* (from APS)

Values of MEF_c for a particular livestock species can be found in Table 7.3, while annual livestock population values are sourced from the agricultural production survey. Further explanations for the MEF_c values for specific livestock species are below.

7.1.5.1 Goats and Horses

New Zealand-specific emission factors are not available for CH_4 emissions from manure management for goats and horses. These are minor livestock categories in New Zealand and IPCC default emission factors are used to calculate emissions. All faecal material from goats and horses is deposited directly onto pastures.

7.1.5.2 Swine

New Zealand uses country-specific emission factors (Ritchie, 2024) for estimating CH_4 emissions from swine manure management. Industry data on swine diets (to determine digestible energy of the swine feed and volatile solid excretion levels) and the use of waste management systems used by New Zealand swine producers were used to determine a country-specific manure management emission factor for growing pigs and breeding pigs. The manure management CH_4 emission factors were calculated using the methane conversion factors for each manure management system provided by the 2019 IPCC refinement. Further information on this is provided by Ritchie (2024). For consistency CH_4 EFs from manure management systems prior to 2010 are calculated using data from Hill (2012) using the methane conversion factors recommended in the 2019 refinement. For years 2010-2021 the values are linearly interpolated (see Table 7.2).

Table 7.2 *Average annual methane emissions factor from manure management systems for pig subclasses*

Year	Breeding pigs ($kg\ CH_4\ head^{-1}\ yr^{-1}$)	Growing pigs ($kg\ CH_4\ head^{-1}\ yr^{-1}$)
1990	11.27	5.37
1995	11.27	5.37
2000	11.27	5.37
2005	11.27	5.37
2010	11.21	5.38
2015	10.92	5.41
2020	10.62	5.44
2022+	10.56	5.45

7.1.5.3 Poultry

Methane emissions from poultry manure management use New Zealand specific emission factor values. These are based on New Zealand specific volatile solids and proportions of poultry faeces in each manure management system for each production category. The poultry population in New Zealand has been divided into three different categories (based on production systems) and the manure management systems of Appendix 21 are used to infer the methane emission factors for each category.

7.1.5.4 Alpaca

There is no IPCC default value available for CH_4 emissions from manure management for alpacas. Therefore, this was calculated by assuming a default CH_4 emission from manure management value for alpacas for all years that is equal to the per head value of the average sheep in 1990 (i.e. total sheep emissions/total sheep population). The alpaca emission factor is not indexed to sheep over time because there is no data to support that alpacas had the same level of productivity increases that have been seen in sheep.

Table 7.3: Manure management emission factors for Tier 1 calculations for methane from manure management from non - key source livestock species

Species	Methane (kg CH_4/head/year)	Reference
Goats	0.20	Table 10.15 2006 IPCC guidelines
Swine	5.94	Hill, 2012
Horse	2.34	Table 10.15 2006 IPCC guidelines
Mules and asses	1.1	Table 10.15 Revised 2006 IPCC guidelines
Broilers	0.022	Fick *et al*., 2011
Layers	0.016	Fick *et al*., 2011
Other poultry (e.g., geese, guinea fowl, emus, ostriches etc)	0.117	Fick *et al*., 2011
Alpaca	0.091	New Zealand specific value assumed to be the same as sheep in1990

7.2 Nitrous oxide

In New Zealand, dairy cattle, poultry and swine are the only livestock categories that use waste management systems other than *pasture range and paddock*, and are the only sources of nitrous oxide (N_2O) emissions from manure management. These emissions can be classified as either direct (generated by nitrification and denitrification of nitrogen contained in manure (IPCC, 2006) or indirect (from volatilised or leached N).

Nitrous oxide emissions from manure deposited directly onto pasture (*Pasture Range and Paddock,* or PR&P) are reported in the *Agricultural Soils* section of the inventory, and are explained further in Chapter 8.

7.2.1 Direct nitrous oxide emissions

Direct N_2O emissions from livestock are determined by the amount of nitrogen excreted from an animal as well as the emissions produced by the manure management system that the animal manures are stored in, including the unmanaged direct deposition on pastureland. The proportion of manure from each livestock species in each animal manure management system (MMS) is detailed in Appendix 21.

To calculate emissions for this category, the total N_{ex} from each livestock species for each MMS is summed and the system-specific emission factor is applied.

7.2.1.1 Dairy

A small proportion of dairy manure is managed in anaerobic lagoons (see Table 7.1 in Section 7.1.1 and Appendix 22). The IPCC (2006) Guidelines note that the production of emissions of direct N_2O from managed manure requires aerobic conditions for the formation of oxidised forms of N, but assumes that negligible direct N_2O emissions occur during storage in anaerobic lagoons (IPCC, 2006, Table 10.21). Based on this the emission factor for N_2O emissions from waste in anaerobic lagoons (EF_{3AL}) is set to zero, and it is assumed that there are no direct nitrous oxide emissions from manure management for dairy cattle.

Direct N_2O emissions from stored effluent spread onto agricultural land are reported under the *Agricultural Soils* category (Organic nitrogen fertilisers (CRF 3.D.1.2)).

7.2.1.2 Swine

Waste from swine is distributed across nine different animal waste management systems. More details on these systems, the proportions of waste distributed to these systems and the direct emissions factor associated with these systems are detailed in the table below. Nitrous oxide emissions from swine manure deposited directly onto pasture (*Pasture Range and Paddock,* or PR&P) are calculated in the *Agricultural Soils* section of the inventory, and are explained further in Chapter 8.

Table 7.4: Manure management systems and emission factors used for swine

Name of waste management system	Percentage of swine waste deposited in system	Percentage of swine manure N treated	Short name of direct N_2O manure management emission factor	Value of direct N_2O manure management emission factor used in inventory (IPCC,2019)	Proportion of managed manure which volatilises as NH_3 and NO_x ($Frac_{GasMS}$)
Pasture range and paddock	14.5	14.5	(calculated in agricultural soils chapter)		
Daily spread	7.6	7.6	$EF_{3DailyS}$	0	0.07
Anaerobic lagoon	14.7	16.0	EF_{3AL}	0	0.40
Pit storage below animal confinement <30 days	12.6	13.3	EF_{3PS}	0.002	0.25
Pit storage below animal confinement >30 days	3.9	4.8	EF_{3PS}	0.002	0.25
Anaerobic digester	8.4	9.4	EF_{3AD}	0.0006	0.25 (mid point in IPCC 2019 range chosen)
Cattle and pigs deep bedding < 60 days	22.0	22.0	EF_{3DB}	0.01	0.4
Cattle and pigs deep bedding > 60 days	11.1	10.8	EF_{3DB}	0.01	0.4
Composting passive windrow	5.3	1.9	EF_{3C}	0.005	0.6

Total direct emissions from manure management for swine are determined by adding the nitrous oxide caused by waste in the different manure management systems.

Equation 7.14 *Direct manure management nitrous oxide emissions per animal from swine*

$$mmN_2O_{Direct,swine,y} = \sum_x \left(N_{ex,swine,y} \times Pmms_{swine,x} \times EF_{3,x} \times \frac{44}{28}\right)$$

Where:

$mmN_2O_{Direct,swine,y}$ = annual direct nitrous oxide emissions from manure management per pig in year *y* (kilograms of nitrous oxide per year)

$N_{ex,swine,y}$ = Annual nitrogen excretion per pig in year *y* (kilograms of nitrogen per year)

$Pmms_{swine,x}$ = Proportion of swine waste N deposited in manure management system *x* (see Table 7.4 above)

$EF_{3,x}$ = direct N_2O manure management emission factor for manure management system *x* (see Table 7.4 above)

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

The fraction 44/28 is used to convert nitrogen to nitrous oxide.

The emission factor for N_2O emissions from waste in anaerobic lagoons (EF_{3AL}) is set to zero, and it is assumed that there are no direct nitrous oxide emissions from manure management for swine. Direct N_2O emissions from dairy effluent anaerobic lagoons are reported under the *Agricultural Soils* category when the stored effluent is spread onto agricultural land.

The per-animal value for swine (calculated in Equation 7.14 above) can be multiplied by the swine population to calculate the total direct manure management N_2O emissions from swine.

Equation 7.15 *Total direct manure management nitrous oxide emissions from swine*

$$totmmN_2O_{Direct,swine,y} = mmN_2O_{Direct,swine,y} \times POPswine_y$$

Where:

$totmmN_2O_{Direct,swine,y}$ = annual direct nitrous oxide emissions from manure management for all swine in year *y* (kilograms of nitrous oxide per year)

$mmN_2O_{Direct,swine,y}$ = annual direct nitrous oxide emissions from manure management per pig in year *y* (kilograms of nitrous oxide per year)

$POPswine_y$ = swine population in year *y*

7.2.1.3 Poultry

Direct N_2O manure management emissions from poultry are calculated using different parameters for Broilers, Layers and Other poultry.

Equation 7.16 *Direct manure management nitrous oxide emissions per animal from broilers*

$$mmN_2O_{Direct,broiler} = N_{ex,broiler} \times Pmms_{broiler,other} \times EF_{3,poultry} \times \frac{44}{28}$$

Where:

$mmN_2O_{Direct,broiler}$ = annual direct nitrous oxide emissions from manure management per broiler chicken (kilograms of nitrous oxide per year)

$N_{ex,broiler}$ = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{broiler,x}$ = Proportion of broiler waste deposited in other manure management systems (set at 0.95)

$EF_{3,poultry}$ = direct N_2O manure management emission factor for poultry in *other* manure management systems *x* (set at 0.001 for all poultry)

Equation 7.17 *Direct manure management nitrous oxide emissions per animal from layers*

$$mmN_2O_{Direct,layer} = N_{ex,layer} \times Pmms_{layer,other} \times EF_{3,poultry} \times \frac{44}{28}$$

Where:

$mmN_2O_{Direct,layer}$ = annual direct nitrous oxide emissions from manure management per layer hen (kilograms of nitrous oxide per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer hen (set at 0.42 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{layer,x}$ = Proportion of Layer waste deposited in other manure management systems (set at 0.94)

$EF_{3,poultry}$ = direct N_2O manure management emission factor for poultry in *other* manure management systems *x* (set at 0.001)

Equation 7.18 *Direct manure management nitrous oxide emissions per animal from other poultry*

$$mmN_2O_{Direct,other} = N_{ex,other} \times Pmms_{other,other} \times EF_{3,poultry} \times \frac{44}{28}$$

Where:

$mmN_2O_{Direct,other}$ = annual direct nitrous oxide emissions from manure management per poultry animal classified as *other* (kilograms of nitrous oxide per year)

$N_{ex,other}$ = Annual nitrogen excretion per layer hen (set at 0.60 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{layer,x}$ = Proportion of other poultry waste deposited in *other* manure management systems (set at 0.97)

$EF_{3,poultry}$ = direct N_2O manure management emission factor for poultry in *other* manure management systems *x* (set at 0.001)

The per-animal emission values for the three categories of poultry (calculated in Equation 7.16, Equation 7.17 and Equation 7.18 above) can be multiplied by population estimates to calculate the total direct manure management nitrous oxide emissions from poultry.

Equation 7.19 *Total direct manure management nitrous oxide emissions from poultry*

$$\begin{aligned} &totmmN_2O_{Direct,poultry,y} \\ &\quad = \left(mmN_2O_{Direct,broiler,y} \times POPpoultry_{broiler,y}\right) \\ &\quad + \left(mmN_2O_{Direct,layer,y} \times POPpoultry_{layer,y}\right) \\ &\quad + \left(mmN_2O_{Direct,other,y} \times POPpoultry_{other,y}\right) \end{aligned}$$

Where:

$totmmN_2O_{Direct,poultry,y}$ = annual direct nitrous oxide emissions from manure management for all poultry in year *y* (kilograms of nitrous oxide per year)

$mmN_2O_{Direct,broiler}$ = annual direct nitrous oxide emissions from manure management per broiler chicken (kilograms of nitrous oxide per year)

$POPpoultry_{broiler,y}$ = broiler population in year *y* (from APS)

$mmN_2O_{Direct,layer}$ = annual direct nitrous oxide emissions from manure management per layer hen (kilograms of nitrous oxide per year)

$POPpoultry_{layer,y}$ = layer population in year *y* (from APS)

$mmN_2O_{Direct,other}$ = annual direct nitrous oxide emissions from manure management per poultry animal classified as *other* (kilograms of nitrous oxide per year)

$POPpoultry_{other,y}$ = population of other poultry in year *y* (from APS)

7.2.2 Indirect nitrous oxide emissions

Indirect N_2O emissions from manure management result from diffusion of nitrogen (N) into the surrounding air (volatilisation) and water (leaching and runoff). This N can then subsequently be emitted as N_2O. New Zealand uses the IPPC (2006) Tier 1 methodology for calculating indirect N_2O emissions resulting from N volatilisation from manure management systems.

The IPCC (2006) guidelines provides methodology for estimating leaching and runoff for solid storage and feedlots. Leaching from manure management systems (other than pasture range and paddock) is assumed not to occur.

As stated earlier, N_2O emissions from manure deposited directly onto pasture (*Pasture Range and Paddock,* or PR&P) are reported in the *Agricultural Soils* section of the inventory, and are explained further in chapter 8.

7.2.2.1 Dairy

A proportion of dairy manure stored in anaerobic lagoons volatilises into NH_3 and NO_x, which is later emitted as N_2O. As mentioned earlier, only mature milking cows (lactating cattle) deposit part of their manure onto storage or feed pads (as shown in Table 7.1 from Section 7.1.1), which is then stored in anaerobic lagoons. This means that only mature milking cows have N_2O emissions from manure management, and the equation below only applies to this subcategory of dairy cattle.

Equation 7.20 *Indirect manure management nitrous oxide emissions from dairy cattle*

$$mmN_2O_{indirect,dairy,m,R} = N_{ex,m,R,mm} \times MS_{AL,N2O} \times EF_4 \times Frac_{GasMS(AL_{dairy})} \times \frac{44}{28}$$

Where:

$mmN_2O_{indirect,dairy,m,R}$ = indirect nitrous oxide emissions from manure management per milking cow per day in month *m* and region *R* (kilograms of nitrous oxide per day)

$N_{ex,m,R,mm}$ = nitrogen excretion per mature milking cow in month *m* and region *R* (kilograms of nitrogen per day – see Section 5.2)

$MS_{AL,N2O,y}$ = fraction of total annual dairy manure excreted in anaerobic lagoons in year y, see Table 7.1 for annual values.

EF_4 = Emission factor for N_2O emissions from volatilisation. The IPCC (2006) default value of 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilised) is used

$Frac_{GasMS(AL\_dairy)}$ = proportion of managed manure which volatilises as NH3 and NOx for dairy anaerobic lagoons. (uses default value of 0.35, detailed in Table 7.5)

The fraction 44/28 is used to convert nitrogen to nitrous oxide.

The annual amount of indirect manure management N_2O emissions from all milking cows can be calculated by multiplying the daily per cow emissions by the mature milking cow population in each region and month, and aggregating this value across the different months of the year and regions used in the inventory.

Equation 7.21 *Annual indirect manure management N_2O emissions in the dairy sector*

$$TOTmmN_2O_{indirect,dairy} = \sum_{region} \sum_{month} POPmmc_{m,R} \times nod_m \times mmN_2O_{indirect,dairy,m,R}$$

Where:

$TOTmmN_2O_{indirect,dairy}$ = Total annual indirect nitrous oxide emissions from manure management from the dairy industry (kilograms of nitrous oxide)

$POPmmc_{m,R}$ = population of mature milking cows in month *m* and region *R* (see section 3.1.1)

nod_m = number of days in month *m*

$mmN_2O_{indirect,dairy,m,R}$ = indirect nitrous oxide emissions from manure management per milking cow per day in month m and region *R* (kilograms of nitrous oxide per day)

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

7.2.2.2 Swine

Waste from swine is distributed across nine different animal waste management systems. More details on these systems, the proportions of waste distributed to these systems and the direct emissions factor associated with these systems are detailed Table 7.4. Nitrous oxide emissions from swine manure deposited directly onto pasture (*Pasture Range and Paddock,* or PR&P) are calculated in the *Agricultural Soils* section of the inventory, and are explained further in Chapter 8.

Total indirect emissions from manure management for swine are determined by adding the nitrous oxide caused by volatilisation of waste in the different manure management systems.

Equation 7.22 *Direct manure management nitrous oxide emissions per animal from swine*

$$mmN_2O_{indirect,swine,y} = \sum_{x} \left(N_{ex,swine,y} \times Pmms_{swine,x} \times EF_4 \times Frac_{GasMS(x_{swine})} \times \frac{44}{28} \right)$$

Where:

$mmN_2O_{indirect,swine,y}$ = annual indirect nitrous oxide emissions from manure management per pig in year *y* (kilograms of nitrous oxide per year)

$N_{ex,swine,y}$ = Annual nitrogen excretion per pig in year *y* (kilograms of nitrogen per year)

$Pmms_{swine,x}$ = Proportion of swine waste N deposited in manure management system *x* (see Table 7.4 above)

EF_4 = Emission factor for N_2O emissions from volatilisation. The IPCC (2006) default value of 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilised) is used

$Frac_{GasMS(x\_swine)}$ = proportion of managed manure which volatilises as NH_3 and NO_x used for manure management system *x*. (see Table 7.4 for values).

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

The per-animal value for swine (calculated in Equation 7.22 above) can be multiplied by the swine population to calculate the total indirect manure management nitrous oxide emissions from swine.

Equation 7.23 *Total indirect manure management nitrous oxide emissions from swine*

$$totmmN_2O_{indirect,swine,y} = mmN_2O_{indirect,swine,y} \times POPswine_y$$

Where:

$totmmN_2O_{indirect,swine,y}$ = annual indirect nitrous oxide emissions from manure management for all swine in year *y* (kilograms of nitrous oxide per year)

$mmN_2O_{indirect,swine,y}$ = annual indirect nitrous oxide emissions from manure management per pig in year *y* (kilograms of nitrous oxide per year)

$POPswine_y$ = swine population in year *y*

7.2.2.3 Poultry

Indirect N2O manure management emissions from poultry are calculated using different parameters for Broilers, Layers and Other poultry.

Equation 7.24 *Indirect manure management nitrous oxide emissions per animal from broilers*

$$mmN_2O_{indirect,broiler} = N_{ex,broiler} \times Pmms_{broiler,other} \times EF_4 \times Frac_{GasMS(poultry)} \times \frac{44}{28}$$

Where:

$mmN_2O_{indirect,broiler}$ = annual indirect nitrous oxide emissions from manure management per broiler chicken (kilograms of nitrous oxide per year)

$N_{ex,broiler}$ = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{broiler,x}$ = Proportion of broiler waste deposited in other manure management systems (set at 0.95)

EF_4 = Emission factor for N_2O emissions from volatilisation. The IPCC (2006) default value of 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilised) is used

$Frac_{GasMS(Poultry)}$ = proportion of managed manure which volatilises as NH_3 and NO_x for poultry (set at 0.25).

Equation 7.25 *Indirect manure management nitrous oxide emissions per animal from layers*

$$mmN_2O_{indirect,layer} = N_{ex,layer} \times Pmms_{layer,other} \times EF_4 \times Frac_{GasMS(poultry)} \times \frac{44}{28}$$

Where:

$mmN_2O_{indirect,layer}$ = annual indirect nitrous oxide emissions from manure management per layer hen (kilograms of nitrous oxide per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer hen (set at 0.42 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{layer,x}$ = Proportion of Layer waste deposited in other manure management systems (set at 0.94)

EF_4 = Emission factor for N_2O emissions from volatilisation. The IPCC (2006) default value of 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilised) is used

$Frac_{GasMS(Poultry)}$ = proportion of managed manure which volatilises as NH_3 and NO_x for poultry (set at 0.25).

Equation 7.26 *Indirect manure management nitrous oxide emissions per animal from other poultry*

$$mmN_2O_{indirect,other} = N_{ex,other} \times Pmms_{other,other} \times EF_4 \times Frac_{GasMS(poultry)} \times \frac{44}{28}$$

Where:

$mmN_2O_{indirect,other}$ = annual indirect nitrous oxide emissions from manure management per poultry animal classified as *other* (kilograms of nitrous oxide per year)

$N_{ex,other}$ = Annual nitrogen excretion per layer hen (set at 0.60 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{layer,x}$ = Proportion of other poultry waste deposited in *other* manure management systems (set at 0.97)

EF_4 = Emission factor for N_2O emissions from volatilisation. The IPCC (2006) default value of 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilised) is used

$Frac_{GasMS(Poultry)}$ = proportion of managed manure which volatilises as NH_3 and NO_x for poultry (set at 0.25).

The per-animal emission values for the three categories of poultry (calculated in Equation 7.24, Equation 7.25 and Equation 7.26) can be multiplied by population estimates to calculate the total indirect manure management nitrous oxide emissions from poultry.

Equation 7.27 *Total indirect manure management nitrous oxide emissions from poultry*

$$\begin{aligned} totmmN_2O_{indirect,poultry,y} \\ &= \left(mmN_2O_{indirect,broiler,y} \times POPpoultry_{broiler,y}\right) \\ &+ \left(mmN_2O_{indirect,layer,y} \times POPpoultry_{layer,y}\right) \\ &+ \left(mmN_2O_{indirect,other,y} \times POPpoultry_{other,y}\right) \end{aligned}$$

Where:

$totmmN_2O_{indirect,poultry,y}$ = annual indirect nitrous oxide emissions from manure management for all poultry in year *y* (kilograms of nitrous oxide per year)

$mmN_2O_{indirect,broiler}$ = annual indirect nitrous oxide emissions from manure management per broiler chicken (kilograms of nitrous oxide per year)

$POPpoultry_{broiler,y}$ = broiler population in year y (from APS)

$mmN_2O_{indirect,layer}$ = annual indirect nitrous oxide emissions from manure management per layer hen (kilograms of nitrous oxide per year)

$POPpoultry_{layer,y}$ = layer population in year y (from APS)

$mmN_2O_{indirect,other}$ = annual indirect nitrous oxide emissions from manure management per poultry animal classified as *other* (kilograms of nitrous oxide per year)

$POPpoultry_{other,y}$ = population of other poultry in year y (from APS)

Table 7.5: Values for the fraction of manure that volatilises as NH_3 and NO_x ($Frac_{GasMS}$/100) for livestock category per manure management system in New Zealand. (Table 10.22 in IPCC (2019))

Manure management system	Livestock category	Value
Anaerobic lagoons	Dairy	0.35
	Swine	0.4
Daily spread	Swine	0.07
Solid storage and dry lot	Swine	0.45
Anaerobic digester	Swine	0.25
Cattle and pigs deep bedding less than 60 days	Swine	0.4
Cattle and pigs deep bedding more than 60 days	Swine	0.4
Composting passive windrow	Swine	0.6
Pit storage below animal confinement less than 30 days	Swine	0.25
Pit storage below animal confinement more than 30 days	Swine	0.25
Other	Swine	0.25
	Poultry - boilers	0.25
	Poultry - layers	0.25
	Poultry - other	0.25

8 Nitrous oxide emissions from Agricultural Soils

Several sources contribute to N_2O emissions from agricultural soils, from both direct and indirect pathways (see figure 5.5.1). Direct N_2O emissions come directly from the soils to which nitrogen has been added or released. Indirect emissions come from the volatilisation (evaporation or sublimation) of nitrogen from the land. A fraction of this volatilised nitrogen returns to the ground during rainfall and is then re-emitted as N_2O. Indirect emissions also arise from leaching and runoff of nitrogen (IPCC, 2006).

New Zealand uses a combination of default and country-specific emission factors and parameters to calculate N_2O emissions from Agricultural Soils.

N_2O-N[j] emissions are calculated for each source and then converted to N_2O emissions for reporting purposes by multiplying by 44/28. Nitrous oxide emissions for each source are then added together to produce the total amount of direct N_2O emissions from Agricultural Soils.

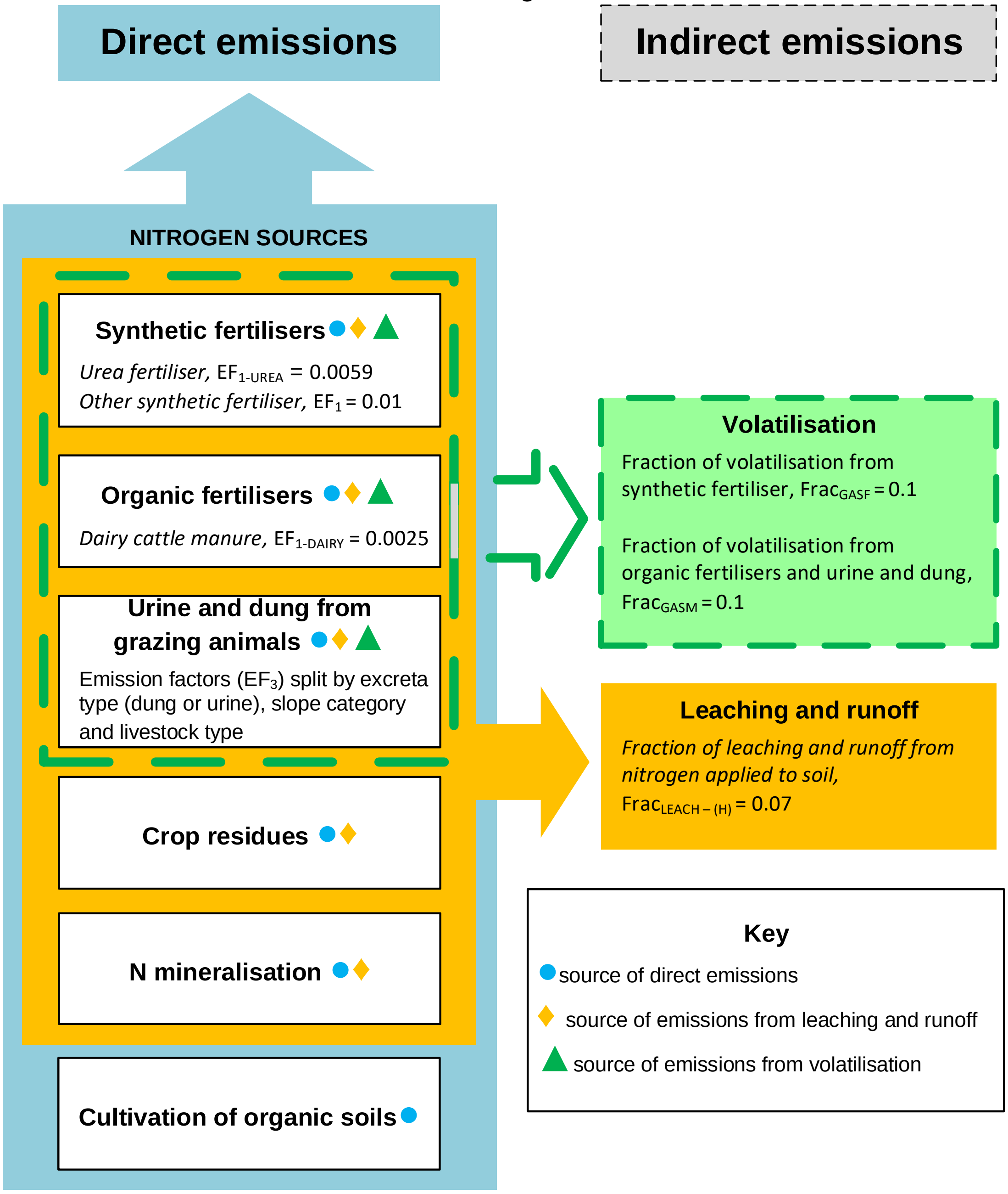
Figure 8.1 shows that there are six main sources of direct and indirect N_2O emissions from Agricultural Soils:

- Synthetic fertilisers
- Organic fertilisers
- Urine and dung from grazing animals
- Crop residues
- Nitrogen mineralisation
- Cultivation of organic soils

All six of these sources generate direct N_2O emissions, but only the first five generate indirect emissions from leaching and runoff. Only the first three sources listed here generate emissions from volatilisation.

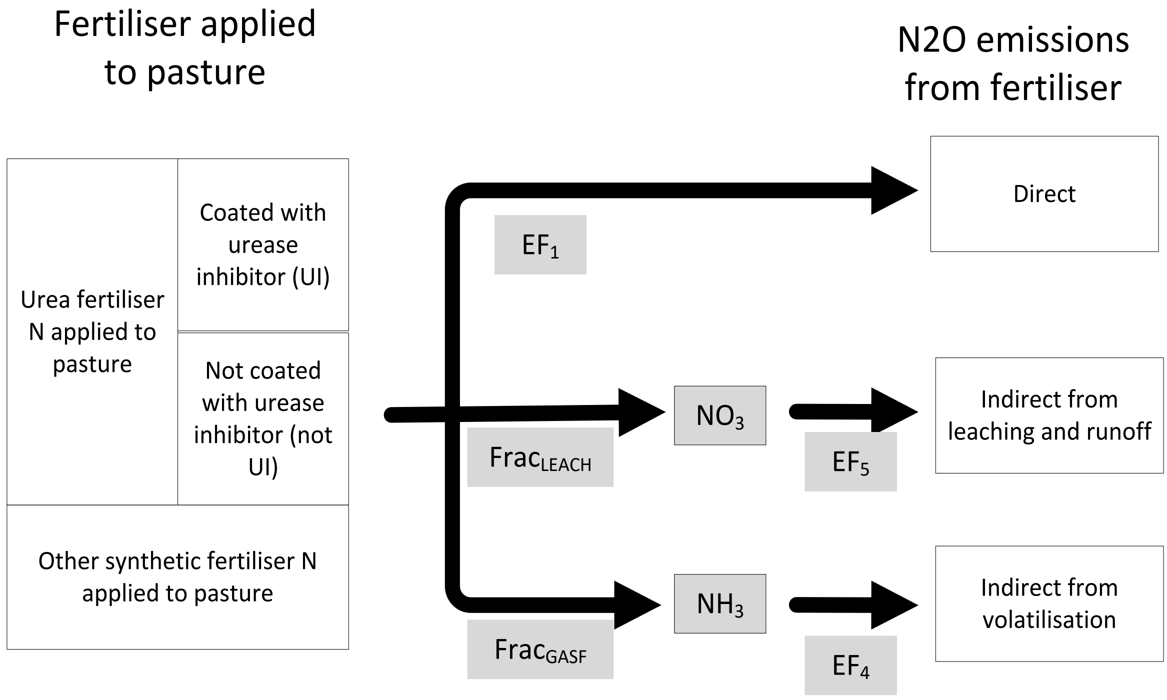
[j] N_2O-N refers to the mass of nitrogen in molecules of N_2O.

Figure 8.1: Sources of nitrous oxide emissions from agricultural soils



The next two figures more detail on the generation of emissions from two of these sources. Figure 8.2 shows the pathways in which nitrous oxide can be formed from the application of nitrogen fertiliser.

Figure 8.2: Flow chart depicting direct and indirect sources of N_2O from synthetic fertiliser usage in New Zealand agriculture



<u>Currently used values:</u>

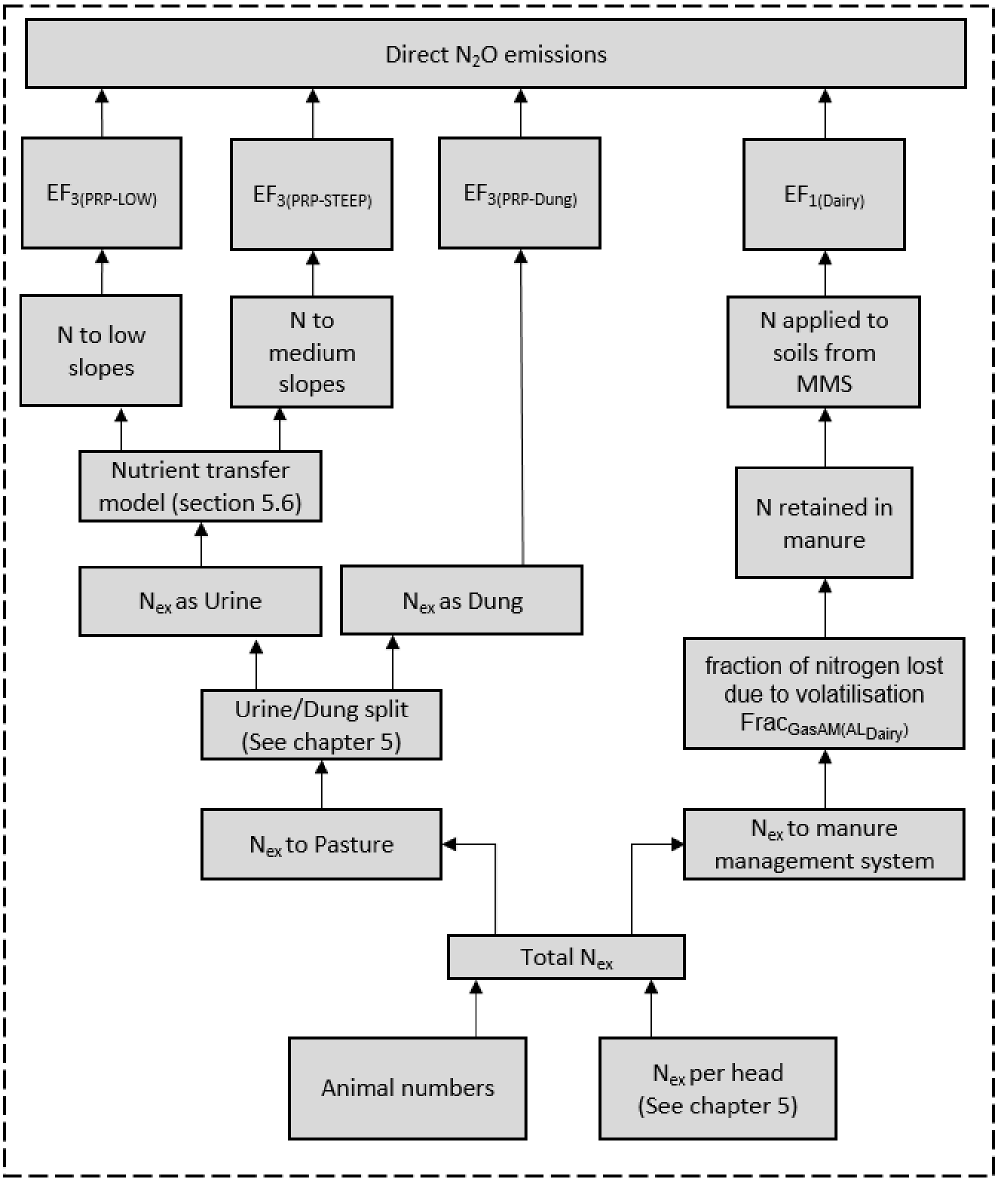
$EF_{1(other)}$ = 0.01
$EF_{1(urea)}$ = 0.0059
EF_4 = 0.01
EF_5 = 0.0075

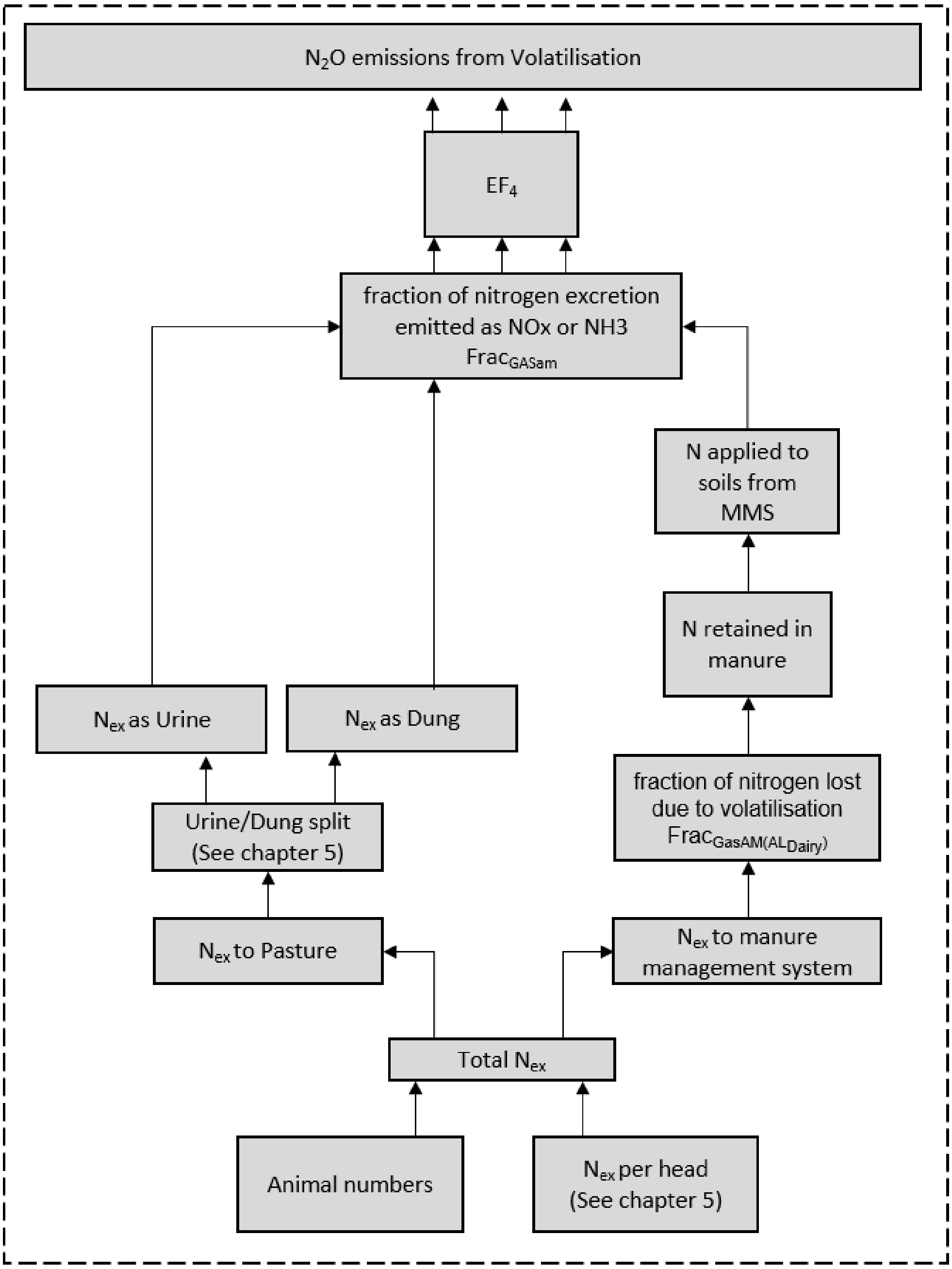
$Frac_{GASF(UI\ coated)}$ = 0.055
$Frac_{GASF(not\ UI\ coated)}$ = 0.1

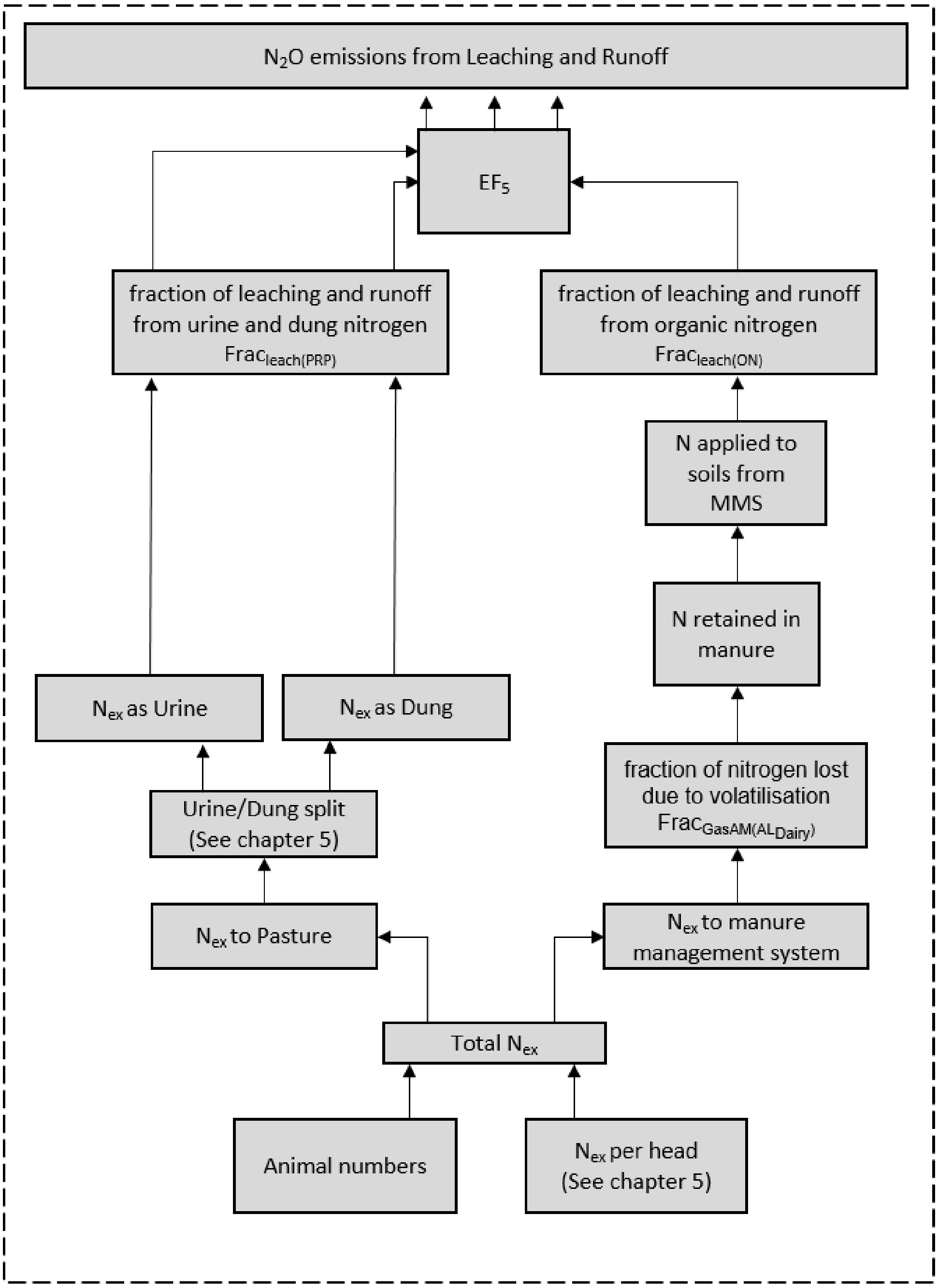
Figure 8.3 shows the pathways that lead to N_2O from livestock manure. The majority of the nitrogen excreted follows the left hand pathway and is deposited on pasture. This includes almost all nitrogen from dairy cattle (95%) and all nitrogen from beef cattle, sheep, deer, horses, goats and alpaca. A small portion of nitrogen from swine and poultry is also deposited onto pasture, the rest entering other manure management systems. The pathway on the right of the diagram shows the nitrogen entering manure management systems.

The amount of nitrogen excreted from dairy cattle, beef cattle, sheep, deer and other animal species are determined in Section 5. The nitrogen excreted from goats, horses, alpaca, swine and poultry are as detailed in Table 5.1. Full details of proportions of nitrogen in each animal manure management system (MMS) for all livestock species are summarised in Appendix 21.

Figure 8.3: Flow chart of the current IPCC national N_2O inventory methodology showing N_2O emissions from cattle, sheep and deer excreta for pastoral agriculture in NZ.




N_2O emissions from Volatilisation
EF_4
fraction of nitrogen excretion emitted as NOx or NH3 $Frac_{GASam}$
N applied to soils from MMS
N retained in manure
N_{ex} as Urine
N_{ex} as Dung
fraction of nitrogen lost due to volatilisation $Frac_{GasAM(AL_{Dairy})}$
Urine/Dung split (See chapter 5)
N_{ex} to Pasture
N_{ex} to manure management system
Total N_{ex}
Animal numbers
N_{ex} per head (See chapter 5)



Note: Emissions from daily spread of swine manure are included with Excreta N deposited during grazing. Emission factor and fractions used to determine direct and indirect N_2O emissions from Agricultural soils are available in Appendix 22.

8.1 Direct agricultural soils emissions

As stated earlier, there are six main sources of direct N_2O emissions from Agricultural Soils. Section 8.1 goes through the calculation of each of these direct emissions sources. The basic form of the equation used to calculate direct emissions is below:

Equation 8.1 *Direct N_2O emissions from generic nitrogen source:*

$$N_2Odirect_N = \frac{44}{28} \times N \times EF$$

Where:

$N_2Odirect_{N,t}$ = Direct N_2O emissions from nitrogen applied to soil (kg N_2O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N = amount of nitrogen applied to soils (kg N); (see Appendix 23)

EF = Emission factor, or the proportion of nitrogen input to soil that is directly emitted as N_2O (kg (N_2O-N)/kg (N applied)

The emission factor can either be EF_1 or EF_3 depending on the nitrogen source.

8.1.1 Synthetic fertiliser application

Emissions from nitrogen from synthetic fertiliser are a relatively small proportion of total N_2O emissions, but have grown significantly over the past two decades. The majority of synthetic nitrogen fertiliser used in New Zealand is urea fertiliser which is mostly applied to dairy pasture land to increase pasture growth during spring and autumn. As shown in Figure 8.2 there are three main routes in which nitrogen from synthetic fertiliser can be emitted in the form of nitrous oxide. The majority of emissions arises from the direct conversion of nitrogen to N_2O, (explained in this section). There are also two indirect routes that result in nitrous oxide from synthetic fertiliser. These routes are leaching from the soil, and volatilisation of nitrogen into ammonia and NO_X (explained in further sections below).

The Fertiliser Association of New Zealand provides data on the use of urea and non-urea synthetic fertiliser (Appendix 23). Currently available data is limited to total fertiliser sold in New Zealand, and therefore a breakdown per farming system or region is not possible. The equation used to calculate direct nitrous oxide emission from synthetic fertiliser is as follows and this is consistent with IPCC (2006) guidelines:

Equation 8.2 *Direct N_2O emissions from synthetic fertiliser :*

$$N_2Odirect_{SN,t} = \frac{44}{28} \times \left((F_{SN(UREA),t} \times EF_{1(UREA)}) + (F_{SN(OTHER),t} \times EF_1) \right)$$

Where:

$N_2Odirect_{SN,t}$ = Direct N_2O emissions from synthetic nitrogen fertiliser in year *t* (kilograms per year)

$F_{SN(UREA),t}$ = the total nitrogen amount of urea fertiliser applied to soils in year *t* (kg N/yr); (see Appendix 23)

$EF_{1\ (urea)}$ = Proportion of nitrogen input to soil that is directly emitted for urea fertiliser (0.0059 kg (N_2O-N)/kg (N applied) (see Figure 8.2 and Appendix 22).

$F_{SN(OTHER),t}$ = the total nitrogen annual amount of non-urea synthetic nitrogen fertiliser applied to soils in year *t* (kg N/yr); (see Appendix 23)

EF_1 = Proportion of nitrogen input to soil that is directly emitted (0.01 kg (N_2O-N)/kg (N applied) from other synthetic fertilizers (see Figure 8.2 and Appendix 22).

The emission factor EF_1 is based on the report by Kelliher and de Klein (2006) while the emission factor $EF_{1(UREA)}$ is based on the report by Van der Weerden et al (2016).

8.1.2 Organic nitrogen fertilisers

In New Zealand, emissions from *Organic nitrogen fertilisers* are primarily from animal manure that is spread on pasture after collection in manure management systems. In New Zealand, this only occurs for dairy cattle, swine and poultry. There is also a small component that comes from other (non-manure organic fertilisers applied to soils, such as dairy processing wastewater, compost sold to the rural sector, and meat processing wastewater.

The majority of animal manure in New Zealand is excreted directly onto pasture, but some manure from dairy farms is kept in manure management systems and applied to soils as an organic fertiliser. Some manure is also collected but not stored; rather, it is spread directly onto pasture daily (e.g., swine manure and some dairy manure). These emissions occur irrespective of the animal waste management system it was initially stored in.

The calculation of emissions from *Organic nitrogen fertilisers* excludes manure deposited directly on pasture by grazing livestock.

8.1.2.1 Direct organic nitrogen fertiliser emissions for dairy

The following equations are used to estimate direct organic nitrogen fertiliser emissions for dairy cattle. A key part of these equations is the estimate of nitrogen applied to soils from anaerobic lagoons.

Equation 8.3 *Direct N_2O emissions from organic nitrogen fertiliser for dairy cattle :*

$$N_2Odirect_{ON,dairy,t} = \frac{44}{28}\left(F_{AM(dairy),t} \times \left(1 - Frac_{GasAM(AL_{Dairy})}\right) \times EF_{1(DAIRY)}\right)$$

Where:

$N_2Odirect_{ON,dairy,t}$ = direct annual N_2O emissions from organic nitrogen fertilisers for dairy cattle in year *t* (kg per year)

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year *t* (kg per year)

$Frac_{GasAM(AL\text{-}Dairy)}$ = fraction of nitrogen lost due to volatilisation (currently set at 0.35, as per IPCC (2006) guidelines

$EF_{1(DAIRY)}$ is the proportion of direct N_2O emissions from animal manure (dairy cattle) applied to soils, set at 0.0025 from van der Weerden et al (2016)

Equation 8.4 *Total amount of dairy animal manure nitrogen applied to soils*

$$F_{AM(dairy),t} = \sum_{class}\sum_{region}\sum_{month}\left(N_{ex,c,m,R} \times nod_m \times POPdairy_{c,m,r}\right) \times MS_{AL,N2O}$$

Where:

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year t (kg per year)

$N_{ex,x,m,R}$ = daily nitrogen excretion per dairy cow of class c in month m and region R (kilograms of nitrogen per day – see Section 5.2, Equation 5.2)

$MS_{AL,N2O}$ = fraction of total annual dairy manure excreted in anaerobic lagoons. currently set at 5% (see appendix 21).

nod_m = number of days in month m

$POPdairyc_{c,m,r}$ = population of dairy animals in subcategory *c*, month *m* and region *r*

class refers to the different categories of dairy cattle populations used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

8.1.2.2 Direct organic nitrogen fertiliser emissions for swine

Total direct emissions from organic nitrogen fertiliser for swine are determined by adding the nitrous oxide caused by waste in the different manure management systems

Equation 8.5 *Direct N_2O emissions from organic nitrogen fertiliser for swine :*

$$N_2Odirect_{ON,swine,t} = \mathrm{POP}_{\mathrm{swine}_t} \times EF_1 \times \frac{44}{28}\left(\sum_x \left(N_{ex,swine,t} \times Pmms_{swine,x} \times \left(1 - Frac_{GasAM(x,swine)}\right)\right)\right)$$

Where:

$N_2Odirect_{ON,swine,t}$ = total direct annual N_2O emissions from organic nitrogen fertilisers for swine (kg per year)

EF_1 = the proportion of direct N_2O emissions from animal manure applied to soils (0.01)

$N_{ex,swine,t}$ = Annual nitrogen excretion per pig in year *t* (kilograms of nitrogen per year) (see Equation 5.28 in Section 5.7.5)

$Pmms_{swine,x}$ = Proportion of swine waste N deposited in manure management system *x* (see Table 7.4, Section 7.2.1.2 for values)

$Frac_{GasAM(x,swine)}$ = fraction of nitrogen lost due to volatilisation for manure management system *x* (see Table 7.4, Section 7.2.1.2 for values)

$POPswine_t$ = swine population in year *t* (from APS)

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

The fraction 44/28 is used to convert nitrogen to nitrous oxide.

8.1.2.3 Direct organic nitrogen fertiliser emissions for poultry

Direct N_2O organic nitrogen fertiliser emissions from poultry are calculated using parameters for Broilers, Layers and Other poultry. Some of these parameters are different and some are the same

Equation 8.6 *Direct organic nitrogen fertiliser emissions from broilers*

$$N_2Odirect_{ON,broiler,t} = N_{ex,broiler} \times Pmms_{broiler,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_1 \times \frac{44}{28} \times POPbroiler_t$$

Where:

$N_2Odirect_{ON,broiler,t}$ = total direct annual N_2O emissions from organic nitrogen fertilisers for broiler chicken (kg per year)

$N_{ex,broiler}$ = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{broiler,other}$ = Proportion of broiler waste deposited in other manure management systems (set at 0.95)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_1 = the proportion of direct N_2O emissions from animal manure applied to soils (0.01)

$POPbroiler_t$ = Broiler population in year t (from APS)

Equation 8.7 *Direct organic nitrogen fertiliser emissions from layers*

$$N_2Odirect_{ON,layer,t} = N_{ex,layer} \times Pmms_{layer,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_1 \times \frac{44}{28} \times POPlayer_t$$

Where:

$N_2Odirect_{ON,layer,t}$ = total direct annual N_2O emissions from organic nitrogen fertilisers for layer chicken (kg per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer chicken (set at 0.42 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{layer,other}$ = Proportion of layer waste deposited in other manure management systems (set at 0.94)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_1 = the proportion of direct N_2O emissions from animal manure applied to soils (0.01)

$POPlayer_t$ = Layer population in year t (from APS)

Equation 8.8 *Direct organic nitrogen fertiliser emissions from other poultry*

$$N_2Odirect_{ON,other,t} = N_{ex,other} \times Pmms_{other,other} \times (1 - Frac_{GasAM,poultry}) \times EF_1 \times \frac{44}{28} \times POPotherpoultry_t$$

Where:

$N_2Odirect_{ON,other,t}$ = total direct annual N_2O emissions from organic nitrogen fertilisers for other poultry in year t (kg per year)

$N_{ex,other}$ = Annual nitrogen excretion per 'other' chicken (set at 0.6 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{other,other}$ = Proportion of 'other poultry' waste deposited in other manure management systems (set at 0.97)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_1 = the proportion of direct N_2O emissions from animal manure applied to soils (0.01)

$POPotherpoultry_t$ = Other poultry population in year t (from APS)

The results from the above three equations can be summed together to get an estimate of total direct annual N_2O emissions from organic nitrogen fertilisers for all poultry.

8.1.2.4 Direct emissions from other (non-manure) organic fertilizers applied to soils

In total, six industrial sources (dairy processing, composting, meat processing, wine grape processing, vegetable processing wastewater and sewage sludge management) produce organic amendments that are applied to agricultural and forestry soils. The amount of nitrogen from these sources between 1990 and 2022 has been estimated (van der Weerden & Rutherford, 2024). For years after 2022 the latest available value is used, with review intended in 2027. Appendix 28 contains the time series.

The 2019 refinement of the 2006 IPCC guidelines (IPCC, 2019) retained the default value of 1% for N additions to agricultural soils. However, the refinement also provides additional EF values disaggregated by N type and climate, where climate is disaggregated into wet and dry. New Zealand falls into this 'wet climate' category according to the IPCC definition. Therefore, New Zealand uses the 2019 IPCC disaggregated EF1 of 0.6% to ensure calculations are employing the latest scientific knowledge. This provides a more appropriate value for organic N amendments to soils in wet climates rather than remaining with the aggregated value of 1% that is applied to all N inputs, across all climatic zones.

Equation 8.9 *Direct organic nitrogen fertiliser emissions from non-manure organic fertilisers*

$$N_2Odirect_{ON,NM,t} = \frac{44}{28} \times (F_{ON(non-manure),t} \times EF_1)$$

$N_2Odirect_{ON,NM,t}$ = Direct N_2O emissions from non-manure organic nitrogen fertiliser in year *t* (kilograms per year)

$F_{ON(non\text{-}manure),t}$ = the total nitrogen annual amount of non-manure organic nitrogen fertiliser applied to soils in year *t* (kg N/yr); (see Appendix 28)

EF_1 = Proportion of nitrogen input to soil that is directly emitted (0.006 kg (N_2O-N)/kg (N applied) from other synthetic fertilizers.

8.1.3 **Urine and dung deposited by grazing animals**

This section explains how direct N_2O emissions from urine and dung deposited on pasture are calculated. The majority of livestock in New Zealand are grazed outdoors on pasture, with 95 per cent of dairy cattle excreta (Ledgard & Brier, 2004) and 100 per cent of non-dairy cattle, sheep, deer and other livestock excreta falling on pasture. For these major livestock species, emissions from excreta are separated into dung and urine components.

In 2020, MPI adopted a revised methodology and set of emission factors to calculate direct N_2O emissions from cattle, sheep and deer. The new emission factor values (EF_3) are based on a meta-analysis undertaken by van der Weerden et al. (2019) of results from field studies and research undertaken in the past decade (de Klein et al., 2014; Hoogendoorn et al., 2013; Luo et al., 2013, 2016, 2019; and Saggar et al., 2015). The research collectively shows:

- a statistically significant difference in urine emission factors between cattle and sheep
- that emission factors for sheep, beef cattle and dairy cattle excreta deposited on medium (between 12 degrees and 24 degrees) and steep (greater than 24 degrees) sloped land are significantly lower than corresponding emissions on land that is flat or of a low gradient
- that emissions for medium and steep slopes are not statistically different and therefore one emission factor ($EF_{3(PRP\text{-}STEEP)}$) captures both medium and steep slopes

A new emission factor for dung ($EF_{3(PRP\text{-}DUNG)}$ = 0.0012) was adopted in the 2020 inventory, along with a revised set of emission factors for urine ($EF_{3(PRP\text{-}FLAT)}$ and $EF_{3(PRP\text{-}STEEP)}$, see Table 8.1) which are disaggregated by slope and livestock type. The Nutrient Transfer Model, described in Section 5.6 is used to calculate the amount of urinary nitrogen excreta deposited on flat and low sloped land, medium sloped land and steep sloped land. This is a preliminary step required to enable calculation of direct N_2O emissions from livestock excreta deposited on pasture. Dung and urine emission factors for all minor livestock species ($EF_{3,PRP\text{-}MINOR}$) are not disaggregated by hill slope type and have an emission factor value of 0.01, which is consistent with the IPCC default value.

Table 8.1: **Direct nitrous oxide (N_2O) emission factors for urine deposited by cattle, sheep and deer, by livestock type and slope, using values calculated by van der Weerden et al. (2019)**

	Emission factor by slope	
Livestock type	**Flat and low sloped land (less than 12° gradient) $EF_{3,PRP\text{-}FLAT}$**	**Medium and steep sloped land (greater than 12° gradient) $EF_{3,PRP\text{-}STEEP}$**
All cattle (includes dairy and non-dairy)	0.0098	0.0033
Deer	0.0074	0.0020
Sheep	0.0050	0.0008

The lower emission factors observed for urine on steeper slopes are thought to be due to these soils having lower soil fertility and moisture content compared with less steep slopes (Luo et al., 2013).

The new urine emission factor values for each livestock type by slope are lower than the current IPCC default EF_3 value, which is based on common international farming systems where, on average, farmed land has less hill country than common farm land in New Zealand. In addition to a large proportion of farmed hill country, New Zealand's climate and soil characteristics contribute to differences between international default emission factors and New Zealand's country-specific emission factors. When using the new emission factors, the IEF for direct N_2O from dung and urine was 0.0054 in 2018. This value is comparable with that calculated for the United Kingdom (0.0047) and Australia (0.004) in their respective inventory submissions in 2019.

Nitrous oxide measurements have not been taken for deer excreta. Based on animal liveweight, deer excreta characteristics (in terms of total deposition volume and weight) are assumed to be between the excreta characteristics of cattle and sheep (van der Weerden et al., 2019) and therefore, deer EF_3 values were calculated using the average EF_3 values from cattle and sheep.

To apply these emission factors, estimates on the amount of urine and dung deposited onto separate slopes is necessary. The Nutrient Transfer Model developed by Saggar et al. (2015) is used to allocate total excreta (N_{ex}, calculated using the methods described in section 5) by livestock type to the different slope categories. The Nutrient Transfer Model uses data on the area of farm land for each slope type, and accounts for animal behaviour where livestock spend relatively more time on lower slopes, and hence deposit more excreta on these lower slopes. For more information on this model, please refer to Section 5.6.

8.1.3.1 Dairy

For dairy cattle, the following equations are used to determine N_2O emissions separately from urine and dung.

Equation 8.10 *Direct N_2O emissions from dairy urine:*

$$N_2Odirect_{U,Dairy,t} = \frac{44}{28} \times EF_{3(PRP-FLAT)} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Odirect_{U,dairy,t}$ = direct annual N_2O emissions from urine deposited by dairy cattle during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}FLAT)}$ = emission factor for urine from grazing livestock deposited on flat and low sloped land, on pasture, range and paddock currently 0.0098 for dairy cattle, Table 8.1 (van der Weerden et al., 2019)

$MS_{dairy,PRP}$ = proportion of manure excreted on pasture by dairy cattle overall. Assumed to be 100% for all dairy cattle except mature milking cows (values for mature milking cows can be found in Table 7.1, column 3 from Section 7.1.1).

$N_{u,c,m,R}$ = Amount of nitrogen excreted in urine per animal for dairy animal class *c*, in month *m* and region *R* (kg of nitrogen per day). See Section 5.2.4 (Equation 5.8)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

In the above equation, the section in brackets is used to calculate the total amount of urine excreted by all dairy cattle in a given year.

As mentioned, the inventory assumes that all dairy cattle graze on flatland, due to New Zealand farming practices, therefore, the $EF_{3(PRP\text{-}FLAT)}$ value of 0.0098 for cattle is applied to all dairy urinary N_{ex}.

Equation 8.11 *Direct N_2O emissions from dairy dung :*

$$N_2Odirect_{D,Dairy,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Odirect_{D,dairy,t}$ = direct annual N_2O emissions from dung deposited by dairy cattle during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}Dung)}$ = emission factor for dung from grazing animals in pasture, range and paddock, currently 0.0012 (van der Weerden et al., 2019)

$MS_{dairy,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by dairy cattle overall.

$N_{f,c,m,R}$ = Amount of nitrogen excreted in faeces per animal for dairy animal class *c*, in month *m* and region *R* (kg of nitrogen per day). See Section 5.2.4 (Equation 5.8)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all dairy cattle in a given year.

8.1.3.2 Beef

For beef cattle, 100% of urine and dung is spread onto pasture, and the following equations are used to calculate direct N_2O emissions from beef urine and dung. As discussed earlier, the EF_3 values for beef cattle urine are dependent on hill slope ($EF_{3(PRP\text{-}FLAT)}$ = 0.0098, and $EF_{3(PRP\text{-}STEEP)}$ = 0.0033, see Table 8.1). A single beef dung emission factor ($EF_{3(PRP\text{-}DUNG)}$ = 0.0012) is used for all hill slopes. To apply these emission factors, the proportion of beef urine deposited on low, medium and steep slopes ($PropNex_{U,LOW,B}$ and $PropNex_{U,MED\&STEEP,B}$) needs to be calculated (refer to Sections 5.3.5 and 5.6 for this methodology).

Equation 8.12 *Direct N_2O emissions from beef urine:*

$$
\begin{aligned}
N_2Odirect_{U,beef,t} &= \frac{44}{28} \times MS_{beef,PRP} \times \left(\sum_{class} \sum_{month} N_{u,c,m} \times POPbeef_{c,m} \times nod_m \right) \\
&\times \left(PropNex_{U,LOW,B} \times EF_{3(PRP-LOW)} + PropNex_{U,MED\&STEEP,B} \times EF_{3(PRP-STEEP)} \right)
\end{aligned}
$$

Where:

$N_2Odirect_{U,beef,t}$ = direct annual N_2O emissions from urine deposited by beef cattle during grazing (kg of N_2O per year)

$MS_{beef,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by beef cattle overall. Assumed to be 100%.

$N_{u,c,m}$ = Amount of nitrogen excreted in urine per animal for beef animal class *c*, in month *m* (kg of nitrogen per day). See Section 5.3.4

$POPbeef_{c,m,R}$ = population of beef animals in subcategory *c* and month *m*

nod_m = number of days in month *m*

$EF_{3(PRP\text{-}LOW)}$ = emission factor for urinary N deposited on flat and low sloped land from grazing animals in pasture, range and paddock currently 0.0098 for beef cattle (van der Weerden et al., 2019)

$EF_{3(PRP\text{-}STEEP)}$ = emission factor for urinary N deposited on medium and steep sloped land from grazing animals in pasture, range and paddock currently 0.0033 for beef cattle (van der Weerden et al., 2019)

$PropNex_{U,LOW,B}$ = calculated proportion of total urine N_{ex} from beef cattle deposited on flat and low sloped land. See Section 5.6 and Table 5.1.

$PropNex_{U,MED\&STEEP,B}$ = calculated proportion of total urine N_{ex} from beef cattle deposited on medium and steep sloped land. See Section 5.6 and Table 5.1.

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the first set of brackets are used to calculate the total amount of urine N_{ex} by all beef cattle in a given year. The second set of brackets account for the effect of slope on emissions. Urinary N_{ex} from beef cattle is allocated to three categories of flat and low, medium, and steep slope types using the methodology described in Section 5.6.

Equation 8.13 *Direct N_2O emissions from beef dung:*

$$N_2Odirect_{D,Beef,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{beef,PRP} \times \left(\sum_{class} \sum_{month} N_{f,c,m} \times POPbeef_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{D,beef,t}$ = direct annual N_2O emissions from dung deposited by beef cattle during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}Dung)}$ = emission factor for dung from grazing animals in pasture, range and paddock, currently 0.0012 (van der Weerden et al., 2019)

$MS_{beef,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by beef cattle overall. Assumed to be 100%.

$N_{f,c,m}$ = Amount of nitrogen excreted in faeces per animal for beef animal class *c*, and month *m* (kg of nitrogen per day). See Section 5.3.4

$POPbeef_{c,m}$ = population of beef animals in subcategory *c* and month *m*

nod_m = number of days in month *m*

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all beef cattle in a given year.

8.1.3.3 Sheep

Direct N_2O emissions from sheep urine and dung are calculated using the same equations in Section 8.1.3.2, but with the beef inputs replaced by sheep inputs. It is assumed that 100% of sheep urine and dung is spread onto pasture.

As discussed earlier, the EF_3 values for sheep urine are dependent on hill slope ($EF_{3(PRP\text{-}FLAT)}$ = 0.0050, and $EF_{3(PRP\text{-}STEEP)}$= 0.0008, see Table 8.1). A single dung emission factor ($EF_{3(PRP\text{-}DUNG)}$ = 0.0012) is used for all hill slopes. To apply these emission factors, the proportion of sheep urine deposited on low, medium and steep slopes ($PropNex_{U,LOW,S}$ and $PropNex_{U,MED\&STEEP,S}$) needs to be calculated (refer to sections 5.3.5 and 5.6 for this methodology).

Equation 8.14 *Direct N_2O emissions from sheep urine:*

$$\begin{aligned} &N_2Odirect_{U,sheep,t} \\ &\quad = \frac{44}{28} \times MS_{sheep,PRP} \times \left(\sum_{class} \sum_{month} N_{u,c,m} \times POPsheep_{c,m} \times nod_m \right) \\ &\quad \times \left(PropNex_{U,LOW,S} \times EF_{3(PRP-LOW)} + PropNex_{U,LMED\&STEEP,S} \times EF_{3(PRP-STEEP)} \right) \end{aligned}$$

Where:

$N_2Odirect_{U,sheep,t}$ = direct annual N_2O emissions from urine deposited by sheep during grazing (kg of N_2O per year)

$MS_{sheep,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by sheep overall. Assumed to be 100%.

$EF_{3(PRP-URINE)}$ = emission factor for urine from grazing animals in pasture, range and paddock. Currently set at 0.01 (Carran *et al*., 1995; Muller *et al*., 1995; de Klein *et al*., 2003)

$N_{u,c,m}$ = Amount of nitrogen excreted in urine per animal for sheep animal class *c*, in month *m* (kg of nitrogen per day). See Section 5.3.5

$POPsheep_{c,m,R}$ = population of sheep animals in subcategory *c* and month *m*

nod_m = number of days in month *m*

$EF_{3(PRP-LOW)}$ = emission factor for urinary N deposited on flat and low sloped land from grazing animals in pasture, range and paddock, currently 0.005 for sheep (van der Weerden et al., 2019)

$EF_{3(PRP-STEEP)}$ = emission factor for urinary N deposited on medium and steep sloped land from grazing animals in pasture, range and paddock currently 0.0008 for sheep (van der Weerden et al., 2019)

$PropNex_{U,LOW,S}$ = calculated proportion of total urine N_{ex} from sheep deposited on flat and low sloped land. See Section 5.6 and Table 5.1.

$PropNex_{U,MED\&STEEP,S}$ = calculated proportion of total urine N_{ex} from sheep deposited on medium and steep sloped land. See Section 5.6 and Table 5.1.

class refers to the different categories of sheep used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the first set of brackets are used to calculate the total amount of urine N_{ex} by all sheep in a given year. The second set of brackets account for the effect of slope on emissions. Urinary N_{ex} from sheep is allocated to three categories of flat and low, medium, and steep slope types using the methodology described in Section 5.6.

Equation 8.15 *Direct N_2O emissions from sheep dung:*

$$N_2Odirect_{D,Sheep,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{sheep,PRP} \times \left(\sum_{class} \sum_{month} N_{f,c,m} \times POPsheep_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{D,sheep,t}$ = direct annual N_2O emissions from dung deposited by sheep during grazing (kg of N_2O per year)

$EF_{3(PRP-Dung)}$ = emission factor for dung from grazing animals in pasture, range and paddock currently 0.0012 (van der Weerden et al., 2019)

$MS_{sheep,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by sheep overall. Assumed to be 100%.

$N_{f,c,m}$ = Amount of nitrogen excreted in faeces per animal for sheep animal class *c*, and month *m* (kg of nitrogen per day). See Section 5.3.5

$POPsheep_{c,m}$ = population of sheep animals in subcategory *c*, month *m*

nod_m = number of days in month *m*

class refers to the different categories of sheep used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all sheep in a given year.

8.1.3.4 Deer

Direct N_2O emissions from deer urine and dung are calculated using the same equations in Section 8.1.3.2 and Section 8.1.3.3, but with the beef and sheep inputs replaced by deer inputs. It is assumed that 100% of deer urine and dung is spread onto pasture.

As discussed earlier, the EF_3 values for deer urine are dependent on hill slope ($EF_{3(PRP\text{-}FLAT)}$ = 0.0074, and $EF_{3(PRP\text{-}STEEP)}$= 0.0020, see Table 8.1). A single dung emission factor ($EF_{3(PRP\text{-}DUNG)}$ = 0.0012) is used for all hill slopes. To apply these emission factors, the proportion of sheep urine deposited on low, medium and steep slopes ($PropNex_{U,LOW,Deer}$ and $PropNex_{U,MED\&STEEP,Deer}$) needs to be calculated (refer to sections 5.3.5 and 5.6 for this methodology).

Equation 8.16 *Direct N_2O emissions from deer urine:*

$$N_2Odirect_{U,deer,t} = \frac{44}{28} \times MS_{deer,PRP} \times \left(\sum_{class}\sum_{month} N_{u,c,m} \times POPdeer_{c,m} \times nod_m\right) \times \left(PropNex_{U,LOW,Deer} \times EF_{3(PRP-LOW)} + PropNex_{U,LMED\&STEEP,Deer} \times EF_{3(PRP-STEEP)}\right)$$

Where:

$N_2Odirect_{U,deer,t}$ = direct annual N_2O emissions from urine deposited by deer during grazing (kg of N_2O per year)

$MS_{deer,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by deer overall. Assumed to be 100%.

$N_{u,c,m}$ = Amount of nitrogen excreted in urine per animal for deer animal class *c*, in month *m* (kg of nitrogen per day). See Section 5.5.5

$POPdeer_{c,m,R}$ = population of deer animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

$EF_{3(PRP\text{-}LOW)}$ = emission factor for urinary N deposited on flat and low sloped land from grazing animals in pasture, range and paddock, currently 0.0074 for deer (van der Weerden et al., 2019)

$EF_{3(PRP\text{-}STEEP)}$ = emission factor for urinary N deposited on medium and steep sloped land from grazing animals in pasture, range and paddock, currently 0.002 for deer (van der Weerden et al., 2019)

$PropNex_{U,LOW,Deer}$ = calculated proportion of total urine N from deer deposited on low slopes. See Section 5.6 and Table 5.1.

$PropNex_{U,MED\&STEEP,Deer}$ = calculated proportion of total urine N from deer deposited on medium and steep slopes. See Section 5.6 and Table 5.1.

class refers to the different categories of deer used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the first set of brackets are used to calculate the total amount of urine N_{ex} by all sheep in a given year. The second set of brackets account for the effect of slope on emissions. Urinary N from deer is allocated to three categories of flat and low, medium, and steep slope types using the methodology described in Section 5.6.

Equation 8.17 *Direct N_2O emissions from deer dung:*

$$N_2Odirect_{D,deer,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{deer,PRP} \times \left(\sum_{class}\sum_{month} N_{f,c,m} \times POPdeer_{c,m} \times nod_m\right)$$

Where:

$N_2Odirect_{D,deer,t}$ = direct annual N_2O emissions from dung deposited by deer during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}Dung)}$ = emission factor for dung from grazing animals in pasture, range and paddock, currently 0.0012 (van der Weerden et al., 2019)

$MS_{deer,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by deer overall. Assumed to be 100%.

$N_{f,c,m}$ = Amount of nitrogen excreted in faeces per animal for deer animal class *c*, and month *m* (kg of nitrogen per day). See Section 5.5.5

$POPdeer_{c,m}$ = population of deer animals in subcategory *c*, month *m*

nod_m = number of days in month *m*

class refers to the different categories of deer used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all deer in a given year.

8.1.3.5 Minor livestock

For minor livestock species, the direct N_2O emissions from urine and dung deposited onto pasture are not separated into the urine and dung components. This section shows how direct N2O emissions from urine and dung deposited on pasture are calculated for these animal species.

Nitrous oxide from these minor species is not calculated separately for dung and urine and therefore a single emission factor, $EF_{3PRP\text{-}MINOR}$ (set at 0.01) is used.

8.1.3.5.1 Poultry

Direct N_2O emissions from urine and dung deposited on pasture by poultry are calculated by using different parameters for broilers, layers and other poultry.

Equation 8.18 *Direct N_2O emissions from urine and dung for poultry :*

$$N_2Odirect_{UD,poultry,t} = \frac{44}{28} \times EF_{3(PRP-MINOR)} \times \sum_x \left(N_{ex,x,t} \times POPminorpoultry_{x,t} \times MS_{x,PRP}\right)$$

Where:

$N_2Odirect_{UD,x,t}$ = direct annual N_2O emissions from urine and dung deposited by poultry type *x* (i.e. broilers, layers, and other poultry) during grazing in year *t* (kg of N_2O per year)

$EF_{3(PRP\text{-}MINOR)}$ = emission factor for minor animal species in pasture, range and paddock. Currently set at 0.01 (Carran *et al*., 1995; Muller *et al*., 1995; de Klein *et al*., 2003)

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year *t*, for poultry type x (kg of nitrogen per year). See Section 5.7.2 (nitrogen excretion, poultry) for specific values

$POPpoultry_{x,t}$ = population of poultry type *x* in year *t* (from APS)

$MS_{x,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by poultry type *x*. Assumed to be 4.9% for broilers, 5.8% for layers and 3% for other poultry (Appendix 21).

The $MS_{x,PRP}$ values for broilers and layers were determined from a study by Fick et al (2011) while the $MS_{x,PRP}$ value for other poultry is taken from the IPCC 1996 guidelines.

8.1.3.5.2 Swine

Direct N_2O emissions from urine and dung deposited on pasture by swine are calculated using the following equation.

Equation 8.19 *Direct N_2O emissions from urine and dung for swine:*

$$N_2Odirect_{UD,swine,t} = \frac{44}{28} \times EF_{3(PRP-MINOR)} \times N_{ex,swine,t} \times POPswine_t \times MS_{swine,PRP}$$

Where:

$N_2Odirect_{UD,swine,t}$ = direct annual N2O emissions from urine and dung deposited by swine during grazing in year *t* (kg of N_2O per year)

$EF_{3(PRP\text{-}MINOR)}$ = emission factor for minor animal species in pasture, range and paddock, currently 0.01 (Carran *et al*.,1995; Muller *et al*., 1995; de Klein *et al*., 2003)

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year t, for swine (kg of nitrogen per year). See Section 5.7.5 (nitrogen excretion, swine) and Equation 5.28

$POPswine_t$ = population of swine in year *t* (from APS)

$MS_{swine,PRP}$ = proportion of total manure N excreted directly onto pasture, range and paddock by swine. See Table 7.4 for details.

8.1.3.5.3 Goats, horses, alpaca, llamas, mules and asses

For these animals, it is assumed that all manure is excreted directly onto pasture. This means that direct N_2O emissions from urine and dung can be calculated from the following equation.

Equation 8.20 *Direct N_2O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses:*

$$N_2Odirect_{UD,x,t} = \frac{44}{28} \times EF_{3(PRP-MINOR)} \times N_{ex,x,t} \times POPminor_{x,t}$$

Where:

$N_2Odirect_{UD,x,t}$ = direct annual N_2O emissions from urine and dung deposited by animal type *x* (i.e. goats, horses…) during grazing in year *t* (kg of N_2O per year)

$EF_{3(PRP\text{-}MINOR)}$ = emission factor for minor animal species in pasture, range and paddock, currently 0.01 (Carran *et al*.,1995; Muller *et al*., 1995; de Klein *et al*., 2003)

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year *t*, for animal type *x* (kg of nitrogen per year). See Section 5.6 (nitrogen excretion, other livestock sources)

$POPminor_x$ = population of animal type *x* in year *t* (from APS)

Specific values of N_{ex} for the different animal categories are outlined in sections 5.6.1 (goats), 5.6.3 (horses, mules and asses) and 5.6.4 (alpacas).

8.1.3.6 Nitrification inhibitor dicyandiamide

A methodology has been developed to incorporate the nitrification inhibitor dicyandiamide (DCD), an N_2O mitigation technology, into the inventory. The N_2O emissions reported in the *Agricultural soils* category take into account the use of nitrification inhibitors on dairy farms using the methodology described in Clough *et al*. (2008). Greenhouse gas mitigation estimates from DCD are reported in the inventory only up until 2012, because it was no longer used after this time. Sales were suspended due to the detection of low levels of DCD residues in milk.

Research has shown that DCD reduces N_2O emissions and nitrate (NO_3–) leaching in pastoral grassland systems grazed by ruminant animals. The inventory methodology incorporates DCD use by modifying the emission factors $EF_{3(PRP)}$ and the parameter $Frac_{LEACH}$. These were modified based on comprehensive field-based research that showed significant reductions in direct and indirect N_2O emissions and NO_3– leaching where the DCD was applied. It was determined that, on a national basis, reductions in $EF_{3(PRP)}$ and $Frac_{LEACH}$ of 67 per cent and 53 per cent respectively could be made (Clough *et al*., 2008).

There has been some research into the effect of the inhibitor on dung ($EF_{3(PRP\text{-}DUNG)}$); however, these data are limited and further work would need to be carried out before incorporating this research into the inventory. Application of this inhibitor was found to have no effect on NH_3 volatilisation and this is supported by the results of field studies (Clough et al., 2008; Sherlock et al., 2008). Therefore the parameter for volatilisation remains unchanged.

In the inventory it is assumed that DCD only affects:

A. Direct N_2O emissions from dairy urine deposited on pasture

B. Indirect N_2O emissions (from leaching and runoff) from dairy urine deposited on pasture

C. Emissions during the months from May to September, when DCD was applied on farms

Point A is discussed in this section (8.1.3.6), and point B is explained more in Section 8.2.3.3

The effect of DCD on emissions are estimated by using weighting factors. The DCD weighting factors are calculated based on reductions in emission factors and parameters, and the fraction of dairy land treated with the inhibitor, as follows:

Equation 8.21 *DCD weighting factor:*

$$DCD\ weighting\ factor = \left(1 - \left(reduction\ in\ EF_{3(PRP-URINE)} \times \frac{DCD\ area\ treated}{Total\ area\ of\ dairy}\right)\right)$$

Where:

DCD weighting factor = amount that $EF_{3(PRP\text{-}URINE)}$ (which leads to direct N_2O emissions from dairy urine) needs to be multiplied by to account for the effect of DCD between 2007 and 2012

reduction in $EF_{3(PRP\text{-}URINE)}$ = proportion by which $EF_{3(PRP\text{-}URINE)}$ is lower following use of DCD. Currently set at 0.67 (Clough *et al*., 2008).

DCD area treated = area of dairy land treated with DCD per year between 2007 and 2012 (from APS)

Total area of dairy = total effective dairy area per year (from APS)

In the years before 2007, and after 2012, DCD was not used in New Zealand, so the DCD weighting factor for these years would be set at 1.

The appropriate weighting factor is then used as an additional multiplier in the current methodology for calculating indirect and direct dairy emissions of N_2O from grazed pastures. This emission factor is only used from May to September, the months when DCD was applied

Equation 8.22 *Calculating EF3 for dairy, accounting for the use of DCD, for May to September:*

Where:

$$EF_{3(PRP-URINE),DCD} = EF_{3(PRP-URINE)} \times DCD\ weighting\ factor$$

$EF_{3(PRP\text{-}URINE),DCD}$ = emission factor for urine from dairy animals in pasture, range and paddock between May and September, after accounting for the effects of DCD use.

$EF_{3(PRP\text{-}URINE)}$ = emission factor for urine from grazing animals in pasture, range and paddock. Currently set at 0.01 (Carran *et al*., 1995; Muller *et al*., 1995; de Klein *et al*., 2003)

DCD weighting factor = amount that $N_2Odirect_{U,dairy,t}$ (see Equation 8.21) needs to be multiplied by to account for the effect of DCD between 2007 and 2012

The addition of the weighting factor results in a modified $EF_{3(PRP\text{-}URINE)}$ of around 0.0099 between 2007 and 2012 for the dairy grazing area in the months that the inhibitor is applied (May to September). The weighting factor is based on information from Statistics New Zealand's Agricultural Production survey that about 3 per cent of the effective dairying area in New Zealand received the inhibitor from 2007 to 2012.

In the years before 2007, and after 2012, DCD was not used in New Zealand, so $EF_{3(PRP\text{-}URINE),DCD}$ for these years would be equal to $EF_{3(PRP\text{-}URINE)}$.

It was assumed that the inhibitor was applied to pastures based on good management practice to maximise N_2O emission reductions. This is an application rate of 10 kilograms of DCD per hectare, applied twice per year in autumn and early spring within seven days of the application of animal excreta. 'Good practice' application methods of DCD can be by slurry or DCD-coated granules.

8.1.4 Nitrous oxide from crop residues returned to soils

This section of the inventory includes emissions from:

- nitrogen added to soils by above and below-ground crop residue (including residue left behind after crop burning), and
- nitrogen added to soils as a result of mineralisation of forages during pasture renewal

Crop residues are materials left in an agricultural field or orchard after the crop has been harvested. Pasture renewal is the destruction of low quality pasture followed by the sowing of improved pasture species and/or varieties, and is promoted as a simple method to increase farm productivity. As these crop residues and pastures decay or are destroyed, the nitrogen in these plant materials are released into the surrounding soil and result in direct and indirect N_2O emissions. Both of these emission sources include N-fixing and non-N-fixing crop species.

The methodology for calculating direct emissions from agricultural residue that is burnt is outlined in section 9 of this document.

The activity data required to estimate direct agricultural soils emissions from crop residues and pasture renewal is supplied by Statistics New Zealand from their agricultural production survey and includes data on the amount of different crops grown. The country-specific value for $Frac_{BURN}$ was derived from Statistics New Zealand data and farm surveys (Thomas *et al.,* 2011). The parameters used to estimate the N added by both above- and below-ground crop residues were compiled from published and unpublished reports from New Zealand-grown crops (Cichota et al., 2010) and typical values derived by OVERSEER® nutrient budget model for New Zealand. The OVEERSEER® model provides average estimates of nitrogen pathways for a range of pastoral, arable and horticultural systems (Wheeler et al., 2003; see also http://www.overseer.org.nz).

8.1.4.1 Nitrogen from crop residue

The non-nitrogen fixing crops grown in New Zealand are:

- barley,
- wheat,
- oats,
- potatoes,
- maize grain,
- brassica seeds,
- herbage seeds,
- onions,
- squash, and
- sweet corn.

The nitrogen-fixing crops grown in New Zealand are:

- legumes,
- peas (fresh and processed),
- seed peas, and
- lentils.

The annual tonnage of most non-nitrogen fixing crops in New Zealand is supplied by Statistics New Zealand from its Agricultural Production Survey. Additional information is provided by PotatoesNZ and information on seed crops from AsureQuality (Thomas *et al.,* 2010). The tonnage of nitrogen fixing crops is supplied by Statistics New Zealand from it Agricultural Production census and survey (i.e. lentils and legumes) and HortNZ (peas). A country-specific methodology (Thomas *et al.,* 2008) is used to calculate emissions from nitrogen fixing crops (kt (N)/yr). Most of the specific parameters used to calculate above ground and below ground crop nitrogen returned to soils (AGN and BGN) are outlined by Thomas et al (2011).

Equation 8.23 *Direct N_2O emissions from decay of crop residue:*

$$N_2Odirect_{CR,t} = \frac{44}{28} \times EF_1 \times \sum_c \left(AG_{N,c} + BG_{N,x}\right)$$

Where:

$N_2Odirect_{CR,t}$ = direct annual N2O emissions from crop residues (kg of N_2O per year)

EF_1 = the proportion of direct N_2O emissions from nitrogen input to the soil (0.01).

$AG_{N,c}$ = Amount of above-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year) (see Equation 8.24)

$BG_{N,c}$ = Amount of below-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year) (see Equation 8.26)

c refers to the different crop types listed in Table 8.1

Equation 8.24 *Amount of above ground crop residue:*

$$AG_{N,c} = DMF_c \times \left(\frac{Prod_c}{HI_c} - Prod_c\right) \times \left(1 - Frac_{burn} - Frac_{remove,c}\right) \times N_{AG,c}$$

Where:

$AG_{N,c}$ = Amount of above-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year)

DMF_c = Dry matter factor, used to convert total production to dry matter crop production for crop type *c* (see Table 8.1 for values)

$Prod_c$ = Annual production of crop type, *c* (kg/yr) see Appendix 23 for values)

HI_c = Harvest index, fraction of the crop (*c*) that is harvested for the primary purpose of growing the crop (see Table 8.1 for values)

$Frac_{burn,c}$ = fraction of above-ground biomass burned for crop type *c* (equal to zero for all crops except barley, oats and wheat; see Equation 8.25 below)

$Frac_{remove,c}$ = fraction of above-ground biomass removed for harvest for crop type *c* (set to zero for all crop types)

$N_{AG,c}$ = Nitrogen content of above-ground residue for crop type *c* (kg N/kg DM) (see Table 8.1 for values)

The variable $Frac_{burn,c}$ is zero for all crops except wheat, oats and barley. For these crops the following formula can be used to calculate $Frac_{burn}$ for a particular year.

Equation 8.25 *Fraction of above-ground biomass burned, for barley, oats and wheat:*

$$Frac_{burn,c} = \frac{AG_{BURN,c}}{AGresd_c}$$

Where:

$Frac_{burn,c}$ = fraction of above-ground biomass burned for crop type *c* (barley, oats or wheat)

$AG_{BURN,c}$ = Biomass of crop burnt (tonnes per year) for crop type *c* (i.e. barley, oats or wheat) (see Equation 9.9, Section 9.2)

$AGresd_c$ = Above-ground residue for crop *c* (tonnes of dry matter per year) (see Equation 9.10, Section 9.2)

Equation 8.26 *Amount of below ground crop residue:*

$$BG_{N,c} = DMF_c \times \left(\frac{Prod_c}{HI_c}\right) \times RS_c \times N_{BG,c}$$

Where:

$BG_{N,c}$ = Amount of below-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year)

DMF_c = Dry matter factor, used to convert total production to dry matter crop production for crop type *c* (see Table 8.1 for values)

$Prod_c$ = Annual production of crop type, *c* (kg/yr) see Appendix 23 for values

HI_c = Harvest index, fraction of the crop (*c*) that is harvested for the primary purpose of growing the crop (see Table 8.1 for values)

RS_c = Root:shoot ratio for crop type *c*. assumed to be 0.1 for all crops (Thomas et al. 2011)

$N_{BG,c}$ = Nitrogen content of below-ground residue for crop type *c* (kg N/kg DM) (see Table 8.1 for values)

Table 8.2: Parameter values for New Zealand's cropping emissions

Species	Harvest index (HI)	AGN	BGN	Dry Matter factor (DMF)
Wheat	0.41	0.005	0.009	0.86
Barley	0.46	0.005	0.009	0.86
Oats	0.30	0.005	0.009	0.86
Maize grain	0.50	0.007	0.007	0.86
Field Seed peas	0.50	0.02	0.015	0.21
Lentils	0.50	0.02	0.015	0.86
Peas fresh and process	0.45	0.03	0.015	0.86
Potatoes	0.90	0.02	0.01	0.22
Onions	0.80	0.02	0.01	0.11
Sweet corn	0.55	0.009	0.007	0.24
Squash	0.80	0.02	0.01	0.20
Herbage seeds	0.11	0.015	0.01	0.85
Legume seeds	0.09	0.04	0.01	0.85
Brassica seeds	0.20	0.01	0.008	0.85

Values taken from Thomas *et al*. (2011)

8.1.4.2 Nitrous oxide from pasture renewal

The IPCC (2006) lists four categories of perennial forage for pasture renewal. However, only two of these categories are appropriate for New Zealand:

- Grass-clover pastures
- Lucerne (a nitrogen-fixing perennial forage)

Emissions from pasture renewal occur when improved pasture species are sown and the existing low-quality pasture is destroyed.

In the New Zealand inventory, nitrogen from pasture residues are grouped into three sections:

- Rye/clover pasture on sheep, beef and deer land
- Rye/clover pasture on dairy land
- Lucerne on all farm types

The areas for perennial forage are obtained from the Statistics New Zealand Agricultural Production survey which includes data on grassland and annual crops (Thomas *et al.,* 2014). New Zealand calculates the N_2O emissions from these pastures separately with the following equations:

Equation 8.27 *Direct N_2O emissions from pasture renewal:*

$$N_2Odirect_{Renew,t} = \frac{44}{28} \times EF_1 \times \sum_p F_{CR-Renew,p,t}$$

Where:

$N_2Odirect_{renew,t}$ = Direct N_2O emissions from pasture renewal in year *t* (kilograms per year)

EF_1 = the proportion of direct N_2O emissions from nitrogen input to the soil (0.01 kg (N_2O-N)/kg (N applied). See Appendix 22.

$F_{CR-Renew,p,t}$ = Amount of nitrogen in residues (kg) for pasture type *p* in year *t*

p refers to the three sections of nitrogen from pasture renewal (either Lucerne on all farms, rye/clover on dairy farms, and rye/clover on sheep, beef and deer farms)

The amount of nitrogen in pasture residues ($F_{CR-Renew,x}$) can be calculated from the equation below.

Equation 8.28 *Nitrogen in residues from pasture renewal:*

$$F_{CR-Renew,p,t} = Area_{p,t} \times Freq_{renew,p,t} \times \left(\left(R_{AG,p} \times N_{AG} \times \left(1 - Frac_{remove,p}\right)\right) + \left(R_{BG,p} \times N_{BG}\right)\right)$$

Where:

$F_{CR-Renew,p,t}$ = Amount of nitrogen in residues (kg) for pasture type *p* in year *t*

$Area_{p,t}$ = Area of land in pasture and farm type *p*, in year *t* (hectares)

$Freq_{renew,p,t}$ = Percentage of land in pasture type *p* that is renewed annually. See Appendix 24 for values.

$R_{AG,p}$ = Above-ground dry matter residue for pasture type *p* (kilograms of dry matter per hectare). Set at:

- 750 kg/ha for rye/clover pasture on sheep, beef and deer land
- 1,400 kg/ha for rye/clover pasture on dairy land
- 900 kg/ha for lucerne

$N_{AG,x}$ = Nitrogen content of above-ground residue for pasture type *p* (kilograms of nitrogen per/kilogram of dry matter). Set at:

- 2% for rye/clover pasture on sheep, beef and deer land
- 2% for rye/clover pasture on dairy land
- 1.9% kg/ha for Lucerne

$Frac_{remove,p}$ = Fraction of above-ground residue for crop (T) removed annually for feed (ha removed/ha crop). This is assumed to be zero for New Zealand as pastures are generally grazed before renewing the pasture (Thomas et al., 2014).

$R_{BG,p}$ = Below-ground dry matter residue for pasture type p (kilograms of dry matter per hectare). Set at:

- 7,200 kg/ha for rye/clover pasture on sheep, beef and deer land
- 2,800 kg/ha for rye/clover pasture on dairy land
- 3,900 kg/ha for lucerne

$N_{BG,x}$ = Nitrogen content of below-ground residue for pasture type p (kilograms of nitrogen per/kilogram of dry matter). Set at:

- 1.2% for rye/clover pasture on sheep, beef and deer land
- 1.6% for rye/clover pasture on dairy land

- 1.4% kg/ha for Lucerne

The values for $R_{AG,p}$, $N_{AG,x}$, $R_{BG,p}$, and $N_{BG,x}$ were defined by Thomas et al (2014).

8.1.5 Nitrogen mineralisation from loss of soil organic matter in mineral soils

Nitrogen mineralisation is the process by which organic nitrogen is converted to plant-available inorganic forms. Nitrogen mineralisation occurs when soil carbon is lost due to land-use or management change. Most of New Zealand's emissions due to nitrogen mineralised during the loss of soil organic matter are covered under the LULUCF sector. The exception is for activities under the *Cropland remaining cropland* land-use category, which are reported under the Agriculture sector (IPCC, 2006).

Equation 8.29 *Direct N_2O emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils*

$$N_2Odirect_{FSOM,t} = \frac{44}{28} \times EF_1 \times F_{SOM}$$

Where:

$N_2Odirect_{FSOM,t}$ = Direct N_2O emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils in year *t* (kilograms per year)

EF_1 = the proportion of direct N_2O emissions from nitrogen input to the soil (0.01).

F_{SOM} = amount of nitrogen mineralised from loss of soil organic matter in mineral soils through land management for *cropland remaining cropland* (kg) (see Equation 8.30)

Equation 8.30 *Nitrogen mineralised due to the loss of soil organic matter in mineral soils*

$$F_{SOM} = \frac{\Delta C_{Mineral,CrC}}{R_{C:N}}$$

Where:

F_{SOM} = amount of nitrogen mineralised from loss of soil organic matter in mineral soils through land management for *cropland remaining cropland* (kg)

$\Delta C_{Mineral,CrC}$ = loss of soil carbon in mineral soil during management of cropland (kilograms of carbon). Activity data on the soil carbon loss associated with cropland since 1990 is provided by the Ministry for the Environment (see Appendix 25).

$R_{C:N}$ = C:N ratio, The IPCC (2006) default value of 10 is used.

8.1.6 Cultivation of organic soils

Histosols, or soils composed mainly of organic materials, emit nitrogen dioxide into the atmosphere. Direct N_2O emissions from organic soils are calculated by multiplying the area of cultivated organic soils by an emission factor (EF_2). This area includes cultivated organic agricultural soil as delineated by LULUCF and the area of mineral agricultural soils with a peaty layer that are cultivated.

Mineral soils with a peaty layer are included in the definition of organic soils under the Agriculture Sector as it was determined that these soils will have similar emissions behaviour to that of organic soils (Dresser *et al.,* 2011). Therefore, this is included with organic soils when estimating nitrous oxide emissions. The full definition for organic soils (plus mineral soils with a peaty layer) is as follows:

- 17% organic matter content (includes slightly peaty, peaty and peat soils of 17 – 30, 30 – 50 and > 50% organic matter content)
- 0.1 m of this depth occurring within 0.3 m of the surface.

The total area of cultivated organic soils in New Zealand has been provided by the Ministry for the Environment. This takes into account organic soils under cropland and grassland in the LULUCF section of the National Inventory Report (see Appendix 27). The total area has been increasing slowly since 1990, and in 2019 totalled 174,301 hectares.

New Zealand uses the IPCC default emission factor (EF_2 equal to 8 kg N_2O-N/ha/yr; see Appendix 22) and Tier 1 methodology for all years of the time-series. The contribution of organic soils (plus mineral soils with a peaty layer) to New Zealand's overall agricultural emissions has been relatively small (approximately 0.1 percent of agricultural emissions) since 1990.

Equation 8.31 *Direct N_2O emissions from cultivation of organic soils*

$$N_2Odirect_{OAS-C,t} = \frac{44}{28} \times EF_2 \times Area_{OAS-C}$$

Where:

$N_2Odirect_{OAS-C,t}$ = Direct N_2O emissions from the cultivation of organic soils (kilograms per year)

EF_2 = emission factor for direct emissions from organic soil mineralisation due to cultivation (8 kilograms of N_2O per hectare)

$Area_{OAS-C}$ = Area of organic agricultural soils

8.2 Indirect N_2O emissions associated with nitrogen leached from soils

In the New Zealand Inventory, there are five sources of indirect agricultural soils emissions from leaching and runoff:

- Synthetic nitrogen fertiliser
- Organic fertiliser
- Urine and dung from grazing animals
- Crop residues returned to soils
- Nitrogen mineralisation from loss of soil organic matter in mineral soils

Emissions from each of these sources are discussed in turn. The basic form of the equation used to calculate indirect leaching and runoff emissions is below:

Equation 8.32 *Indirect leaching and runoff N_2O emissions from generic nitrogen source:*

$$N_2Oindirect, leaching_N = \sum_{source} \frac{44}{28} \times N_s \times EF_5 \times Frac_{leach(s)}$$

Where:

$N_2Oindirect,leaching_N$ = Indirect leaching and run-off N_2O emissions from nitrogen applied to soil (kg N_2O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N_s = amount of nitrogen applied to soils (kg N) for source *s*; (see Appendix 23)

EF_5 = Emission factor, or the proportion of nitrogen input to soil that is emitted indirectly through leaching and runoff as N_2O (kg (N_2O-N)/kg (N applied)

$Frac_{leach(s)}$ = fraction of leaching and runoff from nitrogen applied to soil for source *s*. Currently set at 0.10 for cropping systems and 0.08 for other sources (see Appendix 22)

8.2.1 Synthetic fertiliser application

The following equation is used to calculate indirect leaching and runoff N_2O emissions from synthetic nitrogen fertiliser.

Equation 8.33 *Indirect leaching and run-off N_2O emissions from synthetic fertiliser:*

$$N_2Oindirect, leaching_{SN,t} = \frac{44}{28} \times F_{SN,t} \times EF_5 \times Frac_{leach(SN)}$$

Where:

$N_2Oindirect,leaching_{SN,t}$ = indirect leaching and run-off N_2O emissions from synthetic nitrogen fertiliser in year *t* (kilograms per year)

$F_{SN,t}$ = the total nitrogen amount of all synthetic fertiliser applied to soils in year *t* (kg N/yr); (see Appendix 23)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(SN)}$ = fraction of leaching and runoff from synthetic nitrogen applied to soil. Currently set at 0.082 (see Appendix 22)

Additional information of synthetic fertiliser is provided in Section 8.1.1. A slightly modified form of the above equation is used to calculate N_2O emissions from the other sources of indirect leaching and runoff emissions.

8.2.2 **Organic nitrogen fertilisers**

In New Zealand, emissions from *Organic nitrogen fertilisers* are solely from animal manure that is spread on pasture after collection in manure management systems. In New Zealand, this only occurs for dairy cattle, swine and poultry. Additional information on organic nitrogen fertilisers are contained in Section 8.1.2.

8.2.2.1 Indirect leaching and runoff organic nitrogen fertiliser emissions for dairy

Equation 8.34 *Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for dairy cattle*

$$N_2Oindirect, leaching_{ON,dairy,t} = \frac{44}{28} \times F_{AM(dairy),t} \times \left(1 - Frac_{GasAM(AL_{Dairy})}\right) \times Frac_{leach(ON)} \times EF_5$$

Where:

$N_2Oindirect,leaching_{ON,dairy,t}$ = indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for all dairy cattle in year *t* (kg per year)

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year *t* (kg per year). See Equation 8.4, Section 8.1.2.1

$Frac_{GasAM(AL\text{-}Dairy)}$ = fraction of nitrogen lost due to volatilisation (currently set at 0.35, as per IPCC (2006) guidelines

$Frac_{leach(ON)}$ = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

8.2.2.2 Indirect leaching and runoff organic nitrogen fertiliser emissions for swine

Total indirect leaching emissions from organic nitrogen fertiliser for swine are determined by adding the nitrous oxide caused by waste in the different manure management systems

Equation 8.35 *Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for swine:*

$$N_2Oindirect, leaching_{ON,swine,t} = EF_5 \times Frac_{leach(ON)} \times \frac{44}{28}\left(\sum_x \left(N_{ex,swine,t} \times Pmms_{swine,x} \times \left(1 - Frac_{GasAM(x,swine)}\right) \times POPswine_t\right)\right)$$

Where:

$N_2Oindirect,leaching_{ON,swine,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for swine (kg per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(ON)}$ = fraction of leaching and runoff from organicnitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$N_{ex,swine,t}$ = Annual nitrogen excretion per pig in year *t* (kilograms of nitrogen per year) (see Equation 5.28 in section 5.7.5.

$Pmms_{swine,x}$ = Proportion of swine waste deposited in manure management system *x* (see Table 7.4, Section 7.2.1.2 for values)

$Frac_{GasAM(x,swine)}$ = fraction of nitrogen lost due to volatilisation for manure management system *x* (see Table 7.4, Section 7.2.1.2 for values)

$POPswine_t$ = swine population in year t (from APS)

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

8.2.2.3 Indirect leaching and runoff organic nitrogen fertiliser emissions for poultry

Indirect leaching and runoff N_2O organic nitrogen fertiliser emissions from poultry are calculated using parameters for broilers, layers and other poultry. Some of these parameters are different and some are the same.

Equation 8.36 *Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for broilers*

$$N_2Oindirect, leaching_{ON,broiler,t} = N_{ex,broiler} \times Pmms_{broiler,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_5 \times Frac_{leach(ON)} \times \frac{44}{28} \times POPbroiler_t$$

Where:

$N_2Oindirect,leaching_{ON,broiler,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for broiler chicken in year *t* (kg per year)

$N_{ex,broiler}$ = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{broiler,other}$ = Proportion of broiler waste deposited in other manure management systems (set at 0.95)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(ON)}$ = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

POPbroiler$_t$ = Broiler population in year t (from APS)

Equation 8.37 *Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for layers*

$$N_2Oindirect, leaching_{ON,layer,t} = N_{ex,layer} \times Pmms_{layer,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_5 \times Frac_{leach(ON)} \times \frac{44}{28} \times POPlayer_t$$

Where:

$N_2Oindirect,leaching_{ON,layer,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for layer chicken in year *t* (kg per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer chicken (set at 0.42 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{layer,other}$ = Proportion of layer waste deposited in other manure management systems (set at 0.94)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(ON)}$ = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

POPlayer$_t$ = Layer population in year t (from APS)

Equation 8.38 *Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for other poultry*

$$N_2Oindirect, leaching_{ON,other,t} = N_{ex,other} \times Pmms_{other,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_5 \times Frac_{leach(ON)} \times \frac{44}{28} \times POPotherpoultry_t$$

Where:

$N_2Oindirect,leaching_{ON,other,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for other poultry in year *t* (kg per year)

$N_{ex,other}$ = Annual nitrogen excretion per ‘other’ chicken (set at 0.6 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{other,other}$ = Proportion of ‘other poultry’ waste deposited in other manure management systems (set at 0.97)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(ON)}$ = fraction of leaching and runoff from organicnitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

POPotherpoultry$_t$ = Other poultry population in year t (from APS)

The results from the above three equations can be summed together to get an estimate of total indirect leaching and runoff N_2O emissions from organic nitrogen fertilisers for all poultry per year.

8.2.3 Urine and dung deposited by grazing animals

This section explains how indirect leaching and runoff N_2O emissions from urine and dung deposited on pasture are calculated.

8.2.3.1 Dairy

For dairy cattle, the following equations are used to determine N_2O emissions separately from urine and dung.

Equation 8.39 *Indirect leaching and runoff N_2O emissions from dairy urine:*

$$N_2Oindirect, leaching_{U,dairy,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(PRP)} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,leaching_{U,dairy,t}$ = annual indirect leaching and runoff N_2O emissions from urine deposited by dairy cattle during grazing (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(PRP)}$ = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$MS_{dairy,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by dairy cattle overall. Assumed to be 100% for all dairy cattle except mature milking cows (values for mature milking cows can be found in Table 7.1, column 3 from Section 7.1.1).

$N_{u,c,m,R}$ = Amount of nitrogen excreted in urine per animal for dairy animal class *c*, in month *m* and region *R* (kg of nitrogen per day). See Section 5.2.4 (Equation 5.8)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in urine by all dairy cattle in a given year

Equation 8.40 *Indirect leaching and runoff N_2O emissions from dairy dung:*

$$N_2Oindirect, leaching_{D,Dairy,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(PRP)} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,leaching_{D,dairy,t}$ = annual indirect leaching and runoff N_2O emissions from dung deposited by dairy cattle during grazing (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(PRP)}$ = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$MS_{dairy,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by dairy cattle overall.

$N_{f,c,m,R}$ = Amount of nitrogen excreted in faeces per animal for dairy animal class *c*, in month *m* and region *R* (kg of nitrogen per day). See Section 5.2.4 (Equation 5.9)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

8.2.3.2 Beef, sheep and deer

For beef cattle, sheep and deer, 100% of urine and dung is spread onto pasture, and the following equations are used to calculate indirect leaching and runoff N_2O emissions from urine and dung. These equations are effectively identical to the equations in Section 8.1.3, although the emission factor EF_5 is used instead of EF_3, and there is an additional parameter, Fracleach, to account for the proportion of nitrogen (applied to water) that is lost to water.

Equation 8.41 *Indirect leaching and runoff N_2O emissions from urine, for animal species x:*

$$N_2Oindirect, leaching_{U,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(PRP)} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,u,c,m} \times POPx_{c,m} \times nod_m \right)$$

Equation 8.42 *Indirect leaching and runoff N_2O emissions from dung, for animal species x:*

$$N_2Oindirect, leaching_{D,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(PRP)} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,f,c,m} \times POPx_{c,m} \times nod_m \right)$$

Where:

$N_2Oindirect,leaching_{U,x,t}$ = annual indirect leaching and runoff N_2O emissions from urine deposited by animal species *x* during grazing (kg of N_2O per year)

$N_2Oindirect,leaching_{D,x,t}$ = annual indirect leaching and runoff N_2O emissions from dung deposited by animal species *x* during grazing (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22

$Frac_{leach(PRP)}$ = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$MS_{x,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by animal species *x*. Assumed to be 100% for all species.

$N_{x,u,c,m}$ = Amount of nitrogen excreted in urine per animal for animal species *x* class *c*, in month *m* (kg of nitrogen per day). See sections 5.2.4, 5.3.5, and 5.4.5

$N_{x,f,c,m}$ = Amount of nitrogen excreted in dung per animal for animal species *x* class *c*, in month *m* (kg of nitrogen per day). See sections 5.2.4, 5.3.5, and 5.4.5

$POPx_{c,m,R}$ = population of animal species *x* in subcategory *c* and month *m*

nod_m = number of days in month *m*

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

x refers to the different animal species, either sheep, beef cattle or deer (but not dairy cattle)

In these equations, the section in brackets is used to calculate the total amount of nitrogen excreted in urine and dung by all animals in a particular category (i.e. sheep, beef cattle or deer) in a given year.

8.2.3.3 Nitrification inhibitor dicyandiamide

DCD was used in New Zealand's pastoral farming system for dairy between 2007 and 2012, and affects indirect leaching emissions from urine and dung. The inventory accounts for the use of DCD by using the methodology described in Clough et al. (2008).

The use of DCD reduces N_2O emissions and nitrate (NO_3–) leaching in pastoral grassland systems grazed by ruminant animals. The inventory methodology incorporates DCD use by modifying the parameter $Frac_{LEACH}$.

The effect of DCD on emissions are estimated by using weighting factors. The DCD weighting factors are calculated based on reductions in emission factors and parameters, and the fraction of dairy land treated with the inhibitor, as follows:

Equation 8.43 *DCD weighting factor for $Frac_{LEACH}$:*

$$DCD\ weighting\ factor_{Fracleach} = \left(1 - \left(\%\ reduction\ in\ Frac_{leach} \times \frac{DCD\ area\ treated}{Total\ area\ of\ dairy}\right)\right)$$

Where:

DCD weighting $factor_{Fracleach}$ = amount that $Frac_{leach}$ needs to be multiplied by to account for the effect of DCD between 2007 and 2012

% reduction in $Frac_{leach(PRP)}$ = percentage amount by which $Frac_{leach}$ is lower following use of DCD. Currently set at 53% (Clough et al., 2008).

DCD area treated = area of dairy land treated with DCD per year between 2007 and 2012 (from APS)

Total area of dairy = total effective dairy area per year (from APS)

In the years before 2007, and after 2012, DCD was not used in New Zealand, so the DCD weighting factor for these years would be set at 1.

The appropriate weighting factor is then used as an additional multiplier in the current methodology for calculating indirect and direct dairy emissions of N_2O from grazed pastures.

Equation 8.44 *Calculating $Frac_{leach}$ for dairy, accounting for the use of DCD, for May to September:*

Where:

$$Frac_{leach,DCD} = Frac_{leach(PRP)} \times DCD\ weighting\ factor_{Fracleach}$$

$Frac_{leach,DCD}$ = fraction of leaching and runoff from nitrogen in urine applied to soil by dairy cattle between May and September, after accounting for the effects of DCD use.

$Frac_{leach(PRP)}$ = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

DCD weighting $factor_{Fracleach}$ = amount that $Frac_{leach}$ (see Equation 8.42) needs to be multiplied by to account for the effect of DCD between 2007 and 2012

The addition of the weighting factor results in a modified $Frac_{leach}$ of around 0.0696 between 2007 and 2012 for the dairy grazing area in the months that the inhibitor is applied (May to September). The weighting factor is based on information from Statistics New Zealand's Agricultural Production survey that about 3 per cent of the effective dairying area in New Zealand received the inhibitor from 2007 to 2012.

In the years before 2007, and after 2012, DCD was not used in New Zealand, so $Frac_{leach,DCD}$ for these years would be equal to $Frac_{leach}$.

It was assumed that the inhibitor was applied to pastures based on good management practice to maximise N_2O emission reductions. This is an application rate of 10 kilograms per hectare, applied twice per year in autumn and early spring within seven days of the application of animal excreta. ‘Good practice’ application methods of DCD can be by slurry or DCD-coated granules

8.2.3.4 Minor livestock

For minor livestock species, the indirect N_2O emissions from urine and dung deposited onto pasture are not separated into the urine and dung components. This section shows how indirect leaching and run-off N_2O emissions for these species are calculated

8.2.3.4.1 Poultry

Indirect N_2O emissions (from leaching and run-off) from urine and dung deposited on pasture by poultry are calculated by using different parameters for broilers, layers and other poultry.

Equation 8.45 *Indirect leaching and run-off N_2O emissions from urine and dung for poultry:*

$$N_2Oindirect, leaching_{UD,poultry,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(PRP)} \times \sum_x \left(N_{ex,x,t} \times POPpoultry_{x,t} \times MS_{x,PRP}\right)$$

Where:

$N_2Oindirect,leaching_{UD,x,t}$ = indirect N2O emissions from leaching and run-off from urine and dung deposited by poultry type x (i.e. broilers, layers, and other poultry) during grazing in year t (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(PRP)}$ = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year t, for poultry type x (kg of nitrogen per year). See Section 5.7.2 (nitrogen excretion, poultry) for specific values

$POPpoultry_{x,t}$ = population of poultry type *x* in year *t* (from APS)

$MS_{x,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by poultry type x. Assumed to be 4.9% for broilers, 5.8% for layers and 3% for other poultry.

The $MS_{x,PRP}$ values for broilers and layers were determined from a study by Fick et al (2011) while the $MS_{x,PRP}$ value for other poultry is taken from the IPCC 1996 guidelines.

8.2.3.4.2 Swine

Indirect N2O emissions (from leaching and run-off) from urine and dung deposited on pasture by swine are calculated using the following equation.

Equation 8.46 *Indirect leaching and run-off N_2O emissions from urine and dung for swine:*

$$N_2Oindirect, leaching_{UD,swine,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(PRP)} \times N_{ex,swine,t} \times POPswine_t \times MS_{swine,PRP}$$

Where:

$N_2Oindirect,leaching_{UD,swine,t}$ = indirect N_2O emissions from leaching and run-off from urine and dung deposited by swine during grazing in year t (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(PRP)}$ = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year t, for swine (kg of nitrogen per year). See Section 5.7.5 (nitrogen excretion, swine) and Equation 5.28

$POPswine_t$ = population of swine in year *t* (from APS)

$MS_{swine,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by swine. Assumed to be 9% (Hill et al., 2011).

8.2.3.4.3 Goats, horses, alpaca, llamas, mules and asses

For these animals, it is assumed that all manure is excreted directly onto pasture. This means that indirect N_2O emissions (from leaching and run-off) from urine and dung can be calculated from the following equation.

Equation 8.47 *Indirect leaching and run-off N_2O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses:*

$$N_2Oindirect, leaching_{UD,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(PRP)} \times N_{ex,x,t} \times POPminor_{x,t}$$

Where:

$N_2Oindirect,leaching_{UD,x,t}$ = indirect N2O emissions from leaching and run-off from urine and dung deposited by animal type x (i.e. goats, horses…) during grazing in year t (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(PRP)}$ = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year t, for animal type x (kg of nitrogen per year). See Section 5.7 (nitrogen excretion, other livestock sources)

$POPminor_x$ = population of animal type x in year t (from APS)

Specific values of N_{ex} for the different animal categories are outlined in Sections 5.7.1 (goats), 5.7.3 (horses, mules and asses) and 5.7.4 (alpacas).

8.2.4 Crop residues returned to soils

Indirect emissions from crop residues are caused by:

- nitrogen added to soils by above and below-ground crop residue (including residue left behind by crop burning), and
- nitrogen added to soils as a result of mineralisation of forages during pasture renewal.

8.2.4.1 Nitrogen from crop residue (indirect emissions from leaching and runoff)

The equation for estimating indirect N_2O emissions from crop residue decay uses many of the same variables for estimating direct N_2O emissions from crop residue decay. However, the emission factor EF_5 is used instead of EF_3, and there is an additional parameter, $Frac_{leach}$, to account for the proportion of nitrogen (applied to water) that is lost to water. The $Frac_{leach(CR)}$ value of 0.1 is based on research by Welten et al. (2021).

Equation 8.48 *Indirect N_2O emissions from decay of crop residue:*

$$N_2Oindirect_{CR,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(CR)} \times \sum_c \left(AG_{N,c} + BG_{N,c}\right)$$

Where:

$N_2Oindirect_{CR,t}$ = indirect annual N2O emissions from crop residues (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(CR)}$ = fraction of leaching and runoff from nitrogen applied to cropland. Currently set at 0.1 (see Appendix 22)

$AG_{N,c}$ = Amount of above-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year) (see Equation 8.24)

$BG_{N,c}$ = Amount of below-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year) (see Equation 8.26)

c refers to the different crop types listed in Table 8.2 (Section 8.1.4.1)

8.2.4.2 Nitrogen from pasture renewal (indirect emissions from leaching and runoff)

The equation for estimating indirect N_2O emissions from pasture renewal uses many of the same variables for estimating direct N_2O emissions from pasture renewal. However, the emission factor EF_5 is used instead of EF_3, and there is an additional parameter, $Frac_{leach}$, to account for the proportion of nitrogen (applied to water) that is lost to water

Equation 8.49 *Indirect N_2O emissions from pasture renewal:*

$$N_2Oindirect_{Renew,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(Renew)} \times \sum_p F_{CR-Renew,p,t}$$

Where:

$N_2Oindirect_{renew,t}$ = indirect N_2O emissions from pasture renewal in year *t* (kilograms per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(Renew)}$ = fraction of leaching and runoff from nitrogen applied to soil. Currently set at 0.08 (see Appendix 22)

$F_{CR-Renew,p,t}$ = Amount of nitrogen in residues (kg) for pasture type *p* in year t (see Equation 8.28, Section 8.1.4.2)

p refers to the three sections of nitrogen from pasture renewal (either Lucerne on all farms, rye/clover on dairy farms, and rye/clover on sheep, beef and deer farms)

8.2.5 Nitrogen mineralisation

Indirect N2O emissions from nitrogen mineralisation can be calculated using the formula below.

Equation 8.50 *Indirect N_2O emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils*

$$N_2Oindirect_{FSOM,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(CR)} \times F_{SOM}$$

Where:

$N_2Oindirect_{FSOM,t}$ = indirect N_2O emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils in year t (kilograms per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 22).

$Frac_{leach(CR)}$ = fraction of leaching and runoff from nitrogen applied to cropland. Currently set at 0.1 (see Appendix 22)

F_{SOM} = amount of nitrogen mineralised from loss of soil organic matter in mineral soils through land management for *cropland remaining cropland* (kg) (see Equation 8.30 in Section 8.1.5)

8.3 Indirect N_2O emissions associated with nitrogen volatilisation from soils

Nitrogen can be volatised as ammonia or NO_X (reactive oxides of nitrogen) before it is later returned to the soil by wet or dry deposition to be again a candidate for conversion to nitrous oxide. This is another indirect pathway for N_2O production (in addition to leaching and runoff).

In the New Zealand Inventory, there are three sources of indirect agricultural soils emissions from volatilisation:

- Synthetic nitrogen fertiliser
- Organic fertiliser
- Urine and dung from grazing animals

Emissions from each of these sources are discussed in turn.

The basic form of the equation used to calculate indirect volatilisation emissions is below:

Equation 8.51 *Indirect volatilisation N_2O emissions from generic nitrogen source:*

$$N_2Oindirect, volatilisation_N = \frac{44}{28} \times N \times EF_4 \times Frac_{GAS}$$

Where:

$N_2Oindirect, volatilisation_N$ = Indirect volatilisation N_2O emissions from nitrogen applied to soil (kg N_2O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N = amount of nitrogen applied to soils (kg N); (see Appendix 23)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$Frac_{GAS}$ = fraction of nitrogen applied to soil emitted as NO_x or NH_3.

The parameter $Frac_{GAS}$ can either be $Frac_{GASF}$ or $Frac_{GasAM}$ depending on the type or source of nitrogen applied to the soil.

8.3.1 Synthetic fertiliser application and urease inhibitor

Some of the nitrogen fertiliser sold in New Zealand is coated with a substance called urease inhibitor (UI). Urease inhibitors restrict the action of the enzyme urease, which is a catalyst for the volatilisation of the nitrogen into ammonia gas.

The application of all nitrogen fertiliser leads to indirect N_2O emissions from volatilisation[k], but urease inhibitor coated fertiliser (when used instead of non-UI coated fertiliser) can be regarded as a mitigation option as it leads to lower N_2O emissions.

Research from Saggar et al. (2013) has quantified the mitigation effect of urease inhibitor, which is included in New Zealand's Agriculture inventory by adjusting the value of the $Frac_{GASF}$ parameter from 0.1 to 0.055 when urease inhibitor is used.

The equations used to estimate indirect N_2O emissions from volatilisation (by UI and non-UI coated fertiliser) are below.

Equation 8.52 *Indirect volatilisation N_2O emissions from synthetic fertiliser coated with urease inhibitor:*

$$N_2Oindirect, volatilisation_{SN,UI,t} = \frac{44}{28} \times F_{SN,UI,t} \times EF_4 \times Frac_{GASF,UI}$$

[k] in addition to direct N2O emissions (see Section 8.1.1) and indirect leaching N2O emissions (see Section 8.2.1)

Equation 8.53 *Indirect volatilisation N_2O emissions from synthetic fertiliser NOT coated with urease inhibitor :*

$$N_2Oindirect, volatilisation_{SN,no\ UI,t} = \frac{44}{28} \times F_{SN,no\ UI,t} \times EF_4 \times Frac_{GASF}$$

Where:

$N_2Oindirect,volatilisation_{SN,UI,t}$ = indirect volatilisation N_2O emissions from UI coated synthetic nitrogen fertiliser in year *t* (kilograms per year)

$N_2Oindirect,volatilisation_{SN,no\ UI,t}$ = indirect volatilisation N_2O emissions from synthetic nitrogen fertiliser NOT coated with UI in year *t* (kilograms per year)

$F_{SN,UI,t}$ = nitrogen amount of all UI coated synthetic fertiliser applied to soils in year *t* (kg N/yr)

$F_{SN,no\ UI,t}$ = nitrogen amount of synthetic fertiliser NOT coated with UI applied to soils in year *t* (kg N/yr)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$Frac_{GASF,UI}$ = fraction of UI coated synthetic fertiliser emitted as NOx or NH3. Currently set at 0.055 (see Appendix 22)

$Frac_{GASF}$ = fraction of synthetic fertiliser NOT coated with UI emitted as NOx or NH3. Currently set at 0.1 (see Appendix 22)

Urea fertiliser coated with urease inhibitors was first commercially used in New Zealand in 2001. Data on the use of urease inhibitor is collected by the Fertiliser Association of New Zealand. This activity data records the total amount of nitrogen in urea fertiliser that has been treated with a urease inhibitor. Some urea fertiliser coated with urease inhibitors is also blended into other fertiliser products.

8.3.2 Organic nitrogen fertilisers

In New Zealand, emissions from *Organic nitrogen fertilisers* are solely from animal manure that is spread on pasture after collection in manure management systems. In New Zealand, this only occurs for dairy cattle, swine and poultry. Additional information on organic nitrogen fertilisers are contained in Section 8.1.2.

8.3.2.1 Indirect volatilisation organic nitrogen fertiliser emissions for dairy

Equation 8.54 *Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for dairy cattle*

Where:

$$N_2Oindirect, volatilisation_{ON,dairy,t} = \frac{44}{28} \times F_{AM(dairy),t} \times \left(1 - Frac_{GasAM(AL_{Dairy})}\right) \times Frac_{GASam} \times EF_4$$

$N_2Oindirect,volatilisation_{ON,dairy,t}$ = indirect volatilisation N_2O emissions from organic nitrogen fertilisers for all dairy cattle in year *t* (kg per year)

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year *t* (kg per year). See Equation 8.4, Section 8.1.2.1.

$Frac_{GasAM(AL-Dairy)}$ = fraction of nitrogen lost due to volatilisation (currently set at 0.35, as per IPCC (2006) guidelines

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

EF_4 = N_2O emission factor indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

8.3.2.2 Indirect volatilisation organic nitrogen fertiliser emissions for swine

Total indirect leaching emissions from organic nitrogen fertiliser for swine are determined by adding the nitrous oxide caused by waste in the different manure management systems

Equation 8.55 *Indirect volatilisation N_2O emissions from organic nitrogen fertiliser for swine:*

$$N_2Oindirect, volatilisation_{ON,swine,t} = EF_4 \times Frac_{GASam} \times \frac{44}{28}\left(\sum_x \left(N_{ex,swine,t} \times Pmms_{swine,x} \times \left(1 - Frac_{GasAM(x,swine)}\right) \times POPswine_t\right)\right)$$

Where:

$N_2Oindirect,volatilisation_{ON,swine,t}$ = total annual indirect volatilisation N_2O emissions from organic nitrogen fertilisers for swine (kg per year)

EF_4 = N_2O emission factor indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

$N_{ex,swine,t}$ = Annual nitrogen excretion per pig in year *t* (kilograms of nitrogen per year) (see Equation 5.28 in Section 5.7.5.

$Pmms_{swine,x}$ = Proportion of swine waste deposited in manure management system *x* (see Table 7.4, Section 7.2.1.2 for values)

$Frac_{GasAM(x,swine)}$ = fraction of nitrogen lost due to volatilisation for manure management system *x* (see Table 7.4, Section 7.2.1.2 for values)

$POPswine_t$ = swine population in year t (from APS)

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

8.3.2.3 Indirect volatilisation organic nitrogen fertiliser emissions for poultry

Indirect N2O emissions from the volatilisation of organic nitrogen fertiliser from poultry are calculated using parameters for broilers, layers and other poultry. Some of these parameters are different and some are the same.

Equation 8.56 *Indirect volatilisation N_2O emissions from organic nitrogen fertiliser for broilers:*

$$N_2Oindirect, volatilisation_{ON,broiler,t} = N_{ex,broiler} \times Pmms_{broiler,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POPbroiler_t$$

Where:

$N_2Oindirect,volatilisation_{ON,broiler,t}$ = total annual indirect volatilisation N_2O emissions from organic nitrogen fertilisers for broiler chicken (kg per year)

$N_{ex,broiler}$ = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{broiler,other}$ = Proportion of broiler waste deposited in other manure management systems (set at 0.95)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

$POPbroiler_t$ = Broiler population in year t (from APS)

Equation 8.57 *Indirect volatilisation N_2O emissions from organic nitrogen fertiliser for layers:*

$$N_2Oindirect, volatilisation_{ON,layer,t} = N_{ex,layer} \times Pmms_{layer,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POPlayer_t$$

Where:

$N_2Oindirect,volatilisation_{ON,layer,t}$ = total annual indirect volatilisation N_2O emissions from organic nitrogen fertilisers for layer chicken (kg per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer chicken (set at 0.42 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{layer,other}$ = Proportion of layer waste deposited in other manure management systems (set at 0.94)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

$POPlayer_t$ = Layer population in year *t* (from APS)

Equation 8.58 *Indirect volatilisation N_2O emissions from organic nitrogen fertiliser for other poultry:*

$$N_2Oindirect, volatilisation_{ON,other,t} = N_{ex,other} \times Pmms_{other,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POPotherpoultry_t$$

Where:

$N_2Oindirect,leaching_{ON,other,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for other poultry in year t (kg per year)

$N_{ex,other}$ = Annual nitrogen excretion per ‘other’ chicken (set at 0.6 kilograms of nitrogen per year – see Section 5.7.2)

$Pmms_{other,other}$ = Proportion of ‘other poultry’ waste deposited in other manure management systems (set at 0.97)

$Frac_{GasAM,poultry}$ = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

EF_4 = N_2O emission factor indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

$POPotherpoultry_t$ = Other poultry population in year t (from APS)

The results from the above three equations can be summed together to get an estimate of total indirect leaching and runoff N_2O emissions from organic nitrogen fertilisers for all poultry per year.

8.3.3 Urine and dung deposited by grazing animals

This section explains how indirect volatilisation N_2O emissions from urine and dung deposited on pasture are calculated.

8.3.3.1 Dairy

For dairy cattle, the following equations are used to determine indirect N_2O emissions due to volatilisation separately from urine and dung.

Equation 8.59 *Indirect volatilisation N_2O emissions from dairy urine:*

$$N_2Oindirect, volatilisation_{U,dairy,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,volatilisation_{U,dairy,t}$ = annual indirect volatilisation N_2O emissions from urine deposited by dairy cattle during grazing (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$MS_{dairy,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by dairy cattle overall. Assumed to be 100% for all dairy cattle except mature milking cows (values for mature milking cows can be found in Table 7.1, column 3 from Section 7.1.1).

$N_{u,c,m,R}$ = Amount of nitrogen excreted in urine per animal for dairy animal class *c*, in month *m* and region *R* (kg of nitrogen per day). See Section 5.2.4 (Equation 5.8)

$POPdairy_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month m

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of Section 4.4)

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in urine by all dairy cattle in a given year

Equation 8.60 *Indirect volatilisation N_2O emissions from dairy dung:*

$$N_2Oindirect, volatilisation_{D,Dairy,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,volatilisation_{D,dairy,t}$ = annual indirect volatilisation N_2O emissions from dung deposited by dairy cattle during grazing (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$MS_{dairy,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by dairy cattle overall. Assumed to be 100% for all dairy cattle except mature milking cows (values for mature milking cows can be found in Table 7.1, column 3 from Section 7.1.1).

$N_{f,c,m,R}$ = Amount of nitrogen excreted in faeces per animal for dairy animal class *c*, in month *m* and region *R* (kg of nitrogen per day). See Section 5.2.4 (Equation 5.9)

$POPdairy_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month m

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see Section 4.4)

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all dairy cattle in a given year.

8.3.3.2 Beef, sheep and deer

For beef cattle, sheep and deer, 100% of urine and dung is spread onto pasture, and the following equations are used to calculate indirect volatilisation N_2O emissions from urine and dung. These equations are effectively identical to the equations in Section 8.1.3, although the emission factor EF_4 is used instead of EF_3, and there is an additional parameter, $Frac_{GASam}$, to account for the proportion of nitrogen that is emitted as NOx or NH3.

Equation 8.61 *Indirect volatilisation N_2O emissions from urine, for animal species x:*

$$N_2Oindirect, volatilisation_{U,x,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,u,c,m} \times POPx_{c,m} \times nod_m \right)$$

Equation 8.62 *Indirect volatilisation N_2O emissions from dung, for animal species x:*

$$N_2Oindirect, volatilisation_{D,x,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,f,c,m} \times POPx_{c,m} \times nod_m \right)$$

Where:

$N_2Oindirect,volatilisation_{U,x,t}$ = annual indirect volatilisation N_2O emissions from urine deposited by animal species x during grazing (kg of N_2O per year)

$N_2Oindirect,volatilisation_{D,x,t}$ = annual indirect volatilisation N_2O emissions from dung deposited by animal species x during grazing (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$MS_{x,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by animal species *x*. Assumed to be 100% for beef cattle, sheep and deer.

$N_{x,u,c,m}$ = Amount of nitrogen excreted in urine per animal for animal species *x* class *c*, in month *m* (kg of nitrogen per day). See sections 5.2.4, 5.3.5, and 5.4.5

$N_{x,f,c,m}$ = Amount of nitrogen excreted in dung per animal for animal species *x* class *c*, in month *m* (kg of nitrogen per day). See sections 5.2.4, 5.3.5, and 5.4.5

$POPx_{c,m,R}$ = population of animal species *x* in subcategory *c* and month *m*

nod_m = number of days in month *m*

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

x refers to the different animal species, either sheep, beef cattle or deer (but not dairy cattle)

In these equations, the section in brackets is used to calculate the total amount of nitrogen excreted in urine and dung by all beef cattle, sheep or deer in a given year.

8.3.3.3 Minor livestock

This section shows how indirect volatilisation N2O emissions for minor livestock species are calculated. These equations are effectively identical to the equations in Section 8.2.3.4, although the emission factor EF_4 is used instead of EF_5, and $Frac_{GASam}$ is used instead of $Frac_{leach}$.

8.3.3.3.1 Poultry

Indirect N2O emissions (from volatilisation) from urine and dung deposited on pasture by poultry are calculated by using different parameters for broilers, layers and other poultry.

Equation 8.63 *Indirect volatilisation N_2O emissions from urine and dung for poultry:*

$$N_2Oindirect,volatilisation_{UD,poultry,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times \sum_x \left(N_{ex,x,t} \times POPpoultry_{x,t} \times MS_{x,PRP}\right)$$

Where:

$N_2Oindirect,volatilisation_{UD,poultry,x,t}$ = indirect N2O emissions from volatilisation from urine and dung deposited by poultry type x (i.e. broilers, layers, and other poultry) during grazing in year t (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year t, for poultry type x (kg of nitrogen per year). See Section 5.7.2 (nitrogen excretion, poultry) for specific values

$POPpoultry_{x,t}$ = population of poultry type *x* in year *t* (from APS)

$MS_{x,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by poultry type x. Assumed to be 4.9% for broilers, 5.8% for layers and 3% for other poultry.

The $MS_{x,PRP}$ values for broilers and layers were determined from a study by Fick et al (2011) while the $MS_{x,PRP}$ value for other poultry is taken from the IPCC 1996 guidelines.

8.3.3.3.2 Swine

Indirect N2O emissions (from volatilisation) from urine and dung deposited on pasture by swine are calculated using the following equation. This equation is effectively identical to the equation in Section 8.2.3.4.2, although the emission factor EF_4 is used instead of EF_5, and $Frac_{GASam}$ is used instead of $Frac_{leach}$.

Equation 8.64 *Indirect volatilisation N_2O emissions from urine and dung for swine:*

$$N_2Oindirect,volatilisation_{UD,swine,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times N_{ex,swine,t} \times POPswine_t \times MS_{swine,PRP}$$

Where:

$N_2Oindirect,volatilisation_{UD,swine,t}$ = indirect N2O emissions from volatilisation from urine and dung deposited by swine during grazing in year t (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

EF_4 = N_2O emission factor indirect emissions from volatising nitrogen (0.01) (see Figure 8.2 and Appendix 22).

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year t, for swine (kg of nitrogen per year). See Section 5.7.5

$POPswine_t$ = population of swine in year *t* (from APS)

$MS_{swine,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by swine. Assumed to be 9% (Hill et al., 2011).

8.3.3.3.3 Goats, horses, alpaca, llamas, mules and asses

For these animals, it is assumed that all manure is excreted directly onto pasture. This means that indirect N_2O emissions (from volatilisation) from urine and dung can be calculated from the following equation. This equation is effectively identical to the equation in Section 8.2.3.4.3, although the emission factor EF_4 is used instead of EF_5, and $Frac_{GASam}$ is used instead of $Frac_{leach}$.

Equation 8.65 *Indirect volatilisation N_2O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses:*

$$N_2Oindirect, volatilisation_{UD,x,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times N_{ex,x,t} \times POPminor_{x,t}$$

Where:

$N_2Oindirect,volatilisation_{UD,x,t}$ = indirect N2O emissions from volatilisation from urine and dung deposited by animal type x (i.e. goats, horses…) during grazing in year *t* (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 22)

EF_4 = N_2O emission factor indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 22).

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year t, for animal type *x* (kg of nitrogen per year). See Section 5.6 (nitrogen excretion, other livestock sources)

$POPminor_x$ = population of animal type *x* in year t (from APS)

Specific values of N_{ex} for the different animal categories are outlined in sections 5.6.1 (goats), 5.6.3 (horses, mules and asses) and 5.6.4 (alpacas).

9 Field burning of agricultural residues

The burning of crop residues following harvest results in emissions of CH_4, CO, N_2O and NO_x. These emissions are estimated using country-specific parameters, emission factors and methodology which is aligned with the 1996 IPCC methodology (Thomas *et al.,* 2011). Based on industry information, it is assumed that only the residues from barley, oat and wheat crops are burnt.

The calculation of emissions from crop residues uses country-specific data on:

- crop production
- burning statistics, along with
- the proportion of residue actually burnt,
- harvest indices,
- dry matter fractions,
- fraction oxidised
- carbon and nitrogen fractions of the residue.

Country specific values for these parameters are identical to those from the OVERSEER® nutrient budget model for New Zealand (Wheeler *et al.,* 2003) and are the same as those used for estimates of emissions from crop residues (section 8). This provides consistency between the two emissions estimates for crop residue and crop burning.

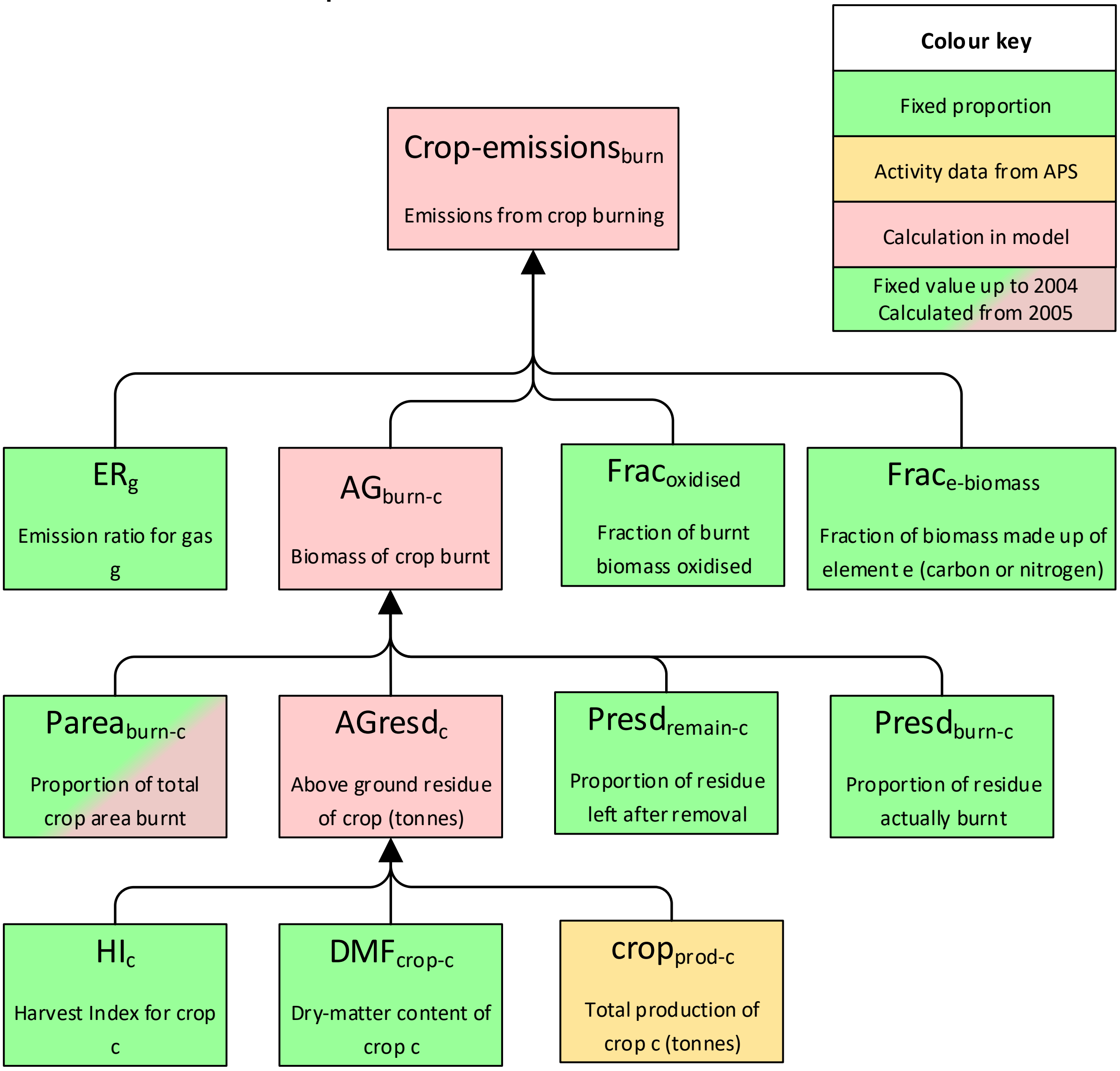
The amount of crop residue burned is estimated from crop production and burning statistics. Country specific data for each crops is then used to calculate the amount of carbon and nitrogen contained in the crop residues

Emissions of CH_4, CO, N_2O and NO_x are estimated by:

- calculating the amount of carbon and nitrogen released and
- multiplying these amounts by various emission ratios.

The diagram below summarises how the different parameters are combined to estimate emissions from crop burning. Statistics New Zealand did not start collecting crop burning area information until 2005. Before 2005, crop burning data is based on farmer survey information (Thomas *et al.,* 2011).

Figure 9.1: Calculation of field burning emissions. Boxes describe activity data, emission factors and calculations required.



9.1 Activity data, parameters and the proportion and areas of crop burning

9.1.1 Activity data

The main activity data sources used to calculate crop burning emissions are:

- Annual production (in tonnes) of barley, oats and wheat crops (from APS),
- Annual area (in hectares) of barley, oats and wheat crops harvested (from APS), and
- Total area (in hectares) of crop residues burnt, (from APS since 2005, note that APS burning area is NOT collected for the individual crop area).

9.1.2 Proportion and area of crop burning

For the years from 2005 onwards, data on the area of crops harvested and the total area of crop residues burnt are used to calculate the area of crop residues burnt for each individual crop ($area_{Burn\text{-}c}$) and the proportion of residues burnt for each crop ($Parea_{Burn\text{-}c}$).

For the years from 1990 to 2004, the proportion of crop area burned was determined by a farmer survey. From this survey it was found that:

- 70 percent of wheat,
- 50 percent of barley, and
- 50 percent of oat.

crop areas were burnt (Thomas *et al.,* 2011). These values are in alignment with Statistics New Zealand data for 2005 – 2007 (2005 being the first year Statistics New Zealand gathered this data from the APS) and were therefore applied to the years 1990 - 2004.

Since areas for each individual crop burnt ($area_{burn-c}$) are not collected in the APS, burning for each crop is apportioned based on the total area burned ($area_{burn,total}$) (Equations 9.4, 9.5 and 9.6 to 316). The proportions are from the farmer survey data used in the pre-2005 calculations (see above). These areas then applied to Equations 9.1, 9.2, and 9.3 to calculate $Parea_{burn-c}$.

The following equations are used to estimate the annual proportions and areas of crop burning for oats and barley, from 2005 onwards.

Equation 9.1 *Proportion of oat area burnt from 2005 onwards:*

$$Parea_{burn-oats} = \frac{area_{burn-oats}}{area_{oats}}$$

Where:

$Parea_{burn-oats}$ = area of oat crop burnt as a proportion of total oat production area (fixed at 0.5 before 2005)

$area_{burn-oats}$ = area of oat crop burnt (hectares)

$area_{oats}$ = production area of oat crop (hectares, from APS)

Equation 9.2 *Proportion of barley area burnt from 2005 onwards:*

$$Parea_{burn-barley} = \frac{area_{burn-barley}}{area_{barley}}$$

Where:

$Parea_{burn-barley}$ = area of barley crop burnt as a proportion of total barley production area (fixed at 0.5 before 2005)

$area_{burn-barley}$ = area of barley crop burnt (hectares)

$area_{barley}$ = production area of barley crop (hectares, from APS)

Equation 9.3 *Proportion of wheat area burnt from 2005 onwards:*

$$Parea_{burn-wheat} = \frac{area_{burn-wheat}}{area_{wheat}}$$

Where:

$Parea_{burn-wheat}$ = area of wheat crop burnt as a proportion of total wheat production area (fixed at 0.7 before 2005)

$area_{burn-wheat}$ = area of wheat crop burnt (hectares)

$area_{wheat}$ = production area of wheat crop (hectares, from APS)

Equation 9.4 *Oat area burnt from 2005 onwards:*

$$area_{burn-oats} = area_{oats} \times 0.5 \times \left(\frac{area_{burn,total}}{area_{oats} \times 0.5 + area_{barley} \times 0.5 + area_{wheat} \times 0.7} \right)$$

Where:

$area_{burn-oats}$ = area of oat crop burnt (hectares)

$area_{oats}$ = production area of oat crop (hectares, from APS)

$area_{burn,total}$ = total area of crop residues burnt (hectares, from APS)

$area_{barley}$ = production area of barley crop (hectares, from APS)

$area_{wheat}$ = production area of wheat crop (hectares, from APS)

Equation 9.5 *Barley area burnt from 2005 onwards:*

$$area_{burn-barley} = area_{barley} \times 0.5 \times \left(\frac{area_{burn,total}}{area_{oats} \times 0.5 + area_{barley} \times 0.5 + area_{wheat} \times 0.7}\right)$$

Where:

$area_{burn-barley}$ = area of barley crop burnt (hectares)

$area_{barley}$ = production area of barley crop (hectares, from APS)

$area_{burn,total}$ = total area of crop residues burnt (hectares, from APS)

$area_{oats}$ = production area of oat crop (hectares, from APS)

$area_{wheat}$ = production area of wheat crop (hectares, from APS)

Equation 9.6 *Wheat area burnt:*

$$area_{burn-wheat} = area_{wheat} \times 0.7 \times \left(\frac{area_{burn,total}}{area_{oats} \times 0.5 + area_{barley} \times 0.5 + area_{wheat} \times 0.7}\right)$$

Where:

$area_{burn-wheat}$ = area of wheat crop burnt (hectares)

$area_{wheat}$ = production area of wheat crop (hectares, from APS)

$area_{burn,total}$ = total area of crop residues burnt (hectares, from APS)

$area_{oats}$ = production area of oat crop (hectares, from APS)

$area_{barley}$ = production area of barley crop (hectares, from APS)

9.1.3 Parameters used in crop burning model

The following tables show the fixed parameters that are used to calculate N_2O, NO_x, CH_4 and CO emissions from crop burning.

Table 9.1: Values used to calculate New Zealand emissions from burning of agricultural residues. Values taken from Thomas *et al.* (2011).

	Barley	Wheat	Oats
Fraction of residue actually burnt (kg above ground residue/kg DM) $Presd_{burn-C}$	0.7	0.7	0.7
Fraction of above ground residue oxidized (kg oxidized/ kg DM) $Frac_{OXIDISED}$	0.9	0.9	0.9
Fraction of nitrogen in biomass (kg N/ kg DM) $Frac_{N-BIOMASS}$	0.005	0.005	0.005
Fraction of carbon in biomass (kg C/ kg DM) crop) $Frac_{C-BIOMASS}$	0.4567	0.4853	0.4567
Dry matter fraction (kg DM/ kg crop DMF_{crop-C}	0.86	0.86	0.86
Harvest Index (see Table 8.1 for values) HI_c	0.46	0.41	0.30

Table 9.2: Emission ratios for agricultural residue burning (Revised IPCC 1996 Guidelines, Table 4-16).

Compound	Emission ratio (kg compound released/kg total compound released during burning)
CH_4	0.005
CO	0.06
N_2O	0.007
NO_x	0.121

9.2 Nitrous oxide field burning emissions

The following equations are used to calculate N_2O emissions from the burning of barley, oats and wheat residues (kt/yr):

Equation 9.7 *Total annual nitrous oxide emissions from field burning of all crops:*

$$cropN_2O_{BURN} = N_2O_{BURN-barley} + N_2O_{BURN-oats} + N_2O_{BURN-wheat}$$

Where:

$cropN_2O_{BURN}$ = annual nitrous oxide emissions from field burning of barley, oats and wheat (kilotonnes per year)

$N_2O_{BURN\text{-}barley}$ = annual nitrous oxide emissions from field burning of barley (kilotonnes per year)

$N_2O_{BURN\text{-}oats}$ = annual nitrous oxide emissions from field burning of oats (kilotonnes per year)

$N_2O_{BURN\text{-}wheat}$ = annual nitrous oxide emissions from field burning of wheat (kilotonnes per year)

Equation 9.8 *Annual nitrous oxide emissions from field burning by crop type:*

$$N_2O_{BURN-c} = \frac{44}{28} \times AG_{BURN-c} \times Frac_{OXIDISED} \times Frac_{N-BIOMASS} \times ER_{N2O}$$

Where:

$N_2O_{BURN\text{-}c}$ = annual nitrous oxide emissions from field burning of crop *c* (i.e. barley, oats or wheat)(kilotonnes per year)

$AG_{BURN\text{-}c}$ = Biomass of crop burnt (tonnes per year) for crop type *c* (i.e. barley, oats or wheat)

$Frac_{OXIDISED}$ = Fraction of burnt biomass that is oxidised (currently set at 0.9 for barley, oats and wheat – see Table 9.1).

$Frac_{N\text{-}BIOMASS}$ = Fraction of biomass made up of nitrogen, (currently set at 0.005 for barley, oats and wheat– see Table 9.1).

ER_{N2O} = Emission ratio for N_2O (currently set at 0.007 – see Table 9.2)

Equation 9.9 *Calculation of biomass burned by crop type:*

$$AG_{BURN-c} = AGresd_c \times Parea_{Burn-c} \times Presd_{Remain-c} \times Presd_{Burn-c}$$

Where:

AG_{BURN-c} = Biomass of crop burnt (tonnes per year) for crop type *c* (i.e. barley, oats or wheat)

$AGresd_c$ = Above-ground residue for crop *c* (tonnes of dry matter per year)

$Parea_{Burn-c}$ = area of crop *c* burnt as a proportion of total production area (see Section 9.1)

$Presd_{Remain-c}$ = proportion of crop residue remaining after any removal, for crop type *c* (set at one for all crop types and years)

$Presd_{Burn-c}$ = proportion of crop residue remaining that is actually burnt, for crop type *c* (set at 0.7 for all crop types and years)

Expert opinion is that if crop residue is to be burned, there is generally no prior removal for feed and bedding. Therefore 100 percent of residue ($Presd_{Remain-c}$) is left for burning after the harvested proportion has been removed (Thomas *et al.,* 2011).

The proportion of residue actually burned ($Presd_{Burn-c}$) has been estimated as 70 percent for all years and crop types as this takes into account required fire break areas and differences in the methods used. It is also assumed that farmers will generally aim to have as close to complete combustion as possible.

The amount of above-ground residue is a function of the amount of biomass produced for each crop and the proportion of total biomass that is harvested.

Equation 9.10 *Above-ground residue by crop type*

$$AGresd_c = Prod_{crop-c} \times DMF_{crop-c} \times \left(\frac{1}{HI_c} - 1\right)$$

Where:

$AGresd_C$ = Above-ground residue for crop *c* (tonnes of dry matter per year)

$Prod_{crop-c}$ = annual production of crop *c*, in tonnes (from APS)

DMF_{crop-c} = Dry matter factor, or the factor used to convert total crop production to dry matter crop production (Currently set to 0.86 for barley, oats and wheat)

HI_c = Harvest index, or the proportion of crop biomass that is harvested for production (see values in Table 9.1)

For each crop residue, the different emission estimates of each gas species is determined and then combined for all different gas types.

9.3 Methane field burning emissions

Methane emissions from field burning are calculated using the following equations.

Equation 9.11 *Total annual methane emissions from field burning of all crops*

$$cropCH_{4_{BURN}} = CH_{4_{BURN-barley}} + CH_{4_{BURN-oats}} + CH_{4_{BURN-wheat}}$$

Where:

$cropCH_{4BURN}$ = annual methane emissions from field burning of barley, oats and wheat (kilotonnes per year)

$CH_{4BURN-barley}$ = annual methane emissions from field burning of barley (kilotonnes per year)

$CH_{4BURN-oats}$ = annual methane emissions from field burning of oats (kilotonnes per year)

$CH_{4BURN-wheat}$ = annual methane emissions from field burning of wheat (kilotonnes per year)

Equation 9.12 *Annual methane emissions from field burning by crop type*

$$CH_{4_{BURN-c}} = CarbonR_{BURN-c} \times molw_{CH4} \times ER_{CH4}$$

Where:

$CH_{4BURN-c}$ = annual methane emissions from field burning of crop *c* (i.e. barley, oats or wheat)(kilotonnes per year)

$CarbonR_{BURN-c}$ = amount of carbon released from burning residues of crop *c*

$molw_{CH4}$ = molecular weight conversion of carbon to methane, (currently set at 16/12).

ER_{CH4} = Emission ratio for methane (currently set at 0.005 – see Table 9.2)

Equation 9.13 *Amount of carbon released from field burning by crop type*

$$CarbonR_{BURN-c} = AG_{BURN-c} \times Frac_{OXIDISED} \times Frac_{c-BIOMASS}$$

Where:

$CarbonR_{BURN-c}$ = amount of carbon released from burning residues of crop *c*

AG_{BURN-c} = Biomass of crop burnt (tonnes per year) for crop type *c* (i.e. barley, oats or wheat; see Equation 9.9, Section 9.2)

$Frac_{OXIDISED}$ = Fraction of burnt biomass that is oxidised (currently set at 0.9 for barley, oats and wheat – see Table 9.1).

$Frac_{c-BIOMASS}$ = Fraction of biomass made up of carbon, for crop type *c* (see Table 9.1 for values).

9.4 Carbon monoxide field burning emissions

Although carbon monoxide is not a greenhouse gas, their emissions have an indirect greenhouse effect. Carbon monoxide emissions from field burning can be calculated by using the equations below.

Equation 9.14 *Total annual carbon monoxide emissions from field burning of all crops*

$$cropCO_{BURN} = CO_{BURN-barley} + CO_{BURN-oats} + CO_{BURN-wheat}$$

Where:

$cropCO_{BURN}$ = annual carbon monoxide emissions from field burning of barley, oats and wheat (kilotonnes per year)

$CO_{BURN-barley}$ = annual carbon monoxide emissions from field burning of barley (kilotonnes per year)

$CO_{BURN-oats}$ = annual carbon monoxide emissions from field burning of oats (kilotonnes per year)

$CO_{BURN-wheat}$ = annual carbon monoxide emissions from field burning of wheat (kilotonnes per year)

Equation 9.15 *Annual carbon monoxide emissions from field burning by crop type*

$$CO_{BURN-C} = CarbonR_{BURN-C} \times molw_{CO} \times ER_{CO}$$

Where:

CO_{BURN-C} = annual carbon monoxide emissions from field burning of crop c (i.e. barley, oats or wheat)(kilotonnes per year)

$CarbonR_{BURN-C}$ = amount of carbon released from burning residues of crop c (see Equation 9.13 in Section 9.3)

$molw_{CO}$ = molecular weight conversion of carbon to carbon monoxide, (currently set at 14/6).

ER_{CO} = Emission ratio for carbon monoxide (currently set at 0.06 – see table 13)

9.5 NO_x field burning emissions

NO_x refers to nitrogen oxides such as nitric oxide (NO) and nitrogen dioxide (NO_2). Although they are not a greenhouse gases, their emissions have an indirect greenhouse effect. NO_x emissions from field burning can be calculated by using the equations below.

Equation 9.16 *Total NO_x emissions from field burning of all crops*

$$cropNO_{X_{BURN}} = NO_{X_{BURN-barley}} + NO_{X_{BURN-oats}} + NO_{X_{BURN-wheat}}$$

Where:

$cropNO_{XBURN}$ = annual NO_x emissions from field burning of barley, oats and wheat (kilotonnes per year)

$NO_{XBURN-barley}$ = annual NO_x emissions from field burning of barley (kilotonnes per year)

$NO_{XBURN-oats}$ = annual NO_x emissions from field burning of oats (kilotonnes per year)

$NO_{XBURN-wheat}$ = annual NO_x emissions from field burning of wheat (kilotonnes per year)

Equation 9.17 *Annual NO_x emissions from field burning by crop type*

$$NO_{XBURN-c} = NitrogenR_{BURN-c} \times molw_{CH4} \times ER_{CH4}$$

Where:

CO_{BURN-c} = annual NO_x emissions from field burning of crop *c* (i.e. barley, oats or wheat)(kilotonnes per year)

$NitrogenR_{BURN-c}$ = amount of nitrogen released from burning residues of crop *c* (see Equation 9.18)

$molw_{CO}$ = molecular weight conversion of nitrogen to NO_x, (uses a value of 46/14).

ER_{NOx} = Emission ratio for NO_x (currently set at 0.06 – see Table 9.2)

Equation 9.18 *Amount of nitrogen released from field burning by crop type*

$$NitrogenR_{BURN-c} = AG_{BURN-c} \times Frac_{OXIDISED} \times Frac_{N-BIOMASS}$$

Where:

$NitrogenR_{BURN-c}$ = amount of nitrogen released from burning residues of crop *c*

AG_{BURN-c} = Biomass of crop burnt (tonnes per year) for crop type *c* (i.e. barley, oats or wheat; see Equation 9.9, Section 9.2)

$Frac_{OXIDISED}$ = Fraction of burnt biomass that is oxidised (currently set at 0.9 for barley, oats and wheat – see Table 9.1).

$Frac_{N-BIOMASS}$ = Fraction of biomass made up of nitrogen, (currently set at 0.005, see Table 9.1 for values).

10 Carbon dioxide from lime, dolomite and urea application

10.1 Lime and Dolomite

In New Zealand, lime and dolomite fertilizers are mainly applied to acidic grassland and cropland soils to reduce soil acidity and to maintain or increase the production of pasture and crops.

Emissions associated with liming are estimated using a Tier 1 methodology and equation 11.12 from Annex 2 of the IPCC (2006) guidelines, using the default emission factors for carbon (C) conversion of 0.12 and 0.13 for limestone and dolomite, respectively. A single national correction factor of 0.82 is applied to agricultural lime to account for its impurities and moisture content. The value for the national correction factor was determined from a study by Thomson et al (2021). The same study recommended that a similar adjustment not be made to the dolomite calculations, based on the samples analysed for dolomite.

Because of gaps in the time-series of this data for 1991 and from 1997-2001, a linear interpolation was used to estimate data on the use of limestone and dolomite for these years. For the remaining years, the equation used to determine carbon dioxide (CO_2) emissions from the application of limestone and dolomite is shown below.

Equation 10.1 *Carbon dioxide emissions from limestone and dolomite application*

$$CO_{2lime\&dolomite} = (M_{Lime} \times conc_{Lime} \times EF_{Lime} \times molw_{CO2}) + (M_{dolomite} \times conc_{Dolomite} \times EF_{dolomite} \times corr_{CO2})$$

Where:

$CO_{2lime\&dolomite}$ = annual CO_2 emissions from the use of limestone and dolomite (kg CO_2 per year)

M_{Lime} = Total annual amount of calcic limestone applied on farms (kg per year) (see Appendix 26)

$conc_{Lime}$ = Concentration factor to account for purity of agricultural lime (set at 0.82)

EF_{Lime} = Emission factor for calcic limestone (carbonate content of limestone, currently set at 0.12)

$corr_{CO2}$ = molecular weight of CO_2 relative to that for carbon (set at 44/12, or 3.666666)

$M_{dolomite}$ = Total annual amount of dolomite applied on farms (kg per year)(See Appendix 26)

$conc_{Dolomite}$ = Concentration factor to account for purity of dolomite (set at 1)

$EF_{dolomite}$ = Emission factor for dolomite (carbonate content of dolomite, currently set at 0.13)

The variable $molw_{CO2}$ is a conversion factor to convert from the mass of C in CO_2, to the total mass of CO_2.

10.2 Urea Application

The use of urea fertilizer, which accounts for the majority of synthetic nitrogen fertilizer used in New Zealand, produces CO_2 emissions following application to soil. The CO_2 is formed from bicarbonate, which is produced when the urea is converted to ammonium via hydrolysis. The CO_2 emissions are estimated using a Tier 1 methodology and equation 11.13 from Annex 2 of the IPCC (2006) guidelines, using the default emission factor ($EF_{urea\text{-}carbon}$) of 0.20. Data on the annual total weight of synthetic N fertilizer applied on farms and the percentage represented as urea is sourced from the Fertiliser Association of New Zealand. This data is also used to calculate N_2O emissions from urea fertilizer as in Section 8. The following equation is used to calculate the CO_2 emissions from the application of urea fertilizer.

Equation 10.2 *Carbon dioxide emissions from urea application*

$$CO_{2urea} = M_{urea} \times EF_{urea-carbon} \times corr_{CO2}$$

Where:

CO_{2urea}= annual CO_2 emissions from the use of urea (kg CO_2 per year)

M_{urea} = Total annual amount of urea applied on farms (kg per year)(see Appendix 26)

$EF_{urea\text{-}carbon}$ = Emission factor for CO_2 emissions from urea after reaction in soil (currently set at 0.2)

$corr_{CO2}$ = molecular weight of CO_2 relative to that for carbon (set at 44/12, or 3.666666)

For this equation it is important to note that M is the *total* weight of urea applied to farms in New Zealand, not just the N or C content.

11 Prescribed burning of savannah

From 1990-2014, New Zealand has reported this Section under New Zealand's Agricultural Greenhouse Gas inventory. As from 2015 onwards it is being reported under the LULUCF Section of New Zealand's Greenhouse Gas inventory.

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13 Appendices

Appendix 1: Key annual dairy inputs

Live weight of cow is calculated as weighted average of cow weights for three main dairy breeds as reported in New Zealand Dairy Statistics (example see Appendix 12). See section 4.8.1 for details on the live weight calculations. Milk yield, butterfat and protein values from New Zealand Dairy Statistics are adjusted from litres to kg by multiply by a factor of 1.03.

Year	Bull Weight (kg)	Bull Live Weight Change (kg/yr)	Cow Weight (kg)	Milk fat kg(fat)/100 litres(milk))	Protein (kg(protein)/ 100 litres(milk))	Nitrogen retained in tissue (N_{te}) (% kg(N)/ 100kg (live weight)	National annual milk yield (L per year)
1990	500	0.5	446.18	4.80	3.52	3.26	7,199,076,204
1995	500	0.5	452.44	4.88	3.61	3.26	8,957,454,544
2000	500	0.5	454.91	4.81	3.62	3.26	11,630,000,000
2005	500	0.5	455.35	4.92	3.68	3.26	14,102,595,458
2006	500	0.5	445.44	4.93	3.69	3.26	14,701,975,135
2007	500	0.5	444.21	4.96	3.74	3.26	15,134,213,303
2008	500	0.5	456.30	4.90	3.71	3.26	14,744,861,642
2009	500	0.5	451.51	4.93	3.75	3.26	16,043,994,818
2010	500	0.5	460.53	4.95	3.77	3.26	16,482,852,896
2011	500	0.5	458.04	4.95	3.77	3.26	17,338,831,557
2012	500	0.5	464.66	4.99	3.82	3.26	19,128,618,744
2013	500	0.5	463.60	4.97	3.81	3.26	18,882,664,882
2014	500	0.5	464.57	5.00	3.83	3.26	20,657,382,978
2015	500	0.5	472.35	5.02	3.87	3.26	21,252,748,077
2016	500	0.5	471.74	5.02	3.88	3.26	20,914,138,460
2017	500	0.5	478.14	5.03	3.91	3.26	20,701,764,421
2018	500	0.5	477.81	5.00	3.88	3.26	20,723,508,239
2019	500	0.5	479.94	4.98	3.90	3.26	21,217,087,727
2020	500	0.5	480.60	5.01	3.96	3.26	21,148,494,195
2021	500	0.5	490.83	5.02	3.96	3.26	21,708,623,242
2022	500	0.5	488.94	5.04	3.95	3.26	20,777,111,475
2023	500	0.5	488.77	5.07	3.98	3.26	20,701,526,405

Appendix 2: Age used for each species category for the calculation of basal energy

Species class	Species Class	Age used (yr)
Dairy	Milking cows - mature	4
	Growing heifers 0 – 1	0.5
	Growing heifers 1 – 2	1.5
	Breeding Bulls	4
Beef	Breeding growing cows 0 – 1	0.5
	Breeding growing cows 1 – 2	1.5
	Breeding growing cows 2 – 3	2.5
	Breeding mature cows	4
	Breeding Bulls – mixed age	4
	Slaughter Heifers 0 – 1	0.5
	Slaughter Heifers 2 – 3	2.5
	Slaughter steers 0 – 1	0.5
	Slaughter steers 1 – 2	1.5
	Slaughter steers 2 – 3	2.5
	Slaughter Bulls 0 - 1	0.5
	Slaughter Bulls 1 – 2	1.5
	Slaughter Bulls 2 – 3	2.5
Sheep	Breeding ewes	4
	Dry ewes	4
	Growing breeding sheep	1.5
	Growing non-breeding sheep	1.5
	Wethers	4
	Lambs	0.5
	Rams	3
Deer	Hinds 0 -1	0.5
	Hinds 1 -2	1.5
	Mature hinds	4
	Stags 0 - 1	1
	Stags 1 - 2	1.5
	Stags 2 - 3	2.5
	Mature stags	4

Appendix 3: Monthly energy concentration, digestibility, and nitrogen concentration of pasture for entire time series

Provided through an analysis of nationally collated data on metabolisable energy, dry matter digestibility, and nitrogen content (Giltrap & McNeill, 2020). Note this is different to the values for the total diet, which includes supplementary feed.

Metabolisable Energy (MJ/kg)			
Month	**Dairy**	**Beef**	**Sheep**
July	11.8	10.8	10.8
August	12.1	11.1	11.1
September	12.3	11.3	11.3
October	12.3	11.3	11.3
November	11.3	10.3	10.3
December	11.1	10.1	10.1
January	10.6	9.6	9.6
February	10.3	9.2	9.2
March	10	9	9
April	10.6	9.6	9.6
May	10.8	9.7	9.7
June	11.5	10.5	10.5

Digestibility (DMD)			
Month	**Dairy**	**Beef**	**Sheep**
July	0.782	0.728	0.728
August	0.798	0.746	0.746
September	0.810	0.761	0.761
October	0.807	0.757	0.757
November	0.760	0.701	0.701
December	0.743	0.682	0.682
January	0.732	0.669	0.669
February	0.704	0.638	0.638
March	0.691	0.623	0.623

April	0.729	0.666	0.666
May	0.744	0.683	0.683
June	0.772	0.715	0.715

	Nitrogen %		
Month	**Dairy**	**Beef**	**Sheep**
July	3.98	3.55	3.55
August	4.09	3.65	3.65
September	4.16	3.72	3.72
October	3.69	3.25	3.25
November	3.23	2.8	2.8
December	3.15	2.72	2.72
January	3.02	2.59	2.59
February	2.86	2.43	2.43
March	3.1	2.66	2.66
April	3.4	2.97	2.97
May	3.57	3.13	3.13
June	3.79	3.36	3.36

Appendix 4: Deer split between Land Use Classes (LUC)

The ME, digestibility, and nitrogen content of deer pasture are calculated as a weighted average of pasture values on dairy and beef-sheep land (Suttie 2012). Over time the deer herd has grazed less on dairy land and more on land used for sheep and beef. From 2010 onwards, it is assumed only 10 percent of the deer herd remains on dairy land, and 90 percent on sheep and beef land (Suttie 2012).

Year	LUC 1-4 (Dairy)	LUC6-7 (Sheep and Beef)
1990	46.0	54.0
1991	46.5	53.5
1992	45.0	55.0
1993	43.5	56.5
1994	42.0	58.0
1995	40.5	59.5
1996	39.0	61.0
1997	38.7	61.3
1998	38.3	61.7
1999	38.0	62.0
2000	37.7	62.3
2001	37.3	62.7
2002	37.0	63.0
2003	36.5	63.5
2004	36.0	64.0
2005	32.5	67.5
2006	29.0	71.0
2007	24.5	75.5
2008	20.0	80.0
2009	15.0	85.0
2010	10.0	90.0

Appendix 5: energy concentration, digestibility, and nitrogen concentration of non-pasture feed for entire time series

Feed quality data for supplementary feeds was obtained from Provision of Laboratory Data on Feed Quality prepared by Hill Laboratories (Calvert, 2020). Data included ME content (MJ/kg), nitrogen content (N%), and digestibility (DMD%) for most feed types. Those not included were assumed to be the same as pasture.

Feed	Metabolisable Energy (MJ/kg)	DMD	Nitrogen %
Barley	12.96	0.90	1.90
Barley silage	9.80	0.64	1.81
Cereal whole crop silage	9.49	0.62	1.86
Cottonseed	11.12	0.76	8.11
Fodder Beet	12.12	0.86	1.96
Kale	12.67	0.85	2.81
Maize Grain	13.77	0.94	1.40
Maize Silage	10.86	0.72	1.25
Baleage	9.97	0.66	2.29
Oats	9.00	0.58	1.91
PKE	11.56	0.82	2.79
Rape	13.02	0.88	3.42
Soyabean	12.75	0.89	8.27
Tapioca	11.29	0.80	0.63
Swedes	13.54	0.86	3.09
Wheat	13.38	0.94	2.12
Turnips	13.54	0.86	3.09

Appendix 6: Dairy cattle diet composition

Data on non-pasture feed consumed by dairy cattle was sourced from (DairyNZ Economics Group, 2019). The report provides a summary of the annual trends in feed use on New Zealand dairy farms from 1990-91 to 2017-18 as well as forecasts for the 2018-19 and 2019-20 seasons.

Season	Pasture	Palm kernel extract	Maize Grain	Maize Silage	Cereal whole crop silage	Fodder Beet	Kale	Turnips	Swedes	Other Supplements
1990-91	96%	0%	0%	1%	0%	0%	0%	1%	0%	1%
1995-96	95%	0%	0%	1%	0%	0%	0%	1%	0%	1%
2000-01	94%	0%	0%	2%	0%	0%	0%	1%	1%	1%
2001-02	93%	0%	0%	2%	1%	0%	1%	1%	1%	2%
2002-03	93%	0%	0%	2%	1%	0%	1%	1%	1%	2%
2003-04	92%	0%	0%	3%	1%	0%	1%	1%	1%	1%
2004-05	91%	1%	0%	3%	1%	0%	1%	1%	1%	2%
2005-06	90%	1%	0%	3%	1%	0%	1%	1%	1%	2%
2006-07	88%	2%	0%	5%	1%	0%	1%	1%	1%	2%
2007-08	85%	3%	0%	6%	1%	0%	1%	1%	1%	2%
2008-09	85%	4%	0%	6%	0%	0%	1%	1%	1%	2%
2009-10	86%	4%	0%	5%	0%	0%	1%	1%	1%	2%
2010-11	85%	5%	0%	4%	0%	0%	1%	1%	1%	2%
2011-12	84%	5%	0%	4%	0%	1%	1%	1%	1%	2%
2012-13	83%	5%	0%	5%	0%	1%	1%	1%	1%	2%
2013-14	81%	6%	0%	5%	0%	3%	1%	1%	1%	2%
2014-15	81%	6%	0%	4%	0%	3%	1%	1%	1%	2%
2015-16	81%	6%	0%	4%	0%	3%	1%	1%	1%	2%
2016-17	82%	6%	0%	3%	0%	4%	1%	1%	1%	2%
2017-18	81%	7%	0%	4%	0%	3%	1%	1%	1%	2%
2018-19	82%	5%	0%	4%	0%	3%	1%	1%	1%	2%
2019-20	82%	6%	0%	4%	0%	3%	1%	1%	1%	2%
2020-21	83%	5%	0%	4%	0%	3%	1%	1%	1%	2%
2021-22	82%	6%	0%	4%	0%	3%	1%	1%	1%	2%
2022-23	82%	6%	0%	4%	0%	3%	1%	1%	1%	2%
2023-24	82%	6%	0%	4%	0%	3%	1%	1%	1%	2%

Appendix 7: Beef cattle and sheep diet composition

Data on supplementary feed consumed by beef cattle was sourced from the report Supplementary Feed Use in the Beef Industry prepared by AbacusBio in 2018 (Sise, et al., 2018).

Data on supplementary feed consumed by sheep was sourced from the report Supplementary Feed Use in the Sheep Industry prepared by AbacusBio in 2017 (Sise, et al., 2017).

		Beef cattle				Sheep						
Season	Month	Baleage	Kale	Swedes	Pasture	Baleage	Barley silage	Kale	Leafy turnip	Sheep nuts	Swedes	Pasture
1990-91	July	5%	11%	10%	73%	4%	0%	1%	0%	1%	12%	82%
1990-91	August	8%	10%	11%	71%	5%	0%	0%	0%	1%	12%	82%
1990-91	September	3%	0%	11%	86%	2%	0%	0%	0%	0%	4%	94%
1990-91	October	2%	0%	0%	98%	0%	0%	0%	0%	0%	0%	100%
1990-91	November	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
1990-91	December	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
1990-91	January	0%	0%	0%	100%	0%	0%	0%	3%	0%	0%	97%
1990-91	February	0%	0%	0%	100%	1%	0%	0%	4%	0%	0%	95%
1990-91	March	0%	0%	0%	100%	1%	0%	0%	3%	1%	0%	96%
1990-91	April	0%	0%	0%	100%	0%	0%	0%	2%	1%	0%	97%
1990-91	May	0%	0%	1%	99%	2%	0%	0%	0%	0%	2%	95%
1990-91	June	1%	13%	2%	84%	4%	0%	0%	0%	0%	13%	83%
1994-95	July	6%	7%	8%	79%	5%	0%	0%	0%	1%	11%	83%
1994-95	August	7%	8%	9%	76%	6%	0%	0%	0%	1%	12%	81%
1994-95	September	2%	6%	6%	86%	1%	0%	0%	0%	0%	3%	96%
1994-95	October	2%	0%	5%	93%	0%	0%	0%	0%	0%	0%	100%
1994-95	November	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
1994-95	December	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
1994-95	January	0%	0%	0%	100%	0%	0%	0%	1%	0%	0%	99%
1994-95	February	0%	0%	0%	100%	0%	0%	0%	6%	0%	0%	94%
1994-95	March	0%	0%	0%	100%	0%	0%	0%	4%	1%	0%	95%
1994-95	April	0%	0%	0%	100%	0%	0%	0%	2%	1%	0%	98%
1994-95	May	0%	0%	2%	98%	2%	0%	0%	0%	0%	2%	96%
1994-95	June	1%	2%	7%	89%	5%	0%	0%	0%	0%	11%	84%
1998-99	July	4%	7%	10%	79%	4%	0%	0%	0%	1%	12%	84%
1998-99	August	5%	9%	9%	78%	5%	0%	0%	0%	1%	12%	82%

1998-99	September	2%	3%	5%	90%	2%	0%	0%	0%	0%	2%	96%
1998-99	October	2%	0%	4%	94%	0%	0%	0%	0%	0%	0%	100%
1998-99	November	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
1998-99	December	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
1998-99	January	0%	0%	0%	100%	0%	0%	0%	2%	0%	0%	98%
1998-99	February	0%	0%	0%	100%	0%	0%	0%	7%	0%	0%	93%
1998-99	March	0%	0%	0%	100%	0%	0%	0%	4%	1%	0%	95%
1998-99	April	0%	0%	0%	100%	0%	0%	0%	1%	1%	0%	98%
1998-99	May	0%	0%	1%	99%	1%	0%	0%	0%	0%	2%	96%
1998-99	June	1%	7%	6%	86%	4%	0%	0%	0%	0%	11%	86%
2002-03	July	2%	6%	7%	86%	2%	0%	0%	0%	1%	10%	87%
2002-03	August	5%	9%	7%	79%	5%	0%	0%	0%	1%	11%	84%
2002-03	September	4%	4%	7%	85%	1%	0%	0%	0%	0%	2%	96%
2002-03	October	3%	0%	3%	94%	0%	0%	0%	0%	0%	0%	100%
2002-03	November	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2002-03	December	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2002-03	January	0%	0%	0%	100%	0%	0%	0%	2%	0%	0%	98%
2002-03	February	0%	0%	0%	100%	0%	0%	0%	7%	0%	0%	92%
2002-03	March	0%	0%	0%	100%	0%	0%	0%	4%	1%	0%	95%
2002-03	April	0%	0%	0%	100%	0%	0%	0%	3%	1%	0%	97%
2002-03	May	0%	0%	3%	97%	2%	0%	0%	0%	0%	3%	96%
2002-03	June	1%	6%	6%	87%	2%	0%	0%	0%	0%	9%	89%
2006-07	July	2%	4%	8%	86%	3%	0%	0%	0%	1%	12%	84%
2006-07	August	5%	11%	11%	73%	4%	1%	0%	0%	1%	11%	83%
2006-07	September	4%	1%	7%	88%	1%	1%	0%	0%	0%	2%	96%
2006-07	October	3%	0%	5%	92%	0%	0%	0%	0%	0%	0%	100%
2006-07	November	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2006-07	December	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2006-07	January	0%	0%	0%	100%	0%	0%	0%	3%	0%	0%	97%
2006-07	February	0%	0%	0%	100%	0%	0%	0%	9%	0%	0%	91%
2006-07	March	0%	0%	0%	100%	1%	0%	0%	5%	1%	0%	93%
2006-07	April	0%	0%	0%	100%	0%	0%	0%	3%	0%	0%	97%
2006-07	May	0%	0%	2%	98%	1%	0%	0%	0%	0%	2%	96%

2006-07	June	1%	7%	6%	87%	2%	0%	0%	0%	0%	10%	87%
2010-11	July	2%	4%	12%	82%	2%	0%	0%	0%	1%	12%	86%
2010-11	August	3%	9%	12%	76%	4%	1%	0%	0%	1%	12%	82%
2010-11	September	3%	3%	8%	87%	1%	1%	0%	0%	0%	2%	96%
2010-11	October	2%	0%	3%	95%	0%	0%	0%	0%	0%	0%	100%
2010-11	November	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2010-11	December	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2010-11	January	0%	0%	0%	100%	0%	0%	0%	3%	0%	0%	97%
2010-11	February	0%	0%	0%	100%	0%	0%	0%	10%	0%	0%	90%
2010-11	March	0%	0%	0%	100%	2%	0%	0%	4%	1%	0%	94%
2010-11	April	0%	0%	0%	100%	0%	0%	0%	3%	0%	0%	97%
2010-11	May	0%	0%	2%	98%	3%	0%	0%	0%	0%	3%	95%
2010-11	June	1%	5%	10%	84%	2%	0%	0%	0%	0%	11%	87%
2014-15	July	3%	4%	8%	86%	2%	0%	0%	0%	1%	12%	85%
2014-15	August	4%	7%	11%	78%	5%	2%	0%	0%	1%	13%	80%
2014-15	September	3%	1%	20%	75%	2%	1%	0%	0%	0%	3%	94%
2014-15	October	4%	0%	7%	90%	0%	0%	0%	0%	0%	0%	100%
2014-15	November	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2014-15	December	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%
2014-15	January	0%	0%	0%	100%	0%	0%	0%	3%	0%	0%	97%
2014-15	February	0%	0%	0%	100%	0%	0%	0%	9%	0%	0%	90%
2014-15	March	0%	0%	0%	100%	0%	0%	0%	6%	1%	0%	94%
2014-15	April	0%	0%	0%	100%	0%	0%	0%	4%	0%	0%	95%
2014-15	May	0%	4%	1%	95%	1%	0%	0%	0%	0%	1%	98%
2014-15	June	0%	8%	3%	89%	1%	0%	0%	0%	0%	9%	90%

Appendix 8: Proportion of annual milk yield each month

Month	Dairy (2023)*	Beef	Sheep	Deer
July	0.013	0	0	0
August	0.060	0	0	0
September	0.112	0.167	0.164	0
October	0.135	0.167	0.254	0
November	0.127	0.167	0.246	0.1
December	0.119	0.167	0.254	0.258
January	0.108	0.167	0.082	0.258
February	0.087	0.167	0	0.233
March	0.093	0	0	0.150
April	0.082	0	0	0
May	0.053	0	0	0
June	0.011	0	0	0

- **Dairy values vairy annually based on DCANZ data**

Appendix 9: Cumulative pregnancy of days pregnant used in ME requirement equations

Month	Dairy	Beef	Sheep	Deer
July	257	215	97	159
August	269	246	128	190
September	0	269	138	220
October	0	0	0	251
November	14	0	0	269
December	45	3	0	0
January	76	34	0	0
February	104	62	0	6
March	135	93	0	37
April	165	123	5	67
May	196	154	36	98
June	226	184	66	128

Appendix 10: Dairy population data from Statistics NZ

Values are June year end. Population models are used to adjust populations on a monthly basis, enabling aggregations by calendar year. See Clark (2008) for further details. Regional population data is available but confidential.

June year end	Population Data			
	Dairy Cows & Heifers (1 Year and Over) NOT in Milk or in Calf	Dairy Cows & Heifers (1 Year and Over) in Milk or in Calf	Dairy Cattle Total	Dairy Breeding Bulls
1990	86692	2723288	3440815	31174
1995	158394	3153235	4089818	31544
2000	202156	3505508	4598136	49300
2001	211846	3673531	4879862	51663
2002	221538	3841553	5161589	54027
2003	149190	3928140	5101603	43707
2004	174124	4103318	5152492	44661
2005	212040	4120176	5087178	38535
2006	234881	4137696	5169557	45190
2007	305727	4167121	5260850	53331
2008	335564	4347656	5578440	56466
2009	331427	4606970	5860775	60489
2010	339284	4680097	5915451	57807
2011	403707	4816190	6174503	66448
2012	407820	5009795	6445681	70410
2013	418867	5004635	6483601	75141
2014	483231	5175869	6698063	79571
2015	335787	5056402	6485536	70549
2016	345398	5202469	6618799	69582
2017	414784	5043813	6529811	71079
2018	391343	5012313	6385932	79886
2019	333450	4876113	6260894	68619
2020	359786	4836728	6200221	76958
2021	371628	4804582	6185437	84604
2022	313503	4622551	5930033	72791
2023	299345	4625226	5884628	59048

Appendix 11: Mature milking cow loss distribution

Monthly distribution (% of annual losses) of dairy cows (aged 2 years or older) slaughter (went to works). Average of 5 year means July 1990 to June 2020. Sourced from the Dairy Industry Good Animal Database (DIGAD).

Month	% of annual slaughter deaths	Percentage of the 1 July population remaining at the end of the month, using an annual loss of 16.9%
Jul	5.3	99.1
Aug	5.3	98.2
Sep	5.4	97.3
Oct	5	96.4
Nov	3.9	95.8
Dec	4	95.1
Jan	5.1	94.3
Feb	7.2	93
Mar	11.9	91
Apr	14.9	88.5
May	21.4	84.9
Jun	10.7	83.1

Appendix 12: Dairy cow weights

An example for June year end 2010 of how dairy cow weights are determined from the model the data are obtained from Dairy NZ statistics. The proportion of cow weights in each age class are determined from the proportion of the number of cows in each age class to the total number of cows multiplied by the specific weight of the cow for its respective age class. Cows in the "Other" category are assumed to have a weight equal to the mean of the named categories.

Example for June year end 2010. Data obtained from Dairy NZ Statistics:

Season	Breed	Percent	Liveweight (kg)
2010	Ayrshire (Other)	0.8	444
2010	Friesian	36.2	492
2010	Friesian-Jersey cross	41.8	454
2010	Jersey	12.7	385
2010	Other	8.5	444

Appendix 13: Beef inputs for the Tier Two Inventory program

The live weight of mature cow is calculated using dairy cow weights and slaughter weights (Appendix 15). See section 4.8.2 for details. Milk yield is kept constant for beef cows. Butterfat and protein values from New Zealand Dairy Statistics are applied to beef cow milk (Appendix 1) adjusted from litres to kg by multiply by a factor of 1.03.

Year	Steer cwt weight (kg)	Heifer cwt weight (kg)	Bull cwt weight (kg)	Breeding bull live weight (kg)	Live weight change breeding bull (kg/yr)	Milk yield per cow per annum (kg/year)	Milk fat (kg(fat)/ 100 L(milk))	Protein (kg(protein)/ 100 L(milk))	Nitrogen retained in tissue (N_{te}) (kg(N)/ 100kg(live weight)
1990	281.66	203.92	275.10	600.00	0.50	824.00	4.80	3.34	3.26
1995	301.35	218.17	294.54	600.00	0.50	824.00	4.88	3.34	3.26
2000	301.33	220.67	300.01	600.00	0.50	824.00	4.81	3.34	3.26
2001	308.81	220.78	304.81	600.00	0.50	824.00	4.84	3.34	3.26
2002	306.00	222.80	299.02	600.00	0.50	824.00	4.83	3.34	3.26
2003	307.02	227.22	304.38	600.00	0.50	824.00	4.86	3.34	3.26
2004	311.84	229.38	308.03	600.00	0.50	824.00	4.90	3.34	3.26
2005	311.30	229.21	310.03	600.00	0.50	824.00	4.92	3.34	3.26
2006	317.76	232.86	314.09	600.00	0.50	824.00	4.93	3.34	3.26
2007	311.84	230.80	307.57	600.00	0.50	824.00	4.96	3.34	3.26
2008	303.86	231.46	299.26	600.00	0.50	824.00	4.90	3.34	3.26
2009	301.54	229.11	299.50	600.00	0.50	824.00	4.93	3.34	3.26
2010	311.74	237.49	311.14	600.00	0.50	824.00	4.95	3.34	3.26
2011	304.26	231.18	297.90	600.00	0.50	824.00	4.95	3.34	3.26
2012	314.04	242.50	308.00	600.00	0.50	824.00	4.99	3.34	3.26
2013	310.53	240.47	304.83	600.00	0.50	824.00	4.97	3.34	3.26
2014	304.40	235.29	302.36	600.00	0.50	824.00	5.00	3.34	3.26
2015	299.72	232.15	296.95	600.00	0.50	824.00	5.02	3.34	3.26
2016	305.85	234.31	302.33	600.00	0.50	824.00	5.02	3.34	3.26
2017	312.92	240.60	305.33	600.00	0.50	824.00	5.03	3.34	3.26
2018	311.33	240.68	301.49	600.00	0.50	824.00	5.00	3.34	3.26
2019	312.30	241.93	299.65	600.00	0.50	824.00	4.98	3.34	3.26
2020	311.29	242.57	298.82	600.00	0.50	824.00	5.01	3.34	3.26
2021	311.21	244.23	300.95	600.00	0.50	824.00	5.02	3.34	3.26
2022	308.40	244.79	299.35	600.00	0.50	824.00	5.04	3.34	3.26
2023	312.70	250.51	306.76	600.00	0.50	824.00	5.07	3.34	3.26

Appendix 14: Beef population and slaughter data from Statistics NZ and MPI

Values are June year end. Population models are used to adjust populations on a monthly basis, enabling aggregations by calendar year. See Clark (2008) for further details.

Year	Lc7056 Beef cows and heifers in calf 2 years and over	Lc7057 Beef cows and heifers in calf over 1 year but under 2 years	Lc7058 Beef cows and heifers NOT in calf 2 years and over	Lc7059 Beef cows and heifers NOT in calf over 1 year but under 2 years	Lc7064 Beef heifer and calves under 1 year old	Lc7065 Steers 2 years and over	Lc7066 Steers over 1 year but under 2 years	Lc7067 Steers under 1 year old	Lc7071 Non-breeding bulls 2 years and over	Lc7072 Non-breeding bulls over 1 year but under 2 years	Lc7073 Non-breeding bulls under 1 year old	Lc7068 Breeding bulls (all ages)	Lc7077 TOTAL beef cattle
1990	1256786	129631.6	109922	307848	536532	526399	629252	527829	86943.42	193262.1	209789.5	78965	4593160
1995	1447269	169590.8	147484.4	395919.6	647782	405751	679788	596650	106037.7	240699.9	257483.3	88052	5182508
2000	1230185	161862.9	130916	337141.7	574736.6	299542.8	512329.4	449176	141969.3	329098.6	346951.1	80120.31	4594029
2001	1169398	157284.1	130189.9	332528.3	572806	273431.7	477099.4	449443.9	156305	363855.7	382480.3	79531.16	4544354
2002	1101633	157557	131723	359264	574996	246180	426886	426834	143730	390705	452828	78945	4491281
2003	1135527	152687	152075	370399	581091	286053	461958	440415	171220	384315	410448	80428	4626617
2004	1107806	155437	140717	350439	572225	268586	478746	462388	145705	352965	344836	67548	4447400
2005	1099978	155277	153911	366756	556116	273413	469575	478843	123355	320441	354656	71305	4423626
2006	1081071	187910	128804	351984	575131	271008	460509	467128	130089	342172	371620	71709	4439136
2007	1027882	167216	144122	361882	566534	279570	483442	491284	128112	327968	335181	80424	4393617
2008	957999	145604	147588	350581	532105	270289	495081	469133	132057	304735	265364	66336	4136872
2009	947746	148268	169664	365651	461970	308160	507998	423970	165710	287177	236146	78259	4100718
2010	964561	153098	145976	331257	489122	278676	443804	445114	107415	246311	272803	70383	3948520
2011	904520	148302	154323	317487	476153	248427	456881	431021	109860	249529	277532	72379	3846414
2012	911380	148404	136532	310185	467841	241164	435902	401162	112726	246684	244098	78334	3734412
2013	887939	131073	134662	308066	483433	246866	429707	395835	89067	250605	266055	75214	3698522
2014	862530	149384	136014	319243	458402	245051	424892	389359	104618	253174	246156	81037	3669862
2015	838483	143373	124913	306703	459530	242914	398201	369719	110795	253474	217019	82105	3547228
2016	817423	136195	131342	316336	458500	223152	384460	370479	105120	249294	266780	73972	3533054
2017	827443	148651	129185	298968	482240	209779	379215	384359	94346	285947	299462	76302	3616091
2018	862696	166453	129108	301425	487458	201654	405034	414159	104000	272117	291159	85992	3721262
2019	902256	202444	126112	318316	504842	208696	423420	471870	95839	257838	290513	87849	3889996
2020	894165	172838	143275	328393	521786	240784	438789	446216	86671	256746	273550	79355	3882566
2021	891691	175454	164829	336318	517304	278580	442313	449472	108751	267596	261143	71360	3964811

2022	852706	168569	166073	329290	494905	258674	447215	413851	114294	267436	231700	76443	3821156
2023	829776	159497	150047	313422	470629	266325	427860	415436	107871	237322	201128	74719	3654034

Year	Heifers Total Kill	Steers Total Kill	Bulls Total Kill
1990	376,170	581,095	382,936
1995	427,974	708,551	514,929
2000	486,969	588,710	486,552
2001	437,632	544,873	610,512
2002	401,716	467,291	626,450
2003	453,700	488,552	640,547
2004	513,956	583,473	698,050
2005	509,613	596,501	577,052
2006	500,590	621,409	531,330
2007	492,805	607,224	525,898
2008	500,652	647,770	553,518
2009	516,472	604,933	485,606
2010	508,558	616,462	439,024
2011	480,440	595,519	431,793
2012	460,527	569,194	445,098
2013	443,404	577,346	426,003
2014	454,416	573,443	435,835
2015	488,372	566,632	482,586
2016	481,561	525,297	465,016
2017	478,249	531,140	460,669
2018	480,967	535,268	537,108
2019	491,773	562,093	548,557

2020	503,443	580,350	545,182
2021	576,482	667,309	551,729
2022	551,589	668,186	534,744
2023	565,715	666,484	510,192

Appendix 15: Mature beef cow live weight inputs

For further details see Clark (2008).

Values from Appendix 1 for dairy cow weight are used also in this calculation

Year	Cows slaughtered Number	Beef breeding cows Number	Killing out dairy cows %	Total weight all cow carcases kg	Beef cow replacement rate (%)	Killing out beef cows %
1990	581,472	1,386,418	0.42	104,113,209	0.17	0.426
1995	657,411	1,616,860	0.42	123,991,226	0.17	0.426
2000	687,825	1,392,048	0.42	134,357,518	0.17	0.426
2001	596,814	1,326,682	0.42	121,038,567	0.17	0.426
2002	674,042	1,259,190	0.42	133,117,998	0.17	0.426
2003	816,993	1,288,214	0.42	161,643,304	0.17	0.426
2004	853,640	1,263,243	0.42	169,172,543	0.17	0.426
2005	795,344	1,255,255	0.42	158,599,700	0.17	0.426
2006	668,020	1,268,981	0.42	136,453,282	0.17	0.426
2007	709,163	1,195,098	0.42	144,305,545	0.17	0.426
2008	642,858	1,103,603	0.42	130,105,840	0.17	0.426
2009	837,919	1,096,014	0.42	166,708,922	0.17	0.426
2010	826,812	1,117,659	0.42	165,000,115	0.17	0.426
2011	869,841	1,052,822	0.42	171,962,939	0.17	0.426
2012	742,864	1,059,784	0.42	152,511,600	0.17	0.426
2013	925,345	1,019,012	0.42	183,748,092	0.17	0.426
2014	910,092	1,011,914	0.42	181,208,065	0.17	0.426
2015	1,089,436	981,856	0.42	215,207,216	0.17	0.426
2016	1,155,295	953,618	0.42	225,281,810	0.17	0.426
2017	946,801	976,094	0.42	187,586,293	0.17	0.426
2018	1,032,175	1,029,149	0.42	203,916,297	0.17	0.426
2019	978,818	1,104,700	0.42	195,655,439	0.17	0.426
2020	1,026,705	1,067,003	0.42	207,124,625	0.17	0.426
2021	1,018,111	1,067,145	0.42	206,024,129	0.17	0.426
2022	935,373	1,065,161	0.42	189,028,527	0.17	0.426
2023	1,020,006	989,273	0.42	207,664,482	0.17	0.426

Appendix 16: Final Inputs for sheep for the Tier Two Inventory program

Live weights calculated using slaughter weight and a killing out percentage of 45% for lambs and 40% for ewes and multiplying the slaughter weight of ewes by 1.4 to obtain ram weight. Lamb birth weight is estimated as 9% of adult ewe weight with linear growth rates between birth and 6 months (lamb slaughter age). Hoggets assumed same linear rate as lambs to 6 months of age then at a rate to reach full adult weight at 20 months. Adult wethers assumed to be same weight as adult breeding female. Milk yield (per animal), butterfat and protein values are assumed to be constant. Note: Lambing percentage is the number of lambs tailed from ewes expressed as a percentage. For further details see Clark, 2008.

Year	Carcass Weight Lamb (kg)	Carcass Weight Other Adult Sheep (breeding ewe) kg	National wool yield (t/yr)	Annual Milk Yield (kg/yr)	Butterfat (kg(fat)/ 100kg(milk))	Nitrogen retained in tissue (N_{te}) (kg(N)/100 kg (live weight))	Nitrogen in wool (kg N/kg wool)	Live weight change ram (kg/yr)
1990	13.73	20.36	309,000	103	8	2.6	0.134	0.1
1995	14.57	21.09	288,600	103	8	2.6	0.134	0.1
2000	16.43	23.24	257,300	103	8	2.6	0.134	0.1
2001	16.57	23.94	236,700	103	8	2.6	0.134	0.1
2002	16.69	23.29	228,800	103	8	2.6	0.134	0.1
2003	16.84	23.46	229,600	103	8	2.6	0.134	0.1
2004	17.24	24.21	217,700	103	8	2.6	0.134	0.1
2005	17.39	24.71	215,500	103	8	2.6	0.134	0.1
2006	17.23	24.72	224,500	103	8	2.6	0.134	0.1
2007	16.82	24.10	221,900	103	8	2.6	0.134	0.1
2008	16.48	23.33	201,300	103	8	2.6	0.134	0.1
2009	17.44	23.99	164,800	103	8	2.6	0.134	0.1
2010	17.63	24.76	177,900	103	8	2.6	0.134	0.1
2011	17.87	23.85	168,500	103	8	2.6	0.134	0.1
2012	18.48	25.28	168,300	103	8	2.6	0.134	0.1
2013	18.03	24.99	167,100	103	8	2.6	0.134	0.1
2014	18.21	25.15	158,400	103	8	2.6	0.134	0.1
2015	18.12	25.10	153,800	103	8	2.6	0.134	0.1
2016	18.33	25.04	151,600	103	8	2.6	0.134	0.1
2017	18.58	25.52	143,400	103	8	2.6	0.134	0.1
2018	18.47	25.60	141,100	103	8	2.6	0.134	0.1
2019	19.06	26.75	144,700	103	8	2.6	0.134	0.1
2020	19.10	25.81	126,200	103	8	2.6	0.134	0.1
2021	19.13	26.18	134,700	103	8	2.6	0.134	0.1
2022	19.08	25.59	127,000	103	8	2.6	0.134	0.1
2023	19.34	26.00	122,000	103	8	2.6	0.134	0.1

Appendix 17: Sheep population data from Statistics NZ

Values are June year end. Population models are used to adjust populations on a monthly basis, enabling aggregations by calendar year. See Clark (2008) for further details.

Year	Rams (lc6720)	Breeding ewes (lc6721)	Dry ewes (lc6722)	Breeding ewe hoggets (lc6723)	Dry ewe hoggets (lc6724)	Ram hoggets	Wether hoggets	Wethers (lc6727)	Lambs (lc6701 and lc6700)	Total Sheep excluding lambs (lc6731
1990	734,540	41,414,031	2,102,176	1,082,028	10,167,504	739,466	2,494,105	1,834,803	39,997,294	60,568,653
1995	541,283	34,437,986	767,898	1,316,284	8,319,053	608,261	2,106,872	1,274,690	37,017,649	49,372,327
2000	767,626	30,364,254	529,901	1,869,499	6,786,549	916,809	3,092,256	1,352,998	34,840,000	45,679,892
2001	476,268	30,646,410	328,773	2,570,348	6,295,226	568,827	1,918,566	839,457	35,748,000	43,643,874
2002	454,049	29,216,733	313,435	2,450,439	6,001,549	542,291	1,829,064	800,296	32,647,387	41,607,855
2003	433,584	26,784,582	380,693	2,374,210	5,684,176	707,121	2,385,010	822,461	33,247,115	39,571,837
2004	420,945	27,086,569	290,583	2,271,780	5,563,982	726,371	2,449,937	741,947	31,853,940	39,552,113
2005	398,788	26,742,440	301,198	2,662,492	5,364,817	706,796	2,366,229	728,378	33,225,836	39,271,138
2006	382,371	26,418,797	236,632	3,130,399	5,850,583	748,380	2,505,446	607,059	33,809,880	39,879,667
2007	384,896	26,904,995	280,756	3,022,987	5,682,274	755,582	2,529,559	520,545	33,005,451	40,081,594
2008	389,810	26,063,325	286,441	2,524,730	5,551,909	717,699	2,402,730	523,833	31,020,153	38,460,477
2009	344,846	23,485,548	310,820	1,470,068	4,965,623	687,364	2,301,173	522,422	27,888,325	34,087,864
2010	348,318	22,214,044	223,869	1,821,217	4,667,610	610,784	2,044,798	452,950	28,152,100	32,383,590
2011	313,444	21,793,694	224,066	2,077,197	4,834,558	675,500	2,261,458	382,694	24,967,363	32,562,611
2012	316,280	20,484,792	339,381	2,015,897	4,650,351	670,229	2,243,808	411,592	25,954,154	31,132,330
2013	295,056	20,411,382	320,032	2,380,597	4,619,158	659,772	2,208,801	367,917	25,966,836	31,262,715
2014	302,274	20,232,933	191,635	1,998,722	4,681,623	708,418	2,371,661	299,495	24,976,628	30,786,761
2015	297,419	19,779,205	244,900	2,072,038	4,189,670	671,628	2,248,493	300,047	25,832,974	29,803,400
2016	290,187	19,074,356	313,941	1,750,318	4,561,932	664,272	2,223,868	241,954	24,570,347	29,120,828
2017	271,085	18,137,180	322,511	1,694,888	4,294,238	591,911	1,981,617	290,242	24,127,372	27,583,672
2018	264,731	17,755,322	371,132	1,980,740	4,281,532	602,254	2,016,241	254,258	24,707,163	27,526,210
2019	274,231	17,161,744	379,309	2,018,126	4,264,600	678,974	2,273,086	245,697	23,806,092	27,295,767
2020	273,225	16,845,367	338,699	2,073,458	4,224,674	652,706	2,185,145	228,574	23,172,282	26,821,847
2021	251,067	16,569,832	299,684	1,860,128	4,133,510	615,174	2,059,497	240,042	22,907,449	26,028,934
2022	247,485	16,326,488	372,202	1,863,573	4,076,348	603,526	2,020,500	222,767	21,952,415	25,732,889
2023	242,240	15,370,992	337,109	1,815,052	4,160,378	686,051	2,296,781	224,094	21,040,389	25,132,697

Appendix 18: Deer inputs

Year	CWT Weight Mature Hind (kg)	CWT Weight Mature Stag (kg)	Annual Milk yield (kg/head/yr)	Nitrogen in body tissue (kg(N)/100kg (tissue)	Nitrogen in velvet (kg(N)/ 100kg(velvet))	Velvet yield (kg/head/yr)
1990	42.47	51.50	204	3.71	9	1.6
1995	44.84	58.41	204	3.71	9	2.8
2000	49.63	59.61	204	3.71	9	2.7
2001	50.54	57.68	204	3.71	9	3.0
2002	49.76	58.37	204	3.71	9	3.2
2003	50.19	56.38	204	3.71	9	3.1
2004	50.96	56.66	204	3.71	9	2.9
2005	51.51	58.15	204	3.71	9	3.1
2006	51.75	58.17	204	3.71	9	3.2
2007	51.02	57.11	204	3.71	9	3.5
2008	50.64	56.75	204	3.71	9	3.6
2009	50.86	59.29	204	3.71	9	3.8
2010	52.08	58.36	204	3.71	9	3.9
2011	51.80	58.19	204	3.71	9	4.4
2012	52.73	59.45	204	3.71	9	4.2
2013	52.24	58.80	204	3.71	9	4.3
2014	51.95	58.19	204	3.71	9	5.6
2015	51.66	58.07	204	3.71	9	5.1
2016	52.74	58.72	204	3.71	9	6.1
2017	52.76	61.02	204	3.71	9	6.0
2018	53.23	61.28	204	3.71	9	6.4
2019	54.02	62.80	204	3.71	9	6.5
2020	54.36	62.63	204	3.71	9	7.0
2021	54.36	61.76	204	3.71	9	7.1
2022	53.90	62.31	204	3.71	9	7.0
2023	54.22	63.79	204	3.71	9	6.7

Appendix 19: Deer population data

Values are June year end

Year	Fawns (Lc7696)	Hinds mated 2 + years (Lc7600)	Hinds mated 1-2 years (Lc7605)	Hinds NOT mated 2 + years (Lc7610)	Hinds NOT mated 1-2 years (Lc7615)	Hinds under 1 year (Lc7618)	Stags under 1 year (Lc7630)	Non-breeding stags 2 + years (Lc7620)	Non-breeding stags 1-2 years (Lc7625)	Breeding stags 2 + years (Lc7645)	Breeding stags 1-2 years (Lc7648)	TOTAL deer (Lc7699)
1990	379,705	424,564	75,949	6,747	14,166	115,028	169,599	102,166	35,856	27,456	4,759	976,290
1995	458,429	436,651	78,111	10,126	21,261	172,635	203,678	163,520	43,061	43,945	5,716	1,178,704
2000	648,406	723,955	129,506	15,310	32,147	261,027	278,759	125,880	58,934	33,830	7,823	1,667,171
2006	595,782	626,102	112,001	18,108	38,022	308,731	288,773	99,331	61,051	26,695	8,104	1,586,918
2007	536,604	576,907	103,201	14,892	31,268	253,890	248,891	84,627	52,619	22,743	6,984	1,396,023
2008	494,163	504,542	90,256	12,871	27,025	219,432	218,377	77,657	46,168	20,870	6,128	1,223,324
2009	431,921	478,216	85,546	11,608	24,373	197,906	210,655	68,655	44,536	18,451	5,911	1,145,858
2010	428,470	468,964	83,891	11,651	24,464	198,642	200,993	67,750	42,493	18,207	5,640	1,122,695
2011	426,660	450,394	80,569	11,394	23,925	194,265	191,181	71,740	40,419	19,280	5,365	1,088,533
2012	413,283	441,348	76,306	14,868	20,746	192,963	184,800	68,974	36,051	18,924	5,714	1,060,694
2013	398,938	420,731	77,223	8,325	18,548	181,954	186,485	74,021	38,560	18,446	4,090	1,028,382
2014	375,146	396,495	71,477	8,825	26,697	165,133	164,881	63,208	38,424	17,898	5,181	958,219
2015	352,568	357,519	72,981	6,746	20,671	153,271	150,916	81,310	37,607	14,094	4,983	900,100
2016	321,031	337,599	68,259	6,375	15,786	139,922	138,869	77,110	31,607	15,838	3,243	834,608
2017	313,212	326,067	66,222	5,238	13,031	141,234	142,799	88,665	30,844	17,143	5,131	836,337
2018	320,281	323,693	77,085	4,153	12,081	136,448	147,981	92,420	33,206	17,719	6,640	851,424
2019	304,621	313,685	64,907	3,016	10,254	131,747	136,922	100,373	29,024	16,218	4,297	810,443
2020	313,649	308,868	65,202	6,268	11,255	142,538	142,493	103,009	34,232	15,717	3,676	833,258
2021	298,709	299,106	61,567	6,752	12,650	132,295	140,983	107,281	34,874	14,165	4,307	813,980
2022	288,112	281,351	53,084	6,504	13,188	132,389	136,670	115,168	36,325	15,333	4,097	794,109
2023	254,750	244,139	49,798	6,949	12,122	123,091	133,853	121,046	35,482	11,925	3,194	741,598

Appendix 20: Population numbers for non-key source livestock categories

Year	Alpacas	Breeding Sows over 1 Year Old	Mated Gilts	Other Pigs	Broiler Chickens	Layers Chickens	Other Poultry	Donkey	Goat	Horse
1990	397	44665	6325	340013	5126046	2995596	597525	1500	1062900	94000
1995	1032	51140	8110	371755	7296114	2947275	343494	1500	336800	68600
2000	2677	49513	6473	303944	7243554	3214764	1214404	1500	175295	73137
2001	3434	45144	6202	299626	7513327	3216062	1388586	1500	164189	74497
2002	4356	40774	5932	295309	8044056	3217360	1562768	1500	153084	75856
2003	6091	43109	6272	327868	8787132	3057973	2089050	1500	179435	80397
2004	7811	41187	7266	340187	9275948	3176349	2315977	1500	141206	76918
2005	10337	36931	5668	298867	9772536	3348916	1958520	1500	136120	72847
2006	12586	36507	6799	312195	9393902	3011425	1982478	1500	131033	67679
2007	14794	39743	7168	319760	9155685	2994202	2075956	1500	111981	66215
2008	15334	37004	5623	281967	8956065	3405415	1896394	1500	95731	62511
2009	17231	33771	5701	283317	8306073	3321059	1799805	1500	82229	65149
2010	18481	33821	6614	294679	8381172	3350290	1878022	1500	95281	64105
2011	19318	34404	4876	287508	8703501	3275711	1760078	1500	85970	56505
2012	19882	32274	5229	276200	9183586	3254568	1562754	1500	90096	56878
2013	19962	31133	4902	261689	9249111	3192896	1735472	1500	79977	57427
2014	19702	27616	3999	255356	9954251	3450845	1677300	1500	97370	51611
2015	18993	26562	4654	237084	10683077	3452002	1840159	1500	74718	40935
2016	18279	24319	4223	226065	11672688	3665679	1794865	1500	112385	48801
2017	17490	26872	4728	242257	12063013	3775472	1938423	1500	98812	43684
2018	16743	27450	4881	254720	12401794	3693825	1853522	1500	88828	40525
2019	16358	26028	4936	224970	12708114	3941913	2106497	1500	93606	38445
2020	15986	23343	6240	204949	12585708	4144998	2091584	1500	96416	38647
2021	15583	23492	5884	219341	13217953	4146832	1981504	1500	116666	40276
2022	15026	25995	5791	243505	12303404	3815856	1692493	1500	88428	33531
2023	15443	22365	4805	222626	12547876	4017735	1535172	1500	78055	31184

Appendix 21: Fraction of manure excreted in each animal manure management system (MMS) - for all livestock species

Livestock category	Anaerobic lagoon (%)	Daily spread[12] (%)	Pit storage (%)	Deep bedding (%)	Pasture, range and paddock[13] (%)	Composting (%)	Digesters (%)	Other (%)
Dairy cattle[14]	7.2	0	0	0	92.8	0	0	0
Non-dairy *(beef)* cattle	0	0	0	0	100	0	0	0
Sheep	0	0	0	0	100	0	0	0
Deer	0	0	0	0	100	0	0	0
Goats	0	0	0	0	100	0	0	0
Horses	0	0	0	0	100	0	0	0
Swine[15]	16.0	7.6	18.0	32.7	14.5	1.9	9.4	0
Poultry – broilers[16]	0	0	0	0	4.9	0	0	95.1
Poultry – layers[17]	0	0	0	0	5.8	0	0	94.2
Poultry – other[18]	0	0	0	0	3.0	0	0	97.0
Llamas and alpacas	0	0	0	0	100	0	0	0
Mules and asses	0	0	0	0	100	0	0	0

12 Reported under *Agricultural soils*, under *Organic nitrogen fertilisers* (3.D.1.2).

13 Reported under *Agricultural soils*, under *Urine and dung deposited by grazing animals* (3.D.1.3).

14 Rollo et al. (2017).

15 Hill (2012), Ritchie (2024).

16 Fick et al. (2011) and pers. comm. (2010).

17 Fick et al. (2011) and pers. comm. (2010).

18 IPCC (1996) default waste management proportions for Oceania.

Appendix 22: Emission factor and fractions used to determine direct and indirect N_2O emissions from Agricultural soils

Parameter	Emission factor or fraction value	Units	Reference
$Frac_{gasf}$	0.1	$kg(NH_3\text{-}N + NO_X\text{-}N)/kg(N\ applied)$	Sherlock *et al.*, 2008
$Frac_{gasf,UI}$	0.055	$kg(NH_3\text{-}N + NO_X\text{-}N)/kg(N\ applied)$	Saggar *et al.*, (2013)
$Frac_{gasm}$	0.1	$kg(NH_3\text{-}N + NO_X\text{-}N)/kg(N\ applied)$	Sherlock *et al.*, 2008
$Frac_{LEACH(ON,PRP,Renew)}$	0.08	kg N/kg of fertiliser or manure N	Welten *et al.,* (2021)
$Frac_{LEACH(CR)}$	0.1	kg N/kg of fertiliser or manure N	Welten *et al.,* (2021)
$Frac_{LEACH(SN)}$	0.082	kg N/kg of fertiliser	Welten *et al.,* (2021)
$Frac_{BURN}$	Crop specific	kg N/kg crop-N	Thomas *et al.*, 2008
$Frac_{RENEW}$	Year specific		Beare *et al.*, 2012; Thomas *et al.*, 2014
$Frac_{REMOVE}$	0	kg N/kg crop-N	Thomas *et al.*, 2014
EF_1	0.01	$kg(N_2O\text{-}N)/kg(N\ applied)$	Kelliher & de Klein, 2006
$EF1_{urea}$	0.0059	kg(N2O-N)/kg(N applied)	Kelliher *et al.,* 2014
$EF1_{organic}$	0.006	kg(N2O-N)/kg(N applied)	IPCC (2019, table 11.1)
$EF1_{Dairy}$	0.0025	kg(N2O-N)/kg(N applied)	van der Weerden et al. (2016a, 2016b)
EF_2	8	$kg(N_2O\text{-}N)/ha/yr$	IPCC 2006, Table 11.1
$EF_{3PR\&P\ DUNG}$	0.0012	$kg(N_2O\text{-}N)/kg(excreted\ N)$	van der Weerden *et al.*, 2019
$EF_{3PR\&P}$	based on slope and livestock category, see Table 8.1		
$EF_{3PR\&P\ MINOR}$	0.01	$kg(N_2O\text{-}N)/kg(excreted\ N)$	Based on Carran *et al.*, 1995; Muller *et al.*, 1995; de Klein *et al.*, 2003; Kelliher *et al.*, 2003
EF_{3AL}	0	$kg(N_2O\text{-}N)/kg(excreted\ N)$	IPCC 2019, pg. 10.91. Table 10.21
$EF_{3poultry}$	0.001	$kg(N_2O\text{-}N)/kg(excreted\ N)$	Fick *et al.*, 2011
EF_4	0.01	$kg(N_2O\text{-}N/kg(deposited\ NH_3\text{-}N + NO_X\text{-}N)$	IPCC 2006, Table 11.3
EF_5	0.0075	$kg(N_2O\text{-}N)/kg(leached\ N)$	IPCC 2006, Table 11.3

Appendix 23: Nitrogen fertiliser application and yield of nitrogen fixing and other crops

Year	Synthetic fertiliser use (t N/yr)	Urease inhibitor use (t N/yr)	Urea use (t N/yr)	Pea yield (t/yr)	Field seed peas (t/yr)	Lentil yield (t/yr)	Barley yield (t/yr)	Wheat yield (t/yr)	Maize yield (t/yr)	Oats yield (t/yr)	Potatoes yield (t/yr)	Onions (t/yr)	Sweet corn (t/yr)	Squash (t/yr)	Herbage seeds (t/yr)	Legume seeds (t/yr)	Brassica seeds (t/yr)
1990	59,265	0	24,586	24,000	57,378	3,386	434,856	188,047	161,651	78,877	467,866	162,240	57,960	73,540	28,492	6,732	1,062
1995	151,263	0	85,797	24,000	56,448	923	302,804	245,173	160,797	38,735	494,060	341,820	147,660	136,620	33,727	8,419	1,656
2000	189,096	0	143,359	36,000	64,000	0	302,000	326,000	181,000	35,398	504,520	422,640	127,600	134,260	28,789	4,363	1,109
2001	248,000	10,443	187,452	36,000	37,700	0	365,000	364,000	177,000	22,394	497,300	379,950	121,700	139,360	24,543	3,476	809
2002	309,200	9,200	244,835	36,000	29,457	3,302	440,883	301,499	148,847	34,986	526,080	337,260	115,800	131,200	32,504	3,990	1,302
2003	337,400	12,420	272,303	31,200	31,200	2,000	371,837	318,916	197,182	29,934	555,160	344,880	140,820	136,080	39,456	4,226	1,778
2004	348,000	23,000	285,437	30,944	31,912	2,000	226,082	255,860	234,248	30,844	567,060	320,370	141,560	168,860	43,400	4,573	2,433
2005	350,320	4,600	286,410	30,688	29,068	2,000	302,023	318,947	210,253	25,000	560,720	295,860	142,300	139,620	37,141	5,554	1,952
2006	329,700	22,154	264,869	27,256	22,506	2,000	277,020	261,798	227,054	28,478	513,840	285,750	133,250	160,840	29,738	5,028	1,269
2007	315,920	14,242	286,221	23,824	22,053	847	335,627	344,434	185,627	27,531	516,320	275,640	124,200	155,480	35,159	3,578	2,279
2008	328,157	14,242	276,208	27,849	20,047	1,863	408,730	343,350	205,557	25,463	486,220	273,150	112,690	132,020	44,919	3,234	2,187
2009	279,752	22,154	234,543	21,071	21,201	1,445	435,270	403,463	237,844	33,703	501,080	270,660	101,180	136,500	43,247	4,531	2,900
2010	332,981	19,325	281,871	21,071	37,094	3,800	308,298	444,890	188,812	47,608	521,440	289,590	86,170	132,920	29,812	3,671	1,851
2011	360,284	16,496	311,756	21,071	32,401	4,573	367,958	383,262	210,175	28,466	579,540	308,520	71,160	129,340	40,365	3,392	2,069
2012	362,508	21,603	310,020	22,500	20,148	2,865	438,789	488,614	211,231	18,118	521,900	343,080	93,280	136,740	44,102	3,446	2,348
2013	366,600	28,162	326,297	22,500	24,532	2,490	416,478	447,799	201,659	28,225	502,135	323,560	91,951	133,382	40,003	3,773	2,438
2014	376,890	64,630	320,357	23,571	28,070	1,800	405,747	413,497	237,165	34,741	488,043	304,020	90,620	130,020	55,706	6,554	4,797
2015	428,682	61,941	381,527	23,750	25,353	1,637	437,144	413,533	226,278	29,119	445,556	320,876	85,669	127,091	41,395	4,629	3,053
2016	432,200	95,400	360,300	22,143	41,321	2,363	364,186	459,349	210,325	46,645	488,120	337,732	80,719	124,163	41,334	7,026	4,137
2017	443,000	102,500	369,000	22,143	38,192	2,778	298,407	405,713	175,022	35,366	507,880	354,588	75,768	121,234	41,197	7,784	3,979
2018	458,000	113,900	381,500	15,714	24,784	2,998	380,264	371,611	190,543	24,809	508,680	354,894	75,484	128,447	48.438	7,715	5,252
2019	452,000	127,000	358,000	25,143	23,887	2,617	383,651	398,091	195,955	26,824	514.340	355,200	75,200	135,660	55,735	6,416	7,290
2020	470,000	142,000	340,000	28,929	27,235	2,484	337,666	453,749	190,098	23,264	479,500	335,280	66,460	141,400	58,852	6,319	8,489
2021	441,000	174,000	347,000	24,832	33,260	2,982	325,057	422,831	209,281	24,805	439,020	355,568	72,954	133,330	64,161	5,670	6,845
2022	367,000	144,000	241,000	20,893	25,509	4,543	329,728	402,557	188,249	32,991	398,020	293,040	66,400	96,000	66,547	5,264	6,794

2023	376,000	127,000	267,000	26,418	27,588	4,824	357,882	391,615	192,504	30,259	437,020	293,040	3,320	96,000	50,368	6,781	6,577

Appendix 24: Forage crops for pasture renewal

Year	Rye-Clover mix (sheep, beef, deer)		Rye-Clover mix (dairy)		Lucerne (dairy, sheep, beef, deer)	
	Area (ha)	Frequency of renewal (%)	Area (ha)	Frequency of renewal (%)	Area (ha)	Frequency of renewal (%)
1990	12,464,774	1.5	1,348,773	5.6	84,000	10
1995	11,899,584	1.9	1,620,211	6.1	107,085	10
2000	10,583,428	2.6	1,816,354	7.0	113,257	10
2001	10,310,998	2.6	1,872,373	7.0	113,117	10
2002	10,060,296	2.6	1,906,658	7.0	119,626	10
2003	9,964,856	2.6	1,879,512	7.0	121,016	10
2004	9,825,489	2.6	1,896,293	7.0	122,900	10
2005	9,730,753	3.0	1,868,443	7.4	123,162	10
2006	9,586,894	3.0	1,889,716	7.4	118,061	10
2007	9,439,214	3.0	1,914,814	7.4	116,868	10
2008	9,335,328	3.0	2,018,700	7.4	117,402	10
2009	9,302,090	3.0	2,110,918	7.4	124,185	10
2010	9,180,291	3.0	2,122,181	7.4	119,105	10
2011	9,076,514	3.0	2,213,448	7.4	121,895	10
2012	8,841,788	3.0	2,255,360	7.4	129,314	10
2013	8,722,107	3.0	2,289,094	7.4	132,187	10
2014	8,629,040	3.0	2,328,691	7.4	133,695	10
2015	8,376,775	3.0	2,336,090	7.4	138,056	10
2016	8,308,394	3.0	2,305,414	7.4	148,965	10
2017	8,308,394	3.0	2,340,683	7.4	155,634	10
2018	8,172,676	3.0	2,325,380	7.4	168,626	10
2019	8,012,481	3.0	2,307,645	7.4	176,131	10
2020	7,828,502	3.0	2,285,161	7.4	183,205	10
2021	7,749,380	3.0	2,290,793	7.4	184,927	10
2022	7,749,380	3.0	2,213,033	7.4	187,284	10
2023	8,266,000	3.0	2,271,677	7.4	197,455	10

Appendix 25: Loss of soil carbon in mineral soil during cropland management

Year	Soil carbon loss (tonne)
1990	-62.04
1991	-81.21
1992	-100.39
1993	-119.56
1994	-138.74
1995	-157.92
1996	-177.09
1997	-196.27
1998	-215.44
1999	-234.62
2000	-253.79
2001	-272.97
2002	-292.14
2003	-311.32
2004	-330.49
2005	-349.67
2006	-368.84
2007	-388.02
2008	-398.01
2009	-412.15
2010	-411.62
2011	-415.66
2012	-423.54
2013	-420.84
2014	-419.63
2015	-420.93
2016	-424.88
2017	-422.88
2018	-417.48
2019	-417.33
2020	-426.05

2021	-414.02
2022	-401.98
2023	-389.95

Appendix 26: Limestone and dolomite usage

Year	Limestone (tonne)	Dolomite (tonne)
1990	802,760	14,367
1991	866,597	15,510
1992	930,435	16,652
1993	1,007,628	18,034
1994	1,107,066	19,814
1995	1,206,504	21,593
1996	1,081,801	19,362
1997	1,191,928	21,333
1998	1,302,056	23,304
1999	1,412,183	25,275
2000	1,522,310	27,246
2001	1,632,438	29,217
2002	1,742,565	31,188
2003	1,536,886	27,506
2004	1,494,224	26,743
2005	1,644,880	29,439
2006	1,374,290	24,596
2007	1,460,817	26,145
2008	1,370,382	16,515
2009	1,614,132	19,894
2010	1,371,608	35,578
2011	1,411,414	28,251
2012	1,517,235	31,734
2013	1,190,855	33,756
2014	1,312,257	30,597
2015	1,190,169	26,419
2016	1,144,648	22,586
2017	1,019,861	22,785
2018	1,097,270	25,294
2019	1,216,694	22,648
2020	1,101,847	25,031
2021	958,518	20,564
2022	1,191,136	21,370
2023	729,502	22,176

Appendix 27: Area of organic soils (hectares)

Year	Cropland - annual	Cropland - perennial	Grassland – high producing	Grassland – low producing	Grassland – with woody biomass	Total Area
1990	7,428	2,235	127,680	29,966	8,519	175,829
1991	7,449	2,259	128,745	28,990	8,502	175,945
1992	7,469	2,283	129,791	27,985	8,470	175,998
1993	7,490	2,307	130,830	26,970	8,433	176,030
1994	7,511	2,330	131,848	25,923	8,381	175,994
1995	7,532	2,354	132,881	24,898	8,340	176,004
1996	7,552	2,378	133,907	23,864	8,294	175,995
1997	7,573	2,402	134,947	22,884	8,266	176,071
1998	7,593	2,427	135,993	21,914	8,242	176,170
1999	7,613	2,452	137,045	20,954	8,224	176,289
2000	7,634	2,477	138,111	20,000	8,210	176,432
2001	7,654	2,502	139,178	19,049	8,198	176,580
2002	7,675	2,525	140,247	18,068	8,180	176,696
2003	7,697	2,549	141,326	17,090	8,164	176,825
2004	7,719	2,573	142,418	16,120	8,152	176,983
2005	7,741	2,597	143,529	15,157	8,143	177,166
2006	7,764	2,620	144,650	14,196	8,136	177,367
2007	7,788	2,644	145,792	13,239	8,131	177,594
2008	7,789	2,648	146,035	13,167	8,106	177,745
2009	7,791	2,652	146,287	13,096	8,080	177,906
2010	7,793	2,656	146,531	13,027	8,060	178,068
2011	7,795	2,660	146,776	12,952	8,035	178,218
2012	7,797	2,664	147,028	12,879	8,009	178,377
2013	7,798	2,663	147,040	12,885	7,983	178,369
2014	7,809	2,663	147,059	12,913	7,981	178,425
2015	7,811	2,663	147,073	12,939	7,945	178,432
2016	7,811	2,664	147,107	12,940	7,915	178,436
2017	7,811	2,664	147,111	12,972	7,891	178,449
2018	7,811	2,664	147,107	12,976	7,870	178,428
2019	7,811	2,663	147,097	12,979	7,820	178,371
2020	7,811	2,663	147,086	12,982	7,735	178,276
2021	7,811	2,663	147,074	12,985	7,626	178,159

This area is updated annually by the Ministry for the Environment

Appendix 28: Total organic-N amendment (t) applied to agricultural land in New Zealand from 1990 to 2022

Year	Dairy processing waste-water	Compost	Meat processing wastewater	Grape marc	Vegetable processing wastewater	Domestic wastewater sludge	Total N input (t N)
1990	93	73	519	19	46	83	832
1991	100	73	540	18	46	83	859
1992	115	73	566	15	46	82	897
1993	123	73	592	12	46	82	927
1994	169	73	617	15	46	82	1002
1995	170	73	643	20	46	82	1034
1996	209	351	669	20	46	82	1377
1997	275	351	695	16	59	82	1478
1998	297	351	737	21	55	82	1543
1999	291	351	763	22	62	82	1571
2000	376	358	790	22	52	82	1679
2001	497	358	816	19	98	81	1870
2002	570	358	843	32	90	82	1975
2003	604	358	869	21	95	82	2029
2004	687	358	895	45	105	83	2173
2005	627	358	1045	39	104	83	2255
2006	700	358	984	50	105	83	2280
2007	756	358	831	56	174	83	2258
2008	844	358	1163	77	156	84	2682
2009	1112	878	1080	77	173	82	3403
2010	1039	905	618	72	149	82	2865
2011	862	937	887	89	144	82	3002
2012	1096	1139	899	73	188	82	3478
2013	1655	1181	741	94	182	82	3936
2014	1731	1181	1018	121	132	82	4266
2015	2100	1181	1022	89	112	82	4587
2016	1950	1181	763	118	101	82	4196
2017	1515	1181	1362	108	116	82	4364
2018	1736	1181	1420	114	119	82	4652
2019	2280	1181	1281	112	119	82	5056
2020	2132	1181	1158	124	107	82	4785
2021	2384	1181	1163	100	105	82	5016
2022	2273	1181	1209	144	83	82	4973
2023	2273	1181	1209	144	83	82	4973