



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

**Version 8**

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	<p>New methodologies and inclusion of new crops to estimate emissions from nitrogen-fixing crops and from crop residue.</p> <p>Changes to the emission factors and methodology used to estimate emissions from prescribed burning of savannas and field burning of agricultural residues.</p> <p>Revised methodologies and emissions factors for minor species, goats, swine and poultry.</p> <p>Updated activity data appendix.</p>
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	<p>Revised introduction and title of document changed.</p> <p>New section detailing activity data sources.</p> <p>New section detailing the livestock population models for dairy cattle, beef cattle, sheep and deer.</p> <p>Updated methodology for sheep enteric methane.</p> <p>Revised and updated sections on:</p> <ul style="list-style-type: none"> <li>• energy requirements,</li> <li>• nitrogen excretion,</li> <li>• enteric methane,</li> <li>• manure management,</li> <li>• agricultural soils,</li> <li>• field burning,</li> </ul> <p>in order to improve completeness, transparency and readability.</p> <p>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.</p> <p>Re-formatted equations.</p> <p>Updated activity data appendix.</p>
5.0	Hazelle Tomlin and Joel Gibbs	September 2019	<p>Metabolisable energy (ME) required for gestation (ME<sub>c</sub>) separated from production term (ME<sub>p</sub>) in accordance with improvements made to the inventory model in 2019.</p> <p>Updated the methodology for emissions from nitrogen excretion based on methodology developed by Pacheco, Waghorn and Rollo (2018).</p> <p>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.</p> <p>Minor edits, corrections and amendments (to equations, appendices and text).</p>

6.0	Joel Gibbs	June 2020	<p>Included text on topography data in section 2.</p> <p>Minor edits and corrections to energy requirements section</p> <p>Addition of new text and methodology in section 5 on the allocation of nitrogen excreta to different hill slopes</p> <p>Revision of various sections discussing the calculation of emissions from goats</p> <p>Revision of text and equations in section 8.1.3 to account for the new emission factors (EF3) being used for livestock</p> <p>Minor corrections to equations in sections 5.1.4, 5.3.5, 8.2.2 and 8.3.2</p>
7.0	Ben Morrow and Joel Gibbs	June 2021	<p>Minor editorial changes and corrections throughout</p> <p>Updated HI value for wheat (from 0.46 to 0.41)</p> <p>Addition of new pasture quality data for Metabolisable Energy, Organic Matter Digestibility and Nitrogen Content in Appendix 3, 9, and 19</p> <p>Addition of Appendix 24, providing total area of organic soils</p> <p>Update to population data in Appendixes, providing data for years 2017 - 19</p> <p>Update to hill country data (from 2018 – 2019)</p>
8.0	Catherine Sangster, Joel Gibbs and Ben Morrow	April 2022	<p>Disaggregation of the <math>Frac_{LEACH}</math> parameter. Updated parameter value for nitrogen leaching on cropland.</p> <p>Updated assumption used for purity of agricultural lime applied to farmland.</p>

# Contents

Page

<b>1</b>	<b>Introduction</b>	<b>5</b>
1.1	International climate change agreements	5
1.2	Guidelines for reporting emissions	6
1.3	Complexity of reporting – tiers 1, 2, and 3	7
1.4	New Zealand's agricultural emissions context	7
1.5	Sources of New Zealand's agricultural emissions	8
<b>2</b>	<b>Activity data – sources and assumptions</b>	<b>10</b>
2.1	Animal population data - Dairy	10
2.2	Animal population data - Beef	11
2.3	Animal population data - Sheep	11
2.4	Animal population data - Deer	11
2.5	Animal population data – Minor Species	12
2.6	Meat, wool and dairy production	12
2.7	Fertiliser data	12
2.8	Topography data	12
2.9	Additional information	12
<b>3</b>	<b>Monthly population model</b>	<b>13</b>
3.1	Dairy population model	13
3.2	Beef population model	18
3.3	Sheep population model	34
3.4	Deer population model	41
<b>4</b>	<b>Estimation of energy requirements</b>	<b>58</b>
4.2	Components of metabolisable energy	60
4.3	Energy requirements for dairy cattle	61
4.4	Energy requirements for beef cattle	69
4.5	Energy requirements for sheep	72
4.6	Energy requirements for deer	76
4.7	Calculation of live weight and live weight gain	80
<b>5</b>	<b>Nitrogen excretion</b>	<b>96</b>
5.1	Dairy	97
5.2	Beef	99
5.3	Sheep	101
5.4	Deer	106
5.5	Allocation of urine and dung to different hill slopes	109
5.6	Other livestock	113
<b>6</b>	<b>Methane emissions from enteric fermentation</b>	<b>117</b>
6.1	Dairy	118
6.2	Beef	119

6.3	Sheep	120
6.4	Deer	122
6.5	Other livestock sources	122
<b>7</b>	<b>Methane and nitrous oxide from manure management</b>	<b>125</b>
7.1	Methane	125
7.2	Nitrous oxide	132
<b>8</b>	<b>Nitrous oxide emissions from agricultural soils</b>	<b>140</b>
8.1	Direct agricultural soils emissions	143
8.2	Indirect N <sub>2</sub> O emissions associated with nitrogen leached from soils	161
8.3	Indirect N <sub>2</sub> O emissions associated with nitrogen volatilisation from soils	171
<b>9</b>	<b>Field burning of agricultural residues</b>	<b>179</b>
9.1	Activity data, parameters and the proportion and areas of crop burning	180
9.2	Nitrous oxide field burning emissions	183
9.3	Methane field burning emissions	184
9.4	Carbon monoxide field burning emissions	185
9.5	NO <sub>x</sub> field burning emissions	186
<b>10</b>	<b>Carbon dioxide from lime, dolomite and urea application</b>	<b>188</b>
10.1	Lime and Dolomite	188
10.2	Urea Application	188
<b>11</b>	<b>Prescribed burning of savannah</b>	<b>190</b>
<b>12</b>	<b>References</b>	<b>191</b>
<b>13</b>	<b>Appendix</b>	<b>196</b>

# 1 Introduction

This document describes in detail how New Zealand's agricultural greenhouse gas (GHG) emissions (referred to in this document as the agriculture inventory) are calculated. The methodology in this document is used to help calculate the official statistics for anthropogenic (human-induced) emissions of agricultural greenhouse gases in New Zealand. This information is used for reporting, forecasting, and policy development purposes.

Emissions from agriculture include sources such as methane (CH<sub>4</sub>) from livestock digestive systems (referred to as enteric CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) from animal manure and fertiliser added to the soil. Emissions included under the agriculture sector are what we call biological emissions, that is, emissions from processes in living things. 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.

New Zealand is required to report on its emissions every year under international agreements. The methods used to calculate emissions are based on internationally-agreed rules and guidelines. At the same time, countries are encouraged to improve the accuracy of their estimates by developing methods that are best suited to 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 emissions. The model has been developed based on the reporting guidelines as well as on both 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<sub>2</sub>O emissions from agricultural soils.

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

Chapter 10 discusses emissions of carbon dioxide (CO<sub>2</sub>) 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 (UNFCCC), which 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 achieve stabilisation of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. 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 Kyoto Protocol, a subsidiary agreement under the UNFCCC, was developed to bring about more powerful and urgent action on climate change. It was adopted in 1997 and came into force in 2005. The Kyoto Protocol shares and expands on the objective, 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).

A second commitment period under the Kyoto Protocol runs 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 will apply the Kyoto Protocol framework of rules to its unconditional 2020 target to ensure that actions are transparent and have integrity.

The Paris Agreement, which builds on the UNFCCC and – for the first time – brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to help developing countries do so, came into force on 4 November 2016. Under this Agreement New Zealand is committed to reducing its GHG emissions by 30 per cent below 2005 levels by 2030.

## 1.2 Guidelines for reporting emissions

Under the UNFCCC and the Kyoto Protocol, Annex I Parties are required to report on their GHG emissions and show how they are tracking towards their targets. New Zealand calculates its emissions following guidelines and reporting rules. 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.

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).

The IPCC guidelines provide tiered reporting levels (described in section 1.3 of this chapter). Countries decide which method to follow based on the significance of a particular emissions source in their country, on their capability and the availability of data, and on the importance of a particular GHG source category in that inventory. The guidelines ensure emissions are estimated at a detailed level, but can also be aggregated up to a common minimum level of details for comparison with all other reporting countries.

Since 2015, emissions are calculated using methodologies from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. 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. The use of standard guidelines enables the inventories of different countries to be compared.

Countries are required to calculate direct and indirect emissions and removals of the following gases: CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, 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.

Estimated emissions of different gasses are aggregated into one emissions value using the concept of Global Warming Potential (GWP), which provides a measure of how much a given GHG contributes to the Earth's radiative forcing over a specified time period. Beginning with the 2015 submissions, Annex I Parties use the GWP values for the 100-year horizon published in the *Fourth Assessment Report of the IPCC* as the CO<sub>2</sub>-e conversion metric. (UNFCCC, 2013).

In the *Fourth Assessment Report* for a 100-year time span, CO<sub>2</sub> is set as the reference gas, and has a GWP of 1, while CH<sub>4</sub> and N<sub>2</sub>O have GWPs of 25 and 298, respectively (Myhre et al., 2013). For each gas, the amount of emissions (by mass) is multiplied by its associated GWP value to obtain a measure of carbon-dioxide equivalent (CO<sub>2</sub>-e) emissions.



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).

### 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.

The guidelines encourage countries to improve the estimation of emissions by developing country-specific emission factors and related parameters through research and application of country-specific information. A more complex methodology, *Tier 2*, can be used if disaggregated population data and production data for a country are available. 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<sub>4</sub> and N<sub>2</sub>O emissions can then be calculated based on estimates of dry matter intake.

There is also a third tier, *Tier 3*, where countries develop their own country-specific models and measurement systems that are tailored to address national circumstances, repeated over time and use high-resolution sub-national datasets. Approaches under the hierarchy of tiers conform to a standard reporting format common to all tiers. This ensures that estimates calculated at a detailed level that can also be aggregated up to a common minimum level of detail for comparison with all other reporting countries.

### 1.4 New Zealand's agricultural emissions context

Pastoral grazing is a major component of the New Zealand agricultural sector, and pastoral agricultural products (i.e. excluding seafood and forestry) comprise around 61 percent of total merchandise exports (Statistics New Zealand, 2017). 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 for cattle is based on the US feeding systems with high levels of grain feed.

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 extensive outdoor grazing systems with a greater 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 on pasture all year round. 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

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.

Because of this New Zealand has developed its own Tier 2 methodology to determine the energy requirements of cattle, sheep and deer, and subsequently the CH<sub>4</sub> and N<sub>2</sub>O emissions from each species (Clark *et al*, 2003). This methodology was developed to conform to the IPCC good practice guidelines and takes into account 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 fixed default emission factors. 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 seventh national communication (<http://www.mfe.govt.nz/publications/climate/nz-sixth-national-communication/index.html>).

## 1.5 Sources of New Zealand's agricultural emissions

New Zealand uses a range of methods to calculate agricultural emissions that are appropriate to the size of the different emission categories. In 2016, 91.7 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.

Other livestock species (Swine, Goats, Horses, Llama and alpacas, Mules and asses, and Poultry – referred to as 'minor' livestock categories) account for only 0.5 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 factors to estimate emissions for these minor livestock species.

Direct and indirect N<sub>2</sub>O emissions from synthetic fertiliser account for 4.2 per cent of New Zealand's agricultural emissions and are calculated using country-specific emission factors. CO<sub>2</sub> emissions from liming and urea contributed a combination of 2.8 per cent towards total agricultural emissions in 2016.

The remaining 0.8 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.

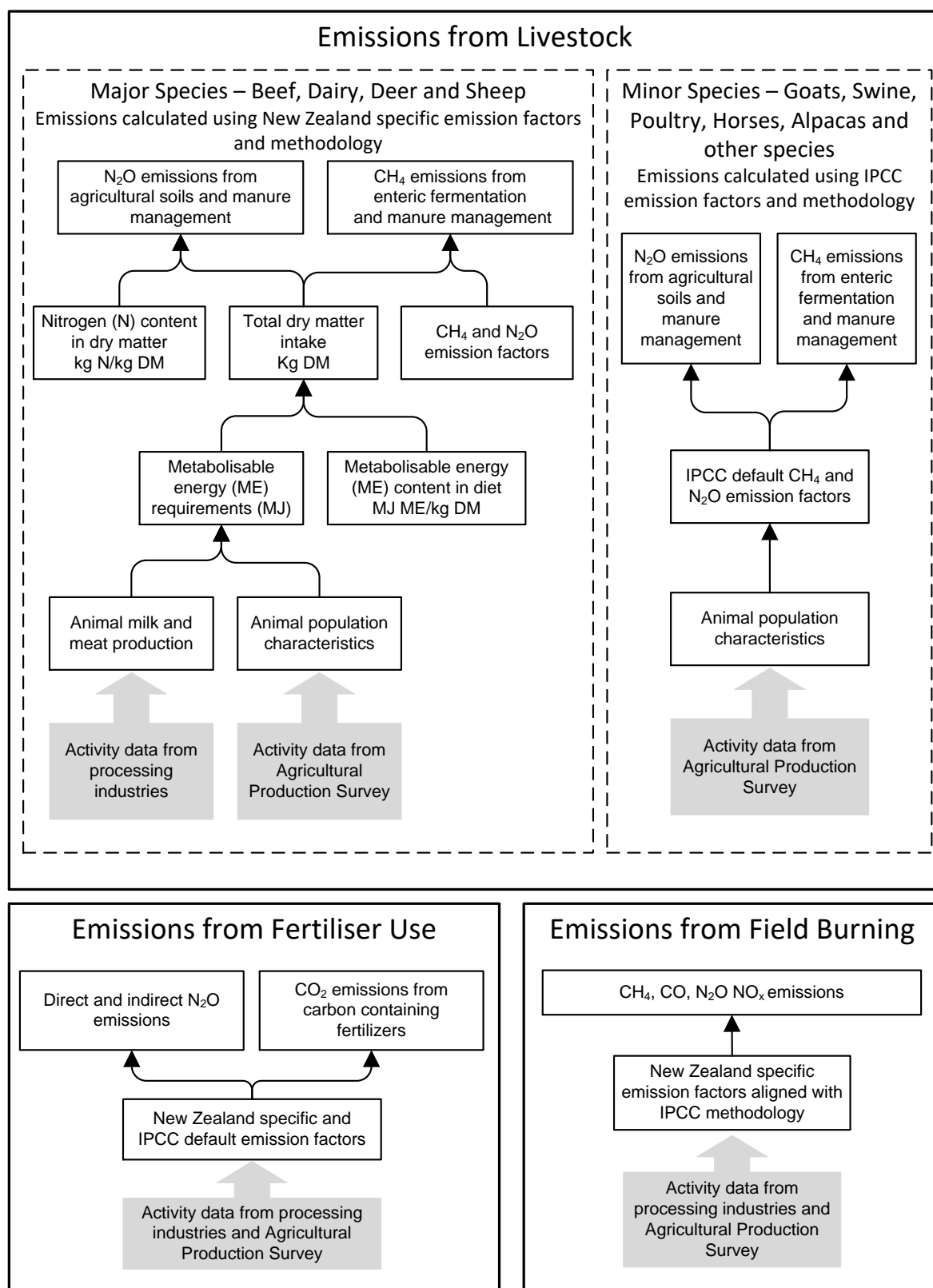
The diagram below outlines how the inventory calculates different emission categories. Livestock emissions from dairy and beef cattle, sheep and deer are calculated by using activity data to calculate the energy and intake requirements of these animals. Methodology specific to New Zealand is then used to calculate the resulting CH<sub>4</sub> and N<sub>2</sub>O emissions from the calculated intake level.

Emissions from minor species such as goats and swine are calculated using activity data and IPCC emission factors and methodology.

Emissions associated with the use of fertiliser are calculated from activity data and a mixture of New Zealand and IPCC emission factors.

Emissions from field burning are calculated using activity data and New Zealand specific emission factors aligned with IPCC methodology.

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



## 2 Activity data – sources and assumptions

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 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 from the Ministry for Primary Industries.

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

Most inventory data is collected on a June year-end basis but the Inventory is calculated on a calendar year. 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. 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 June year. 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)
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 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

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:

- Breeding hinds
- Hinds < 1 year old
- Hinds 1-2 years old
- Stags < 1 year old
- Stags 1 – 2 years old

- Stags 2 – 3 years old
- Mixed age and breeding stags

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. 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

As stated in the previous section, a population model is used to calculate monthly populations for the major livestock (Dairy cattle, beef cattle, sheep and deer) species. This model is outlined below, and in the paper by Clark (2008). Additional refinements to the population models, as recommended by Thompson *et.al.* (2010).

The population models have been constructed to reflect the natural variation in livestock populations that occur throughout the year. Data from the Agricultural Production Survey (APS) as well as fixed parameters and assumptions are used in these models. To calculate month-by-month populations for an entire particular calendar year, APS data from three years is required (see figure 3.1).

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

To calculate the population of mature milking cows for a particular month, data from two agricultural production surveys are required. The figure below shows the survey data that would be required to calculate the population of mature milking cows from January 2001 to December 2003.

**Figure 3.1: data required to estimate monthly populations in the agriculture inventory model**

Agricultural Production Survey Year					
2001	January	APS 2000	APS 2001		
	February				
	March				
	April				
	May				
	June				
	July				
	August				
	September				
	October				
	November				
	December				
2002	January	APS 2002			
	February				
	March				
	April				
	May				
	June				
	July				
	August				
	September				
	October				
	November				
	December				
2003	January	APS 2003			
	February				
	March				
	April				
	May				
	June				
	July				

August		
September		
October		
November		
December		APS 2004

The equations used to calculate monthly populations on mature milking cows for a particular year have been constructed to ensure that the population peaks between May, June, and July. Individual equations need to be specified for May, June, July, and August. For the months from September to April the same equation format is used.

*Population of mature milking cows, in May of year  $t$  (Equation 3.1)*

$$POPmmc_{may(t)} = POPmmc_{june(t)} + Dmmc_{excl.aug(t-1)}$$

Where:

$POPmmc_{may(t)}$  = population of mature milking cows in May (year  $t$ )

$POPmmc_{june(t)}$  = population of mature milking cows in June (year  $t$ )

$Dmmc_{excl.aug(t-1)}$  = number of mature milking cow deaths per month between July (year  $t-1$ ) and June (year  $t$ ), excluding august (year  $t-1$ )

This equation uses the June mature milking cow population (calculated in equation 3.2) to back-calculate the population for May, and assumes that  $Dmmc_{excl.aug(t-1)}$  number of deaths will occur in May.

*Population of mature milking cows, in June of year  $t$  (Equation 3.2)*

$$POPmmc_{june(t)} = POPdm_t + Dmmc_{excl.aug(t-1)}$$

Where:

$POPmmc_{june(t)}$  = population of mature milking cows in June (year  $t$ )

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

$Dmmc_{excl.aug(t-1)}$  = number of mature milking cow deaths per month between July (year  $t-1$ ) and June (year  $t$ ), excluding August (year  $t-1$ )

*Population of mature milking cows, in July of year  $t$  (Equation 3.3)*

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

Where:

$POPmmc_{july(t)}$  = population of mature milking cows in 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%)

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  $POP_{dnmc_t}$  are dry cows (as opposed to heifers).

*Population of mature milking cows, in August of year  $t$  (Equation 3.4)*

$$POP_{mmc_{aug(t)}} = POP_{dm_t} - Dmmc_{aug(t)}$$

Where:

$POP_{mmc_{aug(t)}}$  = population of mature milking cows in August (year  $t$ )

$POP_{dm_t}$  = Total number of dairy cows and heifers, in milk or calf in year  $t$  (using data from APS)

$Dmmc_{aug(t)}$  = number of mature milking cow deaths in August of year  $t$

*Monthly population of mature milking cows, between September (year  $t$ ) and April (year  $t+1$ ) (Equation 3.5)*

$$POP_{mmc_m} = POP_{mmc_{m-1}} - Dmmc_{excl.aug(t)}$$

Where:

$POP_{mmc_m}$  = population of mature milking cows in particular month  $m$

$POP_{mmc_{m-1}}$  = population of mature milking cows in previous month  $m-1$

$Dmmc_{excl.aug(t)}$  = number of mature milking cow deaths per month between July (year  $t$ ) and June (year  $t+1$ ), excluding August (year  $t$ )

Equations 3.6-3.10 outline the equations used to calculate the number of mature milking cow deaths occurring in a particular month.

*Number of deaths per month for mature milking cows, from July of year  $t-1$  to June of year  $t$ , (excluding August) (Equation 3.6)*

$$Dmmc_{excl.aug(t-1)} = \frac{Dmmc_{jul(t-1)-jun(t)} - Dmmc_{aug(t-1)}}{11}$$

Where:

$Dmmc_{excl.aug(t-1)}$  = number of mature milking cow deaths per month between July (year  $t-1$ ) and June (year  $t$ ), excluding August (year  $t-1$ )

$Dmmc_{jul(t-1) - apr(t)}$  = number of mature milking cow deaths, between July (year  $t-1$ ) and June (year  $t$ )

$Dmmc_{aug(t-1)}$  = number of mature milking cow deaths, in August of year  $t-1$

*Number of deaths for mature milking cows, in August of year  $t-1$  (Equation 3.7)*

$$Dmmc_{aug(t-1)} = Dmmc_{jul(t-1)-jun(t)} \times PDmmc_{aug}$$

Where:

$Dmmc_{aug(t-1)}$  = number of mature milking cow deaths, in August of year  $t-1$

$Dmmc_{jul(t-1) - apr(t)}$  = number of mature milking cow deaths, between July (year  $t-1$ ) and June (year  $t$ )

$PD_{mmc_{aug}}$  = proportion of total deaths in 12 month period that occur in August (currently set at 50%)

*Number of deaths for mature milking cows, between July of year  $t-1$  to June of year  $t$  (Equation 3.8)*

$$D_{mmc_{jul(t-1)-jun(t)}} = D_{mmc_{jul(t-1)-apr(t)}} + D_{mmc_{may(t)-jun(t)}}$$

Where:

$D_{mmc_{jul(t-1)-jun(t)}}$  = number of mature milking cow deaths, between July (year  $t-1$ ) and June (year  $t$ )

$D_{mmc_{jul(t-1)-apr(t)}}$  = number of mature milking cow deaths, between July (year  $t-1$ ) and April (year  $t$ )

$D_{mmc_{jul(t-1)-apr(t)}}$  = number of mature milking cow deaths, between May and June in year  $t$

*Number of deaths for mature milking cows, between July of year  $t-1$  to April of year  $t$  (Equation 3.9)*

$$D_{mmc_{jul(t-1)-apr(t)}} = POP_{dm_{t-1}} \times \left( \frac{DR_{mmc}}{nod_{year}} \right) \times nod_{jul-apr}$$

Where:

$D_{mmc_{jul(t-1)-apr(t)}}$  = number of mature milking cow deaths, between July (year  $t-1$ ) and April (year  $t$ )

$POP_{dm_{t-1}}$  = Total number of dairy cows and heifers, in milk or calf in year  $t-1$  (using data from the APS)

$DR_{mmc}$  = annual death rate for mature milking cows (currently set at 2.1%)

$nod_{year}$  = number of days in year  $t$

$nod_{jul-apr}$  = number of days from the beginning of July (year  $t-1$ ) to the end of April (year  $t$ )

*Number of deaths for mature milking cows, between May of year  $t$  to June of year  $t$  (Equation 3.10)*

$$D_{mmc_{may(t)-jun(t)}} = POP_{dm_t} \times \left( \frac{DR_{mmc}}{nod_{year}} \right) \times nod_{jul-apr}$$

Where:

$D_{mmc_{may(t)-jun(t)}}$  = number of mature milking cow deaths, between May and June in year  $t$

$POP_{dm_t}$  = Total number of dairy cows and heifers, in milk or calf in year  $t$  (using data from the APS)

$DR_{mmc}$  = annual death rate for mature milking cows (currently set at 2.1%)

$nod_{year}$  = number of days in year  $t$

$nod_{may-jun}$  = number of days from the beginning of May (year  $t$ ) to the end of June (year  $t$ )

### 3.1.2 Growing Heifers 0-1 years

For each physiological year (July to June), the number of growing heifers aged 0-1 remains constant, and the death rate over the year is assumed to be zero. The following equation is used to calculate the

monthly population of growing heifers aged between zero and one years. All of the required data are from the Agricultural Production Survey.

*Monthly population of growing heifers aged between zero and one, between August (year  $t$ ) and June (year  $t+1$ ) (Equation 3.11)*

$$POPgh_{0-1month(t)} = POPtotaldairy_t - POPdm_t - POPdnm_t - POPdbb_t$$

Where:

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

$POPtotaldairy_t$  = Total number of dairy cows (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)

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.

### 3.1.3 Growing Heifers 1-2 years

For each physiological year between July and April, number of growing heifers aged between zero and one remains constant, and the death rate over the year is assumed to be zero. The following equation is used to calculate the monthly population of growing heifers aged between one and two years.

*Monthly population of growing heifers aged between one and two, between July (year  $t$ ) and April (year  $t+1$ ) (Equation 3.12)*

$$POPgh_{1-2month} = POPgh_{0-1month(t-1)} + POPdnm_t \times (1 - P_{dry})$$

Where:

$POPgh_{1-2month}$  = population of growing heifers aged between one and two in particular month

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

$POPdnm_t$  = 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%)

In May and June the population of growing heifers aged 1-2 is assumed to be zero as the population of heifers in this age group move into the mature milking cows category.

### 3.1.4 Breeding Bulls

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

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:

*Monthly population of breeding bulls, from March to June in year  $t$  (Equation 3.13)*

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

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  $t$ )

$POPbb_{APS(t-1)}$  = 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.

*Monthly population of breeding bulls, from August in year  $t$  to February in year  $t+1$  (Equation 3.14)*

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

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:

- Breeding Growing Cows 0-1
- Breeding Growing Cows 1-2
- Breeding Bulls Mixed Age
- Slaughter Heifers 0-1
- Slaughter Heifers 1-2
- Slaughter Steers 0-1
- Slaughter Steers 1-2
- Slaughter Bulls 0-1
- Slaughter Bulls 1-2
- Breeding Growing Cows 2-3
- Breeding Mature Cows

### 3.2.1 Breeding growing cows 0-1 (less than one year old)

The four classes of breeding growing cow are:

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

These populations are calculated using the same APS data (beef cows and heifers in calf). The inventory assumes that the July population of breeding growing cows aged 0-1, 1-2, and 2-3 are the same.

In July, it is assumed that the number of breeding cows less than one year old will be equal to 17% of the number of beef cows and heifers in calf found from the APS in that year (line codes 7056 and 7057).

In August, the population of breeding growing cows aged between 0 and 1 is calculated using the following equation:

*Population of breeding growing cows aged between 0 and 1, for August in year  $t$  (Equation 3.15)*

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

Where:

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

$POPbgc1_{jul(t)}$  = population of breeding growing cows aged 0-1 in July in year  $t$  (equal to 17% of the number of beef cows and heifers in calf found from the APS in that year – line codes 7056 and 7057)

$DR_{bgc1}$  = annual death rate of breeding growing cows aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

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

In September, breeding cows move into the next age group. A new population of breeding cows less than one year old is calculated in the inventory using the following formula:

*Population of breeding growing cows aged 0-1, for September in year  $t$  (Equation 3.16)*

$$POPbgc1_{sep(t)} = 17\% \times POPbmc_{sep(t)}$$

Where:

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

$POPbmc_{sep(t)}$  = population of breeding mature cows in September in year  $t$  (see equation 3.29)

The calculation of the September population of breeding mature cows is outlined in section 3.2.4 in equation 3.29.

From October to February, the population of breeding growing cows aged between 0 and 1 is calculated using the following equation:

*Monthly population of breeding growing cows aged 0 to 1, from October in year  $t$  to February in year  $t+1$  (Equation 3.17)*

$$POPbgc1_m = POPbgc1_{(m-1)} \times \left( 1 - \frac{DR_{bgc1}}{nod_{year}} \times nod_{m-1} \right)$$

Where:

$POP_{bgc1m}$  = population of breeding growing cows aged 0-1 in month  $m$

$POP_{bgc1m-1}$  = 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 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in month  $m$

The March to June populations of breeding growing cows aged between 0 and 1 is calculated in reverse order

*June population of breeding growing cows aged 0 to 1 (Equation 3.18)*

$$POP_{bgc1_{june}} = 17\% \times POP_{bmc_{jul}} \times \left( 1 + \frac{DR_{bgc1}}{nod_{year}} \times nod_{jun} \right)$$

Where:

$POP_{bgc1_{june}}$  = population of breeding growing cows aged 0-1 in June

$POP_{bmc_{jul}}$  = population of breeding mature cows in July (see equation 3.29)

$DR_{bgc1}$  = annual death rate of breeding growing cows aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_{jun}$  = number of days in June

*Monthly population of breeding growing cows aged 0 to 1, from March to May (Equation 3.19)*

$$POP_{bgc1_m} = POP_{bgc1_{m+1}} \times \left( 1 + \frac{DR_{bgc1}}{nod_{year}} \times nod_m \right)$$

Where:

$POP_{bgc1_m}$  = population of breeding growing cows aged 0-1 in month  $m$

$POP_{bgc1_{m+1}}$  = population of breeding growing cows in next month  $m+1$

$DR_{bgc1}$  = annual death rate of breeding growing cows aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in month  $m$

### 3.2.2 Breeding growing cows 1-2 (one to two years old)

The population of breeding growing cows varies throughout the year. In July, it is assumed that the number of breeding cows between one and two years old will be equal to 17% of the number of beef cows and heifers in calf found from the APS in that year.

The number of breeding growing cows aged 1-2 for any particular month is assumed to be equal to the number of breeding growing cows aged 2-3, so the equations outlined in this section can also be used to calculate the population for breeding growing cows aged 2-3.

In August, the population of breeding growing cows aged between 1 and 2 is calculated using the same formula that is used to calculate the population of breeding growing cows aged between 0 and 1.

*Population of breeding growing cows aged 1 to 2 years old, for August in year  $t$  (Equation 3.20)*

$$POPbgc2_{aug(t)} = POPbgc2_{jul(t)} \times \left( 1 - \frac{DR_{bgc2}}{nod_{year}} \times nod_{jul} \right)$$

Where:

$POPbgc2_{aug(t)}$  = population of breeding growing cows aged 1-2 in August in year  $t$

$POPbgc2_{jul(t)}$  = population of breeding growing cows aged 1-2 in July in year  $t$  (equal to 17% of the number of beef cows and heifers in calf found from the APS in that year – line codes 7056 and 7057)

$DR_{bgc1}$  = annual death rate of breeding growing cows aged 1-2 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_{jul}$  = number of days in July

In September, breeding cows move into the next age group. A new population of breeding cows between one and two years old is calculated in the inventory using the following formula:

*Population of breeding growing cows aged 1-2, for September in year  $t$  (Equation 3.21)*

$$POPbgc2_{sep(t)} = POPbgc1_{aug(t)} \times \left( 1 - \frac{DR_{bgc2}}{nod_{year}} \times nod_{aug} \right)$$

Where:

$POPbgc2_{sep(t)}$  = population of breeding growing cows aged 1-2 in September of year  $t$

$POPbgc1_{aug(t)}$  = population of breeding growing cows aged 1-2 in August of year  $t$

$DR_{bgc1}$  = annual death rate of breeding growing cows aged 1-2 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_{aug}$  = number of days in August

From October to February, the population of breeding growing cows aged between 1 and 2 is calculated using the following equation:

*Monthly population of breeding growing cows aged 1 to 2, from October in year  $t$  to February in year  $t+1$  (Equation 3.22)*

$$POPbgc2_m = POPbgc2_{(m-1)} \times \left( 1 - \frac{DR_{bgc2}}{nod_{year}} \times nod_{m-1} \right)$$

Where:

$POPbgc1_m$  = population of breeding growing cows aged 1-2 in month  $m$

$POPbgc1_{m-1}$  = population of breeding growing cows aged 1-2 in previous month  $m-1$

$DR_{bgc1}$  = annual death rate of breeding growing cows aged 1-2 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

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

The March to June populations of breeding growing cows 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).

*June population of breeding growing cows aged 1 to 2 (Equation 3.23)*

$$POPbgc2_{june(t)} = 17\% \times POPbmc_{jul(t)} \times \left( 1 + \frac{DR_{bgc2}}{nod_{year}} \times nod_{jun} \right)$$

Where:

$POPbgc2_{june(t)}$  = population of breeding growing cows aged 1-2 in June of year  $t$

$POPbmc_{jul(t)}$  = population of breeding mature cows in July of year  $t$  (see equation 3.29)

$DR_{bgc2}$  = annual death rate of breeding growing cows aged 1-2 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in June

*Monthly population of breeding growing cows aged 1 to 2, from March to May (Equation 3.24)*

$$POPbgc2_{m(t)} = POPbgc2_{m+1(t)} \times \left( 1 + \frac{DR_{bgc2}}{nod_{year}} \times nod_m \right)$$

Where:

$POPbgc2_{m(t)}$  = population of breeding growing cows aged 1-2 in month  $m$  and year  $t$

$POPbgc2_{m+1(t)}$  = population of breeding growing cows aged 1-2 in next month  $m+1$ , year  $t$

$DR_{bgc1}$  = annual death rate of breeding growing cows aged 1-2 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in month  $m$

### 3.2.3 Breeding growing cows 2-3 (two to three years old)

As stated at the start of section 3.2.2, the number of breeding growing cows aged 2-3 for any particular month is assumed to be equal to the number of breeding growing cows aged 1-2, so the equations outlined in section 3.2.3 can also be used to calculate the population for breeding growing cows aged 2-3.

### 3.2.4 Breeding mature cows

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

#### Step 1

A first iteration of breeding mature cow populations are calculated using the equations detailed in section 3.2.2, with a few key differences:

- The death rate parameter ( $DR_{bgc1}$ , now  $DR_{bmc}$ ) is 2.7% instead of 2%
- The 17% value used to calculate the population of cows in July is changed to 83%, to reflect the assumption that the number of breeding mature cows will be equal to 83% of the number of beef cows and heifers in calf found from the APS in that year

In July, it is assumed that the number of breeding cows less than one year old will be equal to 83% of the number of beef cows and heifers in calf found from the APS in that year.

The calculated monthly populations from step 1 *are not* the final population figures used in the model.

#### 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:

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

$$Dbmc_{m(t)} = POPbmc_{m(t)} \times \left( \frac{DR_{bmc}}{nod_{year}} \times nod_m \right)$$

Where:

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

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

$DR_{bmc}$  = annual death rate of breeding growing cows aged 1-2 (currently assumed to be 2.7% per year)

$nod_{year}$  = 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).

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

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

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.

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

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

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%

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

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

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 are 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.

In July, it is assumed that the number of breeding mature cows will be equal to 83% of the number of beef cows and heifers in calf found from the APS in that year (line codes 7056 and 7057). The equations below are used to calculate the monthly populations of mature breeding cows for the remaining months.

*Population of breeding mature cows, for August in year  $t$  (Equation 3.29)*

$$POPbmc_{jul(t)} = 83\% \times POPbchc_{jul(t)}$$

Where:

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

$POPbchc_{jul(t)}$  = population of beef cows and heifers in calf in July of year  $t$  (using data from the APS, line codes 7056 and 7057)

*Population of breeding mature cows, for August in year  $t$  (Equation 3.30)*

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

Where:

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

$POPbmc_{jul(t)}$  = population of breeding mature cows in July of year  $t$  (see equation 3.29)

$Dbmc_{exl.sep}$  = 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

The calculation of  $Dbmc_{exl.sep}$  is outlined in equation 3.28

*Population of breeding mature cows, for September in year  $t$  (Equation 3.31)*

$$POPbmc_{sep(t)} = POPbmc_{aug(t)} - Dbmc_{sep(t)}$$

Where:

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

$POPbmc_{aug(t)}$  = population of breeding mature cows in August of year  $t$  (see equation 3.30)

$Dbmc_{sep(t)}$  = Number of deaths calculated to occur in September (see equation 3.27)

*Population of breeding mature cows, for October in year  $t$  to February in year  $t+1$  (Equation 3.32)*

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

Where:

POPbmc<sub>m</sub> = population of breeding mature cows in month *m*

POPbmc<sub>m-1</sub> = population of breeding mature cows in previous month *m-1*

Dbmc<sub>exl.sep</sub> = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September

nod<sub>year</sub> = number of days in year

nod<sub>sep</sub> = number of days in September

nod<sub>m-1</sub> = number of days in previous month *m*

The March 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).

*Population of breeding mature cows in June (Equation 3.33)*

$$POPbmc_{june(t)} = POPbmc_{july(t)} + \frac{Dbmc_{exl.sep}}{nod_{year} - nod_{sep}} \times nod_{june}$$

Where:

POPbmc<sub>june(t)</sub> = population of breeding mature cows in June of year *t*

POPbmc<sub>july(t)</sub> = population of breeding mature cows in July of year *t*

Dbmc<sub>exl.sep</sub> = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September (see equation 3.28)

nod<sub>year</sub> = number of days in year

nod<sub>sep</sub> = number of days in September

nod<sub>june</sub> = number of days in June

*Monthly population of breeding mature cows, from March to May (Equation 3.34)*

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

Where:

POPbmc<sub>m(t)</sub> = population of breeding mature cows in month *m* and year *t*

POPbmc<sub>m-1(t)</sub> = population of breeding mature cows in next month *m+1* and year *t*

Dbmc<sub>exl.sep</sub> = number of deaths of breeding mature cows calculated to occur over the course of a year excluding September (see equation 3.28).

nod<sub>year</sub> = number of days in year

nod<sub>sep</sub> = number of days in September

nod<sub>m</sub> = number of days in month *m*

### 3.2.5 Slaughter Heifers 0-1

The population of slaughter heifers aged 0-1 are calculated monthly, using an assumed annual death rate of 2%. Information on the number of slaughtered beef cattle is also required to calculate monthly populations for this class.

*Population of slaughter heifers aged 0-1 in July (Equation 3.35)*

$$POPsh1_{jul(t)} = POPheifer_{jul(t)} \times Psc_{heifer}$$

Where:

$POPsh1_{jul(t)}$  = population of slaughter heifers aged 0-1 in July of year  $t$

$POPheifer_{jul(t)}$  = population of heifers in July of year  $t$  (calculated in equation 3.36)

$Psc_{heifer}$  = percentage of slaughter heifers that are calves (currently assumed to be 50%)

The population of heifers in July is calculated using the following formulae:

*Population of heifers in July (Equation 3.36)*

$$POPheifer_{jul(t)} = \frac{slau_{heifer(t)}}{slau_{beef(t)}} \times slau_{aval(t)}$$

Where:

$POPheifer_{jul(t)}$  = population of heifers in July of year  $t$

$slau_{heifer}$  = number of heifers slaughtered during financial year ending in June of year  $t$  (from slaughter statistics)

$slau_{beef}$  = total number of beef cattle slaughtered during financial year ending in June of year  $t$  (from slaughter statistics)

$slau_{aval(t)}$  = number of beef available for slaughter (see equation 3.37)

*Calculation of beef available for slaughter (Equation 3.37)*

$$slau_{aval(t)} = POPbeef_{jul(t)} - (POPbbc_{July} \times (Pbca + 3 \times Pbch) + POPbbb_{July(t)})$$

Where:

$slau_{aval}$  = number of beef available for slaughter in year  $t$

$POPbbc_{July(t)}$  = population of beef breeding cows in July of year  $t$  (from APS, sum of line codes 7056 and 7057)

$Pbca$  = proportion of beef breeding cows assumed to be adults (currently set at 83%)

$Pbch$  = proportion of beef breeding cows assumed to be heifers (currently set at 17%)

$POPbbb_{July(t)}$  = population of beef breeding bulls in July of year  $t$  (from APS, line code 7068)

*Calculation of total beef slaughtered (Equation 3.38)*

$$slau_{beef(t)} = slau_{heifer(t)} + slau_{steer(t)} + slau_{bull(t)}$$

Where:

$slau_{beef(t)}$  = total number of beef cattle slaughtered during financial year ending in June of year  $t$

$slau_{heifer(t)}$  = number of heifers slaughtered during financial year ending in June of year  $t$  (from slaughter statistics)

$slau_{steer(t)}$  = number of steers slaughtered during financial year ending in June of year  $t$  (from slaughter statistics)

$slau_{bull(t)}$  = number of bulls slaughtered during financial year ending in June of year  $t$  (from slaughter statistics)

For August and September the population of slaughter heifers aged 0-1 is calculated using the following formula:

*Monthly population of slaughter heifers aged 0 to 1, for August and September (Equation 3.39)*

$$POP_{sh1_{m(t)}} = POP_{sh1_{(m-1)(t)}} \times \left( 1 - \frac{DR_{sh1}}{nod_{year}} \times nod_{m-1} \right)$$

Where:

$POP_{sh1_{m(t)}}$  = population of slaughter heifers aged 0-1 in month  $m$  and year  $t$

$POP_{bgc1_{m-1(t)}}$  = population of slaughter heifers aged 0-1 in previous month  $m-1$  and year  $t$

$DR_{sh1}$  = annual death rate of slaughter heifers aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in previous month  $m-1$

During September it is assumed that new heifers for the year are born, while 12 month old heifers are either slaughtered or moved into the next age class. These changes are seen in the October population figure.

The October to June populations of slaughter heifers 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).

*June population of slaughter heifers aged 0 to 1 (Equation 3.40)*

$$POP_{sh1_{june(t)}} = POP_{sh1_{jul(t)}} \times \left( 1 + \frac{DR_{sh1}}{nod_{year}} \times nod_{jun} \right)$$

Where:

$POP_{sh1_{june(t)}}$  = population of slaughter heifers aged 0-1 in June of year  $t$

$POP_{sh1_{jul(t)}}$  = population of slaughter heifers aged 0-1 in July of year  $t$

$DR_{sh1}$  = annual death rate of slaughter heifers aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in June

*Monthly population of slaughter heifers aged 0 to 1, from October in year  $t-1$  to May in year  $t$  (Equation 3.41)*

$$POP_{sh1_{m(t)}} = POP_{sh1_{m+1(t)}} \times \left( 1 + \frac{DR_{sh1}}{nod_{year}} \times nod_m \right)$$

Where:

$POP_{sh1_m}$  = population of slaughter heifers aged 0-1 in month  $m$  and year  $t$

$POP_{sh1_{m+1}}$  = population of slaughter heifers aged 0-1 in next month  $m+1$  and year  $t$

$DR_{sh1}$  = annual death rate of slaughter heifers aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in month  $m$

### 3.2.6 Slaughter Heifers 1-2

The monthly population of slaughter heifers aged 1-2 are calculated using identical equations to the ones used to calculate monthly population of slaughter heifers aged 0-1. These formulae are below.

*Population of slaughter heifers aged 1-2 in July (Equation 3.42)*

$$POP_{sh2_{jul(t)}} = POP_{heifer_{jul(t)}} - POP_{sh1_{jul(t)}}$$

Where:

$POP_{sh2_{jul(t)}}$  = population of slaughter heifers aged 1-2 in July of year  $t$

$POP_{sh1_{jul(t)}}$  = population of slaughter heifers aged 0-1 in July of year  $t$  (calculated in equation 3.35)

$POP_{heifer_{jul(t)}}$  = population of heifers in July of year  $t$  (calculated in equation 3.36)

For August and September the population of slaughter heifers aged 1-2 is calculated using the following formula:

*Monthly population of slaughter heifers aged 1 to 2, for August and September (Equation 3.43)*

$$POP_{sh2_{m(t)}} = POP_{sh2_{(m-1)(t)}} \times \left( 1 - \frac{DR_{sh2}}{nod_{year}} \times nod_{m-1} \right)$$

Where:

$POP_{sh2_{m(t)}}$  = population of slaughter heifers aged 1-2 in month  $m$  and year  $t$

$POP_{sh2_{m-1(t)}}$  = population of slaughter heifers aged 1-2 in previous month  $m-1$  and year  $t$

$DR_{sh2}$  = annual death rate of slaughter heifers aged 1-2 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

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

During September it assumed that 12 month old heifers are moved into the next age class, and some of the slaughter heifers aged 1-2 are slaughtered. These changes are seen in the October population figure.

The October to June populations of slaughter heifers 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).

*June population of slaughter heifers aged 1 to 2 (Equation 3.44)*

$$POP_{sh2_{june(t)}} = POP_{sh2_{jul(t)}} \times \left( 1 + \frac{DR_{sh2}}{nod_{year}} \times nod_{jun} \right)$$

Where:

$POP_{sh2_{june(t)}}$  = population of slaughter heifers aged 1-2 in June of year  $t$

POPsh2<sub>jul(t)</sub> = population of slaughter heifers aged 1-2 in July of year *t*

DR<sub>sh2</sub> = annual death rate of slaughter heifers aged 1-2 (currently assumed to be 2% per year)

nod<sub>year</sub> = number of days in year

nod<sub>jul</sub> = number of days in July

*Monthly population of slaughter heifers aged 1 to 2, from October in year t-1 to May in year t (Equation 3.45)*

$$POPsh2_m = POPsh2_{m+1} \times \left( 1 + \frac{DR_{sh2}}{nod_{year}} \times nod_m \right)$$

Where:

POPsh2<sub>m</sub> = population of slaughter heifers aged 1-2 in month *m*

POPsh2<sub>m+1</sub> = population of slaughter heifers aged 1-2 in next month *m+1*

DR<sub>sh1</sub> = annual death rate of slaughter heifers aged 1-2 (currently assumed to be 2% per year)

nod<sub>year</sub> = number of days in year

nod<sub>m</sub> = number of days in month *m*

### 3.2.7 Slaughter Steers 0-1

The following equations show how the monthly population of slaughter steers is calculated.

*Population of slaughter steers aged 0-1 in July (Equation 3.46)*

$$POPss1_{jul(t)} = \frac{slau_{steer(t)}}{slau_{beef(t)}} \times slau_{aval(t)} \times Psc_{steer}$$

Where:

POPss1<sub>jul(t)</sub> = population of slaughter steers aged 0-1 in July of year *t*

Slau<sub>steer(t)</sub> = number of steers slaughtered during financial year ending in June of year *t* (from slaughter statistics)

slau<sub>beef(t)</sub> = total number of beef cattle slaughtered during financial year ending in June of year *t* (from equation 3.38)

slau<sub>aval(t)</sub> = number of beef available for slaughter (from equation 3.37)

Psc<sub>steer</sub> = percentage of slaughter steers that are calves (currently assumed to be 50%)

For August and September the population of slaughter steers aged 0-1 is calculated using the following formula:

*Monthly population of slaughter steers aged 0 to 1, for August and September (Equation 3.47)*

$$POPss1_{m(t)} = POPss1_{m-1(t)} \times \left( 1 - \frac{DR_{ss1}}{nod_{year}} \times nod_{m-1} \right)$$

Where:

POPss1<sub>m(t)</sub> = population of slaughter steers aged 0-1 in month *m* of year *t*

$POP_{ss1_{m-1}(t)}$  = population of slaughter steers aged 0-1 in previous month m-1 of year  $t$

$DR_{ss1}$  = annual death rate of slaughter steers aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in previous month m-1

During September it assumed that new steers for the year are born, while 12 month old steers are either slaughtered or moved into the next age class. These changes are seen in the October population figure.

The October to June populations of slaughter steers 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).

*June population of slaughter steers aged 0 to 1 (Equation 3.48)*

$$POP_{ss1_{june}(t)} = POP_{ss1_{jul}(t)} \times \left( 1 + \frac{DR_{ss1}}{nod_{year}} \times nod_{jun} \right)$$

Where:

$POP_{ss1_{june}(t)}$  = population of slaughter steers aged 0-1 in June of year  $t$

$POP_{ss1_{jul}(t)}$  = population of slaughter steers aged 0-1 in July of year  $t$

$DR_{ss1}$  = annual death rate of slaughter steers aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in June

*Monthly population of slaughter steers aged 0 to 1, from October in year t-1 to May in year t (Equation 3.49)*

$$POP_{ss1_m} = POP_{ss1_{m+1}} \times \left( 1 + \frac{DR_{ss1}}{nod_{year}} \times nod_m \right)$$

Where:

$POP_{ss1_m}$  = population of slaughter steers aged 0-1 in month m

$POP_{ss1_{m+1}}$  = population of slaughter steers aged 0-1 in next month m+1

$DR_{ss1}$  = annual death rate of slaughter steers aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in month m

### 3.2.8 Slaughter Steers 1-2

The population of slaughter steers aged 1-2 is calculated using the same equations as those used to calculate slaughter steers aged 0-1. The only difference is that the steers in the 1-2 age bracket are assumed to be slaughtered in February rather than October

*Population of slaughter steers aged 1-2 in July (Equation 3.50)*

$$POP_{ss2_{jul}(t)} = \left( \frac{slau_{steer}(t)}{slau_{beef}(t)} \times slau_{aval}(t) \right) - POP_{ss1_{jul}(t)}$$



Where:

POPss2<sub>jul(t)</sub> = population of slaughter steers aged 1-2 in July

slau<sub>steer(t)</sub> = number of steers slaughtered during financial year ending in June of year *t* (from slaughter statistics)

slau<sub>beef(t)</sub> = total number of beef cattle slaughtered during financial year ending in June of year *t* (from equation 3.38)

slau<sub>aval(t)</sub> = number of beef available for slaughter in year *t* (from equation 3.37)

POPss1<sub>jul(t)</sub> = population of slaughter steers aged 0-1 in July of year *t*

From August to January the population of slaughter steers aged 1-2 is calculated using the following formula:

*Monthly population of slaughter steers aged 1 to 2, from August to January (Equation 3.51)*

$$POPss2_m = POPss2_{(m-1)} \times \left( 1 - \frac{DR_{ss2}}{nod_{year}} \times nod_{m-1} \right)$$

Where:

POPss2<sub>m</sub> = population of slaughter steers aged 1-2 in month *m*

POPss2<sub>m-1</sub> = population of slaughter steers aged 1-2 in previous month *m-1*

DR<sub>ss2</sub> = annual death rate of slaughter steers aged 1-2 (currently assumed to be 2% per year)

nod<sub>year</sub> = number of days in year

nod<sub>m</sub> = number of days in previous month *m-1*

During February it assumed that 1-2 year old steers are slaughtered. These changes are seen in the February population figure.

The February to June populations of slaughter steers 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).

*June population of slaughter steers aged 1 to 2 (Equation 3.52)*

$$POPss2_{june(t)} = POPss2_{jul(t)} \times \left( 1 + \frac{DR_{ss2}}{nod_{year}} \times nod_{jun} \right)$$

Where:

POPss2<sub>june(t)</sub> = population of slaughter steers aged 1-2 in June of year *t*

POPss2<sub>jul(t)</sub> = population of slaughter steers aged 1-2 in July of year *t*

DR<sub>ss2</sub> = annual death rate of slaughter steers aged 1-2 (currently assumed to be 2% per year)

nod<sub>year</sub> = number of days in year

nod<sub>m</sub> = number of days in June

*Monthly population of slaughter steers aged 1 to 2, from February to May (Equation 3.53)*

$$POPss2_{m(t)} = POPss2_{m+1(t)} \times \left( 1 + \frac{DR_{ss2}}{nod_{year}} \times nod_m \right)$$

Where:

POPss2<sub>m(t)</sub> = population of slaughter steers aged 1-2 in month *m* of year *t*

$POP_{ss2_{m+1}(t)}$  = population of slaughter steers aged 1-2 in next month  $m+1$  of year  $t$

$DR_{ss2}$  = annual death rate of slaughter steers aged 1-2 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in month  $m$

### 3.2.9 Slaughter Bulls 0-1

The following equations show how the monthly population of slaughter bulls aged 0-1 is calculated.

*Population of slaughter bulls aged 0-1 in July (Equation 3.54)*

$$POP_{sb1_{jul}(t)} = \frac{slau_{bull}(t)}{slau_{beef}(t)} \times slau_{aval}(t) \times Psc_{bull}$$

Where:

$POP_{sb1_{jul}(t)}$  = population of slaughter bulls aged 0-1 in July of year  $t$

$slau_{bull}(t)$  = number of bulls slaughtered during financial year ending in June of year  $t$  (from slaughter statistics)

$slau_{beef}(t)$  = total number of beef cattle slaughtered during financial year ending in June of year  $t$  (from equation 3.38)

$slau_{aval}(t)$  = number of beef available for slaughter in year  $t$  (from equation 3.37)

$Psc_{bull}$  = percentage of slaughter bulls that are calves (currently assumed to be 50%)

For August and September the population of slaughter bulls aged 1-2 is calculated using the following formula:

*Monthly population of slaughter bulls aged 0 to 1, for August and September (Equation 3.55)*

$$POP_{sb1_{m(t)}} = POP_{sb1_{m-1}(t)} \times \left( 1 - \frac{DR_{sb1}}{nod_{year}} \times nod_{m-1} \right)$$

Where:

$POP_{sb1_{m(t)}}$  = population of slaughter bulls aged 0-1 in month  $m$  of year  $t$

$POP_{sb1_{m-1}(t)}$  = population of slaughter bulls aged 0-1 in previous month  $m-1$  in year  $t$

$DR_{sb1}$  = annual death rate of slaughter bulls aged 0-1 (currently assumed to be 2% per year)

$nod_{year}$  = number of days in year

$nod_m$  = number of days in previous month  $m-1$

During September it assumed that new bulls for the year are born, while 12 month old bulls are either slaughtered or moved into the next age class. These changes are seen in the October population figure.

The October to June populations of slaughter bulls 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).

*June population of slaughter bulls aged 0 to 1 (Equation 3.56)*

$$POP_{sb1_{june}(t)} = POP_{sb1_{jul}(t)} \times \left( 1 + \frac{DR_{sb1}}{nod_{year}} \times nod_{jun} \right)$$

Where:

POPsb1<sub>june(t)</sub> = population of slaughter bulls aged 0-1 in June of year  $t$

POPsb1<sub>jul(t)</sub> = population of slaughter bulls aged 0-1 in July of year  $t$

DR<sub>sb1</sub> = annual death rate of slaughter bulls aged 0-1 (currently assumed to be 2% per year)

nod<sub>year</sub> = number of days in year

nod<sub>m</sub> = number of days in June

*Monthly population of slaughter bulls aged 0 to 1, from October in year  $t-1$  to May in year  $t$  (Equation 3.57)*

$$POPsb1_{m(t)} = POPsb1_{m+1(t)} \times \left( 1 + \frac{DR_{sb1}}{nod_{year}} \times nod_m \right)$$

Where:

POPsb1<sub>m(t)</sub> = population of slaughter bulls aged 0-1 in month  $m$  of year  $t$

POPsb1<sub>m+1(t)</sub> = population of slaughter bulls aged 0-1 in next month  $m+1$  of year  $t$

DR<sub>sb1</sub> = annual death rate of slaughter bulls aged 0-1 (currently assumed to be 2% per year)

nod<sub>year</sub> = number of days in year

nod<sub>m</sub> = number of days in month  $m$

### 3.2.10 Slaughter Bulls 1-2

The monthly population of slaughter bulls aged 1-2 years is assumed to be exactly the same as the monthly population of slaughter bulls aged 0-1 years i.e:

*Monthly population of slaughter bulls aged 1 to 2 in month  $m$  (Equation 3.58)*

$$POPsb2_{m(t)} = POPsb1_{m(t)}$$

Where:

POPsb2<sub>m(t)</sub> = population of slaughter bulls aged 1-2 in month  $m$  of year  $t$

POPsb1<sub>m(t)</sub> = population of slaughter bulls aged 0-1 in month  $m$  of year  $t$

### 3.2.11 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.

*Monthly population of mixed age breeding bulls, from August in year  $t$  to June in year  $t+1$  (Equation 3.59)*

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

Where:

POPbbma<sub>m</sub> = population of mixed age breeding bulls in month  $m$

POPbbma<sub>m-1</sub> = population of mixed age breeding bulls in previous month  $m$

POPbbma<sub>Jul,t+1</sub> = population of mixed age breeding bulls in July of next year t+1

POPbbma<sub>Jul,t</sub> = population of mixed age breeding bulls in July of current year t

nod<sub>year</sub> = number of days in year

nod<sub>m-1</sub> = 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.

*Annual number of deaths of mature breeding ewes from July to June (Equation 3.60)*

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

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)

*Number of mature breeding ewe deaths that occur in August and September (Equation 3.61)*

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

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:

*Population of mature breeding ewes in August (Equation 3.62)*

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

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  $t$  (see equation 3.60)

$Dmbe_{Aug+Sep(t)}$  = Number of mature breeding ewe deaths that occur in August and September in year  $t$  (see equation 3.61)

$nod_{year}$  = 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:

*Population of mature breeding ewes in September and October (Equation 3.63)*

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

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 3.61)

$nod_{Aug}$  = 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:

*Population of mature breeding ewes between November and March (Equation 3.64)*

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

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 3.60)

$Dmbe_{Aug+Sep}$  = Number of mature breeding ewe deaths that occur in August and September (see equation 3.61)

$nod_{year}$  = number of days in year

$nod_{Aug}$  = number of days in August

nod<sub>Sep</sub> = number of days in September

nod<sub>m-1</sub> = 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).

*Population of mature breeding ewes in June (Equation 3.65)*

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

Where:

POPmbe<sub>Jun(t)</sub> = population of mature breeding ewes in June in year *t*

POPmbe<sub>Jul(t)</sub> = population of mature breeding ewes in July in year *t* (from APS)

Dmbe<sub>AT(t)</sub> = Annual number of deaths of mature breeding ewes in year *t* (see equation 3.60)

Dmbe<sub>Aug+Sep(t)</sub> = Number of mature breeding ewe deaths that occur in August and September in year *t* (see equation 3.61)

nod<sub>year</sub> = number of days in year

nod<sub>Aug</sub> = number of days in August

nod<sub>Sep</sub> = number of days in September

nod<sub>Jun</sub> = number of days in June

*Population of mature breeding ewes in April and May (Equation 3.66)*

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

Where:

POPmbe<sub>m(t)</sub> = population of mature breeding ewes in month *m* in year *t*

POPmbe<sub>m+1(t)</sub> = population of mature breeding ewes in next month *m+1* in year *t*

Dmbe<sub>AT(t)</sub> = Annual number of deaths of mature breeding ewes in year *t* (see equation 3.60)

Dmbe<sub>Aug+Sep(t)</sub> = Number of mature breeding ewe deaths that occur in August and September in year *t* (see equation 3.61)

nod<sub>year</sub> = number of days in year

nod<sub>Aug</sub> = number of days in August

nod<sub>Sep</sub> = number of days in September

nod<sub>Jun</sub> = 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:

*Population of growing breeding sheep in August (Equation 3.67)*

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

Where:

POPgbs<sub>aug(t)</sub> = population of growing breeding sheep in August in year *t*

POPgbs<sub>jul(t)</sub> = population of growing breeding sheep in July in year *t* (from APS)

DR<sub>gbs</sub> = Annual death rate of growing breeding sheep (currently assumed to be 3.6%)

nod<sub>year</sub> = number of days in year

nod<sub>Jul</sub> = number of days in July

*Population of growing breeding sheep between September and March (Equation 3.68)*

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

Where:

POPgbs<sub>m</sub> = population of growing breeding sheep in month *m*

POPgbs<sub>m-1</sub> = population of growing breeding sheep in previous month *m*

DR<sub>ttdh</sub> = Annual death rate of two-tooth dry hoggets (currently assumed to be 4.71%)

nod<sub>year</sub> = number of days in year

nod<sub>m-1</sub> = 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).

*Population of growing breeding sheep in June (Equation 3.69)*

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

Where:

POPgbs<sub>Jun(t)</sub> = population of growing breeding sheep in June in year *t*

POPgbs<sub>jul(t)</sub> = population of growing breeding sheep in July in year *t* (from APS)

DR<sub>gbs</sub> = Annual death rate of growing breeding sheep (currently assumed to be 3.6%)

nod<sub>year</sub> = number of days in year

nod<sub>Jul</sub> = number of days in June

*Population of growing breeding sheep in April and May (Equation 3.70)*

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

Where:

POPgbs<sub>m(t)</sub> = population of growing breeding sheep in month *m* in year *t*

POPgbs<sub>m+1(t)</sub> = population of growing breeding sheep in next month *m+1* in year *t*

DR<sub>gbs</sub> = Annual death rate of growing breeding sheep (currently assumed to be 3.6%)

nod<sub>year</sub> = number of days in year

nod<sub>Jul</sub> = 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:

*Population of growing non-breeding sheep in August (Equation 3.71)*

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

Where:

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

$POP_{gnbs_{jul(t)}}$  = 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:

*Population of growing non-breeding sheep in September (Equation 3.72)*

$$POP_{gnbs_{Sep(t)}} = POP_{deh_{jul(t)}} \times \left( 1 - \frac{DR_{gnbs} \times nod_{jul}}{nod_{year}} \right)$$

Where:

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

$POP_{deh_{jul(t)}}$  = 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:

*Population of growing non-breeding sheep between October and March (Equation 3.73)*

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

Where:

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

$POP_{gnbs_{jul}}$  = 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.

*Population of growing non-breeding sheep in June (Equation 3.74)*

$$\begin{aligned} POP_{gnbs_{Jun(t)}} &= POP_{deh_{Jul(t)}} \times \left( 1 + \frac{DR_{deh} \times nod_{Jun}}{nod_{year}} \right) \\ &+ POP_{rh_{Jul(t)}} \times \left( 1 + \frac{DR_{rh} \times nod_{Jun}}{nod_{year}} \right) \\ &+ POP_{wh_{Jul(t)}} \times \left( 1 + \frac{DR_{wh} \times nod_{Jun}}{nod_{year}} \right) \end{aligned}$$

Where:

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

$POP_{deh_{Jul(t)}}$  = population of dry ewe hoggets in July of year  $t$  (from APS; line code 6724)

$POP_{rh_{Jul(t)}}$  = population of ram hoggets in July of year  $t$  (from APS)

$POP_{wh_{Jul(t)}}$  = 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

*Population of growing non-breeding sheep in April and May (Equation 3.75)*

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

Where:

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

$POP_{gnbs_{m+1}}$  = 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).

Monthly population of wethers from August to June (Equation 3.76)

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

Where:

POPws<sub>m</sub> = population of wethers in month *m*

POPws<sub>m-1</sub> = population of wethers in previous month *m-1*

POPws<sub>jul,p</sub> = population of wethers in the July *before* month *m*

POPws<sub>jul,n</sub> = population of wethers in the next July *after* month *m*

nod<sub>year</sub> = number of days in year

nod<sub>m-1</sub> = 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:

Monthly population of lambs for October, November, December, January, February, May, June, July and August (Equation 3.77)

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

Where:

POPls<sub>m</sub> = population of lambs in month *m*

POPls<sub>jul</sub> = population of lambs in previous month *m-1*

DR<sub>ls</sub> = Annual natural death rate of lambs (currently assumed to be 4.5%)

nod<sub>year</sub> = number of days in year

nod<sub>m-1</sub> = 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

Population of lambs in March (Equation 3.78)

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

Where:

POPls<sub>Mar(t)</sub> = population of lambs in March of year *t*

POPbeh<sub>jul(t)</sub> = population of breeding ewe hoggets in July of year *t* (from APS, line code 6723)

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

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

$\omega_{ls}$  = 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 (currently set at 0.84) is used to calculate the April population of lambs

*Population of lambs in April (Equation 3.79)*

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

Where:

$POP_{ls_{Apr}(t)}$  = population of lambs in April of year  $t$

$POP_{ls_{Mar}(t)}$  = population of lambs in March of year  $t$

$DPls_{Apr}$  = Proportion of lambs sent to slaughter during March (currently assumed to be 84%)

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 3.77).

### 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).

*Monthly population of rams from August to June (Equation 3.80)*

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

Where:

$POP_{rs_m}$  = population of rams in month  $m$

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

$POP_{rs_{Jul,p}}$  = population of rams in the July *before* month  $m$

$POP_{rs_{Jul,n}}$  = 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

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

- Hinds aged 0-1
- Hinds aged 1-2
- Breeding Hinds- Mixed Age
- Stags 0-1
- Stags 1-2
- Stags 2-3
- Breeding Stags- Mixed Age

The July populations of these different classes are calculated by multiplying the total deer population from the agricultural production census by proportions specified in appendix 15. 2-3 year old stags have an additional adjustment in July to account for two slaughter dates in the same year.

The proportions in appendix 15 for the years from 1990-2011 were specified in the report by Suttie (2012)<sup>a</sup>. Population data directly from the APS is used to calculate the proportions for 2012 onwards. Table 3.1 shows the line codes that are used for each class. The populations of these line codes are divided by the total deer population (line code 7699) to calculate the proportion for each class. The proportions for 2-3 year old stags and the mixed age breeding stags are calculated using equations 3.81 and 3.82, which follows the methodology outlined by Suttie (2012).

**Table 3.1: line codes used to calculate deer proportions in the inventory**

Deer class	Linecodes used to calculate proportions
Hind 0-1 years old	lc7618
Hind 1-2 years old	lc7605 + lc7615
Hind Mixed age/breeding	lc7600 + lc7610
Stag 0-1 years old	lc7630
Stag 1-2 years old	lc7625
Stag 2-3 years old	lc7620+lc7645+lc7648
Stag Mixed age/breeding	lc7620+lc7645+lc7649

*Proportion of deer that are stags aged 2-3 in July (Equation 3.81)*

$$Pds3_{jul(t)} = \frac{1}{8} \times \frac{POP_{lc7620(t)} + POP_{lc7645(t)} + POP_{lc7648(t)}}{POP_{deer(t)}}$$

Where:

$Pds3_{jul(t)}$  = proportion of total deer population in July of year  $t$  assumed to be 2-3 year old stags

$POP_{lc7620(t)}$  = population of deer in line code 7620 in year  $t$  (from APS)

$POP_{lc7645(t)}$  = population of deer in line code 7645 in year  $t$  (from APS)

$POP_{lc7648(t)}$  = population of deer in line code 7648 in year  $t$  (from APS)

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

*Proportion of deer that are mixed aged breeding stags in July (Equation 3.82)*

$$Pdsma_{jul(t)} = \frac{7}{8} \times \frac{POP_{lc7620(t)} + POP_{lc7645(t)} + POP_{lc7648(t)}}{POP_{deer(t)}}$$

Where:

$Pdsma_{jul(t)}$  = proportion of total deer population in July of year  $t$  assumed to be mixed age breeding stags

$POP_{lc7620(t)}$  = population of deer in line code 7620 in year  $t$  (from APS)

$POP_{lc7645(t)}$  = population of deer in line code 7645 in year  $t$  (from APS)

$POP_{lc7648(t)}$  = population of deer in line code 7648 in year  $t$  (from APS)

<sup>a</sup> See table 30 of Suttie report

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

### 3.4.1 Hinds aged 0-1

The population of hinds aged 0-1 varies throughout the year. The July population is calculated using the formula below:

*Population of Hinds aged 0-1 in July (Equation 3.83)*

$$POP_{dh1_{jul(t)}} = POP_{deer(t)} \times P_{dh1(t)}$$

Where:

$POP_{dh1_{jul(t)}}$  = population of hinds aged 0-1 in July of year  $t$

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

$P_{dht(t)}$  = proportion of total deer population in July of year  $t$  assumed to be 0-1 year old hinds (using table in appendix 15)

The inventory model assumes that 65% of annual hind 0-1 deaths occur in the months between March and July (inclusive). This higher death rate is reflected in the August population of hinds aged 0-1.

*Population of hinds aged 0 to 1 in August (Equation 3.84)*

$$POP_{dh1_{aug(t)}} = POP_{dh1_{jul(t)}} - \left( \frac{POP_{dh1_{jul(t)}} \times DR_{dh1}}{nod_{mar-jul}} \times PD_{dh1_{mar-jul}} \right) \times nod_{jul}$$

Where:

$POP_{dh1_{aug(t)}}$  = population of hinds aged 0-1 in August in year  $t$

$POP_{dh1_{jul(t)}}$  = 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)

$PD_{dh1_{mar-jul}}$  = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

$nod_{jul}$  = 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:

*Monthly population of hinds aged 0 to 1, for September, October and November (Equation 3.85)*

$$POP_{dh1_{m(t)}} = POP_{dh1_{m-1(t)}} - \left( \frac{POP_{dh1_{jul(t)}} \times DR_{dh1}}{nod_{aug-feb}} \times (1 - PD_{dh1_{mar-jul}}) \right) \times nod_{m-1}$$

Where:

$POP_{dh1_{m(t)}}$  = population of hinds aged 0-1 in month  $m$  of year  $t$

$POP_{dh1_{m-1(t)}}$  = population of hinds aged 0-1 in previous month  $m-1$  of year  $t$

$POP_{dh1_{jul(t)}}$  = 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).

*June population of hinds aged 0 to 1 (Equation 3.86)*

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

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 15)

$POPdh1_{jul(t)}$  = 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

*Monthly population of hinds aged 0 to 1, for May, April and March (Equation 3.87)*

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

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  $m$

*Monthly population of hinds aged 0 to 1, for February, January and December (Equation 3.88)*

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

Where:

POPdh1<sub>m</sub> = population of hinds aged 0-1 in month *m*

POPdh1<sub>m+1</sub> = population of hinds aged 0-1 in next month *m+1*

POPdh1<sub>jul</sub> = population of hinds aged 0-1 in subsequent July

DR<sub>dh1</sub> = Annual death rate of hinds aged 0-1 (assumed to be 5%)

nod<sub>aug-feb</sub> = number of days between August and February (inclusive)

PDdh1<sub>mar-jul</sub> = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod<sub>m</sub> = number of days in month *m*

### 3.4.2 Hinds aged 1-2

The population of hinds aged 1-2 varies throughout the year. The July population is calculated using the formula below:

*Population of Hinds aged 1-2 in July (Equation 3.89)*

$$POPdh2_{jul(t)} = POPdeer_{(t)} \times Pdh2_{(t)}$$

Where:

POPdh2<sub>jul(t)</sub> = population of hinds aged 1-2 in July of year *t*

POPdeer<sub>(t)</sub> = Total number of deer in year *t* (from APS)

Pdh2<sub>(t)</sub> = proportion of total deer population in July of year *t* assumed to be 1-2 year old hinds (using table in appendix 15)

The model assumes that the annual death rate of hinds aged between 1 and 2 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 for hinds aged 1-2.

The August and September populations are calculated using the following formula:

*Population of Hinds aged 1-2 in August and September (Equation 3.90)*

$$POPdh2_{m(t)} = POPdh2_{m-1(t)} - \left( \frac{POPdh2_{jul(t)} \times DR_{dh2} \times PDdh2_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{m-1} \right)$$

Where:

POPdh2<sub>m(t)</sub> = population of hinds aged 1-2 in month *m* of year *t*

POPdh2<sub>m-1(t)</sub> = population of hinds aged 1-2 in previous month *m-1* of year *t*

POPdh2<sub>jul(t)</sub> = population of hinds aged 1-2 in July of year *t*

DR<sub>dh2</sub> = Annual death rate of hinds aged 1-2 (assumed to be 2%)

PDdh2<sub>Jun-Oct</sub> = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

nod<sub>Jun-Oct</sub> = number of days between June and October (inclusive, i.e. 153)

nod<sub>m-1</sub> = number of days in previous month *m-1*

The October and November populations of hinds aged 1-2 are calculated in reverse order using the December population. In December the hind populations move into a new age class (i.e. the 0-1 hind population becomes the 1-2 hind population).

*Population of Hinds aged 1-2 in December (Equation 3.91)*

$$POPdh2_{dec(t)} = POPdh1_{nov(t)} - \left( \frac{POPdh2_{jul(t)} \times DR_{dh2} \times PDdh2_{Dec-May}}{nod_{Dec-May}} \times nod_{nov} \right)$$

Where:

POPdh2<sub>dec(t)</sub> = population of hinds aged 1-2 in December of year *t*

POPdh1<sub>nov(t)</sub> = population of hinds aged 0-1 in November of year *t*

POPdh2<sub>jul(t)</sub> = population of hinds aged 1-2 in July of year *t*

DR<sub>dh2</sub> = Annual death rate of hinds aged 1-2 (assumed to be 2%)

PDdh2<sub>Dec-May</sub> = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 10%

nod<sub>Dec-May</sub> = number of days between December and May (inclusive, i.e. 182)

nod<sub>Nov</sub> = number of days in November

*Population of Hinds aged 1-2 in October (Equation 3.92)*

$$POPdh2_{oct(t)} = POPdh2_{nov(t)} + \left( \frac{POPdh2_{jul(t)} \times DR_{dh2} \times PDdh2_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{oct} \right)$$

Where:

POPdh2<sub>oct(t)</sub> = population of hinds aged 1-2 in October of year *t*

POPdh2<sub>nov(t)</sub> = population of hinds aged 1-2 in November of year *t*

POPdh2<sub>jul(t)</sub> = population of hinds aged 1-2 in July of year *t*

DR<sub>dh2</sub> = Annual death rate of hinds aged 1-2 (assumed to be 2%)

PDdh2<sub>Jun-Oct</sub> = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

nod<sub>Jun-Oct</sub> = number of days between June and October (inclusive, i.e. 153)

nod<sub>Oct</sub> = number of days in October

*Population of Hinds aged 1-2 in November (Equation 3.93)*

$$POPdh2_{nov(t)} = POPdh2_{dec(t)} + (POPdh2_{jul(t)} \times DR_{dh2} \times PDdh2_{Nov})$$

Where:

POPdh2<sub>nov(t)</sub> = population of hinds aged 1-2 in November of year *t*

POPdh2<sub>dec(t)</sub> = population of hinds aged 1-2 in December of year *t*

POPdh2<sub>jul(t)</sub> = population of hinds aged 1-2 in July of year *t*

DR<sub>dh2</sub> = Annual death rate of hinds aged 1-2 (assumed to be 2%)

PDdh2<sub>Nov</sub> = proportion of annual deaths assumed to occur in November. Currently assumed to be 30%

The January to June populations of hinds aged 1-2 are calculated in backwards order using the July population.



### Population of Hinds aged 1-2 in June (Equation 3.94)

$$POPdh2_{Jun(t)} = POPdh2_{Jul(t)} + \left( \frac{POPdh2_{Jul(t)} \times DR_{dh2} \times PDdh2_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{Jun} \right)$$

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%)

$PDdh2_{Jun-Oct}$  = 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

### Monthly Population of Hinds aged 1-2, from January to May (Equation 3.95)

$$POPdh2_{m(t)} = POPdh2_{m+1(t)} + \left( \frac{POPdh2_{Jul(t)} \times DR_{dh2} \times PDdh2_{Dec-May}}{nod_{Dec-May}} \times nod_m \right)$$

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%)

$PDdh2_{December-May}$  = 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  $m$

## 3.4.3 Breeding Hinds

The population of breeding hinds aged varies throughout the year. The July population is calculated using the formula below:

### Population of breeding hinds in July (Equation 3.96)

$$POPdbh_{jul(t)} = POPdeer_{(t)} \times Pdbh_{(t)}$$

Where:

$POPdbh_{jul(t)}$  = population of breeding hinds in July of year  $t$

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

$Pdbh_t$  = proportion of total deer population in July of year  $t$  assumed to be breeding hinds (using table in appendix 15)

The model assumes that the annual death rate of breeding 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:

Monthly population of breeding hinds from August to November (Equation 3.97)

$$POPdbh_{m(t)} = POPdbh_{m-1(t)} - \left( \frac{POPdbh_{jul(t)} \times DR_{dbh} \times PDdbh_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{m-1} \right)$$

Where:

POPdbh<sub>m</sub> = population of breeding hinds in month *m* of year *t*

POPdbh<sub>m-1</sub> = population of breeding hinds in previous month *m-1* of year *t*

POPdbh<sub>jul</sub> = population of breeding hinds in July of year *t*

DR<sub>dbh</sub> = Annual death rate of breeding hinds (assumed to be 2%)

PDdbh<sub>Jun-Oct</sub> = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

nod<sub>Jun-Oct</sub> = number of days between June and October (inclusive, i.e. 153)

nod<sub>m-1</sub> = 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.

Population of breeding hinds in December (Equation 3.98)

$$POPdbh_{Dec(t)} = POPdbh_{Nov(t)} - (POPdbh_{jul(t)} \times DR_{dbh} \times PDdbh_{Nov}) + POPdh2_{Nov(t)}$$

Where:

POPdbh<sub>Dec(t)</sub> = population of breeding hinds in December of year *t*

POPdbh<sub>Nov(t)</sub> = population of breeding hinds in November of year *t*

POPdbh<sub>jul(t)</sub> = population of breeding hinds in July of year *t*

DR<sub>dbh</sub> = Annual death rate of breeding hinds (assumed to be 2%)

PDdbh<sub>Nov</sub> = proportion of annual deaths assumed to occur in November. Currently assumed to be 60%

POPdh2<sub>Nov(t)</sub> = population of hinds aged 1-2 in November of year *t*

The January and February breeding hind population is calculated by using the following equation

Monthly population of breeding hinds from for January and February (Equation 3.99)

$$POPdbh_m = POPdbh_{m-1} - \left( \frac{POPdbh_{jul} \times DR_{dbh} \times PDdbh_{Dec-May}}{nod_{Dec-May}} \times nod_{m-1} \right)$$

Where:

POPdbh<sub>m</sub> = population of breeding hinds in month *m*

POPdbh<sub>m-1</sub> = population of breeding hinds in previous month *m-1*

POPdbh<sub>jul</sub> = population of breeding hinds in the July immediately prior

DR<sub>dbh</sub> = Annual death rate of breeding hinds (assumed to be 2%)

PDdbh<sub>Dec-May</sub> = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 10%

nod<sub>Dec-May</sub> = number of days between June and October (inclusive, i.e. 182)

nod<sub>m-1</sub> = number of days in previous month *m-1*

The March to June populations of breeding hinds are calculated in backwards order using the July population.

### Population of breeding hinds in June (Equation 3.100)

$$POPdbh_{Jun(t)} = POPdbh_{Jul(t)} + \left( \frac{POPdbh_{Jul(t)} \times DR_{dbh} \times PDdbh_{Jun-Oct}}{nod_{Jun-Oct}} \times nod_{Jun} \right)$$

Where:

$POPdbh_{Jun(t)}$  = population of breeding hinds in June of year  $t$

$POPdbh_{Jul(t)}$  = population of breeding hinds in July of year  $t$

$DR_{dbh}$  = Annual death rate of breeding 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

### Monthly Population of breeding hinds, from March to May (Equation 3.101)

$$POPdbh_{m(t)} = POPdbh_{m+1(t)} + \left( \frac{POPdbh_{Jul(t)} \times DR_{dbh} \times PDdbh_{Dec-May}}{nod_{Dec-May}} \times nod_m \right)$$

Where:

$POPdbh_{m(t)}$  = population of breeding hinds in month  $m$  of year  $t$

$POPdbh_{m+1(t)}$  = population of breeding hinds in next month  $m+1$  of year  $t$

$DR_{dbh}$  = Annual death rate of breeding 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  $m$

## 3.4.4 Stags aged 0-1

The population of stags aged 0-1 varies throughout the year. The July population is calculated using the formula below:

### Population of stags aged 0-1 in July (Equation 3.102)

$$POPds1_{Jul(t)} = POPdeer_{(t)} \times Pds1_{(t)}$$

Where:

$POPds1_{Jul(t)}$  = population of stags aged 0-1 in July of year  $t$

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

$Pds1_{(t)}$  = proportion of total deer population in July of year  $t$  assumed to be 0-1 year old stags (using table in appendix 15)

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.

*Population of stags aged 0-1 in August (Equation 3.103)*

$$POPds1_{Aug(t)} = POPds1_{Jul(t)} - \left( \frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1} \right)$$

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  $m-1$

*Population of stags aged 0-1 in September and October (Equation 3.104)*

$$POPds1_{m(t)} = POPds1_{m-1(t)} - \left( \frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1} \right)$$

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).

*Population of stags aged 0-1 in June (Equation 3.105)*

$$POPds1_{Jun(t)} = POPds1_{Jul(t)} + \left( \frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun} \right)$$

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%)

$PDds1_{Mar-Jul}$  = 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)

$nod_{Jun}$  = number of days in June

*Population of stags aged 0-1 between March and May (Equation 3.106)*

$$POPds1_{m(t)} = POPds1_{m+1(t)} + \left( \frac{POPds1_{Jul(t)} \times DR_{ds1} \times PDds1_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_m \right)$$

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%)

$PDds1_{Mar-Jul}$  = 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)

$nod_m$  = number of days in month  $m$

*Population of stags aged 0-1 between November and February (Equation 3.107)*

$$POPds1_m = POPds1_{m+1} + \left( \frac{POPds1_{Jul} \times DR_{ds1} \times PDds1_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_m \right)$$

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%)

$PDds1_{Aug-Feb}$  = 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)

$nod_m$  = number of days in month  $m$

### 3.4.5 Stags aged 1-2

The population of stags aged 1-2 varies throughout the year. The July population is calculated using the formula below:

*Population of stags aged 1-2 in July (Equation 3.108)*

$$POPds2_{Jul(t)} = POPdeer_{(t)} \times Pds2_{(t)}$$

Where:

$POPds2_{Jul(t)}$  = population of stags aged 1-2 in July of year  $t$

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

$Pds2_{(t)}$  = proportion of total deer population in July of year  $t$  assumed to be 1-2 year old stags in year  $t$  (using table in appendix 15)

The Inventory model assumes that 80% of annual stag 1-2 deaths occur in the months between March and July (inclusive). This higher death rate is reflected in the August population of hinds aged 1-2.

*Population of stags aged 1-2 in August (Equation 3.109)*

$$POPds2_{Aug(t)} = POPds2_{Jul(t)} - \left( \frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1} \right)$$

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  $m-1$

*Population of stags aged 1-2 in September, October, November, January and February (Equation 3.110)*

$$POPds2_m = POPds2_{m-1} - \left( \frac{POPds2_{Jul} \times DR_{ds2} \times PDds2_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1} \right)$$

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.

*Population of stags aged 1-2 in December (Equation 3.111)*

$$POPds2_{Dec(t)} = POPds1_{Nov(t)} - \left( \frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1} \right)$$

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).

*Population of stags aged 1-2 in June (Equation 3.112)*

$$POPds2_{Jun(t)} = POPds2_{Jul(t)} + \left( \frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun} \right)$$

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%)

$PDds2_{Mar-Jul}$  = 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

*Population of stags aged 1-2 between March and May (Equation 3.113)*

$$POPds2_{m(t)} = POPds2_{m+1(t)} + \left( \frac{POPds2_{Jul(t)} \times DR_{ds2} \times PDds2_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_m \right)$$

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%)

$PDds2_{Mar-Jul}$  = 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  $m$

### 3.4.6 Stags aged 2-3

The population of stags aged 2-3 varies throughout the year. The July population is calculated using the formula below, and an adjustment is made to account for stags that are slaughtered during June:

*Population of stags aged 2-3 in July (Equation 3.114)*

$$POPds3_{Jul(t)} = POPdeer_{(t)} \times Pds3_{(t)} \times (1 - DPds3_{Jun})$$

Where:

$POPds3_{Jul(t)}$  = population of stags aged 2-3 in July of year  $t$

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

$Pds3_{(t)}$  = proportion of total deer population in July of year  $t$  assumed to be 2-3 year old stags (using table in appendix 15)

$DPds3_{Jun}$  = Proportion of stags aged 2-3 sent to slaughter during June (currently assumed to be 12%)

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.

*Population of stags aged 2-3 in August (Equation 3.115)*

$$POPds3_{Aug(t)} = POPds3_{Jul(t)} - \left( \frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1} \right)$$

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%)

$PDds3_{Mar-Jul}$  = 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  $m-1$

*Population of stags aged 2-3 in September, October, and November (Equation 3.116)*

$$POPds3_{m(t)} = POPds3_{m-1(t)} - \left( \frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1} \right)$$

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).

*Population of stags aged 2-3 in June (Equation 3.117)*

$$POPds3_{Jun(t)} = POPds3_{Jul(t)} + \left( \frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun} \right)$$

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



*Population of stags aged 2-3 between March and May (Equation 3.118)*

$$POPds3_{m(t)} = POPds3_{m+1(t)} + \left( \frac{POPds3_{Jul(t)} \times DR_{ds3} \times PDds3_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_m \right)$$

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  $m$

*Population of stags aged 2-3 between December and February (Equation 3.119)*

$$POPds3_m = POPds3_{m+1} + \left( \frac{POPds3_{Jul} \times DR_{ds3} \times PDds3_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_m \right)$$

Where:

$POPds3_{m+1}$  = 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  $m$

### 3.4.7 Breeding/mixed age stags

The population of mixed age breeding stags varies throughout the year. The July population is calculated using the formula below:

*Population of mixed age breeding stags in July (Equation 3.120)*

$$POPdsma_{jul(t)} = POPdeer_{(t)} \times Pdsma_{(t)}$$

Where:

$POPdsma_{jul(t)}$  = population of mixed age breeding stags in July of year  $t$

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

$Pdsma_{(t)}$  = proportion of total deer population in July of year  $t$  assumed to be mixed age breeding stags (using table in appendix 15)

Between August and June, the population of mixed age breeding stags is calculated in exactly 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.

*Population of mixed age breeding stags in August (Equation 3.121)*

$$POPdsma_{Aug(t)} = POPdsma_{Jul(t)} - \left( \frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{m-1} \right)$$

Where:

$POPdsma_{Aug(t)}$  = population of mixed age breeding stags in August of year  $t$

$POPdsma_{Jul(t)}$  = population of mixed age breeding stags in July of year  $t$

$DR_{dsma}$  = Annual death rate of mixed age breeding 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)

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

*Population of mixed age breeding stags in September, October, and November (Equation 3.122)*

$$POPdsma_{m(t)} = POPdsma_{m-1(t)} - \left( \frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_{m-1} \right)$$

Where:

$POPdsma_{m(t)}$  = population of mixed age breeding stags in month  $m$  of year  $t$

$POPdsma_{m-1(t)}$  = population of mixed age breeding stags in previous month  $m-1$  of year  $t$

$POPdsma_{Jul(t)}$  = population of mixed age breeding stags in July of year  $t$

$DR_{ds3}$  = Annual death rate of mixed age breeding stags (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 mixed age breeding stags is calculated in reverse order (e.g. the June population is used to calculate the May population, and so on).

*Population of mixed age breeding stags in June (Equation 3.123)*

$$POPdsma_{Jun(t)} = POPdsma_{Jul(t)} + \left( \frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_{Jun} \right)$$

Where:

$POPds3_{Jun(t)}$  = population of mixed age breeding stags in June of year  $t$

$POPds3_{Jul(t)}$  = population of mixed age breeding stags in July of year  $t$

$DR_{ds3}$  = Annual death rate of mixed age breeding stags (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

*Population of mixed age breeding stags between March and May (Equation 3.124)*

$$POPdsma_{m(t)} = POPdsma_{m+1(t)} + \left( \frac{POPdsma_{Jul(t)} \times DR_{dsma} \times PDdsma_{Mar-Jul}}{nod_{Mar-Jul}} \times nod_m \right)$$

Where:

$POPdsma_{m(t)}$  = population of mixed age breeding stags in month  $m$  of year  $t$

$POPdsma_{m+1(t)}$  = population of mixed age breeding stags in next month  $m+1$  of year  $t$

$POPds3_{Jul(t)}$  = population of mixed age breeding stags in July of year  $t$

$DR_{dsma}$  = Annual death rate of mixed age breeding 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  $m$

*Population of mixed age breeding stags between December and February (Equation 3.125)*

$$POPdsma_m = POPdsma_{m+1} + \left( \frac{POPdsma_{Jul} \times DR_{dsma} \times PDdsma_{Aug-Feb}}{nod_{Aug-Feb}} \times nod_m \right)$$

Where:

$POPdsma_{m+1}$  = population of mixed age breeding stags in month  $m$

$POPdsma_{m+1}$  = population of mixed age breeding stags in next month  $m+1$

$POPds3_{Jul}$  = population of mixed age breeding stags in next July

$DR_{dsma}$  = Annual death rate of mixed age breeding 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

An understanding of an animal's energy requirements is used to estimate dry matter intake (DMI) from which livestock emissions are calculated. 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). The inventory model currently assumes that dairy cattle, beef cattle, sheep and deer consume only pasture to satisfy their energy requirements, and no supplementary feed is used.

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. Calculations of energy requirements are combined with data on the energy content of pasture to estimate DMI. This information is used to calculate enteric methane emissions and nitrogen excretion (and resulting nitrous oxide emissions) for each livestock category.

New Zealand uses 'metabolisable energy' (ME) to estimate dry matter intake. 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 agricultural inventory model uses data from a range of sources<sup>b</sup> 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.

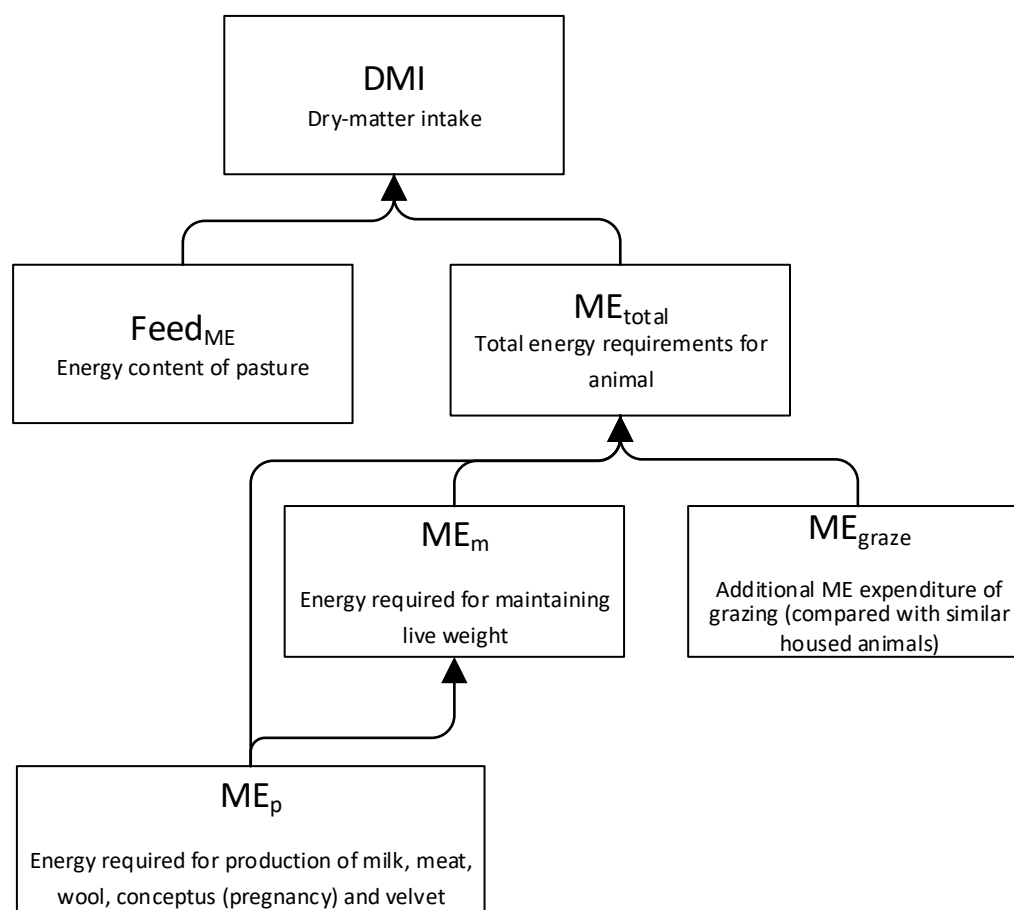
Nearly all animals in New Zealand graze 'improved' sown pastures. However, the default IPCC algorithms used for estimating energy requirements are based on either grain-fed cattle or sheep husbandry under very different circumstances from that in New Zealand. As a result, New Zealand's Inventory model 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<sup>c</sup>. The following diagram summarises how energy requirements are calculated.

---

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)

<sup>c</sup> 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:  $NE = ME - \text{energy lost by the animal as heat}$  (Lassey, 2007, figure 2).

**Figure 4.1: How energy requirements and dry-matter intake are calculated**



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 pasture ( $Feed_{ME}$ ) to estimate the amount of dry matter eaten by a single animal in a single day (DMI).

This calculated DMI provides 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. Specific details relating to each livestock category are outlined in sections 4.3, 4.4, 4.5 and 4.6.

#### 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 pasture ( $Feed_{ME}$ ).

*Calculation of dry matter intake (Equation 4.1)*

$$DMI = \frac{ME_{total}}{Feed_{ME}}$$

Where:

DMI = dry matter intake per day for an average animal (kg/d)

$ME_{total}$  = total metabolisable energy required per day for an average animal representing specified categories (MJ/d)

$Feed_{ME}$  = energy content of feed intake or the metabolisable energy per kilogram of dry matter for pasture (MJ/kg)

For grazing ruminants, the ME content of pasture ( $Feed_{ME}$ ) represents the energy available to the animal for maintenance, production and activity (grazing, walking, etc.) (Waghorn, 2007). The  $Feed_{ME}$  values used in these inventory calculations for different months and animal categories are given in Appendix 3 (dairy) and Appendix 9 (sheep, beef and deer)

## 4.2 Components of metabolisable energy

The total daily metabolisable 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)

*Total metabolisable energy requirements,  $ME_{total}$  (Equation 4.2)*

$$ME_{total} = ME_m + ME_p + ME_{graze} + ME_c$$

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).

$ME_c$  = Metabolisable energy required for gestation or growth of the conceptus (MJ/d)

$ME_m$  is the amount of energy required to maintain the animal<sup>d</sup>.  $ME_p$  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 4.3 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 4.3, 4.4, 4.5 and 4.6. All of the equations in this section are expressed on a per-animal per day basis, unless otherwise stated.

*Metabolisable energy required for maintenance,  $ME_m$  (Equation 4.3):*

$$ME_m = K \times S \times \frac{0.28LW^{0.75} \times e^{-0.03A}}{k_m} + 0.1 \times ME_p$$

Where:

$ME_m$  = metabolisable energy required to maintain animal weight (MJ/d).

<sup>d</sup> The current code in the inventory, as well as previous versions of the methodology document, also refer to  $ME_m$  as BASAL.

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<sub>p</sub> = 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):

*Efficiency of utilisation for maintenance,  $k_m$  (Equation 4.4)*

$$k_m = 0.35 \times Q_m + 0.503$$

Where:

$k_m$  = Efficiency of utilisation of ME for maintenance.

$Q_m$  = ratio of feed ME to gross energy (GE) concentration of pasture

*Ratio of metabolisable to gross energy for pasture,  $Q_m$  (Equation 4.5)*

$$Q_m = \frac{Feed_{ME}}{Feed_{GE}}$$

Where:

$Q_m$  = ratio of feed ME to GE concentration of pasture.

Feed<sub>ME</sub> = ME content of feed (monthly values by species available in appendix 3 and 9 (MJ/kg)

Feed<sub>GE</sub> = gross energy per kilogram of dry matter for feed, assumed to be 18.45 mega joules per kilogram of dry matter (MJ/kg)

$Q_m$  represents the ratio of pasture ME concentration to the gross energy concentration of feed. 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.

Feed<sub>GE</sub> 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.

### 4.3 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

### 4.3.1 Total energy requirements

The total energy requirements for each subcategory of dairy cattle is outlined in the table below, which are based on equation 4.2 outlined in section 4.2.

**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 pasture 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.

### 4.3.2 Energy required for maintenance

As stated in section 4.2, the inventory uses a generic equation to calculate  $ME_m$  for the main animal species, including dairy cattle (equation 4.3). 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 4.3, 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.

### 4.3.3 Metabolisable energy requirements of production

The ME<sub>p</sub> component for dairy cattle is made up of the following components, which are also specified in equations 4.6 to 4.20:

- ME<sub>l</sub>: ME required for milk production (MJ/d)
- ME<sub>g</sub>: ME required for live weight gain (growth) (MJ/d)

*metabolisable energy requirements for dairy cattle production (Equation 4.6)*

$$ME_p = ME_l + ME_g$$

As stated earlier the inventory model assumes that growing females and breeding bulls only *produce* live weight gain (ME<sub>g</sub>), while milking cows produce milk (ME<sub>l</sub>) and calves (gestation – ME<sub>c</sub>)

#### 4.3.3.1 Metabolisable energy requirements for milk production

The energy requirements for milk production (ME<sub>l</sub>) 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<sub>l</sub>:

*Metabolisable energy requirements for milk production (Equation 4.7)*

$$ME_l = \frac{Y \times MILK_{GE}}{k_l}$$

Where:

ME<sub>l</sub> = Metabolisable energy required for milk production (MJ/d)

Y = Daily milk yield per milking cow (kg/d)

MILK<sub>GE</sub> = Gross energy content of milk (MJ/kg)

k<sub>l</sub> = 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 4.10)

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](http://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 4. This information is inserted into the following equation to calculate the daily milk yield (Y) per milking cow in a given month.

*Calculation of daily per cow milk yield for dairy cattle (Equation 4.8)*

$$Y = \frac{N_m \times mp_{month}}{P_{milkingcow} \times D_{month}}$$

Where:

Y = Daily milk yield per milking cow (kg/d)

N<sub>m</sub> = National aggregate annual milk yield (kg)

mp<sub>month</sub> = Milk produced in a given month as a proportion of total annual milk produced (appendix 4)

P<sub>milkingcow</sub> = population of mature milking cows in a given month

$D_{\text{month}}$  = 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:

*gross energy content of milk (Equation 4.9)*

$$MILK_{GE} = 0.376 \times F + 0.209 \times P + 0.948$$

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 4.

$k_l$  is calculated by using the following equation from ARC (1980).

*Efficiency of utilisation for milk production (Equation 4.10)*

$$k_l = 0.35 \times Q_m + 0.42$$

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 pasture ME concentration to the gross energy concentration of pasture. (see equation 4.5, section 4.2)

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.

#### 4.3.3.2 Metabolisable 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

##### 4.3.3.2.1 Live weight gain for non-lactating animals

*Metabolisable energy requirements for live weight gain in non-lactating animals (Equation 4.11):*

$$ME_g = \frac{(6.7 + R) + \frac{20.3 - R}{1 + e^{-6(P_{lw} - 0.4)}}}{k_{gnt}} \times LWG \times 0.92$$

Where:

$ME_g$  = Energy required for live weight gain (MJ/d)

R = An adjustment for rate of change in live weight

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

$k_{gnt}$  = 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.

$k_{gnt}$  is a conversion factor that used to measure how efficiently ME is used by a dairy cow for weight gain (see equation 4.17).

*Calculating rate of gain or loss in live weight (R) (Equation 4.12):*

$$R = \frac{EBC}{4 \times SRW^{0.75}} - 1$$

*Calculating ratio between current live weight and standard reference weight ( $P_{lw}$ ) (Equation 4.13):*

$$P_{lw} = \frac{LW_x}{SRW}$$

*Change in empty body weight (EBC) (Equation 4.14):*

$$EBC = 0.92 \times LWG$$

*Efficiency of utilisation for live weight gain for non-lactating animals (Equation 4.15)*

$$k_{gnt} = 0.042 \times Feed_{me} + 0.006$$

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)

$Feed_{ME}$  = Metabolisable 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 4.7. LWG is assumed to be zero for mature milking cows.

#### 4.3.3.2.2 Live weight gain for growing lactating animals

The equation below outlines the variables and parameters that are used to calculate ME<sub>g</sub> for growing lactating animals.

*Metabolisable energy requirements for live weight gain in growing lactating animals (Equation 4.16):*

$$ME_g = \frac{neclw \times LWG}{k_g}$$

Where:

Neclw = net energy content of liveweight (MJ)

LWG = Live weight gain (kg/day)

k<sub>g</sub> = Net efficiency of dietary metabolisable energy conversion to live weight gain

The variables neclw and k<sub>g</sub> require additional calculations and inputs such as body condition score (cs) and k<sub>l</sub>. 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<sub>l</sub> measures how efficiently ME is used by a dairy cow to produce milk and is also discussed in section 4.3.3.1 (see equation 4.10)

*Calculation of neclw (Equation 4.17):*

$$neclw = 10.1 + 2.47 \times cs$$

*Efficiency of utilisation for live weight gain (Equation 4.18):*

$$k_g = 0.95 \times k_l$$

Where:

Neclw = net energy content of liveweight (MJ)

cs = condition score, assumed to be 6

k<sub>g</sub> = Net efficiency of dietary metabolisable energy conversion to live weight gain

k<sub>l</sub> = Net efficiency of dietary metabolisable energy conversion for milk production (see section 4.3.3.1)

#### 4.3.4 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:

*Metabolisable energy requirements for gestation (Equation 4.19):*

$$ME_c = 0.025 \times LW_c \times \frac{0.0201E_t \times e^{-0.0000576prg}}{k_c}$$

Where:

ME<sub>c</sub> = Metabolisable energy required for gestation or growth of the conceptus (MJ/d)

LW<sub>c</sub> = Calf birth weight (kg).

E<sub>t</sub> = Energy required for the gravid uterus in utero (MJ/d)

prg = Number of days the cow has been pregnant (see Appendix 5)

$k_c$  = 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 11). 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:

*Energy requirement for the gravid uterus (Equation 4.20):*

$$E_t = 10^{151.665 - 151.64e^{-0.0000576prg}}$$

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.

### 4.3.5 Metabolisable energy requirement for grazing

The following equation from CSIRO (1990) is used determine the metabolisable energy required for grazing:

*Metabolisable energy required for grazing (Equation 4.21)*

$$ME_{graze} = \frac{\left( \left( C \times (0.9 - DMD) \times (ME_m + ME_p - Z_1) \right) + 0.05 \times \left( \frac{T}{GF + 3} \right) \times Feed_{ME} \right) W}{k_m \times Feed_{ME} - C \times W \times (0.9 - DMD)}$$

Where:

$C$  = additional energy for eating that grazing animals require compared with confined animals (0.006)

$DMI$  = Dry matter intake from pasture (kg/d),

$DMD$  = Dry matter digestibility

$ME_m$  = metabolisable energy required to maintain animal weight (MJ/d).

$Z_1$  = 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

$Feed_{ME}$  = energy content of feed intake or the metabolisable energy per kilogram of dry matter for pasture (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) of pasture is contained in appendix 3

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.

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  $k_m$ .

### 4.3.6 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. 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 4.22).  $Z_1$  represents the amount of energy received from milk and is determined as follows:

*Energy received from milk (Equation 4.22):*

$$Z_1 = \frac{Z_{mp}}{d} \times \frac{MILK_{GE}}{k_l}$$

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  
 $= 0.019 \times Feed_{ME} + 0.42$  (see Appendix 3)

*Calculation of dairy milk production efficiency (Equation 4.23)*

$$k_l = 0.019 \times Feed_{ME} + 0.42$$

Where:

$k_l$  = Efficiency of use of metabolisable energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk

$Feed_{ME}$  = metabolisable energy content of pasture (MJ/kg) (see Appendix 9)

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 4.3.3.1 (equation 4.9). As discussed in section 4.3.3.1,  $k_l$  represents the factor that measures how efficiently ME is used by a dairy cow to produce milk (see equation 4.10).

### 4.3.7 Summary of metabolisable energy requirements for dairy

The equations outlined in section 4.3 are used to determine the total metabolisable 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.

## 4.4 Energy requirements for beef cattle

### 4.4.1 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 3.

**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 - 2 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 - 2 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 – 2 years	$ME_{total} = ME_m + ME_g + ME_{graze}$

Where:

$ME_{total}$  = Total metabolisable energy requirements of animal (MJ/d)

$ME_m$  = Metabolisable energy required for maintenance (MJ/d)

$ME_l$  = Metabolisable energy required for milk production (MJ/d)

$ME_c$  = Metabolisable energy required for gestation (MJ/d)

$ME_g$  = Metabolisable 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)

### 4.4.2 Metabolisable 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 pasture ME content (Feed<sub>ME</sub>, used to calculate  $k_m$ ) for beef cattle is contained in Appendix 9.

### 4.4.3 Metabolisable energy requirements of production

#### 4.4.3.1 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 4.7, 4.9, 4.10 (in section 4.3.3.1) and 4.24 (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<sub>I</sub> for dairy cattle, which are:

- Fat content of milk (F)
- Protein content of milk (P)
- Gross energy content of milk (MILK<sub>GE</sub>)
- Efficiency of metabolisable energy used for milk production (k<sub>i</sub>)
- Number of days in a given month (D<sub>month</sub>)

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<sub>month</sub>)
- Ratio of pasture ME concentration to the gross energy concentration of pasture (Q<sub>m</sub>). The inventory assumes that beef cattle consume pasture with a different metabolisable energy content (PAST<sub>ME</sub>). PAST<sub>ME</sub> values are provided in appendix 9.
- Population of breeding beef cows in a given month (P<sub>milkingcow</sub>)

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).

*Calculation of daily per cow milk yield for beef cattle (Equation 4.24)*

$$Y = \frac{A_m \times mp_{month}}{D_{month}}$$

Where:

Y = Daily milk yield per milking cow (kg/d)

A<sub>m</sub> = Annual milk yield per breeding beef cow (assumed to be 824 kg)

mp<sub>month</sub> = Milk produced in a given month as a proportion of total annual milk produced (see appendix 4)

D<sub>month</sub> = 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<sub>month</sub>) is contained in appendix 4.

#### 4.4.3.2 Energy requirements for change in live weight

The equations used to calculate ME<sub>g</sub> (energy required for live weight gain) for beef cattle are identical to those used to calculate ME<sub>g</sub> for dairy cattle (equations 4.13 – 4.20 in section 4.3.3.3).

The equations in section 4.3.3.3.1 *live weight gain for non-lactating animals* are used to calculate ME<sub>g</sub> 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 4.3.3.2 *live weight gain for growing lactating animals* are used to calculate ME<sub>g</sub> 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, starting from 9 percent of the average beef cow weight at birth, to the live weight of an adult beef cow at maturity (Rollo, 2017). Data on beef live weights are provided in appendix 11 and 8. No weight gain is assumed for adult beef cows.

#### 4.4.4 Metabolisable energy requirements for gestation

Equation (4.19) in section 4.3.4 is used to determine the energy requirements for beef cattle conception and gestation. As stated in section 4.3.3.2, Calf weight ( $W_c$ ) is assumed to be 9% of an adult milking cow's live weight (see appendix 8). Values for the number of days the cow has been pregnant (prg) are found in Appendix 5.

#### 4.4.5 Additional metabolisable energy expenditure of grazing at pasture

Section 4.3.5 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<sub>graze</sub> 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 4.3.4.
- Dry matter digestibility (DMD). Monthly values of DMD for beef cattle are provided in Appendix 9.
- 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 4.4.3.3.

#### 4.4.6 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 4.22, outlined in section 4.3.5 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.

*Energy received from milk for beef calves 3-8 months (Equation 4.25):*

$$Z_{1bc} = \frac{Z}{d} \times \frac{MILK_{GE}}{k_l}$$

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 metabolisable energy for milk production, or the factor used to measure how efficiently ME is used by a dairy cow to produce milk (see equation 4.23)

$d$  = Number of days receiving milk (assumed to be 182 days)

*Amount of milk fed to beef calves 3-8 months (Equation 4.26):*

$$Z = (0.67 \times Y_{bc} \times \alpha_{bc}) + (0.33 \times Z_{mp})$$

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)

$\alpha_{bc}$  = Calving percentage (assumed to be 85%)

$Z_{mp}$  = Milk fed to each calf from milk powder over the 3-8 month period (200kg)

The calculation of term  $Z$  indicates that 67 per cent of the milk required by each rising one year old comes from its mother, while 33 comes from milk powder ( $Z_{mp}$ ). It is assumed that  $Z_{mp}$  equates to 200 kg per animal (Financial Budget Manual, 2002).

Information on milk yields are provided in appendix 8. For month 9 onwards,  $z_1$  is set to 0.

#### 4.4.7 Determination of Dry Matter Intake

The equations outlined in section 4.4 are used to determine the total metabolisable 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 3.1.1 (equation 1), which is ultimately used to calculate emissions. It is important to note that the ME content of pasture ( $Feed_{ME}$ ) for beef cattle is different to dairy cattle.

#### 4.5 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 (4.2). 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,  $ME_p = ME_m + ME_g + ME_{wool}$ .

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.

**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	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze} - Z_1$
7. Rams	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze}$

### 4.5.1 Metabolisable energy requirements for maintenance

Equation 4.3 in section 4.2 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 12 and the methodology outlined in section 4.7.3. The age (A) in equation 4.3 is detailed for each subcategory in Appendix 2. Pasture properties are detailed in Appendix 9.

### 4.5.2 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.

*Metabolisable energy requirements for gestation for ewes (Equation 4.27):*

$$ME_c = 0.025 \times W_l \times \frac{0.07372E_t \times e^{-0.00643prg}}{k_c}$$

Where:

ME<sub>c</sub> = ME required for gestation (MJ/d)

W<sub>l</sub> = lamb birth weight (kg)

E<sub>t</sub> = Energy required for the “gravid foetus” in utero (MJ)

prg = Number of days the ewe has been pregnant (see Appendix 5)

k<sub>c</sub> = Net efficiency of dietary ME conversion to energy needed for gestation. Currently assumed to be 0.13 (ARC, 1980).

*Energy requirement for gravid fetus in utero (Equation 4.28):*

$$E_t = 10^{(3.322 - 4.979 \times e^{-0.00643prg})}$$

Values for coefficients used in the calculation of the term E<sub>t</sub> 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 12).

### 4.5.3 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.

#### Metabolisable energy requirements of milk production for sheep (Equation 4.29)

$$ME_l = \frac{(0.328F + 0.0028d_{srm} + 2.2033) \times y}{k_l}$$

Where:

$ME_l$  = Metabolisable energy required for milk production (MJ/d)

$F$  = Milk fat percentage (currently set at 8%, see Appendix 12)

$d_{srm}$  = Number of days producing milk (assumed to be 122 days)

$y$  = Daily milk yield (kg/day)

$k_l$  = Efficiency of use of metabolisable energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk (see equation 4.31)

#### Calculation of daily sheep milk yield (Equation 4.30)

$$y = \frac{Y_{sheepm} \times mp_{month}}{d_{month}}$$

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 12)

$MP_{month}$  = proportion of total annual milk produced in a given month (see appendix 4)

$d_{month}$  = number of days in a given month

#### Calculation of sheep milk production efficiency (Equation 4.31)

$$k_l = 0.019 \times Feed_{ME} + 0.42$$

Where:

$k_l$  = Efficiency of use of metabolisable energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk

$Feed_{me}$  = energy content of pasture (MJ/kg) (see Appendix 9)

### 4.5.4 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 4.11 in section 4.3.3.2). 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 12). Live weight change for rams is detailed in the Appendix (see Appendix 12). 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). 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.

*Calculation of sheep live weight gain efficiency for dry ewes, mature breeding ewes and growing breeding sheep (Equation 4.32)*

$$k_g = 0.950 \times k_l$$

Where:

$k_g$  = Net efficiency of dietary ME conversion to live weight gain

$k_l$  = Efficiency of use of metabolisable energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk (see equation 4.31)

For subcategories 4, 5, 6 and 7:

*Calculation of sheep live weight gain efficiency for non-breeding sheep, wethers, lambs and rams (Equation 4.33)*

$$k_g = 0.042 \times \text{Feed}_{ME} + 0.006$$

Where:

$k_g$  = Net efficiency of dietary ME conversion to live weight gain

$\text{Feed}_{me}$  = energy content of pasture (MJ/kg) (see Appendix 9)

#### 4.5.5 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).

*Metabolisable energy required for wool growth in adults (Equation 4.34)*

$$ME_w = 0.13 \times \left( \left( \frac{fl \times 1000}{365} \right) - 6 \right)$$

Where:

$ME_w$  = ME required for wool growth (MJ/d)

$fl$  = Greasy fleece weight (kg per head per year) (see Appendix 12)

*Metabolisable energy required for wool growth in lambs (Equation 4.35)*

$$ME_w = 0.13 \times \left( \left( \frac{fl \times 1000}{365 \times 2} \right) - 6 \right)$$

Where:

$ME_w$  = ME required for wool growth (MJ/d)

$fl$  = Greasy fleece weight (kg per head per year) (see Appendix 12)

#### 4.5.6 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 4.21) 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). Pasture ME content and dry matter digestibility (DMD) can be found in Appendix (9). The current live weight (W) is determined by the model for all classes based on live weight inputs (Appendix 12).

#### 4.5.7 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 (see Appendix 4). The adjustment for methane is applied directly to the methane value itself.

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:

*Energy received from milk for young lambs (Equation 4.36)*

$$z_1 = \frac{Y_{sheepm}}{d_{srm} \times P_{lamb}} \times \frac{0.328F + 0.0028d_{srm} + 2.2033}{k_l}$$

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 12)

$d_{srm}$  = number of days young lambs receive milk (assumed to be 122)

$F$  = Milk fat percentage (assumed to be 8%, see Appendix 12)

$k_l$  = 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 4.31)

For other months of the year  $z_1$  is assumed to be zero.

#### 4.5.8 Determination of Dry Matter Intake

The equations outlined in section 4.5 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.

### 4.6 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.

**Table 4.4: Equations for the total ME requirement for each livestock subcategory of deer**

Deer subcategories	Equation
1. Breeding hinds	$ME_{total} = ME_m + ME_l + ME_c + ME_g$
2. Hinds < 1 year old	$ME_{total} = ME_m + ME_g - z_1$
3. Hinds 1-2 years old	$ME_{total} = ME_m + ME_c + ME_g$

4. Stags < 1 year old	$ME_{total} = ME_m + ME_g - Z_l$
5. Stags 1 – 2 years old	$ME_{total} = ME_m + ME_g + ME_{velvet}$
6. Stags 2 – 3 years old	$ME_{total} = ME_m + ME_g + ME_{velvet}$
7. Mixed age and breeding stags	$ME_{total} = ME_m + ME_g + ME_{velvet}$

#### 4.6.1 Maintenance energy requirements

Equation 4.3 (section 4.2) is also used to determine maintenance energy requirements for Deer. Although the same method is used to calculate  $k_m$ , different deer-specific values for live weight (LW) and age (A) are used.

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 14).

The parameter value for age (A) in this equation is detailed for each class in Appendix 2

Deer-specific estimates of feed ME content ( $Feed_{me}$ , used to calculate  $k_m$ ) are in Appendix 9.

#### 4.6.2 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  $ME_m$ .

#### 4.6.3 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 4.3.3.3, apart from the final term, which uses a deer-specific parameter of 0.92 instead of 0.84.

*Metabolisable energy requirements for live weight gain in deer (Equation 4.37):*

$$ME_g = \frac{(6.7 + R) + \frac{20.3 - R}{1 + e^{-6(P_{lw} - 0.4)}}}{k_{gnl}} \times LWG \times 0.92$$

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 4.3.3.3.1)

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 4.3.3.3.1)

$k_{gnl}$  = Net efficiency of dietary metabolisable energy conversion to live weight gain for non-lactating animals (see equation 4.17, section 4.3.3.3.1)

#### 4.6.4 Metabolisable energy requirements for lactation

The inventory assumes that young deer are born on the 19<sup>th</sup> 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.

#### Metabolisable energy requirements of milk production for deer (Equation 4.38)

$$ME_l = \frac{Y_{deerm} \times mp_{month}}{d_{month}} \times \frac{evl}{k_{ldeer}}$$

Where:

$ME_l$  = Metabolisable 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 14)

$MP_{month}$  = Milk produced in a given month as a proportion of total annual milk produced (see appendix 4)

$d_{month}$  = 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 metabolisable 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 the other months of the year (April to October),  $ME_l$  is set to zero.

#### 4.6.5 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 ( $z_1$ ) from the other components of ME (such as maintenance – see table 4.4).

*Energy received from milk for young deer (Equation 4.39)*

$$z_1 = \frac{Y_{deerm}}{d_{drm}} \times evl_{deer} \times k_{ldeer}$$

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 14)

$d_{drm}$  = 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 metabolisable 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.

#### 4.6.6 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):



Energy required for gestation in breeding hinds (Equation 4.40)

$$ME_c = 0.7 \times TF \times LW^{0.75}$$

Where:

$ME_c$  = energy required for gestation (MJ/d)

TF = trimester factor (see table 6)

LW = hind live weight

**Table 4.5: 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

#### 4.6.7 Metabolisable energy requirements for velvet production

The inventory model assumes that mature stags produce velvet each year over a 65 day period, from the 1<sup>st</sup> of September to the 4<sup>th</sup> of November. During this period 0.5 megajoules of ME is required each day to produce velvet (Suttie, 2012).

Energy required for velvet production in mature stags (Equation 4.41)

$$ME_{velvet} = 0.5$$

Where:

$ME_{velvet}$  = energy required for velvet production (MJ/d)

For other months of the year  $ME_{velvet}$  is assumed to be zero.

#### 4.6.8 Determination of Dry Matter Intake

The equations outlined in section 4.6 and table 4.4 are used to determine the  $ME_{total}$  requirements for each class of deer. These figure 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 feed (Feed<sub>ME</sub>) for deer is different to the other animal categories and is calculated using a different methodology.

The ME content of deer pasture is calculated as a weighted average of Feed<sub>ME</sub> for 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). The pasture ME content for deer for 1990 and 2010 are shown in Appendix 9.

## 4.7 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 (e.g. dairy cattle, sheep...) 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 5.5.5). 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 4.6: 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	1-Aug	639	NA	50%	Calculated monthly	Calculated	9%
	Growing females 1-2 years old	Breeding replacements	NA	639	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	20-Sep	1095	NA	50%	Calculated monthly	Calculated	9%
	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	20-Sep	730	NA		Calculated monthly	Calculated	9%
	Slaughter heifers 1 - 2 years	Slaughter	NA	730	20-Sep		Calculated monthly	Calculated	NA
	Slaughter steers 0 – 1 years	Slaughter	20-Sep	730	NA		Calculated monthly	Calculated	10%
	Slaughter steers 1 - 2 years	Slaughter	NA	730	20-Sep		Calculated monthly	Calculated	NA
	Slaughter Bulls 0 - 1 years	Slaughter	20-Sep	730	NA		Calculated monthly	Calculated	10%
	Slaughter Bulls 1 – 2 years	Slaughter	NA	730	20-Sep		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		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	55%	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
	Mixed age breeding stags	Male	NA	NA	NA		uses data in report by Suttie (2012)	0	NA

## 4.7.1 Live weight and live weight gain – dairy

### 4.7.1.1 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.

*Monthly live weight for growing heifers (Equation 4.42)*

$$LWgh_{m,y} = Birth\ weight_{gh,y} + Adult\ weight_{mmc,y}(90\% - 9\%) \times \left( \frac{AgeSOM_{gh,m}}{days\ to\ maturity_{gh}} \right)$$

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 4.7.2.2)

90% : 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)

$AgeSOM_{gh,m}$  = age (in days) of growing heifers at the start of the month  $m$

Days to maturity = days required growing heifers to reach maturity (currently set at 638)

The inventory assumes that all dairy calves (growing heifers 0-1) are born on the first 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 638 days old, at which point their weight is assumed to be 90% of an adult dairy cow's weight (described in the next section). After 638 days, they join the class of mature milking cows and make an instantaneous jump in weight to the full mature dairy cow weight.

The table below further outlines how the parameters used in the calculation of liveweight for growing heifers in equation 4.42 changes in the months following birth, and shows the growing heifer weights over time as a percentage of the mature milking cow weight.

**Table 4.7: Monthly values used to calculate live weight and live weight gain for growing heifers**

Month	Class	days since birth (start of month)	days since birth (end of month)	live weight as a proportion of adult weight		
				start of month	month average	end of month
August (birth)	Growing heifers 0-1	0	31	9.0%	11.0%	12.9%
September	Growing heifers 0-1	31	61	12.9%	14.8%	16.7%
October	Growing heifers 0-1	61	92	16.7%	18.7%	20.7%
November	Growing heifers 0-1	92	122	20.7%	22.6%	24.5%
December	Growing heifers 0-1	122	153	24.5%	26.5%	28.4%
January	Growing heifers 0-1	153	184	28.4%	30.4%	32.4%
February	Growing heifers 0-1	184	212	32.4%	34.1%	35.9%
March	Growing heifers 0-1	212	243	35.9%	37.9%	39.9%
April	Growing heifers 0-1	243	273	39.9%	41.8%	43.7%
May	Growing heifers 0-1	273	304	43.7%	45.6%	47.6%
June	Growing heifers 0-1	304	334	47.6%	49.5%	51.4%
July	Growing heifers 1-2	334	365	51.4%	53.4%	55.3%
August	Growing heifers 1-2	365	396	55.3%	57.3%	59.3%
September	Growing heifers 1-2	396	426	59.3%	61.2%	63.1%
October	Growing heifers 1-2	426	457	63.1%	65.1%	67.0%

November	Growing heifers 1-2	457	487	67.0%	68.9%	70.8%
December	Growing heifers 1-2	487	518	70.8%	72.8%	74.8%
January	Growing heifers 1-2	518	549	74.8%	76.7%	78.7%
February	Growing heifers 1-2	549	577	78.7%	80.5%	82.3%
March	Growing heifers 1-2	577	608	82.3%	84.2%	86.2%
April	Growing heifers 1-2	608	638	86.2%	88.1%	90.0%
May	Milking cows mature				100%	

Live weight gain for growing heifers (in terms of kilograms per day) can be calculated using the formula below:

*Live weight gain for growing heifers (Equation 4.43)*

$$LWG_{gh,m,y} = \frac{Adult\ weight_{mmc,y}(90\% - 9\%)}{days\ to\ maturity_{gh}}$$

Where:

$LWG_{gh,m,y}$  = live weight gain of growing heifers in year  $y$  and month  $m$  (kg per day)

90% : 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<sub>mmc,y</sub> = mature weight of milking cows in year  $y$  (from activity data – see section 4.7.1.2)

Days to maturity<sub>gh</sub> = days required growing heifers to reach maturity (currently set at 638)

#### 4.7.1.2 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.

#### 4.7.1.3 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.

### 4.7.2 Live weight and live weight gain – beef

#### 4.7.2.1 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.

#### 4.7.2.2 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.

#### Live weight for breeding mature beef cows (Equation 4.44)

$$LWbbmc_y = \left( \frac{(TOTcarcwt_{cattle,y} - (LWmmc_y \times KO_{DC})) \times (Ncow_{slaughtered,y} - (RR_{Beef} \times Nbeef_{Bcow,y}))}{Nbeef_{cow} \times RR_{Beef}} \right) / KO_{DC}$$

Where:

LWbbmc<sub>y</sub> = live weight of breeding mature beef cows, for a particular year *y* ending in June (kg)

TOTcarcwt<sub>cattle,y</sub> = 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<sub>y</sub> = live weight of mature milking dairy cows in year *y*, in kilograms (see section 4.7.1.2)

KO<sub>DC</sub> = killing out percentage for dairy cows (currently set at 42%)

Ncow<sub>slaughtered,y</sub> = Number of dairy and beef cows slaughtered, for a particular year ending in June (data provided by Statistics New Zealand)

RR<sub>Beef</sub> = beef cow replacement rate, currently set at 17%

Nbeef<sub>Bcow,y</sub> = number of beef breeding cows, for a particular year ending in June. Data provided by Statistics New Zealand (line codes 7056 and 7057)

#### 4.7.2.3 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 20<sup>th</sup> 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).

#### Monthly live weight for breeding growing cows (Equation 4.45)

$$LWbbgc_{m,y} = Birth\ weight_{bbgc,y} + \left( \frac{AgeMOM_{bbgc,m}}{days\ to\ maturity_{bbgc}} \right) \times (LWbbmc_y - Birth\ weight_{bbgc,y})$$

Where:

LWbbgc<sub>m,y</sub> = live weight of breeding growing cows in month *m*, year *y* (kg)

Birth weight<sub>bbgc,y</sub> = birth weight of breeding growing cows in year *y* (equal to 9% of breeding mature cow live weight) (kg)

AgeMOM<sub>bbgc,m</sub> = age (in days) of breeding growing cows at the middle of month *m*

Days to maturity<sub>bbgc</sub> = number of days from birth to slaughter for breeding growing cows (currently set at 1095)

LWbbmc<sub>y</sub> = live weight of breeding mature beef cows, for a particular year ending in June (kg)

#### Live weight gain for breeding growing cows (Equation 4.46)

$$LWGbbgc_y = \frac{LWbbmc_y - Birth\ weight_{bbgc,y}}{days\ to\ maturity_{bbgc}}$$

Where:

LWGbbgc<sub>m,y</sub> = live weight gain of breeding growing cows in year y (kg)

LWbbmc<sub>y</sub> = live weight of breeding mature beef cows, for a particular year ending in June (kg)

Birth weight<sub>bbgc,y</sub> = birth weight of breeding growing cows in year y (equal to 9% of breeding mature cow live weight) (kg)

Days to maturity<sub>bbgc</sub> = number of days from birth to slaughter for breeding growing cows (currently set at 1095)

#### 4.7.2.4 Slaughter bulls, slaughter heifers and slaughter steers

Slaughter bulls, slaughter heifers and slaughter steers are raised over a period of two years from birth (20<sup>th</sup> September each year). After this period, these animals are sent to slaughter. 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 two years, in any given period there will be two 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 (one group will be aged between zero and one, and the other group will be aged between one and two)

*Monthly live weight for slaughter bulls, slaughter heifers and slaughter steers (Equation 4.47)*

$$\begin{aligned}
 LWbslaughter_{x,m,y} &= Birth\ weight_{bslaughter,x,y} \\
 &+ \left( \frac{AgeMOM_{bslaughter,m}}{days\ to\ slaughter_{bslaughter,x}} \right) \\
 &\times (LWbslaughter_{at\ slaughter,x,y} - Birth\ weight_{bslaughter,x,y})
 \end{aligned}$$

Where:

LWbslaughter<sub>x,m,y</sub> = 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<sub>bslaughter,x,y</sub> = birth weight in kilograms of beef slaughter animals in year y, for animal type x (either slaughter bulls, slaughter heifers and slaughter steers). Equal to 9% of live weight at slaughter for slaughter heifers, and 10% of live weight at slaughter for slaughter bulls and steers.

AgeMOM<sub>bslaughter,x,m</sub> = age (in days) of beef slaughter animals at the middle of month m, for animal type x (either slaughter bulls, slaughter heifers and slaughter steers)

Days to slaughter<sub>bslaughter</sub> = number of days from birth to slaughter for all beef slaughter animals (currently set at 730)

LWbslaughter<sub>at slaughter,x,y</sub> = live weight in kilograms of beef slaughter animals at slaughter (i.e. at 730 days since birth) in year y, for animal type x (either slaughter bulls, slaughter heifers and slaughter steers) (see equation 4.48)

*Live weight at slaughter for slaughter bulls, slaughter heifers and slaughter steers (Equation 4.48)*

$$LWbslaughter_{at\ slaughter,x,y} = \frac{Carcass\ weight_{bslaughter,x,y}}{KO_{beef}}$$

Where:

$LW_{bslaughter_{at\ slaughter,x,y}}$  = live weight in kilograms of beef slaughter animals at slaughter (i.e. at 730 days since birth) in year  $y$ , for animal type  $x$  (either slaughter bulls, slaughter heifers and slaughter steers)

Carcass weight $_{bslaughter,y}$  = average carcass weight in kilograms of beef slaughter animals for year  $y$  ending in June, for animal type  $x$  (either slaughter bulls, slaughter heifers and slaughter steers). Data from Statistics New Zealand

$KO_{beef}$  = killing out percentage for beef animals (currently set at 50%)

*Live weight gain for slaughter bulls, slaughter heifers and slaughter steers (Equation 4.49)*

$$LWG_{bslaughter_{x,y}} = \frac{LW_{bslaughter_{at\ slaughter,x,y}} - Birth\ weight_{bslaughter,x,y}}{days\ to\ slaughter_{bslaughter,x}}$$

Where:

$LWG_{bslaughter_{x,y}}$  = live weight gain in kilograms per day, of beef slaughter animals in year  $y$ , for animal type  $x$  (either slaughter bulls, slaughter heifers and slaughter steers)

$LW_{bslaughter_{at\ slaughter,x,y}}$  = live weight in kilograms of beef slaughter animals at slaughter (i.e. at 730 days since birth) in year  $y$ , for animal type  $x$  (either slaughter bulls, slaughter heifers and slaughter steers) (see equation 4.48)

Birth weight $_{bslaughter,x,y}$  = birth weight in kilograms of beef slaughter animals in year  $y$ , for animal type  $x$  (either slaughter bulls, slaughter heifers and slaughter steers). Equal to 9% of live weight at slaughter for slaughter heifers, and 10% of live weight at slaughter for slaughter bulls and steers.

Days to slaughter $_{bslaughter}$  = number of days from birth to slaughter for all beef slaughter animals (currently set at 730)

### 4.7.3 live weight and live weight gain – sheep

#### 4.7.3.1 Whethers, Dry Ewes, and Mature Breeding Ewes

The live weight for whethers, 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%).

*Monthly live weight for whethers, dry ewes, and mature breeding ewes (Equation 4.50)*

$$LW_{as,y} = \frac{Carcass\ weight_{as,y}}{KO_{as}}$$

Where:

$LW_{as,y}$  = live weight of whethers, 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.

#### 4.7.3.2 Rams

The live weight for rams (for each year ending in June) is assumed to be 40% greater than the live weight for whethers, dry ewes, and mature breeding ewes.



*Monthly live weight for rams (Equation 4.51)*

$$LWram_y = LWas_y \times 1.4$$

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 4.50

It is assumed that rams have a live weight gain of 0.05 kg per day

**4.7.3.3 lambs**

The inventory model assumes that lambs are born on the 11<sup>th</sup> of September each year and are grown for two slaughter dates (28<sup>th</sup> 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 4.54). 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 4.52). Following the first slaughter date, the rate of live weight gain for the remaining lambs from the 1<sup>st</sup> of March to the 31<sup>st</sup> of August is halved (equation 4.55). The middle of the month is used for the estimate of lamb age to calculate the weight for each month.

*Monthly live weight for lambs between September and February inclusive (Equation 4.52)*

$$\begin{aligned} LWlamb_{m,y} &= Birth\ weight_{lamb,y} \\ &+ \left( \frac{AgeMOM_{lamb,m}}{days\ to\ 1st\ Slaughter_{lamb}} \right) \\ &\times (LW1stSlaughter_{lamb,y} - Birth\ weight_{lamb,y}) \end{aligned}$$

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  $m$

$Days\ to\ 1^{st}\ Slaughter_{lamb}$  = 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 4.54)

*Monthly live weight for lambs between March and August inclusive (Equation 4.53)*

$$LWlamb_{m,y} = LWlamb_{m-1,y} + nod_m \times LWG_{lamb,2nd,y}$$

Where:

LW<sub>lamb,m,y</sub> = live weight of lambs in month *m*, year *y*, from March to August (kg)

LW<sub>lamb,m,y</sub> = live weight of lambs in previous month *m* and year *y* (kg)

nod<sub>*m*</sub> = number of days in month *m*

LWG<sub>lamb,2nd,y</sub> = live weight gain of lambs between March and August following first slaughter in year *y*

*Lamb live weight at first slaughter (Equation 4.54)*

$$LW1stSlaughter_{lamb,y} = \frac{Carcass\ weight_{lamb,y}}{KO_{lamb}}$$

Where:

LW1stSlaughter<sub>lamb,y</sub> = live weight of lambs at first slaughter (28 February) in year *y* (kg)

Carcass weight<sub>lamb,y</sub> = average carcass weight of lambs for year *y* ending in June (kg).  
Data from Statistics New Zealand

KO<sub>lamb</sub> = killing out percentage for lambs. Currently set at 45%

*Live weight gain for lambs between September and February inclusive (Equation 4.55)*

$$LWG_{lamb,1st,y} = \frac{LW1stSlaughter_{lamb,y} - Birth\ weight_{lamb,y}}{days\ to\ 1st\ Slaughter_{lamb}}$$

Where:

LWG<sub>lamb,1st,y</sub> = live weight gain of lambs in period before first slaughter in year *y* (kg per day)

LW1stSlaughter<sub>lamb,y</sub> = live weight of lambs at first slaughter (28 February) in year *y* (kg)  
(equation 4.54)

Birth weight<sub>lamb,y</sub> = birth weight of lambs in year *y* (equal to 9% of wethers, dry ewes, and mature breeding ewe live weight) (kg)

Days to 1<sup>st</sup> Slaughter<sub>lamb</sub> = number of days from birth to slaughter for lambs (currently set at 171)

*Live weight gain for lambs between March and August inclusive (Equation 4.56)*

$$LWG_{lamb,2st,y} = LWG_{lamb,1st,y} \times 0.5$$

Where:

LWG<sub>lamb,2st,y</sub> = live weight gain of lambs in period before after first slaughter in year *y* (kg per day)

LWG<sub>lamb,1st,y</sub> = live weight gain of lambs in period before first slaughter in year *y* (kg per day)

#### **4.7.3.4 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 the beginning of April (before this they are in the lambs

category, and have weight characteristics as designated in section 4.7.4.3) to the end of the next March (after which they become whethers, 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.

*Monthly live weight for growing breeding sheep and growing non-breeding sheep (Equation 4.57)*

$$LWsg_{m,y} = LWlamb_{march,y} + \left( \frac{nod_{m,since\ March}}{365} (LWas_y - LWlamb_{march,y}) \right)$$

Where:

$LWsg_{m,y}$  = live weight of growing sheep (growing breeding sheep and growing non-breeding sheep) in month  $m$ , year  $y$  (kg)

$LWlamb_{march,y}$  = live weight of lambs in March of year  $y$  (kg) (equation 4.53)

$nod_{m,since\ march}$  = number of days since March 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)

*Live weight gain for growing breeding sheep and growing non-breeding sheep (Equation 4.58)*

$$LWGsg_y = \frac{LWas_y - LWlamb_{march,y}}{365}$$

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)

$LWlamb_{march,y}$  = live weight of lambs in March of year  $y$  (kg) equation 4.53)

#### 4.7.4 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 19<sup>th</sup> of November each year, and have a weight that increases linearly according to equations 4.63 and 4.69. A portion of these animals are slaughtered after 466 days at the end of February. Following this, the rate of weight gain decreases (equations 4.65 and 4.72). 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

##### 4.7.4.1 Breeding hinds

The inventory model assumes that breeding hinds have reached maturity and have a stable weight. Instead of using killing out percentages, data and methodology from Suttie (2012) is used to calculate live weight.

*Monthly live weight for breeding hinds (Equation 4.59)*

$$LWbh_y = Carcass\ weight_{hind,y} \times \frac{baselineLW_{hind,y}}{Carcass\ weight_{hind,1989}}$$

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

baseline $LW_{hind,y}$  = baseline live weight of hinds in year  $y$ , using data from Suttie (2012).  
See table 4.8 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

#### 4.7.4.2 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).

*Monthly live weight for growing hinds, from birth to first slaughter (Equation 4.60)*

$$LW_{hind, birth\ to\ 1st\ slaughter, m, y} = \left( \frac{AgeMOM_{hind, m, y}}{days\ to\ 1st\ Slaughter_{hind}} \times (LW_{hind, at\ 1st\ slaughter, m, y} - Birth\ weight_{hind, y}) \right)$$

Where:

$LW_{hind, birth\ to\ 1st\ slaughter, m, y}$  = 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)

$LW_{hind, at\ 1st\ slaughter, y}$  = live weight of hinds for a particular year  $y$  at slaughter after 466 days (kg) (equation 4.61)

$Birth\ weight_{hind, y}$  = live weight of hinds at birth in year  $y$  (kg) (equation 4.62)

*Live weight for growing hinds at first slaughter (Equation 4.61)*

$$LW_{hind, at\ 1st\ slaughter, y} = \frac{Carcass\ weight_{hind, y}}{KO_{hind}}$$

Where:

$LW_{hind, at\ 1st\ slaughter, y}$  = 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.

*Live weight of hinds at birth (Equation 4.62)*

$$Birth\ weight_{hind, y} = 9\% \times LWbh_y$$

Where:

Birth weight<sub>hind,y</sub> = live weight of hinds at birth in year y (kg)

LWbh<sub>y</sub> = live weight of breeding hinds for a particular year y ending in June (kg)  
(equation 4.59)

*Live weight gain for growing hinds from birth to first slaughter (Equation 4.63)*

$$LWG_{hind_{birth\ to\ first\ slaughter,y}} = \frac{LW_{hind_{at\ 1st\ slaughter,y}} - Birth\ weight_{hind,y}}{days\ to\ 1st\ Slaughter_{hind}}$$

Where:

LWG<sub>hind<sub>birth to first slaughter,y</sub></sub> = live weight gain of growing hinds from birth to first slaughter in year y (kg per day)

LW<sub>hind<sub>at 1st slaughter,y</sub></sub> = live weight of hinds for a particular year y at slaughter after 466 days (kg) (equation 4.61)

Birth weight<sub>hind,y</sub> = live weight of hinds at birth in year y (kg) (equation 4.62)

days to 1<sup>st</sup> slaughter<sub>hind</sub> = number of days between birth and first slaughter for growing hinds (466)

#### 4.7.4.3 Hinds from first slaughter to maturity

From the 28<sup>th</sup> 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.

*Monthly live weight for growing hinds, from first slaughter to maturity (Equation 4.64)*

$$LW_{hind_{1st\ slaughter\ to\ mature,m,y}} = \left( \frac{AgeMOM_{hind,m,y} - days\ to\ 1st\ Slaughter_{hind}}{days\ to\ maturity_{hind}} \times (LWbh_y - LW_{hind_{at\ 1st\ slaughter,m,y}}) \right)$$

Where:

LW<sub>hind<sub>1st slaughter to maturity,m,y</sub></sub> = live weight of growing hinds for a particular year y and month m, from 466 days of age to maturity

AgeMOM<sub>hind,m,y</sub> = age (in days) of growing hinds at the middle of month m in year y

days to 1<sup>st</sup> slaughter<sub>hind</sub> = number of days between birth and first slaughter for growing hinds (466)

days to maturity<sub>hind</sub> = number of days between first slaughter and maturity for growing hinds (306)

LWbh<sub>y</sub> = live weight of breeding hinds for a particular year y ending in June (kg)  
(equation 4.59)

LW<sub>hind<sub>at 1st slaughter,y</sub></sub> = live weight of hinds for a particular year y at slaughter after 466 days (kg) (equation 4.61)

*Live weight gain for growing hinds from first slaughter to maturity (Equation 4.65)*

$$LWG_{hind_{1st\ slaughter\ to\ maturity,y}} = \frac{LWbh_y - LW_{hind_{at\ 1st\ slaughter,m,y}}}{days\ to\ maturity_{hind}}$$

Where:

$LWG_{hind,slaughter\ to\ maturity,y}$  = live weight gain of growing hinds from first slaughter to maturity in year  $y$  (kg per day)

$LWbh_y$  = live weight of breeding hinds for a particular year  $y$  ending in June (kg) (equation 4.59)

$LW_{hind,at\ 1st\ slaughter,y}$  = live weight of hinds for a particular year  $y$  at slaughter after 466 days (kg) (equation 4.61)

days to maturity<sub>hind</sub> = number of days between first slaughter and maturity for growing hinds (306)

#### 4.7.4.4 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).

*Monthly live weight for growing stags, from birth to first slaughter (Equation 4.66)*

$$LW_{stag,birth\ to\ 1st\ slaughter,m,y} = \left( \frac{AgeMOM_{stag,m,y}}{days\ to\ 1st\ Slaughter_{stag}} \times (LW_{stag,at\ 1st\ slaughter,m,y} - Birth\ weight_{stag,y}) \right)$$

Where:

$LW_{stag,birth\ to\ 1st\ slaughter,m,y}$  = 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<sup>st</sup> slaughter<sub>stag</sub> = number of days between birth and first slaughter for growing stag (466)

$LW_{stag,at\ 1st\ slaughter,y}$  = live weight of stags for a particular year  $y$  at slaughter after 466 days (kg) (equation 4.67)

Birth weight<sub>stag,y</sub> = live weight of stags at birth in year  $y$  (kg) (equation 4.68)

*Live weight for growing stags at first slaughter (Equation 4.67)*

$$LW_{stag,at\ 1st\ slaughter,y} = \frac{Carcass\ weight_{stag,y}}{KO_{stag}}$$

Where:

$LW_{stag,at\ 1st\ slaughter,y}$  = live weight of stags for a particular year  $y$  at slaughter after 466 days (kg).

Carcass weight<sub>stag,y</sub> = 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.

*Live weight of stags at birth (Equation 4.68)*

$$Birth\ weight_{stag,y} = 10\% \times LWbh_y$$

Where:

Birth weight<sub>stag,y</sub> = live weight of stags at birth in year  $y$  (kg)

LWbh<sub>y</sub>= live weight of breeding hinds for a particular year *y* ending in June (kg)  
(equation 4.59)

*Live weight gain for growing stags from birth to first slaughter (Equation 4.69)*

$$LWGstag_{birth\ to\ first\ slaughter,y} = \frac{LWstag_{at\ 1st\ slaughter,y} - Birth\ weight_{stag,y}}{days\ to\ 1st\ Slaughter_{stag}}$$

Where:

LWGstag<sub>birth to first slaughter,y</sub> = live weight gain of growing stags from birth to first slaughter in year *y* (kg per day)

LWstag<sub>at 1st slaughter,y</sub> = live weight of stags for a particular year *y* at slaughter after 466 days (kg) (equation 4.67)

Birth weight<sub>stag,y</sub> = live weight of stags at birth in year *y* (kg) (equation 4.68)

days to 1<sup>st</sup> slaughter<sub>stag</sub> = number of days between birth and first slaughter for growing stags (466)

#### 4.7.4.5 Stags from first slaughter to maturity

From the 28<sup>th</sup> of February, the live weight of stags between the age of one (including mixed age breeding 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).

*Monthly live weight for growing stags, from first slaughter to maturity (Equation 4.70)*

$$LWstag_{1st\ slaughter\ to\ three,m,y} = \left( \frac{AgeMOM_{stag,m,y} - days\ to\ 1st\ Slaughter_{stag}}{days\ to\ maturity_{stag}} \times (LWstag_{age\ three,y} - LWstag_{at\ 1st\ slaughter,m,y}) \right)$$

Where:

LWstag<sub>1st slaughter to three,m,y</sub> = live weight of stags for a particular year *y* and month *m*, from 466 days of age to three years of age

AgeMOM<sub>stag,m,y</sub> = age (in days) of stags at the middle of month *m* in year *y*

days to 1<sup>st</sup> slaughter<sub>stag</sub> = number of days between birth and first slaughter for stags (466)

days to maturity<sub>stag</sub> = number of days between first slaughter and age three for stags (671)

LWstag<sub>age three,y</sub>= live weight of stags at age three for a particular year *y* ending in June (kg) (equation 4.71)

LWstag<sub>at 1st slaughter,y</sub> = live weight of stags for a particular year *y* at slaughter after 466 days (kg) (equation 4.67)

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.

Monthly live weight for stags at three years of age (Equation 4.71)

$$LWstag_{age\ three,y} = Carcass\ weight_{stag,y} \times \frac{baselineLW_{stag,y}}{Carcass\ weight_{stag,1989}}$$

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 4.8 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

Live weight gain for stags from first slaughter to age three (Equation 4.72)

$$LWGstag_{1st\ slaughter\ to\ age\ three,y} = \frac{LWstag_{age\ three,y} - LWstag_{at\ 1st\ slaughter,m,y}}{days\ to\ maturity_{stag}}$$

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 4.71)

$LWstag_{at\ 1st\ slaughter,y}$  = live weight of stags for a particular year  $y$  at slaughter after 466 days (kg) (equation 4.67)

$days\ to\ maturity_{stag}$  = number of days between first slaughter and age three for stags (671)

#### 4.7.4.6 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 4.8: 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

#### **4.7.5 live weight and live weight gain – swine**

Swine weight data compiled by Statistics New Zealand is used to calculate nitrous oxide emissions (see section 5.5.5). However, this weight data is not used to calculate energy requirements or methane emissions.

#### **4.7.6 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  $N_2O$  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 ( $N_{ex}$ ) 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,  $N_{exURINE,LOW}$  (i.e. urine deposited on low slopes),  $N_{exURINE,MED}$  (urine deposited on medium slopes) and  $N_{exURINE,STEEP}$  (urine deposited on steep slopes). For dairy cattle, it is assumed that all urine is deposited on flatland, ( $N_{exURINE,FLAT}$ ). 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 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, live weight gain and 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 4.3.1) 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.

For dairy cattle in the first two months of their life,  $N_{ex}$  is set to zero.

*Nitrogen excretion for dairy cattle (Equation 5.1):*

$$N_{ex} = N_i - (N_m + N_{lwg})$$

Where:

$N_{ex}$  = Nitrogen excretion per animal (kilograms of nitrogen per day)

$N_i$  = Nitrogen intake per animal (kg N/day)

$N_m$  = nitrogen secreted in milk per animal (kg N/day)

$N_{lwg}$  = nitrogen retained in live weight gain per animal (kg N/day)

### 5.1.1 Nitrogen intake

#### 5.1.1.1 Dairy cattle greater than one year old

For cattle greater than 1 year old nitrogen intake ( $N_i$ ) is determined by:

*Nitrogen intake for dairy (and beef) cattle more than 1 year old (Equation 5.2):*

$$N_i = DMI \times Feed_N$$

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)

$Feed_N$  = Nitrogen content of feed consumed by dairy cattle, expressed as a proportion of DMI (see appendix 19)

#### 5.1.1.2 Dairy cattle less than one year old

Intakes are calculated separately for the period when milk forms part of the diet (first 8-12 weeks of life) and for the remainder of the year. During the first 8-12 weeks 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.

*Nitrogen intake through milk by young dairy cattle (Equation 5.3):*

$$z_3 = \frac{Z_{mp}}{d} \times \frac{P_{mp}}{6.25}$$

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 8-12 weeks of life, equation 5.4 (below) is used to calculate N intake for young cattle. For other months, equation 5.2 (above) is used.

*Nitrogen intake for cattle less than 1 year old in the first 8-12 weeks (Equation 5.4):*

$$N_i = (DMI \times Feed_N) + z_3$$

Where:

$N_i$  = Nitrogen intake per animal (kg N per day)

$DMI$  = dry matter intake per animal (kg/day see Section 4.1.1)

$Feed_N$  = Nitrogen content of feed consumed by dairy cattle, expressed as a proportion of DMI (i.e. grams of N per gram of DMI, see appendix 19)

$Z_3$  = nitrogen intake through milk powder per animal (kg N per day)

### 5.1.2 Nitrogen retained in milk

The N secreted as milk production for lactating dairy cows is determined by the following equation:

*Nitrogen secreted in milk for mature milking cows (Equation 5.5):*

$$N_{rm} = Y \times \frac{P}{6.25}$$

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 4.8, section 4.3.3.1)

$P$  = Protein content of milk, expressed as a proportion (i.e. grams of N per gram of milk, see appendix 1 for values)

### 5.1.3 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.

*Nitrogen retained in animal tissues through live weight gain (Equation 5.6):*

$$N_{lwg} = LWG \times \frac{N_{bt}}{100}$$

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 4.7.1)

$N_{bt}$  = nitrogen content of body tissue, currently set at 3.26% (see appendix 1)

### 5.1.4 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 5.1, 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).

*Nitrogen excreted in faeces (Equation 5.7):*

$$N_f = (-4.623 + (Feed_N \times 100 \times 1.970) + (DMI \times 7.890)) \times 0.001$$

Where:

$N_f$  = Amount of nitrogen excreted in faeces per animal (kilograms of nitrogen per day)

$Feed_N$  = Nitrogen content of feed consumed by dairy cattle, expressed as a proportion of DMI (i.e. grams of N per gram of DMI, see appendix 19)

DMI = the dry matter intake (kilograms per day)

$Feed_N$  is currently set at 3.7% for dairy cattle and 3% for sheep, beef cattle and deer for all months and years. The fractional term in this equation ( $Feed_N$ ) should be equal to 0.037 for dairy cattle and 0.03 for sheep, beef cattle and deer.

*Nitrogen excretion in urine (Equation 5.8):*

$$N_u = N_{ex} - N_f$$

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 5.1 (kilograms N per day)

### 5.1.5 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  $EF_{3(PRP\ DUNG)}$  value of 0.0012 is applied to all dairy dung.

## 5.2 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 4.4.1). 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 5.1 in section 5.1.

For cattle in the first two months of their life,  $N_{ex}$  is set to zero.

## 5.2.1 Nitrogen intake

### 5.2.1.1 Nitrogen intake by beef cattle older than one year old

Equation 5.2 (section 5.1.1.1) is used to calculate N intake by beef cattle greater than one year old.

### 5.2.1.2 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 six months of life.

*Nitrogen intake through milk by young beef cattle (Equation 5.9):*

$$Z_{3beef} = \frac{Z}{d} \times \frac{P_{mp}}{6.25}$$

Where:

$Z_{3beef}$  = nitrogen intake through milk per animal (kg of nitrogen per day)

$Z$  = the total amount of milk fed to each calf over the 3-8 month period (kg) (calculated from equation 4.26, section 4.4.5)

$d$  = number of days per year N is consumed through milk (currently set at 182)

$P_{mp}$  = 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 5.10 (below) is used to calculate N intake for young cattle. For other months (when there is no intake of milk), equation 5.2 (section 5.1.1.1) is used.

*Nitrogen intake for beef cattle less than 1 year old in first six months of life (Equation 5.10)*

$$N_i = (DMI \times Feed_N) + Z_{3beef}$$

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)

$Feed_N$  = Nitrogen content of feed consumed by beef cattle, expressed as a proportion of DMI (see appendix 19)

$Z_{3beef}$  = nitrogen intake through milk per animal (kg of nitrogen per day)

## 5.2.2 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 5.11.

*Nitrogen secreted in milk of cows rearing their calves (Equation 5.11):*

$$N_{rm} = Y \times \frac{P}{6.25}$$

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 4.24, section 4.4.3.1)

$P$  = Protein content of milk (see appendix 8)

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.

### 5.2.3 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 5.6 (section 5.1.3) can be used to calculate  $N_{lwg}$  for different subcategories of beef cattle

### 5.2.4 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 equations 5.7 and 5.8 in section 5.1.4.

### 5.2.5 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 5.5.

A single dung emission factor ( $EF_{3(PRP-DUNG)} = 0.0012$ ) is used across all slope categories for cattle, sheep and deer, and therefore dung excreta does not need to be allocated to different slopes.

## 5.3 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 4.5, 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.

*Nitrogen excretion for sheep (Equation 5.12):*

$$N_{ex} = N_i - (N_m + N_{lwg} + N_{wool})$$

Where:

$N_{ex}$  = Nitrogen excretion per animal (kilograms of nitrogen per day)

$N_i$  = Nitrogen intake per animal (kg N/day)

$N_m$  = nitrogen secreted in milk per animal (kg N/day)

$N_{lwg}$  = nitrogen retained in live weight gain per animal (kg N/day)

$N_{\text{wool}}$  = nitrogen retained in wool growth per animal (kg N/day)

### 5.3.1 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.

#### 5.3.1.1 Sheep older than one year

Equation 5.2 (section 5.1.1.1) can be used to calculate N intake by sheep greater than one year old. The sheep-specific values for the nitrogen content of pasture ( $PAST_N$ ) are in appendix 19.

#### 5.3.1.2 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 during the months of September through to December (inclusive) using the term  $z_3$  (the N from milk).

*Nitrogen intake through milk by lambs (Equation 5.13):*

$$z_{3\text{lamb}} = \frac{Y_{\text{sheepm}}}{d_{\text{srn}} \times P_{\text{lamb}}} \times \frac{P_{\text{mp}}}{6.25}$$

Where:

$Z_{3\text{lamb}}$  = nitrogen intake through milk per animal (kg of nitrogen per day)

$Y_{\text{sheepm}}$  = annual milk yield per sheep (kilograms per sheep per year)

$P_{\text{lamb}}$  = annual lambing percentage rate (see appendix 12)

$d_{\text{srn}}$  = number of days young lambs receive milk (assumed to be 122)

$P_{\text{mp}}$  = 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 December, equation 5.14 (below) is used to calculate N intake for lambs. For other months (when the inventory assumes no intake of milk), equation 5.2 (section 5.1.1.1) is used.

*Nitrogen intake for sheep less than 1 year old for September to December (Equation 5.14):*

$$N_i = (DMI \times Feed_N) + z_{3\text{lamb}}$$

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)

$Feed_N$  = Nitrogen content of feed consumed by sheep, expressed as a proportion of DMI (see appendix 19)

$Z_{3\text{lamb}}$  = nitrogen intake through milk per animal (kg of nitrogen per day)

### 5.3.2 Nitrogen secreted in 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



*Nitrogen secreted in milk for mature breeding ewes and growing breeding sheep (Equation 5.15):*

$$N_{rm} = y \times \frac{P}{6.25}$$

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, wethers, 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.

### 5.3.3 Nitrogen retained in wool

Part of the nitrogen taken in by sheep is retained for the growth of wool. The equations in this section outline how the amount of nitrogen retained for wool production is calculated, while staying within the following constraints:

- The model assumes that lambs grow wool at half the rate of adult sheep
- The amount of wool produced by all sheep and lambs in a year is equal to the national annual greasy wool production value published by Beef + Lamb New Zealand

#### 5.3.3.1 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 (POPsheep) is the sum of the population of all the sheep subcategories excluding lambs (i.e. Dry Ewes, Mature Breeding Ewes, Growing Breeding Sheep, Growing Non-Breeding Sheep, Wethers, and Rams). These equations are necessary to account for the monthly variability in sheep populations.

*Daily wool produced by sheep (Equation 5.16):*

$$Wool_{sheep,daily} = \frac{totwool_{sheep,m}/nod_m}{POPsheep_m}$$

Where:

$Wool_{sheep,daily}$  = Amount of wool produced per adult sheep per day (kg)

$totwool_{sheep,m}$  = Amount of wool produced by all adult sheep in month  $m$  (kg). See equation 5.18 (below).

$nod_m$  = number of days in month  $m$

$POPsheep_m$  = Adult sheep population in month  $m$

*Daily wool produced by lambs (Equation 5.17):*

$$Wool_{lamb,daily} = \frac{totwool_{lamb,m}/nod_m}{POP_{ls}_m}$$

Where:

$Wool_{lamb,daily}$  = Amount of wool produced per lamb per day (kg)

$totwool_{lamb,m}$  = Amount of wool produced by all lambs in month  $m$  (kg). See equation 5.18 (below).

$nod_m$  = number of days in month  $m$

$POPls_m$  = Lamb population in month  $m$

*Monthly wool produced by sheep (Equation 5.18):*

$$totWool_{sheep,m} = POPs_{sheep,m} \times F_{greasy} \times \left( \frac{nod_m}{nod_y} \times 12 \right) \times \left( \frac{natWool_{greasy}}{natWool_{unadj,greasy}} \right)$$

Where:

$totwool_{sheep,m}$  = Amount of wool produced by all adult sheep in month  $m$  (kg)

$POPs_{sheep,m}$  = Adult sheep population in month  $m$

$F_{greasy}$  = initial greasy fleece weight (fixed value, set at 5kg)

$nod_m$  = number of days in month  $m$

$nod_y$  = number of days in year (i.e. 365)

$natWool_{greasy}$  = annual greasy wool production (from Beef + Lamb statistics)

$natWool_{unadj,greasy}$  = calculated total annual greasy wool production (assuming fixed greasy fleece weight of 5kg). See equation 5.20 (below)

*Monthly wool produced by lambs (Equation 5.19):*

$$totWool_{lamb,m} = POPls_m \times F_{greasy} \times \left( \frac{nod_m}{nod_y} \times 12 \right) \times \left( \frac{natWool_{greasy}}{natWool_{unadj,greasy}} \right) \times A_{wool_{lamb}}$$

Where:

$totwool_{lamb,m}$  = Amount of wool produced by all lambs in month  $m$  (kg)

$POPls_m$  = lamb population in month  $m$

$F_{greasy}$  = initial greasy fleece weight (fixed value, set at 5kg)

$nod_m$  = number of days in month  $m$

$nod_y$  = number of days in year (i.e. 365)

$natWool_{greasy}$  = annual greasy wool production (from Beef + Lamb statistics)

$natWool_{unadj,greasy}$  = calculated total annual greasy wool production (assuming fixed greasy fleece weight of 5kg). See equation 5.20 (below)

$A_{wool_{lamb}}$  = factor used to adjust for the slower wool growth of lambs compared to adult sheep (currently equal to 0.5)

*Unadjusted annual wool production for all sheep (Equation 5.20):*

$natWool_{unadj,greasy}$

$$\begin{aligned} &= \left( \sum_{month} \left( F_{greasy} \times \left( \frac{nod_m}{nod_y} \times 12 \right) POPls_m \times A_{wool_{lamb}} \right) \right) \\ &+ \left( \sum_{month} \left( F_{greasy} \times \left( \frac{nod_m}{nod_y} \times 12 \right) POPs_{sheep,m} \right) \right) \end{aligned}$$

Where:

$\text{natWool}_{\text{lunadj,greasy}}$  = calculated total annual greasy wool production (assuming fixed greasy fleece weight of 5kg)

$F_{\text{greasy}}$  = initial greasy fleece weight (fixed value, set at 5kg)

$\text{nod}_m$  = number of days in month  $m$

$\text{nod}_y$  = number of days in year (i.e. 365)

$\text{POPIs}_m$  = lamb population in month  $m$

$A_{\text{wool}_{\text{lamb}}}$  = factor used to adjust for the slower wool growth of lambs compared to adult sheep (currently equal to 0.5)

$\text{POPsheep}_m$  = Adult sheep population in month  $m$

$month$  refers to the twelve months of the calendar year.

The use of these equations allows for the calculation of nitrogen retained in wool per animal per day ( $N_{\text{wool}}$ ). This value is constant over the course of the year, although  $N_{\text{wool}}$  for lambs will be half of the  $N_{\text{wool}}$  value for adult sheep.

### 5.3.3.2 Calculating nitrogen retained in wool

The daily amount of nitrogen retained through wool production can be calculated using the equations below.

*Nitrogen retained in wool produced by sheep (Equation 5.21):*

$$N_{\text{wool}} = \text{Wool}_{\text{sheep,daily}} \times \text{wool}_{N\text{content}}$$

Where:

$N_{\text{wool}}$  = Amount of nitrogen retained in wool per animal (kg of nitrogen per day)

$\text{Wool}_{\text{sheep,daily}}$  = Amount of wool produced per adult sheep per day (kg)

$\text{Wool}_{N\text{content}}$  = Proportion of nitrogen content of wool (assumed to be 0.134)

*Nitrogen retained in wool produced by lambs (Equation 5.22):*

$$N_{\text{wool}} = \text{Wool}_{\text{lamb,daily}} \times \text{wool}_{N\text{content}}$$

Where:

$N_{\text{wool}}$  = Amount of nitrogen retained in wool per animal (kg of nitrogen per day)

$\text{Wool}_{\text{sheep,daily}}$  = Amount of wool produced per lamb per day (kg)

$\text{Wool}_{N\text{content}}$  = Proportion of nitrogen content of wool (assumed to be 0.134)

### 5.3.4 Nitrogen retained in live weight gain

Growing animals retain N in animal tissues through live weight gain. The amount of N retained ( $N_{\text{lwg}}$ ) 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.

*Nitrogen retained in tissues of individual sheep through liveweight gain (Equation 5.23):*

$$N_{\text{lwg}} = \text{LWG} \times \frac{N_{\text{bt,sheep}}}{100}$$

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 4.7 for detailed calculations)

$N_{bt, sheep}$  = proportion of nitrogen content of body tissue for sheep, currently set at 0.026% (see appendix 12)

### 5.3.5 Nitrogen in urine and faeces

For sheep, a separate equation to 5.7 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 5.8 in section 5.1.4.

For sheep, N excreted in faeces can be calculated using the following equation developed by Pacheco, Waghorn and Rollo (2018):

*Nitrogen excreted in faeces (Equation 5.24):*

$$N_f = (2.230 + (N_i \times 0.299) + ([Feed_N \times 100]^2 \times -0.237)) \times 0.001$$

Where:

$N_f$  = Amount of nitrogen excreted in faeces per animal (kilograms of nitrogen per day)

$Feed_N$  = Nitrogen content of feed consumed by dairy cattle, expressed as a proportion of DMI (i.e. grams of N per gram of DMI, see appendix 19)

$N_i$  = the nitrogen intake per animal (grams nitrogen per day)

### 5.3.6 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 5.5.

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.

## 5.4 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 4.6, table 4.4) 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.

*Nitrogen excretion for deer (Equation 5.24):*

$$N_{ex} = N_i - (N_m + N_{lwg} + N_{velvet})$$

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)

### 5.4.1 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

#### 5.4.1.1 Deer older than one year

Equation 5.2 (section 5.1.1.1) can be used to calculate N intake by deer older than one year old. The deer-specific values for the nitrogen content of feed ( $Feed_N$ ) are in appendix 19.

#### 5.4.1.2 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).

*Nitrogen intake through milk by deer (Equation 5.25):*

$$z_{3deer} = \frac{Y_{deerm}}{d_{drm}} \times \frac{P_{m,deer}}{6.25}$$

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 14)

$d_{drm}$  = 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 5.26 (below) is used to calculate N intake for deer. For deer older than four months (when there is no intake of milk), equation 5.2 (section 5.1.1.1) is used.

*Nitrogen intake for deer less than four months old (Equation 5.26):*

$$N_i = (DMI \times Feed_N) + z_{3deer}$$

Where:

$N_i$  = Nitrogen intake per animal (kg N per day)

DMI = dry matter intake per animal (kg/day see Section 4.1.1)

$Feed_N$  = Nitrogen content of feed consumed by deer, expressed as a proportion of DMI (see appendix 19)

$Z_{3deer}$  = nitrogen intake through milk per animal (kg of nitrogen per day)

### 5.4.2 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.

*Nitrogen secreted in milk for breeding hinds (Equation 5.27):*

$$N_{rm} = \frac{Y_{deerm}}{d_{drm}} \times \frac{P_{m,deer}}{6.25}$$

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 14)

$d_{drm}$  = 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).

### 5.4.3 Nitrogen retained in velvet

Stags over one year of age produce velvet over a 65 day period from the 1<sup>st</sup> of September to the 4<sup>th</sup> 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.

*Nitrogen retained in velvet production (Equation 5.28):*

$$N_{velvet} = \frac{Prod_{velvet}}{d_{velvet}} \times Velvet_{Ncontent}$$

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 14 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.

### 5.4.4 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.

Nitrogen retained in deer tissues through liveweight gain (Equation 5.29):

$$N_{lwg} = LWG \times \frac{N_{bt,deer}}{100}$$

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 14)

#### 5.4.5 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 equations 5.7 and 5.8 in section 5.1.4. Values on the nitrogen content of forages for deer ( $Feed_N$ ) are listed in Appendix 19.

#### 5.4.6 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 5.5.

Because a single dung emission factor ( $EF_{3(PR\text{-}DUNG)} = 0.0012$ ) is used across all slope categories for cattle, sheep and deer, dung excreta does not need to be allocated to different slopes.

### 5.5 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 ( $EF_{3(PR\text{-}DUNG)} = 0.0012$ , 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  $0.45 \times 0.5 + 0.45 = 0.675$ ),
- 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<sub>2</sub>O 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.

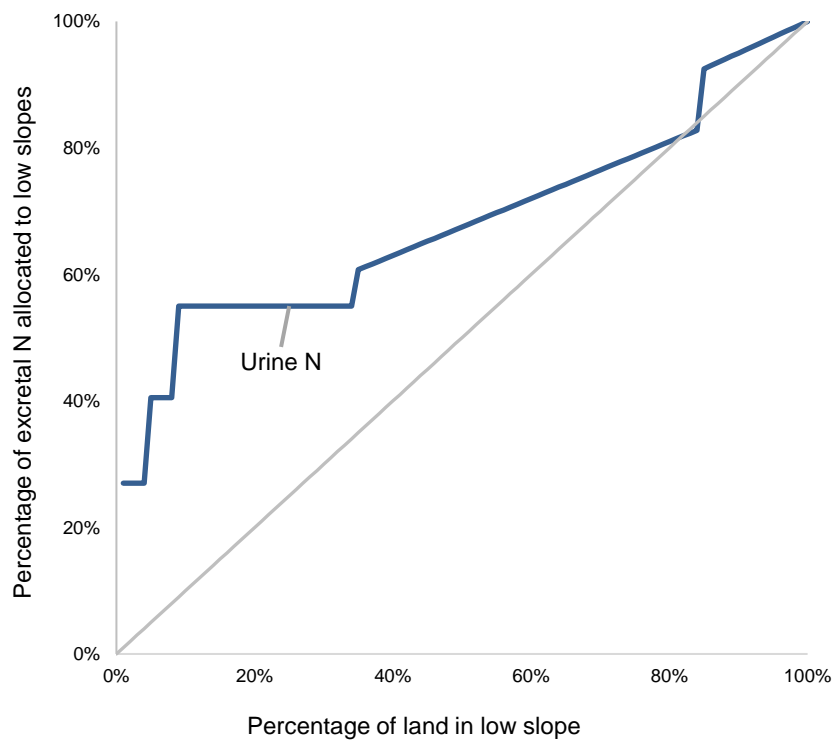
Because a single dung emission factor ( $EF_{3(PRP-DUNG)} = 0.0012$ ) is used across all slope categories for cattle, sheep and deer, dung excreta does not need to be allocated to different slopes.

**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.**

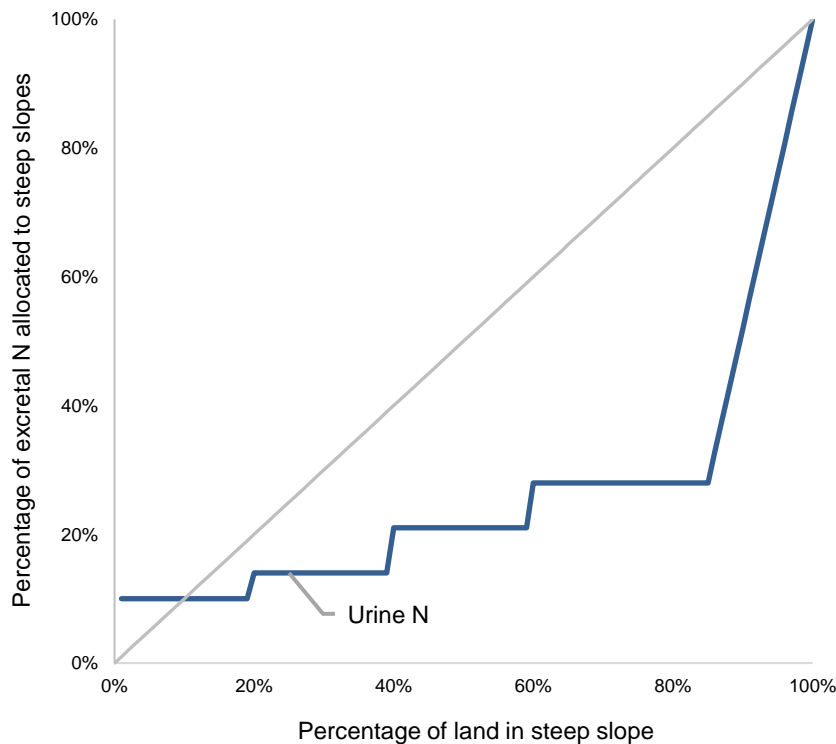
Allocation to flat or low slope land	
Percentage of flat to low sloped land area (<12°)	Fraction urine deposition
Less than 1%	27x
1–5%	0.27
5–9%	0.405
9–35%	0.55
35–85%	$(0.45x + 0.45)$
Greater than 85%	$(0.5x + 0.5)$
Allocation to steep land	
Percentage of steep land area (>24°)	Fraction urine deposition
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
<b>Total</b>		<b>357,094,719</b>		<b>232,894,836</b>		<b>19,829,780</b>

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<sub>2</sub>O 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**

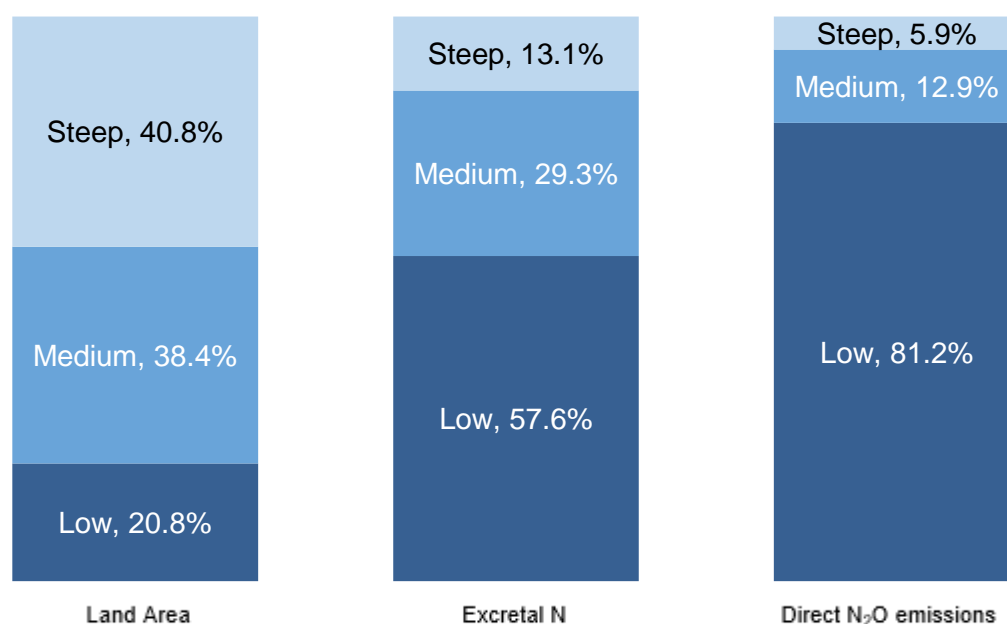
Farm class	Land type by slope		
	Flat/low (0–12° slope) (%)	Rolling/medium (12–24° slope) (%)	Steep (>24° slope) (%)
1. South Island High Country	8.3	26.4	65.2
2. South Island Hill Country	16.2	25.8	58.0
3. North Island Hard Hill Country	8.1	35.7	56.1
4. North Island Hill Country	15.1	54.4	30.5
5. North 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
<b>Total sheep, beef and deer land</b>	<b>20.1</b>	<b>38.1</b>	<b>41.8%</b>

**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
<b>Total sheep urine</b>	<b>0.56</b>	<b>0.30</b>	<b>0.14</b>

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<sub>2</sub>O) emissions by hill slope category for sheep, beef cattle and deer farms in 2019



## 5.6 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	Lassey, 2011
	12.1 for 2009	
	12.7 for 2018	
Swine	10.8 for 2009	Hill, 2012
	11.05 for 2013	
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 <i>et al.</i> , 2011
Poultry - layers	0.42	Fick <i>et al.</i> , 2011
Other Poultry (including ducks, turkeys, emus, and ostriches)	0.60	2006 IPCC –Table 10.19

### 5.6.1 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  $head^{-1} yr^{-1}$ ), 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 ( $P_{goat,milk,y}$ ) 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%

*Annual nitrogen excretion for goats (Equation 5.30):*

$$N_{ex,goat,y} = N_{ex,goat,y-1} + \left( \frac{P_{goat,milk,y} - P_{goat,milk,y-1}}{P_{goat,milk,2009} - P_{goat,milk,1990}} \right) \times (N_{ex,goat,2009} - N_{ex,goat,1990})$$

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)

$P_{goat,milk,y}$  = Proportion of milking goats in total goat population in year  $y$  (see table 5.6 for values)

$P_{goat,milk,y-1}$  = Proportion of milking goats in total goat population in previous year  $y$  (see table 5.6 for values)

$P_{goat,milk,2009}$  = Proportion of milking goats in total goat population in 2009 (see table 5.6 for values)

$P_{goat,milk,1990}$  = 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).

## 5.6.2 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.

## 5.6.3 Horses, mules and asses

New Zealand uses IPCC (2006) default  $N_{ex}$  values (listed in Table 8) for horses, mules and asses.

## 5.6.4 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).

*Annual nitrogen excretion for alpaca (Equation 5.31):*

$$N_{ex,alpaca} = \frac{\sum_{class} \sum_{month} (N_{ex,sheep,c,1990} \times nod_m \times POPs_{c,m,1990})}{POP_{sheep,1990}}$$

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 5.12, section 5.3 (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

POP<sub>sheep1990</sub> = 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.

### 5.6.5 Swine

For swine, country-specific annual nitrogen excretion rates ( $N_{ex,swine}$ ) are calculated for each year using the methodology developed by Hill (2010). The 2010 value is fixed at 10.8 kilograms of nitrogen per head per year (Hill, 2012). Values of  $N_{ex,swine}$  for the years before and after 2010 are calculated based on average pig slaughter weights (for a particular year) relative to the average pig slaughter weight in 2010.

*Annual nitrogen excretion for swine (Equation 5.32):*

$$N_{ex,swine,y} = \frac{Aveslauweight_{swine,y}}{Aveslauweight_{swine,2010}} \times N_{ex,swine,2010}$$

Where:

$N_{ex,swine,y}$  = Annual nitrogen excretion per pig in year  $y$  (kilograms of nitrogen per year)

$Aveslauweight_{swine,y}$  = average slaughter weight per pig in year  $y$ , in kilograms (from Statistics New Zealand)

$Aveslauweight_{swine,2010}$  = average slaughter weight per pig in 2010 in kilograms (set at 93.87kg)

$N_{ex,swine,2010}$  = Annual nitrogen excretion per pig in 2010 (kilograms of nitrogen set at 10.8)

*Average swine slaughter weight (Equation 5.33):*

$$Aveslauweight_{swine,y} = \frac{totslauweight_{swine,y}}{SlauNum_{swine,y}}$$

Where:

$Aveslauweight_{swine,y}$  = average slaughter weight per pig in year  $y$ , in kilograms (from Statistics New Zealand)

$totslauweight_{swine,y}$  = total aggregate slaughter weight of swine in year  $y$ , in kilograms (from Statistics New Zealand)

$SlauNum_{swine,y}$  = number of pigs slaughtered in year  $y$

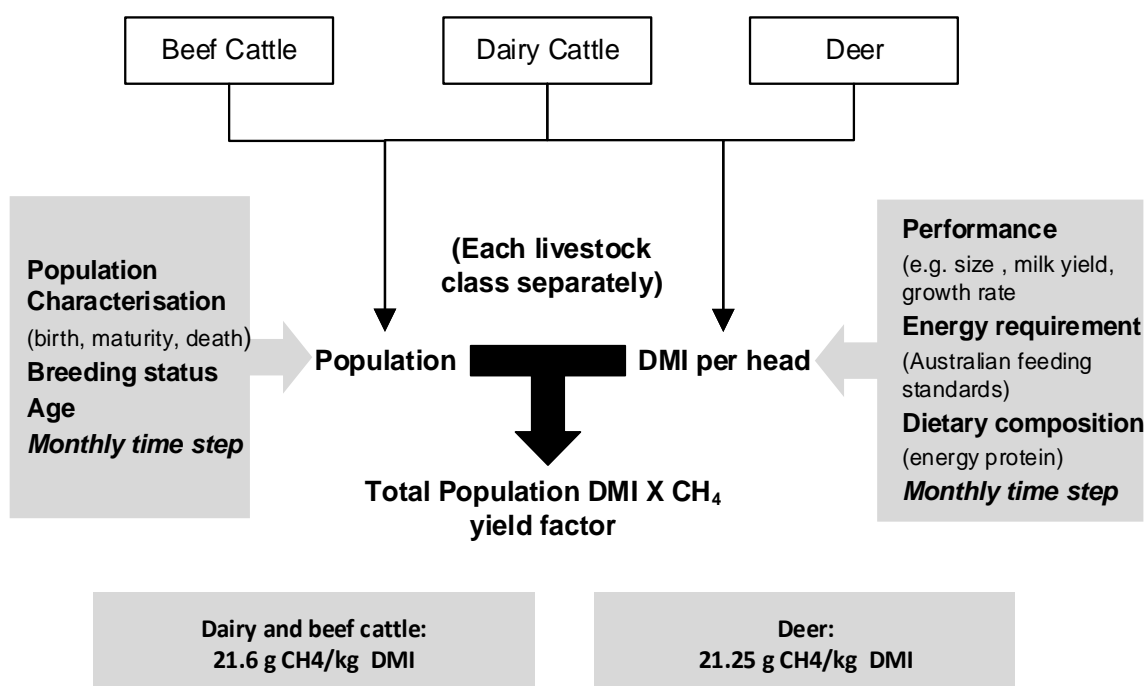
## 6 Methane emissions from enteric fermentation

Methane (CH<sub>4</sub>) 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<sub>4</sub>, which accompanies feed degradation in the rumen. The amount of CH<sub>4</sub> 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.

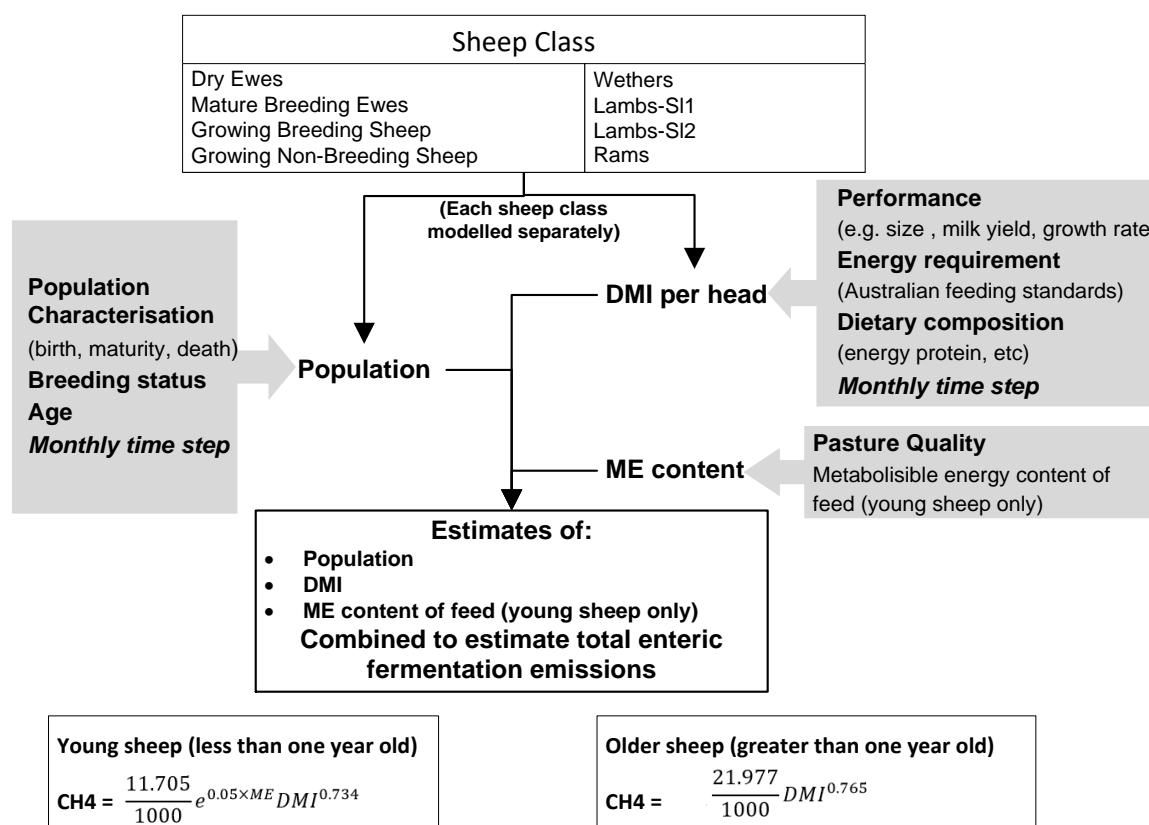
Enteric methane (EM) production from cattle (dairy and beef), sheep and deer was identified as a key source of greenhouse gas emissions for New Zealand through Intergovernmental Panel on Climate Change (IPCC) Tier 1 calculations. Therefore, a New Zealand-specific Tier 2 methodology developed by Clark *et al.* (2003) is used to calculate these CH<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> 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<sub>4</sub> emissions for dairy cattle, beef cattle and deer. A more complex methodology is used to estimate enteric CH<sub>4</sub> 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<sub>4</sub> has been measured in New Zealand from grazing cattle and sheep using the SF<sub>6</sub> tracer technique (Lassey *et al.*, 1997; Ulyatt *et al.*, 1999, 2002a, 2002b, 2005). Since 2008 CH<sub>4</sub> 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<sub>4</sub> emissions determined using the SF<sub>6</sub> 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<sub>4-enteric-cattle</sub> in equation 46) by a particular subcategory of dairy cattle can be determined using the following equation:

*Daily enteric methane emissions per animal – dairy and beef cattle (Equation 6.1)*

$$CH_{4-enteric-cattle} = DMI \times \frac{MCR}{1000}$$

Where:

CH<sub>4-enteric-cattle</sub> = enteric methane emissions per animal per day (kg), for a particular subcategory of cattle (subcategories as defined in table 4.1 in section 4.3.1)

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<sub>4</sub>/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<sub>4</sub><sup>e</sup>.

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<sub>4-enteric-cattle</sub> is set to zero for dairy calves during these months.

As stated in section 4.3, 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).

*Annual enteric methane emissions in the dairy sector (Equation 6.2)*

$$dairyCH_{4-enteric} = \sum_{region} \sum_{month} \sum_{class} POP_{dairy_{c,m,r}} \times nod_m \times CH_{4-enteric-cattle}$$

Where:

dairyCH<sub>4-enteric</sub> = annual enteric methane emissions for all dairy cattle (kg)

POP<sub>dairy<sub>c,m,r</sub></sub> = population of dairy animals in subcategory *c*, month *m* and region *r*

nod<sub>m</sub> = number of days in month *m*

CH<sub>4-enteric-cattle</sub> = 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 4.3.1)

*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 4.3)

## 6.2 Beef

The per-animal production of enteric methane for beef cattle is calculated using the same equation (x, 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 4.4) and the equation in section 4.1.1, for the different subcategories of beef cattle (as defined in table 4.2 in section 4.4.1).

Beef calves are fed on milk for the first two months of their life (September and October) and produce no methane during this period. CH<sub>4-enteric-cattle</sub> 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).

*Annual enteric methane emissions in the beef sector (Equation 6.3)*

$$beefCH_{4-enteric} = \sum_{month} \sum_{class} POP_{beef_{c,m}} \times nod_m \times CH_{4-enteric-cattle}$$

Where:

beefCH<sub>4-enteric</sub> = annual enteric methane emissions for all beef cattle (kg)

<sup>e</sup> That is, the methane loss (as a percentage of gross energy) = 21.6/18.45 x 0.0556 x 100% = 6.5%

POPbeef<sub>c,m,r</sub> = population of beef animals in subcategory *c*, in month *m*

nod<sub>m</sub> = number of days in month *m*

CH<sub>4-enteric-cattle</sub> = 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, section 4.4.1)

*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, equations 6.4 and 6.6 are used, while for sheep older than one year of age, equations 6.5 and 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<sub>4-enteric-sheep<1</sub> is set to zero for lambs during these months.

*Daily enteric methane emissions per animal – sheep younger than one year of age (Equation 6.4)<sup>f</sup>*

$$CH_{4-enteric,sheep<1} = \frac{11.705}{1000} \times e^{0.05 \times Feed_{ME}} \times DMI^{0.734}$$

Where:

CH<sub>4-enteric,sheep<1</sub> = enteric methane emissions per animal per day (kg), for sheep less than one year of age (e.g. lambs), but older than 2 months

Feed<sub>ME</sub> = metabolisable energy per kilogram of dry matter for feed (MJ/kg)

DMI = dry matter intake (kg per animal per day) (see section 4.1.1)

*Daily enteric methane emissions per animal – sheep older than one year of age (Equation 6.5)<sup>g</sup>*

$$CH_{4-enteric,sheep>1} = \frac{21.977}{1000} \times DMI^{0.765}$$

Where:

CH<sub>4-enteric,sheep>1</sub> = 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 cutpasture of varying amounts and quality, were measured in respiration chambers. The meta-analysis confirmed that DMI has the largest influence on CH<sub>4</sub> emissions, and also found that pasture quality (as measured by metabolisable energy content) had a small but statistically significant effect on emissions from sheep younger than one year of age.

<sup>f</sup> The equation displayed here is a re-arranged form of the equation displayed in Swainson, Muetzel and Clark (2016):

$$\ln(CH_4) = 0.734 \times \ln(DMI) + 0.05 \times ME + 2.46$$

<sup>g</sup> The equation displayed here is a re-arranged form of the equation displayed in Swainson, Muetzel and Clark (2016):

$$\ln(CH_4) = 0.765 \times \ln(DMI) + 3.09$$

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 equations 6.6, 6.7, and 6.8.

*Annual enteric methane emissions for lambs (Equation 6.6)*

$$totalCH_{4-enteric,sheep<1} = \sum_{month} POPlamb_m \times nod_m \times CH_{4-enteric-sheep<1}$$

Where:

$totalCH_{4-enteric,sheep<1}$  = 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  $m$

$CH_{4-enteric-sheep<1}$  = 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.

*Annual enteric methane emissions for sheep greater than one year old (Equation 6.7)*

$$totalCH_{4-enteric,sheep>1} = \sum_{month} \sum_{class} POPsheep_{c,m} \times nod_m \times CH_{4-enteric-sheep>1}$$

Where:

$totalCH_{4-enteric,sheep>1}$  = 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  $m$

$CH_{4-enteric-sheep>1}$  = 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.

*Annual enteric methane emissions for all sheep (Equation 6.8)*

$$totalsheepCH_{4-enteric} = totalCH_{4-enteric,sheep>1} + totalCH_{4-enteric,sheep<1}$$

Where:

$totalsheepCH_{4-enteric}$  = annual enteric methane emissions for all sheep (kg)

$totalCH_{4-enteric,sheep>1}$  = annual enteric methane emissions for all sheep greater than one year old (kg) (equation 6.6)

$totalCH_{4-enteric,sheep<1}$  = 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<sub>4</sub> 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 4.6) and the DMI equation in section 4.1.1.

*Daily enteric methane emissions per animal – deer (Equation 6.9)*

$$CH_{4\text{-enteric-deer}} = DMI \times \frac{MCR}{1000}$$

Where:

CH<sub>4-enteric-cattle</sub> = enteric methane emissions per animal per day (kg), for a particular subcategory of deer (e.g. stags 1-2, breeding hinds...)

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<sub>4-enteric-deer</sub> 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).

*Annual enteric methane emissions in the deer sector (Equation 6.10)*

$$deerCH_{4\text{-enteric}} = \sum_{month} \sum_{class} POP_{deer_{c,m}} \times nod_m \times CH_{4\text{-enteric-deer}}$$

Where:

deerCH<sub>4-enteric</sub> = annual enteric methane emissions for all deer (kg)

POP<sub>deer<sub>c,m</sub></sub> = population of deer animals in subcategory *c*, in month *m*

nod<sub>m</sub> = number of days in month *m*

CH<sub>4-enteric-deer</sub> = enteric methane emissions per animal per day (kg) for a particular subcategory of deer (e.g. stags 1-2, breeding hinds...) 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 <sub>4</sub> /head/year)	Reference
---------	---	-----------

Goats	7.4 (for 1990)	Lassey (2011)
	8.5 (for 2009)	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<sub>4</sub> emissions in 2015. For each minor livestock species, the emission factors are multiplied by the species population (Appendix 16) to obtain the total methane emissions.

### 6.5.1 Goats

New Zealand uses specific enteric fermentation emission factors of:

- 7.4 kg CH<sub>4</sub>/head/year for 1990
- 8.5 kg CH<sub>4</sub>/ 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<sub>4</sub> 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 205, section 5.5.1).

*Annual enteric fermentation for goats (Equation 6.11):*

$$CH_{4,goat,y} = CH_{4,goat,y-1} + \left( \frac{P_{goat_{milk,y}} - P_{goat_{milk,y-1}}}{P_{goat_{milk,2009}} - P_{goat_{milk,1990}}} \right) \times (CH_{4,goat,2009} - CH_{4,goat,1990})$$

Where:

CH<sub>4,goat,y</sub> = Annual enteric fermentation per goat in year y (kilograms of methane per year)

CH<sub>4,goat,y-1</sub> = Annual enteric fermentation per goat in previous year y-1 (kilograms of methane per year)

P<sub>goat<sub>milk,y</sub></sub> = Proportion of milking goats in total goat population in year y (see equation 5.31, section 5.5.1)

P<sub>goat<sub>milk,y-1</sub></sub> = Proportion of milking goats in total goat population in previous year y (see table 5.6, section 5.6.1)

P<sub>goat<sub>milk,2009</sub></sub> = Proportion of milking goats in total goat population in 2009 ((see table 5.6)

$P_{\text{goat,milk,1990}}$  = Proportion of milking goats in total goat population in 1990 (see table 5.6)

$\text{CH}_4_{\text{goat,2009}}$  = Annual enteric fermentation per goat in 2009 (set at 7.4 kilograms of methane per year)

$\text{CH}_4_{\text{goat,1990}}$  = Annual enteric fermentation per goat in 1990 (set at 8.5 kilograms of methane per year)

### 6.5.2 Swine

New Zealand uses a country specific emission factor of 1.06 kg CH<sub>4</sub>/head/year, which is lower than the IPCC default of 1.5 kg CH<sub>4</sub>/head/year.

The New Zealand-specific emission factor was developed by Hill (2012), who used data on the composition of swine diets to estimate the energy intake of swine. It was found that the average energy intake of swine in New Zealand was significantly lower than the IPCC default energy intake value for swine, which justifies the use of the lower emission factor.

This factor is multiplied by swine population data to obtain the total CH<sub>4</sub> emissions produced by swine from enteric fermentation for a given inventory year.

### 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<sub>4</sub> emissions produced by horses from enteric fermentation for a given inventory year.

### 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<sub>4</sub> 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<sub>4</sub> 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 emissions from major livestock species (dairy and beef cattle, sheep and deer) are estimated using tier 2 methods, while manure management emissions from minor livestock species (goats, swine, horses, mules and asses, poultry, alpacas) 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<sub>4</sub>. The amount of CH<sub>4</sub> 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 CH<sub>4</sub> 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:

*Production of daily faecal dry matter per animal (Equation 7.1)*

$$FDM = DMI \times (1 - DMD)$$

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 appendix 3 and 9)

#### 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, 2018) (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<sub>4AL</sub>). This equation only applies to mature milking cows.

*Calculation of methane from anaerobic lagoons for dairy cattle (Equation 7.2)*

$$CH_{4AL-dairy} = FDM \times (1 - ASH) \times B_0 \times 0.67 \times MCF \times MS_{AL,CH_4,y}$$

Where:

CH<sub>4AL-dairy</sub> = 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<sub>0</sub> = Maximum methane-producing capacity of manure, 0.24 (IPCC, 2006)

MCF = Methane conversion factor, 0.74 (IPCC, 2006)

MS<sub>AL,CH<sub>4</sub>,y</sub> = 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<sub>4</sub> to kilograms of CH<sub>4</sub><sup>h</sup>. The value used for B<sub>0</sub> 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 15°C 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<sub>AL,CH<sub>4</sub></sub> represents the proportion of mature milking cattle excreta that is deposited specifically to anaerobic lagoons (MS<sub>AL,CH<sub>4</sub>,y</sub>). 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<sub>PRP</sub>).

**Table 7.1: Annual proportion of mature milking cattle manure between management systems**

Year	Trends <sub>project</sub> MM: p	1 - MM:p
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%
2016	8.525%	91.475%

<sup>h</sup> 1mol of CH<sub>4</sub> at NTP = 24.0548L and 16.044g. Thus 1m<sup>3</sup> CH<sub>4</sub> =0.66697 or 0.67.



2017	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):

*Calculation of methane from FDM deposited onto pasture (Equation 7.3)*

$$CH_{4PRP-dairy} = FDM \times MS_{PRP} \times Y_m$$

Where:

$CH_{4PRP-dairy}$  = 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.

$Y_m$  = Methane yield value, currently set at 0.00098198 kg  $CH_4$ /kg FDM (Sherlock *et al.*, 2003; Saggart *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 Saggart *et al.* (2003). For more details on this calculation see table 7.1 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).

*Total annual manure management methane emissions from anaerobic lagoons in the dairy sector (Equation 7.4)*

$$dairyCH_{4-AL} = \sum_{region} \sum_{month} \sum_{class} (POP_{mmc,m,r} \times nod_m \times CH_{4AL-dairy,m,r})$$

Where:

$dairyCH_{4-AL}$  = annual manure management methane emissions from anaerobic lagoons for all dairy cattle (kg)

$POP_{mmc,m,r}$  = population of mature milking cows in month  $m$  and region  $r$

$nod_m$  = number of days in month  $m$

$CH_{4AL-dairy,m}$  = 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 4.3)

*Total annual manure management methane emissions from FDM deposited onto pasture for dairy cattle (Equation 7.5)*

$$dairyCH_{4-PRP} = \sum_{region} \sum_{month} \sum_{class} (POP_{dairy,c,m,r} \times nod_m \times CH_{4PRP-dairy,m,r})$$

Where:

$dairyCH_{4-PRP}$  = annual manure management methane emissions from pasture range and paddock for all dairy cattle (kg)

$POP_{dairy_{c,m,r}}$  = population of dairy animals in subcategory  $c$ , month  $m$  and region  $r$

$nod_m$  = number of days in month  $m$

$CH_{4PRP-dairy}$  = 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 4.3)

*Annual manure management methane emissions in the dairy sector (Equation 7.6)*

$$dairyCH_{4-mm} = dairyCH_{4-AL} + dairyCH_{4-PRP}$$

Where:

$dairyCH_{4-mm}$  = annual manure management methane emissions for all dairy cattle (kg)

$dairyCH_{4-AL}$  = annual manure management methane emissions from anaerobic lagoons for all dairy cattle (kg)

$dairyCH_{4-PRP}$  = 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.

*Calculation of methane emissions from FDM deposited onto pasture for beef cattle (Equation 7.7)*

$$CH_{4PRP-beef} = FDM \times Y_m$$

Where:

$CH_{4PRP-beef}$  = 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 Sagar *et al* (2003). For more details on this calculation see table 7.1 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).

### Annual manure management methane emissions in the beef sector (Equation 7.8)

$$beefCH_{4-mm} = \sum_{month} \sum_{class} (POP_{beef_{c,m}} \times nod_m \times CH_{4PRP-beef})$$

Where:

$beefCH_{4-mm}$  = annual manure management methane emissions for all beef cattle (kg)

$POP_{beef_{c,m}}$  = population of beef animals in subcategory  $c$ , in month  $m$

$nod_m$  = number of days in month  $m$

$CH_{4PRP-beef}$  = 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.

*Calculation of methane from FDM deposited onto pasture (Equation 7.9)*

$$CH_{4PRP-sheep} = FDM \times Y_{msheep}$$

Where:

$CH_{4PRP-sheep}$  = 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<sub>4</sub>/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 (found in appendix 9).

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).

*Annual manure management methane emissions in the sheep sector (Equation 7.10)*

$$sheepCH_{4-mm} = \sum_{month} \sum_{class} (POP_{sheep_{c,m}} \times nod_m \times CH_{4PRP-sheep})$$

Where:

$sheepCH_{4-mm}$  = annual manure management methane emissions for all sheep (kg)

$POP_{sheep_{c,m}}$  = 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.

*Calculation of methane from FDM deposited onto pasture (Equation 7.11)*

$$CH_{4PRP-deer} = FDM \times Y_{mdeer}$$

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**

	Animal measured	Study name/description	CH4 emitted per kilogram of dung-carbon	CH4 emitted per kilogram of dung	
Average of three measures used for cattle	Cattle	Massey D3 (Saggar et al (2003))	2.6613	1.059204	Average of all five measures used for deer
	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 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  $Y_m$  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)<sup>i</sup>.

<sup>i</sup> 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

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 (found in appendix 9).

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).

*Total annual manure management methane emissions in the deer sector (Equation 7.12)*

$$deerCH_{4-mm} = \sum_{month} \sum_{class} (POP_{deer,c,m} \times nod_m \times CH_{4PRP-deer})$$

Where:

$deerCH_{4-mm}$  = annual manure management methane emissions for all deer (kg)

$POP_{deer,c,m}$  = population of deer in subcategory  $c$ , in month  $m$

$nod_m$  = number of days in month  $m$

$CH_{4PRP-deer}$  = manure management methane emissions per animal per day (kg) for a particular subcategory of deer (e.g. breeding hinds, stags aged 0-1...) 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.

*Calculation of total annual methane from manure management for minor livestock species (Equation 7.13)*

$$minorCH_{4-mm-c} = MEF_c \times POP_{minor_c}$$

Where:

$minorCH_{4-mm-c}$  = 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 7.1)

$POP_{minor_c}$  = population of minor livestock species  $c$  (from APS)

Values of  $MEF_c$  for a particular livestock species can be found in table 7.1, 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 a country specific emission factor of 5.94  $CH_4$ /head/year (Hill, 2012) for estimating emission from swine manure management. This is based on New Zealand specific proportions of swine faeces in manure management systems.

### 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 17 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<sub>4</sub> emissions from manure management for alpacas. Therefore, this was calculated by assuming a default CH<sub>4</sub> 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 7.1: Manure management emission factors for Tier 1 calculations for methane from manure management from non - key source livestock species**

Species	Methane (kg CH <sub>4</sub> /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 <i>et al.</i> , 2011
Layers	0.016	Fick <i>et al.</i> , 2011
Other poultry (eg geese, guinea fowl, emus, ostriches etc)	0.117	Fick <i>et al.</i> , 2011
Alpaca	0.091	New Zealand specific value assumed to be the same as sheep in 1990

## 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<sub>2</sub>O) 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<sub>2</sub>O 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 17.

To calculate emissions for this category, the total N<sub>ex</sub> 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 18). The IPCC (2006) Guidelines note that the production of emissions of direct N<sub>2</sub>O from

managed manure requires aerobic conditions for the formation of oxidised forms of N, but assumes that negligible direct N<sub>2</sub>O emissions occur during storage in anaerobic lagoons (IPCC, 2006, table 10.21). Based on this the emission factor for N<sub>2</sub>O emissions from waste in anaerobic lagoons (EF<sub>3AL</sub>) is set to zero, and it is assumed that there are no direct nitrous oxide emissions from manure management for dairy cattle.

Direct N<sub>2</sub>O 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 five 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 7.2: Manure management systems and emission factors used for swine**

Name of waste management system	Percentage of swine waste deposited in system	Short name of direct N <sub>2</sub> O manure management emission factor	Value of direct N <sub>2</sub> O manure management emission factor used in inventory	Proportion of managed manure which volatilises as NH <sub>3</sub> and NO <sub>x</sub>
Anaerobic lagoon	20.5	EF <sub>3AL</sub>	0	FracGasMS(AL_swine)=0.40
Daily spread	25.7	EF <sub>3DailyS</sub>	0	FracGasMS(DS_swine)=0.07
Pasture range and paddock	8.9	(calculated in agricultural soils chapter)		
Solid storage and drylot	42.5	EF <sub>3SSD</sub>	0.02	FracGasMS(SS&D_swine)=0.3
Other management systems	2.4	EF <sub>3OTHER</sub>	0.005	FracGasMS(other_swine)=0.25

Total direct emissions from manure management for swine are determined by adding the nitrous oxide caused by waste in the different manure management systems

*Direct manure management nitrous oxide emissions per animal from swine (Equation 7.14)*

$$mmN_2O_{Direct,swine,y} = \sum_x \left( N_{ex,swine,y} \times Pmms_{swine,x} \times EF_{3,x} \times \frac{44}{28} \right)$$

Where:

mmN<sub>2</sub>O<sub>Direct,swine,y</sub> = annual direct nitrous oxide emissions from manure management per pig in year y (kilograms of nitrous oxide per year)

N<sub>ex,swine,y</sub> = Annual nitrogen excretion per pig in year y (kilograms of nitrogen per year)

Pmms<sub>swine,x</sub> = Proportion of swine waste deposited in manure management system x (see table 7.2 above)

EF<sub>3,x</sub> = direct N<sub>2</sub>O manure management emission factor for manure management system x (see table 7.2 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<sub>2</sub>O emissions from waste in anaerobic lagoons (EF<sub>3AL</sub>) is set to zero, and it is assumed that there are no direct nitrous oxide emissions from manure management for swine. Direct N<sub>2</sub>O 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 7.2 above) can be multiplied by the swine population to calculate the total direct manure management N<sub>2</sub>O emissions from swine.

*Total direct manure management nitrous oxide emissions from swine (Equation 7.15)*

$$totmmN_2O_{Direct,swine,y} = mmN_2O_{Direct,swine,y} \times POP_{swine,y}$$

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)

$POP_{swine,y}$  = swine population in year  $y$

### 7.2.1.3 Poultry

Direct N<sub>2</sub>O manure management emissions from poultry are calculated using different parameters for Broilers, Layers and Other poultry.

*Direct manure management nitrous oxide emissions per animal from broilers (Equation 7.16)*

$$mmN_2O_{Direct,broiler} = N_{ex,broiler} \times Pmms_{broiler,other} \times EF_{3,poultry} \times \frac{44}{28}$$

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 5.5.2)

$Pmms_{broiler,x}$  = Proportion of broiler waste deposited in other manure management systems (set at 0.95)

$EF_{3,poultry}$  = direct N<sub>2</sub>O manure management emission factor for poultry in *other* manure management systems  $x$  (set at 0.001 for all poultry)

*Direct manure management nitrous oxide emissions per animal from layers (Equation 7.17)*

$$mmN_2O_{Direct,layer} = N_{ex,layer} \times Pmms_{layer,other} \times EF_{3,poultry} \times \frac{44}{28}$$

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 5.5.2)

$Pmms_{layer,x}$  = Proportion of Layer waste deposited in other manure management systems (set at 0.94)

$EF_{3,poultry}$  = direct N<sub>2</sub>O manure management emission factor for poultry in *other* manure management systems  $x$  (set at 0.001)



*Direct manure management nitrous oxide emissions per animal from Other poultry (Equation 7.18)*

$$mmN_2O_{Direct,other} = N_{ex,other} \times Pmms_{other,other} \times EF_{3,poultry} \times \frac{44}{28}$$

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 5.5.2)

$Pmms_{layer,x}$  = 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 the three equations 7.16, 7.17, 7.18 above) can be multiplied by population estimates to calculate the total direct manure management nitrous oxide emissions from poultry.

*Total direct manure management nitrous oxide emissions from poultry (Equation 7.19)*

$$\begin{aligned} totmmN_2O_{Direct,poultry,y} &= (mmN_2O_{Direct,broiler,y} \times POP_{poultry,broiler,y}) \\ &+ (mmN_2O_{Direct,layer,y} \times POP_{poultry,layer,y}) \\ &+ (mmN_2O_{Direct,other,y} \times POP_{poultry,other,y}) \end{aligned}$$

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)

$POP_{poultry,broiler,y}$  = 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)

$POP_{poultry,layer,y}$  = 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)

$POP_{poultry,other,y}$  = 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. However, since New Zealand does not have solid storage or feedlot manure management systems (T Wilson, pers. Comm., 2014), leaching from manure management systems (other than pasture range and paddock) is assumed not to occur.

As stated earlier, N<sub>2</sub>O 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<sub>3</sub> and NO<sub>x</sub>, which is later emitted as N<sub>2</sub>O. As mentioned earlier, only mature milking cows (lactating cattle) deposit part (as shown in table 7.1 from section 7.1.1) of their manure onto storage or feed pads, which is then stored in anaerobic lagoons. This means that only mature milking cows have N<sub>2</sub>O emissions from manure management, and the equation below only applies to this subcategory of dairy cattle.

*Indirect manure management nitrous oxide emissions from dairy cattle (Equation 7.20)*

$$mmN_2O_{indirect,dairy,m,R} = N_{ex,m,R,mm} \times MS_{AL,N_2O} \times EF_4 \times Frac_{GasMS(AL_{dairy})} \times \frac{44}{28}$$

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 5.1)

$MS_{AL,N_2O,y}$  = 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<sub>2</sub>O emissions from volatilisation. The IPCC (2006) default value of 0.01 kg N<sub>2</sub>O-N/(kg NH<sub>3</sub>-N + NO<sub>x</sub>-N volatilised) is used

$Frac_{GasMS(AL_{dairy})}$  = proportion of managed manure which volatilises as NH<sub>3</sub> and NO<sub>x</sub> for dairy anaerobic lagoons. (uses default value of 0.35, detailed in Table 7.3).

The fraction 44/28 is used to convert nitrogen to nitrous oxide.

The annual amount of indirect manure management N<sub>2</sub>O 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.

*Annual indirect manure management N<sub>2</sub>O emissions in the dairy sector (Equation 7.21)*

$$TOTmmN_2O_{indirect,dairy} = \sum_{region} \sum_{month} POPmmc_{m,R} \times nod_m \times mmN_2O_{indirect,dairy,m,R}$$

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 4.3)

### 7.2.2.2 Swine

Waste from swine is distributed across five 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 7.2. 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.

*Direct manure management nitrous oxide emissions per animal from swine (Equation 7.22)*

$$mmN_2O_{indirect,swine,y} = \sum_x \left( N_{ex,swine,y} \times Pmms_{swine,x} \times EF_4 \times Frac_{GasMS(x_{swine})} \times \frac{44}{28} \right)$$

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 deposited in manure management system x (see table 7.2 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 tables 7.2 or 7.3 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.

*Total indirect manure management nitrous oxide emissions from swine (Equation 7.23)*

$$totmmN_2O_{indirect,swine,y} = mmN_2O_{indirect,swine,y} \times POP_{swine,y}$$

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)

$POP_{swine,y}$  = swine population in year y

### 7.2.2.3 Poultry

Indirect  $N_2O$  manure management emissions from poultry are calculated using different parameters for Broilers, Layers and Other poultry.

*Indirect manure management nitrous oxide emissions per animal from broilers (Equation 7.24)*

$$mmN_2O_{indirect,broiler} = N_{ex,broiler} \times Pmms_{broiler,other} \times EF_4 \times Frac_{GasMS(poultry)} \times \frac{44}{28}$$

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 5.5.2)

$Pmms_{broiler, x}$  = 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).

*Indirect manure management nitrous oxide emissions per animal from Layers (Equation 7.25)*

$$mmN_2O_{indirect, layer} = N_{ex, layer} \times Pmms_{layer, other} \times EF_4 \times Frac_{GasMS(poultry)} \times \frac{44}{28}$$

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 5.5.2)

$Pmms_{layer, x}$  = 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).

*Indirect manure management nitrous oxide emissions per animal from other poultry (Equation 7.26)*

$$mmN_2O_{indirect, other} = N_{ex, other} \times Pmms_{other, other} \times EF_4 \times Frac_{GasMS(poultry)} \times \frac{44}{28}$$

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 5.5.2)

$Pmms_{layer, x}$  = 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 the three equations 7.24, 7.25, 7.26 above) can be multiplied by population estimates to calculate the total indirect manure management nitrous oxide emissions from poultry.

*Total indirect manure management nitrous oxide emissions from poultry (Equation 7.27)*

$$\begin{aligned}
 & totmmN_2O_{indirect,poultry,y} \\
 &= (mmN_2O_{indirect,broiler,y} \times POPpoultry_{broiler,y}) \\
 &+ (mmN_2O_{indirect,layer,y} \times POPpoultry_{layer,y}) \\
 &+ (mmN_2O_{indirect,other,y} \times POPpoultry_{other,y})
 \end{aligned}$$

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 7.3: 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.**

Manure system	management	Livestock category	Value	Reference
Anaerobic lagoons		Dairy	0.35	IPCC (2006), table 10.22
		Swine	0.4	
Daily spread		Swine	0.07	
Solid storage and dry lot		Swine	0.3	
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<sub>2</sub>O emissions from agricultural soils, from both direct and indirect pathways (see figure 5.5.1). Direct N<sub>2</sub>O 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<sub>2</sub>O. 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<sub>2</sub>O emissions from agricultural soils.

N<sub>2</sub>O-N<sup>j</sup> emissions are calculated for each source and then converted to N<sub>2</sub>O 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<sub>2</sub>O emissions from Agricultural soils.

Figure 8.1 shows that there are six main sources of direct and indirect N<sub>2</sub>O emissions from *Agricultural Soils*:

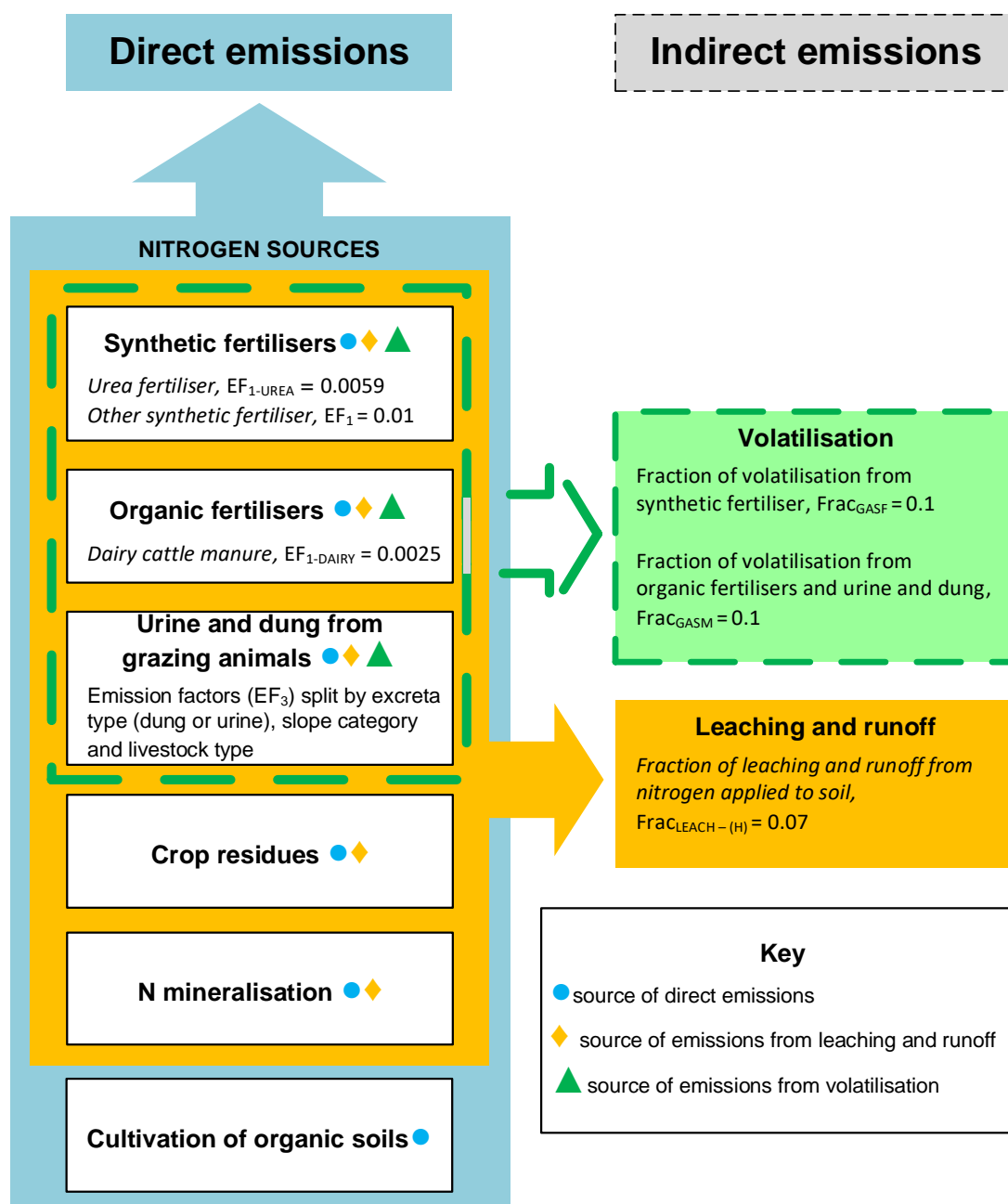
- Synthetic fertilisers
- Organic fertilisers
- Urine and dung from grazing animals
- Crop residues
- Nitrogen mineralisation
- Cultivation of organic soils

All six of these sources generate direct N<sub>2</sub>O emissions, but only the first five generate indirect emissions from leaching and runoff. Only the first three sources listed here generate emissions from volatilisation.

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<sup>j</sup> N<sub>2</sub>O-N refers to the mass of nitrogen in molecules of N<sub>2</sub>O.

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<sub>2</sub>O from fertiliser usage in New Zealand agriculture**

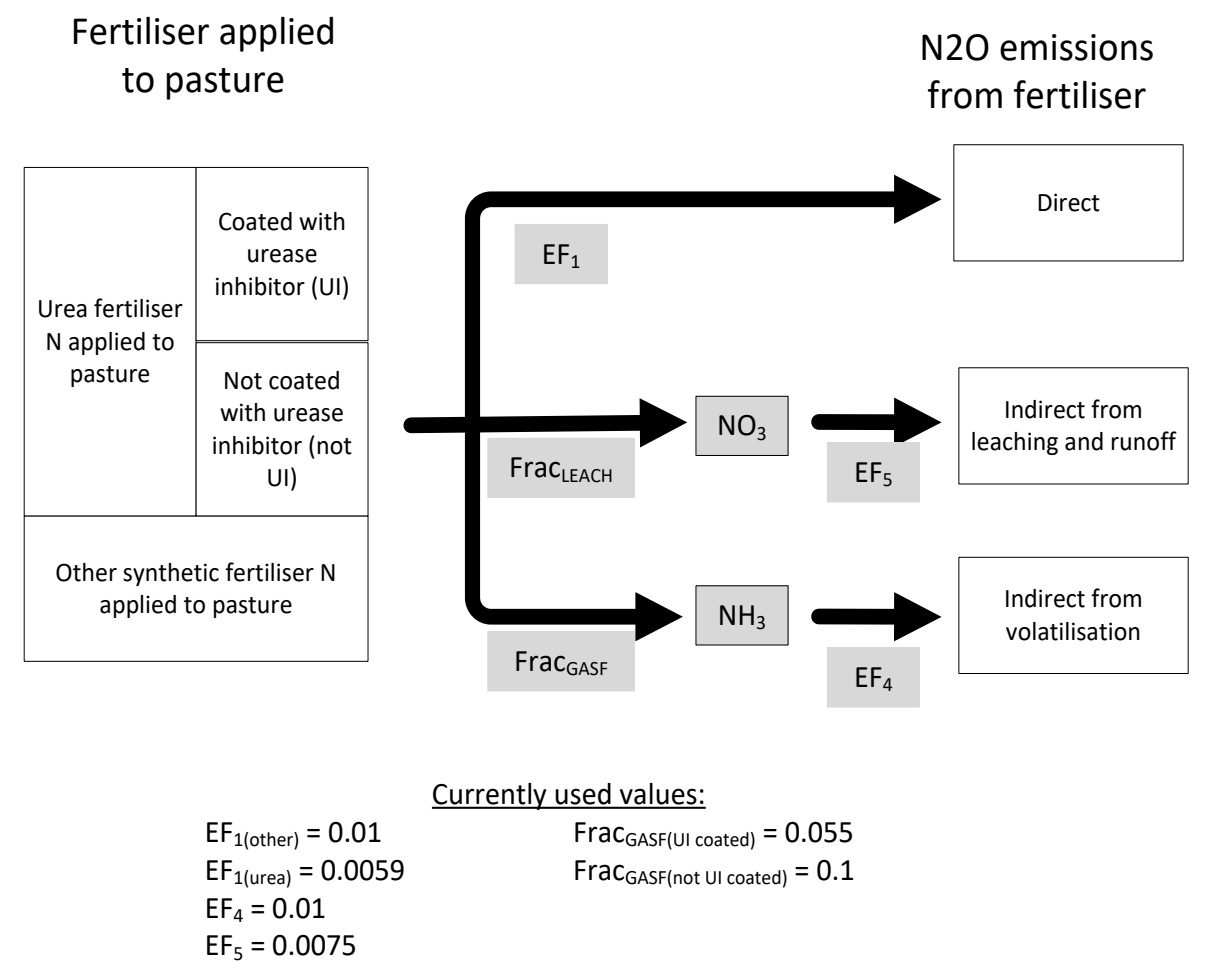
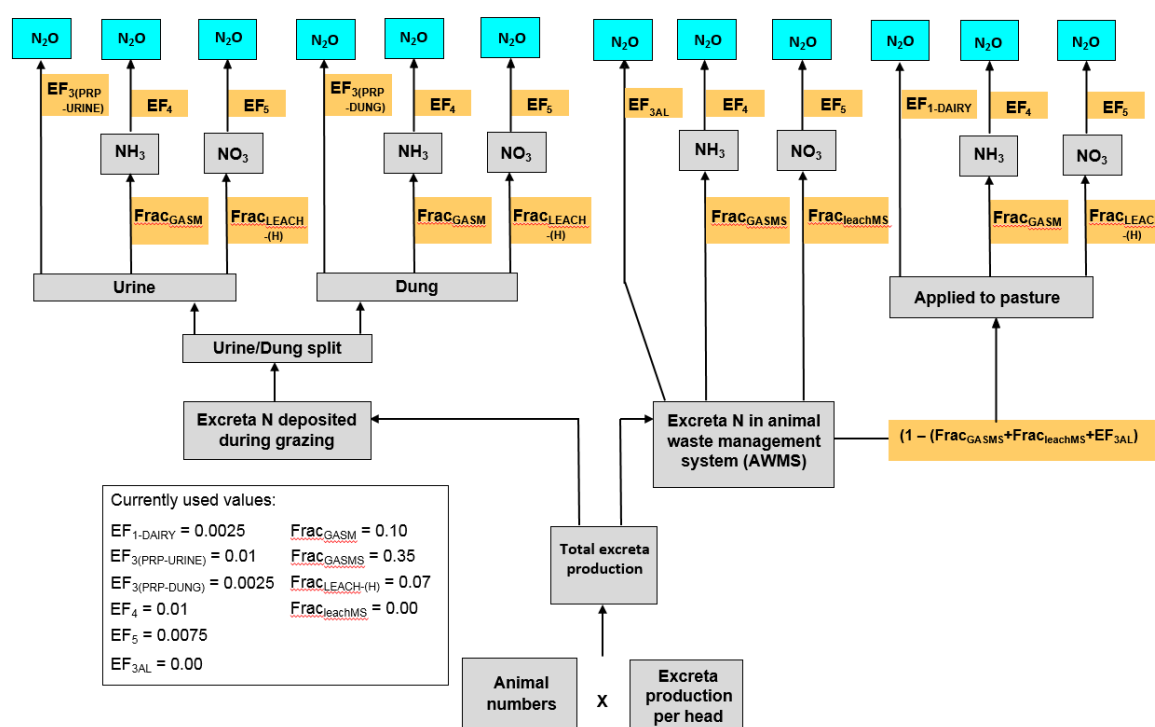


Figure 8.3 shows the pathways that lead to N<sub>2</sub>O from livestock manure. The majority of the nitrogen excreted follows the left hand pathway and is deposited on pasture. This includes almost all nitrogen from dairy cattle (95%) and all nitrogen from beef cattle, sheep, deer, horses, goats and 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 17.



**Figure 8.3: Flow chart of the current IPCC national N<sub>2</sub>O inventory methodology showing N<sub>2</sub>O emissions from cattle, sheep and deer excreta for pastoral agriculture in NZ.**



Note: Emissions from daily spread of swine manure are included with Excreta N deposited during grazing

## 8.1 Direct agricultural soils emissions

As stated earlier, there are six main sources of direct N<sub>2</sub>O 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:

*Direct N<sub>2</sub>O emissions from generic nitrogen source (Equation 8.1):*

$$N_2O_{direct_N} = \frac{44}{28} \times N \times EF$$

Where:

N<sub>2</sub>O<sub>direct<sub>N,t</sub></sub> = Direct N<sub>2</sub>O emissions from nitrogen applied to soil (kg N<sub>2</sub>O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N = amount of nitrogen applied to soils (kg N); (see Appendix 20)

EF = Emission factor, or the proportion of nitrogen input to soil that is directly emitted as N<sub>2</sub>O (kg (N<sub>2</sub>O-N)/kg (N applied))

The emission factor can either be EF<sub>1</sub> or EF<sub>3</sub> 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<sub>2</sub>O 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 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<sub>2</sub>O, (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<sub>x</sub> (explained in further sections below).

The Fertiliser Association of New Zealand provides data on the use of synthetic fertiliser and urea (Appendix 20). 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:

*Direct N<sub>2</sub>O emissions from synthetic fertiliser (Equation 8.2):*

$$N_2O_{direct_{SN,t}} = \frac{44}{28} \times ((F_{SN(UREA),t} \times EF_{1(UREA)}) + (F_{SN(OTHER),t} \times EF_1))$$

Where:

$N_2O_{direct_{SN,t}}$  = Direct N<sub>2</sub>O 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 20)

$EF_{1(urea)}$  = the proportion of direct N<sub>2</sub>O emissions from nitrogen input to the soil for urea fertiliser (0.0059) (see Figure 7.2 and Appendix 18).

$F_{SN(OTHER),t}$  = the total nitrogen annual amount of non-urea synthetic nitrogen fertiliser applied to soils in year  $t$  (kg N/yr); (see Appendix 20)

$EF_1$  = the proportion of direct N<sub>2</sub>O emissions from nitrogen input to the soil (0.01). Proportion of nitrogen input to soil that is directly emitted (kg (N<sub>2</sub>O-N)/kg (N applied) from other synthetic fertilizers (see Figure 7.2 and Appendix 18).

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 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.

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.

*Direct N<sub>2</sub>O emissions from organic nitrogen fertiliser for dairy cattle (Equation 8.3):*

$$N_2O_{direct_{ON,dairy,t}} = \frac{44}{28} (F_{AM(dairy),t} \times (1 - \text{Frac}_{GasAM(AlDairy)}) \times EF_{1(DAIRY)})$$

Where:

$N_2O_{direct_{ON,dairy,t}}$  = direct annual N<sub>2</sub>O 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)

$\text{Frac}_{GasAM(Al-Dairy)}$  = 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)

*Total amount of dairy animal manure nitrogen applied to soils (Equation 8.4)*

$$F_{AM(dairy),t} = \sum_{class} \sum_{region} \sum_{month} (N_{ex,c,m,R} \times nod_m \times POP_{dairy_{c,m,r}}) \times MS_{AL,N_2O}$$

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 5.1, equation 5.1)

$MS_{AL,N_2O}$  = fraction of total annual dairy manure excreted in anaerobic lagoons. currently set at 5% (see appendix 17).

$nod_m$  = number of days in month  $m$

$POP_{dairy_{c,m,r}}$  = 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 4.3)

#### 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

*Direct  $N_2O$  emissions from organic nitrogen fertiliser for swine (Equation 8.5):*

$$N_2O_{direct_{ON,swine,t}} = EF_1 \times \frac{44}{28} \left( \sum_x (N_{ex,swine,t} \times P_{mms_{swine,x}} \times (1 - Frac_{GasAM(x,swine)})) \right)$$

Where:

$N_2O_{direct_{ON,swine,t}}$  = 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 5.34 in section 5.5.5)

$P_{mms_{swine,x}}$  = Proportion of swine waste deposited in manure management system  $x$  (see table 7.2, 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 7.2, section 7.2.1.2 for values)

$POP_{swine,t}$  = 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

*Direct organic nitrogen fertiliser emissions from broilers (Equation 8.6)*

$$N_2O_{direct_{ON,broiler,t}} = N_{ex,broiler} \times Pmms_{broiler,other} \times (1 - Frac_{GasAM,poultry}) \times EF_1 \times \frac{44}{28} \times POP_{broiler,t}$$

Where:

$N_2O_{direct_{ON,broiler,t}}$  = 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 5.5.2)

$Pmms_{broiler,other}$  = 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)

$POP_{broiler,t}$  = Broiler population in year t (from APS)

*Direct organic nitrogen fertiliser emissions from layers (Equation 8.7)*

$$N_2O_{direct_{ON,layer,t}} = N_{ex,layer} \times Pmms_{layer,other} \times (1 - Frac_{GasAM,poultry}) \times EF_1 \times \frac{44}{28} \times POPlayer_t$$

Where:

$N_2O_{direct_{ON,layer,t}}$  = 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 5.5.2)

$Pmms_{layer,other}$  = 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)

*Direct organic nitrogen fertiliser emissions from other poultry (Equation 8.8)*

$$N_2O_{direct_{ON,other,t}} = N_{ex,other} \times Pmms_{other,other} \times (1 - Frac_{GasAM,poultry}) \times EF_1 \times \frac{44}{28} \times POP_{otherpoultry,t}$$

Where:

$N_2O_{direct_{ON,other,t}}$  = 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 5.5.2)

$Pmms_{other,other}$  = 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)

$POP_{otherpoultry_t}$  = 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.

### 8.1.3 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 Saggart 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 ( $EF_{3,PRP-STEEP}$ ) captures both medium and steep slopes

A new emission factor for dung ( $EF_{3,PRP-DUNG} = 0.0012$ ) was adopted in the 2020 inventory, along with a revised set of emission factors for urine ( $EF_{3,PRP-FLAT}$  and  $EF_{3,PRP-STEEP}$ , see table 8.1) which are disaggregated by slope and livestock type. The Nutrient Transfer Model, described in section 5.5 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 ( $EF_{3,PRP-MINOR}$ ) 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)**

Livestock type	Emission factor by slope	
	Flat and low sloped land (less than 12° gradient) $EF_{3,PRP-FLAT}$	Medium and steep sloped land (greater than 12° gradient) $EF_{3,PRP-STEEP}$
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<sub>3</sub> values were calculated using the average EF<sub>3</sub> 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<sub>ex</sub>, 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 5.5.

#### 8.1.3.1 Dairy

For dairy cattle, the following equations are used to determine N<sub>2</sub>O emissions separately from urine and dung.

*Direct N<sub>2</sub>O emissions from dairy urine (Equation 8.9):*

$$N_2O_{direct_{U,Dairy,t}} = \frac{44}{28} EF_{3(PR\text{-}FLAT)} \times MS_{dairy,PRP} \times \left( \sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POP_{dairy_{c,m,R}} \times nod_m \right)$$

Where:

N<sub>2</sub>O<sub>direct<sub>U,dairy,t</sub></sub> = direct annual N<sub>2</sub>O emissions from urine deposited by dairy cattle during grazing (kg of N<sub>2</sub>O per year)

EF<sub>3(PR-FLAT)</sub> = 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<sub>dairy,PRP</sub> = 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<sub>u,c,m,R</sub> = 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 5.1.4 (equation 5.7)

POP<sub>dairy<sub>c,m,R</sub></sub> = population of dairy animals in subcategory *c*, month *m* and region *R*

nod<sub>m</sub> = 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 4.3)

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<sub>3(PR-FLAT)</sub> value of 0.0098 for cattle is applied to all dairy urinary N<sub>ex</sub>.

*Direct N<sub>2</sub>O emissions from dairy dung (Equation 8.10):*

$$N_2O_{direct_{D,Dairy,t}} = \frac{44}{28} \times EF_{3(PR\text{-}Dung)} \times MS_{dairy,PRP} \times \left( \sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POP_{dairy_{c,m,R}} \times nod_m \right)$$

Where:

N<sub>2</sub>O<sub>direct<sub>D,dairy,t</sub></sub> = direct annual N<sub>2</sub>O emissions from dung deposited by dairy cattle during grazing (kg of N<sub>2</sub>O 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)

$MS_{dairy,PRP}$  = 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 5.1.4 (equation 5.8)

$POP_{dairy,c,m,R}$  = 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 4.3)

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 ( $EF_{3(PRP-FLAT)} = 0.0098$ , and  $EF_{3(PRP-STEEP)} = 0.0033$ , see table 8.1). A single beef dung emission factor ( $EF_{3(PRP-DUNG)} = 0.0012$ ) 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 5.2.5 and 5.5 for this methodology).

*Direct  $N_2O$  emissions from beef urine (Equation 8.11):*

$$N_2O_{direct,U,beef,t} = \frac{44}{28} \times MS_{beef,PRP} \times \left( \sum_{class} \sum_{month} N_{u,c,m} \times POP_{beef,c,m} \times nod_m \right) \times (PropNex_{U,LOW,B} \times EF_{3(PRP-LOW)} + PropNex_{U,MED\&STEEP,B} \times EF_{3(PRP-STEEP)})$$

Where:

$N_2O_{direct,U,beef,t}$  = 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 5.2.4

$POP_{beef,c,m,R}$  = population of beef 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 0.0098 for beef cattle (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 0.0033 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 5.5 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 5.5 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 5.5.

*Direct  $N_2O$  emissions from beef dung (Equation 8.12):*

$$N_2O_{direct,D,Beef,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{beef,PRP} \times \left( \sum_{class} \sum_{month} N_{f,c,m} \times POP_{beef,c,m} \times nod_m \right)$$

Where:

$N_2O_{direct,D,beef,t}$  = direct annual  $N_2O$  emissions from dung deposited by beef cattle during grazing (kg of  $N_2O$  per year)

$EF_{3(PRP-Dung)}$  = 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 5.2.4

$POP_{beef,c,m}$  = 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 ( $EF_{3(PRP-FLAT)} = 0.0050$ , and  $EF_{3(PRP-STEEP)} = 0.0008$ , see table 8.1). A single dung emission factor ( $EF_{3(PRP-DUNG)} = 0.0012$ ) 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 5.2.5 and 5.5 for this methodology).

*Direct  $N_2O$  emissions from sheep urine (Equation 8.13):*

$$\begin{aligned} N_2O_{direct,U,sheep,t} &= \frac{44}{28} \times MS_{sheep,PRP} \times \left( \sum_{class} \sum_{month} N_{u,c,m} \times POP_{sheep,c,m} \times nod_m \right) \\ &\times (PropNex_{U,LOW,S} \times EF_{3(PRP-LOW)} + PropNex_{U,MED\&STEEP,S} \times EF_{3(PRP-STEEP)}) \end{aligned}$$

Where:



$N_2O_{directU, sheep, t}$  = 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

$POP_{sheep, c, m, R}$  = 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 5.5 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 5.5 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 5.5.

*Direct  $N_2O$  emissions from sheep dung (Equation 8.14):*

$$N_2O_{directD, Sheep, t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{sheep, PRP} \times \left( \sum_{class} \sum_{month} N_{f, c, m} \times POP_{sheep, c, m} \times nod_m \right)$$

Where:

$N_2O_{directD, sheep, t}$  = 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

$POP_{sheep, c, m}$  = 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<sub>2</sub>O 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<sub>3</sub> values for deer urine are dependent on hill slope (EF<sub>3(PRP-FLAT)</sub> = 0.0074, and EF<sub>3(PRP-STEEP)</sub> = 0.0020, see table 8.1). A single dung emission factor (EF<sub>3(PRP-DUNG)</sub> = 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<sub>U,LOW,Deer</sub> and PropNex<sub>U,MED&STEEP,Deer</sub>) needs to be calculated (refer to sections 5.2.5 and 5.5 for this methodology).

*Direct N<sub>2</sub>O emissions from deer urine (Equation 8.15):*

$$N_2O_{directU,deer,t} = \frac{44}{28} \times MS_{deer,PRP} \times \left( \sum_{class} \sum_{month} N_{u,c,m} \times POP_{deer,c,m} \times nod_m \right) \times (PropNex_{U,LOW,Deer} \times EF_{3(PRP-LOW)} + PropNex_{U,MED\&STEEP,Deer} \times EF_{3(PRP-STEEP)})$$

Where:

N<sub>2</sub>O<sub>directU,deer,t</sub> = direct annual N<sub>2</sub>O emissions from urine deposited by deer during grazing (kg of N<sub>2</sub>O per year)

MS<sub>deer,PRP</sub> = proportion of manure excreted directly onto pasture, range and paddock by deer overall. Assumed to be 100%.

N<sub>u,c,m</sub> = Amount of nitrogen excreted in urine per animal for deer animal class *c*, in month *m* (kg of nitrogen per day). See section 5.4.5

POP<sub>deer,c,m,R</sub> = population of deer animals in subcategory *c*, month *m* and region *R*

nod<sub>m</sub> = number of days in month *m*

EF<sub>3(PRP-LOW)</sub> = 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<sub>3(PRP-STEEP)</sub> = 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<sub>U,LOW,Deer</sub> = calculated proportion of total urine N from deer deposited on low slopes. See section 5.5 and table 5.1.

PropNex<sub>U,MED&STEEP,Deer</sub> = calculated proportion of total urine N from deer deposited on medium and steep slopes. See section 5.5 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<sub>ex</sub> 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 5.5.

*Direct N<sub>2</sub>O emissions from deer dung (Equation 8.16):*

$$N_2O_{directD,deer,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{deer,PRP} \times \left( \sum_{class} \sum_{month} N_{f,c,m} \times POP_{deer,c,m} \times nod_m \right)$$

Where:

N<sub>2</sub>O<sub>directD,deer,t</sub> = direct annual N<sub>2</sub>O emissions from dung deposited by deer during grazing (kg of N<sub>2</sub>O 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)

$MS_{deer,PRP}$  = 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 5.4.5

$POP_{deer,c,m}$  = 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  $N_2O$  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,  $EF_{3PRP-MINOR}$  (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.

*Direct  $N_2O$  emissions from urine and dung for poultry (Equation 8.17):*

$$N_2O_{directUD,poultry,t} = \frac{44}{28} \times EF_{3(PRP-MINOR)} \times \sum_x (N_{ex,x,t} \times POP_{minorpoultry,x,t} \times MS_{x,PRP})$$

Where:

$N_2O_{directUD,x,t}$  = 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)

$EF_{3(PRP-MINOR)}$  = 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 5.5.2 (nitrogen excretion, poultry) for specific values

$POP_{poultry,x,t}$  = 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 17).

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.

Direct N<sub>2</sub>O emissions from urine and dung for swine (Equation 8.18):

$$N_2O_{directUD,swine,t} = \frac{44}{28} \times EF_{3(PRP-MINOR)} \times N_{ex,swine,t} \times POP_{swine,t} \times MS_{swine,PRP}$$

Where:

$N_2O_{directUD,swine,t}$  = direct annual N<sub>2</sub>O emissions from urine and dung deposited by swine during grazing in year  $t$  (kg of N<sub>2</sub>O per year)

$EF_{3(PRP-MINOR)}$  = 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 5.5.5 (nitrogen excretion, swine) and equation 5.34

$POP_{swine,t}$  = 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).

#### 8.1.3.5.3 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<sub>2</sub>O emissions from urine and dung can be calculated from the following equation.

Direct N<sub>2</sub>O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses (Equation 8.19):

$$N_2O_{directUD,x,t} = \frac{44}{28} \times EF_{3(PRP-MINOR)} \times N_{ex,x,t} \times POP_{minor_x,t}$$

Where:

$N_2O_{directUD,x,t}$  = direct annual N<sub>2</sub>O emissions from urine and dung deposited by animal type  $x$  (i.e. goats, horses...) during grazing in year  $t$  (kg of N<sub>2</sub>O per year)

$EF_{3(PRP-MINOR)}$  = 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)

$POP_{minor_x}$  = 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<sub>2</sub>O mitigation technology, into the inventory. The N<sub>2</sub>O 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<sub>2</sub>O emissions and nitrate (NO<sub>3</sub><sup>-</sup>) 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<sub>2</sub>O emissions and NO<sub>3</sub><sup>-</sup> 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 ( $EF_{3(PRP-DUNG)}$ ); 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:

*DCD weighting factor (Equation 8.20):*

$$DCD \text{ weighting factor} = \left( 1 - \left( \text{reduction in } EF_{3(PRP-URINE)} \times \frac{DCD \text{ area treated}}{\text{Total area of dairy}} \right) \right)$$

Where:

DCD weighting factor = amount that  $EF_{3(PRP-URINE)}$  (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  $EF_{3(PRP-URINE)}$  = proportion by which  $EF_{3(PRP-URINE)}$  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

*Calculating  $EF_3$  for dairy, accounting for the use of DCD, for May to September (Equation 8.21):*

Where:

$$EF_{3(PRP-URINE),DCD} = EF_{3(PRP-URINE)} \times DCD \text{ weighting factor}$$

$EF_{3(PRP-URINE),DCD}$  = emission factor for urine from dairy animals in pasture, range and paddock between May and September, after accounting for the effects of DCD use.

$EF_{3(PRP-URINE)}$  = 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  $N_2O_{directU,dairy,t}$  (see equation 8.20) 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  $EF_{3(PRP-URINE)}$  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  $EF_{3(PRP-URINE),DCD}$  for these years would be equal to  $EF_{3(PRP-URINE)}$ .

It was assumed that the inhibitor was applied to pastures based on good management practice to maximise N<sub>2</sub>O 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<sub>2</sub>O 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 OVERSEER® 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 fromASUREQuality (Thomas *et al.*, 2010). The tonnage of nitrogen fixing crops is supplied by Statistics New Zealand from its 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).

*Direct N<sub>2</sub>O emissions from decay of crop residue (Equation 8.22):*

$$N_2O_{direct_{CR,t}} = \frac{44}{28} \times EF_1 \times \sum_c (AG_{N,c} + BG_{N,c})$$

Where:

$N_2O_{direct_{CR,t}}$  = direct annual N<sub>2</sub>O emissions from crop residues (kg of N<sub>2</sub>O per year)

$EF_1$  = the proportion of direct N<sub>2</sub>O 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 8.23)

$BG_{N,c}$  = 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 8.25)

$c$  refers to the different crop types listed in table 8.1

*Amount of above ground crop residue (Equation 8.23):*

$$AG_{N,c} = DMF_c \times \left( \frac{Prod_c}{HI_c} - Prod_c \right) \times (1 - Frac_{burn} - Frac_{remove,c}) \times N_{AG,c}$$

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 20 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 8.24 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.

*Fraction of above-ground biomass burned, for barley, oats and wheat (Equation 8.24):*

$$Frac_{burn,c} = \frac{AG_{BURN,c}}{AG_{resd,c}}$$

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)

Amount of below ground crop residue (Equation 8.25):

$$BG_{N,c} = DMF_c \times \left( \frac{Prod_c}{HI_c} \right) \times RS_c \times N_{BG,c}$$

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 20 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 8.1 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<sub>2</sub>O emissions from these pastures separately with the following equations:

*Direct N<sub>2</sub>O emissions from pasture renewal (Equation 8.26):*

$$N_2O_{direct_{Renew,t}} = \frac{44}{28} \times EF_1 \times \sum_p F_{CR-Renew,p,t}$$

Where:

$N_2O_{direct_{renew,t}}$  = Direct N<sub>2</sub>O emissions from pasture renewal in year  $t$  (kilograms per year)

$EF_1$  = the proportion of direct N<sub>2</sub>O emissions from nitrogen input to the soil (0.01 kg (N<sub>2</sub>O-N)/kg (N applied). See Appendix 18.

$F_{CR-Renew,p,t}$  = 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.

*Nitrogen in residues from pasture renewal (Equation 8.27):*

$$F_{CR-Renew,p,t} = Area_{p,t} \times Freq_{renew,p,t} \times \left( (R_{AG,p} \times N_{AG} \times (1 - Frac_{remove,p})) + (R_{BG,p} \times N_{BG}) \right)$$

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 21 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).

*Direct  $N_2O$  emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils (Equation 8.28)*

$$N_2O_{direct_{FSOM,t}} = \frac{44}{28} \times EF_1 \times F_{SOM}$$

Where:

$N_2O_{direct_{FSOM,t}}$  = 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 8.29)

*Nitrogen mineralised due to the loss of soil organic matter in mineral soils (Equation 8.29)*

$$F_{SOM} = \frac{\Delta C_{Mineral,CrC}}{R_{C:N}}$$

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 22).

$R_{C:N}$  = 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 24). 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 18) 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.

*Direct  $N_2O$  emissions from cultivation of organic soils (Equation 8.30)*

$$N_2O_{direct, OAS-C, t} = \frac{44}{28} \times EF_2 \times Area_{OAS-C}$$

Where:

$N_2O_{direct, OAS-C, t}$  = 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:

*Indirect leaching and runoff  $N_2O$  emissions from generic nitrogen source (Equation 8.31):*

$$N_2O_{indirect, leaching_N} = \sum_{source} \frac{44}{28} \times N_s \times EF_5 \times Frac_{leach(s)}$$

Where:

$N_2O_{indirect, leaching_N}$  = 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 20)

$EF_5$  = 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 0.07 for other sources (see Appendix 18)

## 8.2.1 Synthetic fertiliser application

The following equation is used to calculate indirect leaching and runoff N<sub>2</sub>O emissions from synthetic nitrogen fertiliser.

*Indirect leaching and run-off N<sub>2</sub>O emissions from synthetic fertiliser (Equation 8.32):*

$$N_2O_{\text{indirect, leaching}}_{SN,t} = \frac{44}{28} \times F_{SN,t} \times EF_5 \times \text{Frac}_{\text{leach}(SN)}$$

Where:

$N_2O_{\text{indirect, leaching}}_{SN,t}$  = indirect leaching and run-off N<sub>2</sub>O 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 20)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$\text{Frac}_{\text{leach}(SN)}$  = fraction of leaching and runoff from synthetic nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

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<sub>2</sub>O 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

*Indirect leaching and run-off N<sub>2</sub>O emissions from organic nitrogen fertiliser for dairy cattle (Equation 8.33):*

$$N_2O_{\text{indirect, leaching}}_{ON,dairy,t} = \frac{44}{28} \times F_{AM(dairy),t} \times (1 - \text{Frac}_{\text{GasAM}(AL_{Dairy})}) \times \text{Frac}_{\text{leach}(ON)} \times EF_5$$

Where:

$N_2O_{\text{indirect, leaching}}_{ON,dairy,t}$  = indirect leaching and run-off N<sub>2</sub>O 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

$\text{Frac}_{\text{GasAM}(AL_{Dairy})}$  = fraction of nitrogen lost due to volatilisation (currently set at 0.35, as per IPCC (2006) guidelines)

$\text{Frac}_{\text{leach}(ON)}$  = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

### 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

*Indirect leaching and run-off N<sub>2</sub>O emissions from organic nitrogen fertiliser for swine (Equation 8.34):*

$$N_2O_{\text{indirect, leaching}_{ON, \text{swine}, t}} = EF_5 \times \text{Frac}_{\text{leach}(ON)} \times \frac{44}{28} \left( \sum_x (N_{\text{ex, swine}, t} \times \text{Pmms}_{\text{swine}, x} \times (1 - \text{Frac}_{\text{GasAM}(x, \text{swine})}) \times \text{POP}_{\text{swine}_t} \right)$$

Where:

$N_2O_{\text{indirect, leaching}_{ON, \text{swine}, t}}$  = total annual indirect leaching and run-off N<sub>2</sub>O emissions from organic nitrogen fertilisers for swine (kg per year)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$\text{Frac}_{\text{leach}(ON)}$  = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$N_{\text{ex, swine}, t}$  = Annual nitrogen excretion per pig in year  $t$  (kilograms of nitrogen per year) (see equation 5.34 in section 5.5.5).

$\text{Pmms}_{\text{swine}, x}$  = Proportion of swine waste deposited in manure management system  $x$  (see table 11, section 7.2.1.2 for values)

$\text{Frac}_{\text{GasAM}(x, \text{swine})}$  = fraction of nitrogen lost due to volatilisation for manure management system  $x$  (see table 11, section 7.2.1.2 for values)

$\text{POP}_{\text{swine}_t}$  = 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<sub>2</sub>O 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.

*Indirect leaching and run-off N<sub>2</sub>O emissions from organic nitrogen fertiliser for broilers (Equation 8.35)*

$$N_2O_{\text{indirect, leaching}_{ON, \text{broiler}, t}} = N_{\text{ex, broiler}} \times \text{Pmms}_{\text{broiler, other}} \times (1 - \text{Frac}_{\text{GasAM, poultry}}) \times EF_5 \times \text{Frac}_{\text{leach}(ON)} \times \frac{44}{28} \times \text{POP}_{\text{broiler}_t}$$

Where:

$N_2O_{\text{indirect, leaching}_{ON, \text{broiler}, t}}$  = total annual indirect leaching and run-off N<sub>2</sub>O emissions from organic nitrogen fertilisers for broiler chicken in year  $t$  (kg per year)

$N_{\text{ex, broiler}}$  = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see section 5.5.2)

$\text{Pmms}_{\text{broiler, other}}$  = Proportion of broiler waste deposited in other manure management systems (set at 0.95)

$\text{Frac}_{\text{GasAM, poultry}}$  = fraction of nitrogen lost due to volatilisation for manure management for poultry (currently set at 0.25)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach(ON)}$  = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$POP_{broiler,t}$  = Broiler population in year t (from APS)

*Indirect leaching and run-off N<sub>2</sub>O emissions from organic nitrogen fertiliser for layers (Equation 8.36)*

$N_2O_{indirect, leaching_{ON, layer, t}}$

$$= N_{ex, layer} \times Pmms_{layer, other} \times (1 - Frac_{GasAM, poultry}) \times EF_5 \times Frac_{leach(ON)} \times \frac{44}{28} \times POP_{layer, t}$$

Where:

$N_2O_{indirect, leaching_{ON, layer, t}}$  = total annual indirect leaching and run-off N<sub>2</sub>O 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 5.5.2)

$Pmms_{layer, other}$  = 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<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach(ON)}$  = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$POP_{layer, t}$  = Layer population in year t (from APS)

*Indirect leaching and run-off N<sub>2</sub>O emissions from organic nitrogen fertiliser for other poultry (Equation 8.37)*

$N_2O_{indirect, leaching_{ON, other, t}}$

$$= N_{ex, other} \times Pmms_{other, other} \times (1 - Frac_{GasAM, poultry}) \times EF_5 \times Frac_{leach(ON)} \times \frac{44}{28} \times POP_{otherpoultry, t}$$

Where:

$N_2O_{indirect, leaching_{ON, other, t}}$  = total annual indirect leaching and run-off N<sub>2</sub>O 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 5.5.2)

$Pmms_{other, other}$  = 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<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach(ON)}$  = fraction of leaching and runoff from organic nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$POP_{otherpoultry, t}$  = 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O emissions separately from urine and dung.

*Indirect leaching and runoff N<sub>2</sub>O emissions from dairy urine (Equation 8.38):*

$$N_2O_{\text{indirect,leaching}_{U,dairy,t}} = \frac{44}{28} \times EF_5 \times \text{Frac}_{\text{leach}(U)} \times MS_{\text{dairy,PRP}} \times \left( \sum_{\text{class}} \sum_{\text{region}} \sum_{\text{month}} N_{u,c,m,R} \times \text{POP}_{\text{dairy}_{c,m,R}} \times \text{nod}_m \right)$$

Where:

$N_2O_{\text{indirect,leaching}_{U,dairy,t}}$  = annual indirect leaching and runoff N<sub>2</sub>O emissions from urine deposited by dairy cattle during grazing (kg of N<sub>2</sub>O per year)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$\text{Frac}_{\text{leach}(U)}$  = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$MS_{\text{dairy,PRP}}$  = 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 5.1.4 (equation 5.7)

$\text{POP}_{\text{dairy}_{c,m,R}}$  = population of dairy animals in subcategory  $c$ , month  $m$  and region  $R$

$\text{nod}_m$  = 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 4.3)

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

*Indirect leaching and runoff N<sub>2</sub>O emissions from dairy dung (Equation 8.39):*

$$N_2O_{\text{indirect,leaching}_{D,Dairy,t}} = \frac{44}{28} \times EF_5 \times \text{Frac}_{\text{leach}(U)} \times MS_{\text{dairy,PRP}} \times \left( \sum_{\text{class}} \sum_{\text{region}} \sum_{\text{month}} N_{f,c,m,R} \times \text{POP}_{\text{dairy}_{c,m,R}} \times \text{nod}_m \right)$$

Where:

$N_2O_{\text{indirect,leaching}_{D,dairy,t}}$  = annual indirect leaching and runoff N<sub>2</sub>O emissions from dung deposited by dairy cattle during grazing (kg of N<sub>2</sub>O per year)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$\text{Frac}_{\text{leach}(U)}$  = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$MS_{dairy,PRP}$  = 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 5.1.4 (equation 5.8)

$POP_{dairy,c,m,R}$  = 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 4.3)

### 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,  $Frac_{leach}$ , to account for the proportion of nitrogen (applied to water) that is lost to water.

*Indirect leaching and runoff  $N_2O$  emissions from urine, for animal species  $x$  (Equation 8.40):*

$$N_{2O}^{indirect, leaching}_{U,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(U)} \times MS_{x,PRP} \times \left( \sum_{class} \sum_{month} N_{x,u,c,m} \times POP_{x,c,m} \times nod_m \right)$$

*Indirect leaching and runoff  $N_2O$  emissions from dung, for animal species  $x$  (Equation 8.41):*

$$N_{2O}^{indirect, leaching}_{D,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach(U)} \times MS_{x,PRP} \times \left( \sum_{class} \sum_{month} N_{x,f,c,m} \times POP_{x,c,m} \times nod_m \right)$$

Where:

$N_{2O}^{indirect, leaching}_{U,x,t}$  = annual indirect leaching and runoff  $N_2O$  emissions from urine deposited by animal species  $x$  during grazing (kg of  $N_2O$  per year)

$N_{2O}^{indirect, leaching}_{D,x,t}$  = 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 18).

$Frac_{leach(U)}$  = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$MS_{x,PRP}$  = 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

$POP_{x,c,m,R}$  = 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<sub>2</sub>O emissions and nitrate (NO<sub>3</sub><sup>-</sup>) 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:

*DCD weighting factor for  $Frac_{LEACH}$  (Equation 8.41):*

$$DCD \text{ weighting factor}_{Frac_{leach}} = \left( 1 - \left( \% \text{ reduction in } Frac_{leach} \times \frac{DCD \text{ area treated}}{Total \text{ area of dairy}} \right) \right)$$

Where:

$DCD \text{ weighting factor}_{Frac_{leach}}$  = amount that  $Frac_{leach}$  needs to be multiplied by to account for the effect of DCD between 2007 and 2012

% reduction in  $Frac_{leach(U)}$  = 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<sub>2</sub>O from grazed pastures.

*Calculating  $Frac_{leach}$  for dairy, accounting for the use of DCD, for May to September (Equation 8.42):*

Where:

$$Frac_{leach,DCD} = Frac_{leach(U)} \times DCD \text{ weighting factor}_{Frac_{leach}}$$

$Frac_{leach,DCD}$  = 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.

$Frac_{leach(U)}$  = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$DCD \text{ weighting factor}_{Frac_{leach}}$  = amount that  $Frac_{leach}$  (see equation x) 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<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O emissions for these species are calculated

##### 8.2.3.4.1 Poultry

Indirect N<sub>2</sub>O 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.

*Indirect leaching and run-off N<sub>2</sub>O emissions from urine and dung for poultry (Equation 8.43):*

$$N_2O_{indirect, leaching_{UD, poultry, t}} = \frac{44}{28} \times EF_5 \times Frac_{leach(U)} \times \sum_x (N_{ex, x, t} \times POP_{poultry, x, t} \times MS_{x, PRP})$$

Where:

$N_2O_{indirect, leaching_{UD, x, t}}$  = indirect N<sub>2</sub>O 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<sub>2</sub>O per year)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach(U)}$  = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$N_{ex, x, t}$  = Annual nitrogen excretion per animal in year t, for poultry type x (kg of nitrogen per year). See section 5.5.2 (nitrogen excretion, poultry) for specific values

$POP_{poultry, x, t}$  = 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 N<sub>2</sub>O emissions (from leaching and run-off) from urine and dung deposited on pasture by swine are calculated using the following equation.

*Indirect leaching and run-off N<sub>2</sub>O emissions from urine and dung for swine (Equation 8.44):*

$$N_2O_{indirect, leaching_{UD, swine, t}} = \frac{44}{28} \times EF_5 \times Frac_{leach(U)} \times N_{ex, swine, t} \times POP_{swine, t} \times MS_{swine, PRP}$$

Where:

$N_2O_{indirect, leaching_{UD, swine, t}}$  = indirect N<sub>2</sub>O emissions from leaching and run-off from urine and dung deposited by swine during grazing in year t (kg of N<sub>2</sub>O per year)

$EF_5$  = N<sub>2</sub>O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach(U)}$  = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$N_{ex,x,t}$  = Annual nitrogen excretion per animal in year  $t$ , for swine (kg of nitrogen per year). See section 5.5.5 (nitrogen excretion, swine) and equation 5.34

$POP_{swine,t}$  = 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.

*Indirect leaching and run-off  $N_2O$  emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses (Equation 8.45):*

$$N_2O_{indirect, leaching_{UD,x,t}} = \frac{44}{28} \times EF_5 \times Frac_{leach(U)} \times N_{ex,x,t} \times POP_{minor_{x,t}}$$

Where:

$N_2O_{indirect, leaching_{UD,x,t}}$  = indirect  $N_2O$  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 18).

$Frac_{leach(U)}$  = fraction of leaching and runoff from urine and dung nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$N_{ex,x,t}$  = 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)

$POP_{minor_x}$  = 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).

## 8.2.4 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).

*Indirect  $N_2O$  emissions from decay of crop residue (Equation 8.46):*

$$N_2O_{indirect_{CR,t}} = \frac{44}{28} \times EF_5 \times Frac_{leach(CR)} \times \sum_c (AG_{N,c} + BG_{N,c})$$

Where:

$N_2O_{indirect_{CR,t}}$  = indirect annual  $N_2O$  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 18).

$Frac_{leach(CR)}$  = fraction of leaching and runoff from nitrogen applied to cropland. Currently set at 0.1 (see Appendix 18)

$AG_{N,c}$  = 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 x)

$BG_{N,c}$  = 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 x)

$c$  refers to the different crop types listed in table 11 (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

*Indirect  $N_2O$  emissions from pasture renewal (Equation 8.47):*

$$N_2O_{indirect_{Renew,t}} = \frac{44}{28} \times EF_5 \times Frac_{leach(Renew)} \times \sum_p F_{CR-Renew,p,t}$$

Where:

$N_2O_{indirect_{renew,t}}$  = 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 18).

$Frac_{leach(Renew)}$  = fraction of leaching and runoff from nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$F_{CR-Renew,p,t}$  = Amount of nitrogen in residues (kg) for pasture type  $p$  in year  $t$  (see equation x, 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  $N_2O$  emissions from nitrogen mineralisation can be calculated using the formula below.

*Indirect  $N_2O$  emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils (Equation 8.48)*

$$N_2O_{indirect_{FSOM,t}} = \frac{44}{28} \times EF_5 \times Frac_{leach(CR)} \times F_{SOM}$$

Where:

$N_2O_{indirect_{FSOM,t}}$  = 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 18).

$Frac_{leach(CR)}$  = fraction of leaching and runoff from nitrogen applied to cropland. Currently set at 0.1 (see Appendix 18)

$F_{SOM}$  = amount of nitrogen mineralised from loss of soil organic matter in mineral soils through land management for *cropland remaining cropland* (kg) (see equation x in section 8.1.5)

### 8.3 Indirect N<sub>2</sub>O emissions associated with nitrogen volatilisation from soils

Nitrogen can be volatilised as ammonia or NO<sub>x</sub> (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<sub>2</sub>O 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:

*Indirect volatilisation N<sub>2</sub>O emissions from generic nitrogen source (Equation 8.49):*

$$N_2O_{\text{indirect, volatilisation}_N} = \frac{44}{28} \times N \times EF_4 \times \text{Frac}_{GAS}$$

Where:

$N_2O_{\text{indirect, volatilisation}_N}$  = Indirect volatilisation N<sub>2</sub>O emissions from nitrogen applied to soil (kg N<sub>2</sub>O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N = amount of nitrogen applied to soils (kg N); (see Appendix 20)

EF<sub>4</sub> = N<sub>2</sub>O emission factor for indirect emissions from volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

Frac<sub>GAS</sub> = fraction of nitrogen applied to soil emitted as NO<sub>x</sub> or NH<sub>3</sub>.

The parameter Frac<sub>GAS</sub> can either be Frac<sub>GASF</sub> or Frac<sub>GASAM</sub> 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<sub>2</sub>O emissions from volatilisation<sup>k</sup>, 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<sub>2</sub>O emissions.

Research from Saggart 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<sub>GASF</sub> parameter from 0.1 to 0.055 when urease inhibitor is used.

The equations used to estimate indirect N<sub>2</sub>O emissions from volatilisation (by UI and non-UI coated fertiliser) are below.

<sup>k</sup> in addition to direct N<sub>2</sub>O emissions (see section 8.1.1) and indirect leaching N<sub>2</sub>O emissions (see section 8.2.1)

Indirect volatilisation  $N_2O$  emissions from synthetic fertiliser coated with urease inhibitor (Equation 8.50):

$$N_2O_{indirect, volatilisation_{SN,UI,t}} = \frac{44}{28} \times F_{SN,UI,t} \times EF_4 \times Frac_{GASF,UI}$$

Indirect volatilisation  $N_2O$  emissions from synthetic fertiliser NOT coated with urease inhibitor (Equation 8.51):

$$N_2O_{indirect, volatilisation_{SN,no UI,t}} = \frac{44}{28} \times F_{SN,no UI,t} \times EF_4 \times Frac_{GASF}$$

Where:

$N_2O_{indirect, volatilisation_{SN,UI,t}}$  = indirect volatilisation  $N_2O$  emissions from UI coated synthetic nitrogen fertiliser in year  $t$  (kilograms per year)

$N_2O_{indirect, volatilisation_{SN,no UI,t}}$  = 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 volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$Frac_{GASF,UI}$  = fraction of UI coated synthetic fertiliser emitted as  $NO_x$  or  $NH_3$ . Currently set at 0.055 (see Appendix 18)

$Frac_{GASF}$  = fraction of synthetic fertiliser NOT coated with UI emitted as  $NO_x$  or  $NH_3$ . Currently set at 0.1 (see Appendix 18)

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

Indirect leaching and run-off  $N_2O$  emissions from organic nitrogen fertiliser for dairy cattle (Equation 8.52):

$$N_2O_{indirect, volatilisation_{ON,dairy,t}} = \frac{44}{28} \times F_{AM(dairy),t} \times (1 - Frac_{GasAM(Al_{Dairy})}) \times Frac_{GASam} \times EF_4$$

Where:

$N_2O_{indirect, volatilisation_{ON,dairy,t}}$  = 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 18)

$EF_4$  =  $N_2O$  emission factor indirect emissions from volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

### 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

*Indirect volatilisation  $N_2O$  emissions from organic nitrogen fertiliser for swine (Equation 8.53):*

$$N_2O_{indirect, volatilisation_{ON, swine, t}} = EF_4 \times Frac_{GASam} \times \frac{44}{28} \left( \sum_x (N_{ex, swine, t} \times Pmms_{swine, x} \times (1 - Frac_{GasAM(x, swine)}) \times POP_{swine, t}) \right)$$

Where:

$N_2O_{indirect, volatilisation_{ON, swine, t}}$  = 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 volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$Frac_{GASam}$  = fraction of nitrogen excretion emitted as  $NO_x$  or  $NH_3$ . Currently set at 0.1 (see Appendix 18)

$N_{ex, swine, t}$  = Annual nitrogen excretion per pig in year  $t$  (kilograms of nitrogen per year) (see equation 5.34 in section 5.5.5).

$Pmms_{swine, x}$  = Proportion of swine waste deposited in manure management system  $x$  (see table 7.2, 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 7.2, section 7.2.1.2 for values)

$POP_{swine, t}$  = 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  $N_2O$  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.

*Indirect volatilisation  $N_2O$  emissions from organic nitrogen fertiliser for broilers (Equation 8.54):*

$$N_2O_{indirect, volatilisation_{ON, broiler, t}} = N_{ex, broiler} \times Pmms_{broiler, other} \times (1 - Frac_{GasAM, poultry}) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POP_{broiler, t}$$

Where:

$N_2O_{indirect, volatilisation_{ON, broiler, t}}$  = 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 5.5.2)

$Pmms_{broiler, other}$  = 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 volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$Frac_{GASam}$  = fraction of nitrogen excretion emitted as  $NO_x$  or  $NH_3$ . Currently set at 0.1 (see Appendix 18)

$POP_{broiler, t}$  = Broiler population in year  $t$  (from APS)

*Indirect volatilisation  $N_2O$  emissions from organic nitrogen fertiliser for layers (Equation 8.55):*

$$N_2O_{indirect, volatilisation_{ON, layer, t}} = N_{ex, layer} \times Pmms_{layer, other} \times (1 - Frac_{GasAM, poultry}) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POP_{layer, t}$$

Where:

$N_2O_{indirect, volatilisation_{ON, layer, t}}$  = 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 5.5.2)

$Pmms_{layer, other}$  = 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 volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$Frac_{GASam}$  = fraction of nitrogen excretion emitted as  $NO_x$  or  $NH_3$ . Currently set at 0.1 (see Appendix 18)

$POP_{layer, t}$  = Layer population in year  $t$  (from APS)

*Indirect volatilisation  $N_2O$  emissions from organic nitrogen fertiliser for other poultry (Equation 8.56):*

$$N_2O_{indirect, volatilisation_{ON, other, t}} = N_{ex, other} \times Pmms_{other, other} \times (1 - Frac_{GasAM, poultry}) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POP_{other, poultry, t}$$

Where:

$N_2O_{indirect, leaching_{ON, other, t}}$  = 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 5.5.2)

$Pmms_{other, other}$  = 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 18).

$Frac_{GASam}$  = fraction of nitrogen excretion emitted as  $NO_x$  or  $NH_3$ . Currently set at 0.1 (see Appendix 18)

$POP_{otherpoultry,t}$  = 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.

*Indirect volatilisation  $N_2O$  emissions from dairy urine (Equation 8.57):*

$$N_2O_{indirect, volatilisation_{U,dairy,t}} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{dairy,PRP} \times \left( \sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POP_{dairy_{c,m,R}} \times nod_m \right)$$

Where:

$N_2O_{indirect, volatilisation_{U,dairy,t}}$  = 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 18)

$EF_4$  =  $N_2O$  emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$MS_{dairy,PRP}$  = 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 5.1.4 (equation 5.7)

$POP_{dairy_{c,m,R}}$  = 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 4.3)

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

*Indirect volatilisation  $N_2O$  emissions from dairy dung (Equation 8.58):*

$$N_2O_{indirect, volatilisation_{D,Dairy,t}} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{dairy,PRP} \times \left( \sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POP_{dairy_{c,m,R}} \times nod_m \right)$$

Where:

$N_2O_{indirect, volatilisation_{D,dairy,t}}$  = 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 18)

$EF_4$  =  $N_2O$  emission factor for indirect emissions from volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$MS_{dairy,PRP}$  = 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 5.1.4 (equation 5.8)

$POP_{dairy,c,m,R}$  = 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 4.3)

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  $NO_x$  or  $NH_3$ .

*Indirect volatilisation  $N_2O$  emissions from urine, for animal species  $x$  (Equation 8.59):*

$$N_2O_{indirect, volatilisation_{U,x,t}} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{x,PRP} \times \left( \sum_{class} \sum_{month} N_{x,u,c,m} \times POP_{x,c,m} \times nod_m \right)$$

*Indirect volatilisation  $N_2O$  emissions from dung, for animal species  $x$  (Equation 8.60):*

$$N_2O_{indirect, volatilisation_{D,x,t}} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{x,PRP} \times \left( \sum_{class} \sum_{month} N_{x,f,c,m} \times POP_{x,c,m} \times nod_m \right)$$

Where:

$N_2O_{indirect, volatilisation_{U,x,t}}$  = annual indirect volatilisation  $N_2O$  emissions from urine deposited by animal species  $x$  during grazing (kg of  $N_2O$  per year)

$N_2O_{indirect, volatilisation_{D,x,t}}$  = 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 18)

$EF_4$  =  $N_2O$  emission factor for indirect emissions from volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$MS_{x,PRP}$  = 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

$POP_{x,c,m,R}$  = 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 N<sub>2</sub>O 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 N<sub>2</sub>O emissions (from volatilisation) from urine and dung deposited on pasture by poultry are calculated by using different parameters for broilers, layers and other poultry.

*Indirect volatilisation N<sub>2</sub>O emissions from urine and dung for poultry (Equation 8.61):*

$$N_2O_{indirect, volatilisation_{UD,poultry,t}} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times \sum_x (N_{ex,x,t} \times POP_{poultry_{x,t}} \times MS_{x,PRP})$$

Where:

$N_2O_{indirect, volatilisation_{UD,poultry,x,t}}$  = indirect N<sub>2</sub>O 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<sub>2</sub>O per year)

$Frac_{GASam}$  = fraction of nitrogen excretion emitted as NO<sub>x</sub> or NH<sub>3</sub>. Currently set at 0.1 (see Appendix 18)

$EF_4$  = N<sub>2</sub>O emission factor for indirect emissions from volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$N_{ex,x,t}$  = Annual nitrogen excretion per animal in year  $t$ , for poultry type  $x$  (kg of nitrogen per year). See section 5.5.2 (nitrogen excretion, poultry) for specific values

$POP_{poultry_{x,t}}$  = 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 N<sub>2</sub>O 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  $Frac_{leach}$ .

Indirect volatilisation N<sub>2</sub>O emissions from urine and dung for swine (Equation 8.62):

$$N_2O_{\text{indirect, volatilisation}}_{UD, \text{swine}, t} = \frac{44}{28} \times EF_4 \times \text{Frac}_{GASam} \times N_{ex, \text{swine}, t} \times POP_{\text{swine}, t} \times MS_{\text{swine}, PRP}$$

Where:

$N_2O_{\text{indirect, volatilisation}}_{UD, \text{swine}, t}$  = indirect N<sub>2</sub>O emissions from volatilisation from urine and dung deposited by swine during grazing in year  $t$  (kg of N<sub>2</sub>O per year)

$\text{Frac}_{GASam}$  = fraction of nitrogen excretion emitted as NO<sub>x</sub> or NH<sub>3</sub>. Currently set at 0.1 (see Appendix 18)

$EF_4$  = N<sub>2</sub>O emission factor indirect emissions from volatilising nitrogen (0.01) (see Figure 2 and Appendix 18).

$N_{ex, x, t}$  = Annual nitrogen excretion per animal in year  $t$ , for swine (kg of nitrogen per year). See section 5.5.5

$POP_{\text{swine}, t}$  = population of swine in year  $t$  (from APS)

$MS_{\text{swine}, PRP}$  = 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<sub>2</sub>O 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  $\text{Frac}_{GASam}$  is used instead of  $\text{Frac}_{\text{leach}}$ .

Indirect volatilisation N<sub>2</sub>O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses (Equation 8.63):

$$N_2O_{\text{indirect, volatilisation}}_{UD, x, t} = \frac{44}{28} \times EF_4 \times \text{Frac}_{GASam} \times N_{ex, x, t} \times POP_{\text{minor}, x, t}$$

Where:

$N_2O_{\text{indirect, volatilisation}}_{UD, x, t}$  = indirect N<sub>2</sub>O emissions from volatilisation from urine and dung deposited by animal type  $x$  (i.e. goats, horses...) during grazing in year  $t$  (kg of N<sub>2</sub>O per year)

$\text{Frac}_{GASam}$  = fraction of nitrogen excretion emitted as NO<sub>x</sub> or NH<sub>3</sub>. Currently set at 0.1 (see Appendix 18)

$EF_4$  = N<sub>2</sub>O emission factor indirect emissions from volatilising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$N_{ex, x, t}$  = 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)

$POP_{\text{minor}, x}$  = 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<sub>4</sub>, CO, N<sub>2</sub>O and NO<sub>x</sub>. 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<sub>4</sub>, CO, N<sub>2</sub>O and NO<sub>x</sub> 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 ( $area_{Burn-c}$ ) and the proportion of residues burnt for each crop ( $Parea_{Burn-c}$ ).

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.

*Proportion of oat area burnt from 2005 onwards (Equation 9.1):*

$$Parea_{burn-oats} = \frac{area_{burn-oats}}{area_{oats}}$$

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)

*Proportion of barley area burnt from 2005 onwards (Equation 9.2):*

$$Parea_{burn-barley} = \frac{area_{burn-barley}}{area_{barley}}$$

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)

*Proportion of wheat area burnt from 2005 onwards (Equation 9.3):*

$$Parea_{burn-wheat} = \frac{area_{burn-wheat}}{area_{wheat}}$$

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)

*Oat area burnt from 2005 onwards (Equation 9.4):*

$$area_{burn-oats} = area_{oats} \times 0.5 \times \left( \frac{area_{burn,total}}{area_{oats} \times 0.5 + area_{barley} \times 0.5 + area_{wheat} \times 0.7} \right)$$

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)

*Barley area burnt from 2005 onwards (Equation 9.5):*

$$area_{burn-barley} = area_{barley} \times 0.5 \times \left( \frac{area_{burn,total}}{area_{oats} \times 0.5 + area_{barley} \times 0.5 + area_{wheat} \times 0.7} \right)$$

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)

*Wheat area burnt (Equation 9.6):*

$$= area_{wheat} \times 0.7 \times \left( \frac{area_{burn-wheat}}{area_{oats} \times 0.5 + area_{barley} \times 0.5 + area_{wheat} \times 0.7} \right)$$

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<sub>2</sub>O, NO<sub>x</sub>, CH<sub>4</sub> 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)	0.7	0.7	0.7
$Pres_{burn-C}$			
Fraction of above ground residue oxidized (kg oxidized/ kg DM)	0.9	0.9	0.9
$Frac_{COXIDISED}$			
Fraction of nitrogen in biomass (kg N/ kg DM)	0.005	0.005	0.005
$Frac_{N-BIOMASS}$			
Fraction of carbon in biomass (kg C/ kg DM) crop)	0.4567	0.4853	0.4567
$Frac_{C-BIOMASS}$			
Dry matter fraction (kg DM/ kg crop)	0.86	0.86	0.86



DMF <sub>crop-C</sub>			
Harvest Index (see equation x)	0.46	0.41	0.30
HI <sub>c</sub>			

**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 <sub>4</sub>	0.005
CO	0.06
N <sub>2</sub> O	0.007
NO <sub>x</sub>	0.121

## 9.2 Nitrous oxide field burning emissions

The following equations are used to calculate N<sub>2</sub>O emissions from the burning of barley, oats and wheat residues (kt/yr):

*Total annual nitrous oxide emissions from field burning of all crops (Equation 9.7):*

$$cropN_2O_{BURN} = N_2O_{BURN-barley} + N_2O_{BURN-oats} + N_2O_{BURN-wheat}$$

Where:

cropN<sub>2</sub>O<sub>BURN</sub> = annual nitrous oxide emissions from field burning of barley, oats and wheat (kilotonnes per year)

N<sub>2</sub>O<sub>BURN-barley</sub> = annual nitrous oxide emissions from field burning of barley (kilotonnes per year)

N<sub>2</sub>O<sub>BURN-oats</sub> = annual nitrous oxide emissions from field burning of oats (kilotonnes per year)

N<sub>2</sub>O<sub>BURN-wheat</sub> = annual nitrous oxide emissions from field burning of wheat (kilotonnes per year)

*Annual nitrous oxide emissions from field burning by crop type (Equation 9.8):*

$$N_2O_{BURN-c} = \frac{44}{28} \times AG_{BURN-c} \times Frac_{OXIDISED} \times Frac_{N-BIOMASS} \times ER_{N_2O}$$

Where:

N<sub>2</sub>O<sub>BURN-c</sub> = annual nitrous oxide emissions from field burning of crop c (i.e. barley, oats or wheat)(kilotonnes per year)

AG<sub>BURN-c</sub> = Biomass of crop burnt (tonnes per year) for crop type c (i.e. barley, oats or wheat)

Frac<sub>OXIDISED</sub> = Fraction of burnt biomass that is oxidised (currently set at 0.9 for barley, oats and wheat – see Table 9.1).

Frac<sub>N-BIOMASS</sub> = Fraction of biomass made up of nitrogen, (currently set at 0.005 for barley, oats and wheat– see Table 9.1).

$ER_{N_2O}$  = Emission ratio for  $N_2O$  (currently set at 0.007 – see table 9.2)

Calculation of biomass burned by crop type (Equation 9.9):

$$AG_{BURN-c} = AGresd_c \times Parea_{Burn-c} \times Presd_{Remain-c} \times Presd_{Burn-c}$$

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.

Above-ground residue by crop type (Equation 9.10)

$$AGresd_c = Prod_{crop-c} \times DMF_{crop-c} \times \left( \frac{1}{HI_c} - 1 \right)$$

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.

Total annual methane emissions from field burning of all crops (Equation 9.11)

$$cropCH_{4BURN} = CH_{4BURN-barley} + CH_{4BURN-oats} + CH_{4BURN-wheat}$$

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)

*Annual methane emissions from field burning by crop type (Equation 9.12)*

$$CH_4BURN-c = CarbonR_{BURN-c} \times molw_{CH_4} \times ER_{CH_4}$$

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

$molw_{CH_4}$  = molecular weight conversion of carbon to methane, (currently set at 16/12).

$ER_{CH_4}$  = Emission ratio for methane (currently set at 0.005 – see table 13)

*Amount of carbon released from field burning by crop type (Equation 9.13)*

$$CarbonR_{BURN-c} = AG_{BURN-c} \times Frac_{OXIDISED} \times Frac_{c-BIOMASS}$$

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 12).

$Frac_{c-BIOMASS}$  = Fraction of biomass made up of carbon, for crop type c (see Table 12 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.

*Total annual carbon monoxide emissions from field burning of all crops (Equation 9.14)*

$$cropCO_{BURN} = CO_{BURN-barley} + CO_{BURN-oats} + CO_{BURN-wheat}$$

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)

*Annual carbon monoxide emissions from field burning by crop type (Equation 9.15)*

$$CO_{BURN-c} = CarbonR_{BURN-c} \times molw_{CO} \times ER_{CO}$$

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<sub>x</sub> field burning emissions

NO<sub>x</sub> refers to nitrogen oxides such as nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>). Although they are not a greenhouse gases, their emissions have an indirect greenhouse effect. NO<sub>x</sub> emissions from field burning can be calculated by using the equations below.

*Total NO<sub>x</sub> emissions from field burning of all crops (Equation 9.16)*

$$cropNO_{xBURN} = NO_{xBURN-barley} + NO_{xBURN-oats} + NO_{xBURN-wheat}$$

Where:

$cropNO_{xBURN}$  = annual NO<sub>x</sub> emissions from field burning of barley, oats and wheat (kilotonnes per year)

$NO_{xBURN-barley}$  = annual NO<sub>x</sub> emissions from field burning of barley (kilotonnes per year)

$NO_{xBURN-oats}$  = annual NO<sub>x</sub> emissions from field burning of oats (kilotonnes per year)

$NO_{xBURN-wheat}$  = annual NO<sub>x</sub> emissions from field burning of wheat (kilotonnes per year)

*Annual NO<sub>x</sub> emissions from field burning by crop type (Equation 9.17)*

$$NO_{xBURN-c} = NitrogenR_{BURN-c} \times molw_{CH4} \times ER_{CH4}$$

Where:

$CO_{BURN-c}$  = annual NO<sub>x</sub> 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<sub>x</sub>, (uses a value of 46/14).

$ER_{NOx}$  = Emission ratio for NO<sub>x</sub> (currently set at 0.06 – see table 13)

*Amount of nitrogen released from field burning by crop type (Equation 9.18)*

$$NitrogenR_{BURN-c} = AG_{BURN-c} \times Frac_{OXIDISED} \times Frac_{N-BIOMASS}$$

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 12 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 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<sub>2</sub>) emissions from the application of limestone and dolomite is shown below.

*Carbon dioxide emissions from limestone and dolomite application (Equation 10.1)*

$$\begin{aligned} CO_{2\text{lime\&dolomite}} &= (M_{\text{Lime}} \times \text{conc}_{\text{Lime}} \times EF_{\text{Lime}} \times \text{molw}_{\text{CO}_2}) \\ &+ (M_{\text{dolomite}} \times \text{conc}_{\text{Dolomite}} \times EF_{\text{dolomite}} \times \text{corr}_{\text{CO}_2}) \end{aligned}$$

Where:

$CO_{2\text{lime\&dolomite}}$  = annual CO<sub>2</sub> emissions from the use of limestone and dolomite (kg CO<sub>2</sub> per year)

$M_{\text{Lime}}$  = Total annual amount of calcic limestone applied on farms (kg per year)

$\text{conc}_{\text{Lime}}$  = Concentration factor to account for purity of agricultural lime (set at 0.82)

$EF_{\text{Lime}}$  = Emission factor for calcic limestone (carbonate content of limestone, currently set at 0.12)

$\text{corr}_{\text{CO}_2}$  = molecular weight of CO<sub>2</sub> relative to that for carbon (set at 44/12, or 3.666666)

$M_{\text{dolomite}}$  = Total annual amount of dolomite applied on farms (kg per year)

$\text{conc}_{\text{Dolomite}}$  = Concentration factor to account for purity of dolomite (set at 1)

$EF_{\text{dolomite}}$  = Emission factor for dolomite (carbonate content of dolomite, currently set at 0.13)

The variable  $\text{molw}_{\text{CO}_2}$  is a conversion factor to convert from the mass of C in CO<sub>2</sub>, to the total mass of CO<sub>2</sub>.

### 10.2 Urea Application

The use of urea fertilizer, which accounts for the majority of synthetic nitrogen fertilizer used in New Zealand, produces CO<sub>2</sub> emissions following application to soil. The CO<sub>2</sub> is formed from bicarbonate, which is produced when the urea is converted to ammonium via hydrolysis. The CO<sub>2</sub> emissions are estimated using a Tier 1 methodology and equation 11.13 from the IPCC (2006) guidelines, using the default emission factor ( $EF_{\text{urea-carbon}}$ ) 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<sub>2</sub>O emissions from urea fertilizer as in Section 8. The following equation is used to calculate the CO<sub>2</sub> emissions from the application of urea fertilizer.

*Carbon dioxide emissions from urea application (Equation 10.2)*

$$CO_{2urea} = M_{urea} \times EF_{urea-carbon} \times corr_{CO2}$$

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)

$EF_{urea-carbon}$  = 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 Appendix

### Appendix 1: “Final Inputs” worksheet taken from the dairy inputs file for the Tier Two Inventory program

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 8). 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). 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 Yield per cow per year (kg per year)	Milk fat (% kg(fat)/ litres(milk))	Protein (% kg(protein)/ litres(milk))	Nitrogen retained in tissue (N <sub>16</sub> ) (% kg(N)/ 100kg (live weight))	National annual milk yield (kg per year)
1990	500.00	0.50	446.18	2828.68	4.66	3.42	3.26	7,415,048,490
1991	500.00	0.50	447.36	2802.59	4.71	3.48	3.26	7,632,256,223
1992	500.00	0.50	448.56	3024.93	4.75	3.52	3.26	7,990,992,245
1993	500.00	0.50	449.81	3003.44	4.75	3.53	3.26	8,178,170,507
1994	500.00	0.50	450.52	3274.38	4.77	3.53	3.26	9,194,547,559
1995	500.00	0.50	452.44	3081.53	4.74	3.50	3.26	9,226,178,180
1996	500.00	0.50	453.15	3147.42	4.71	3.49	3.26	9,924,546,701
1997	500.00	0.50	447.12	3416.24	4.75	3.52	3.26	10,998,755,116
1998	500.00	0.50	455.36	3407.06	4.68	3.44	3.26	11,310,334,956
1999	500.00	0.50	443.57	3211.00	4.63	3.47	3.26	10,879,890,000
2000	500.00	0.50	454.91	3589.20	4.67	3.52	3.26	11,978,900,000
2001	500.00	0.50	459.66	3797.67	4.70	3.53	3.26	13,312,750,000
2002	500.00	0.50	454.87	3815.19	4.68	3.54	3.26	14,015,210,000
2003	500.00	0.50	458.38	3728.49	4.72	3.59	3.26	14,323,180,000
2004	500.00	0.50	457.12	3828.01	4.76	3.58	3.26	15,036,970,000
2005	500.00	0.50	455.35	3539.98	4.77	3.57	3.26	14,525,673,322
2006	500.00	0.50	454.50	3675.34	4.78	3.59	3.26	15,143,034,389
2007	500.00	0.50	444.32	3767.37	4.81	3.63	3.26	15,588,239,702
2008	500.00	0.50	454.52	3644.53	4.76	3.61	3.26	15,187,207,491
2009	500.00	0.50	445.93	3800.97	4.79	3.64	3.26	16,525,314,663
2010	500.00	0.50	458.43	3685.14	4.81	3.66	3.26	16,977,338,483
2011	500.00	0.50	452.57	3815.95	4.81	3.66	3.26	17,858,996,504
2012	500.00	0.50	462.64	4090.88	4.84	3.71	3.26	19,702,477,306
2013	500.00	0.50	457.75	3882.22	4.83	3.70	3.26	19,449,144,828
2014	500.00	0.50	458.26	4251.48	4.86	3.72	3.26	21,277,104,467
2015	500.00	0.50	452.29	4229.31	4.87	3.76	3.26	21,890,330,519
2016	500.00	0.50	447.93	4260.25	4.88	3.77	3.26	21,541,562,614
2017	500.00	0.50	450.43	4098.60	4.89	3.80	3.26	21,322,817,354

2018	500.00	0.50	460.88	4231.96	4.85	3.77	3.26	21,345,213,486
2019	500.00	0.50	463.609	4361.71	4.66	3.42	3.26	21,853,600,359

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**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	2.5
	Breeding mature cows	4
	Breeding Bulls – mixed age	4
	Slaughter heifers 0 – 1	0.5
	Slaughter heifers 1 - 2	1.5
	Slaughter steers 0 – 1	0.5
	Slaughter steers 1 – 2	1.5
	Slaughter Bulls 0 - 1	0.5
	Slaughter Bulls 1 – 2	1.5
Sheep	Breeding ewes	4
	Dry ewes	4
	Growing breeding sheep	1
	Growing non-breeding sheep	1
	Wethers	4
	Lambs	0.5
	Rams	3
Deer	Hinds 0 -1	0.5
	Hinds 1 -2	1.5
	Mix age breeding hinds	4
	Stags 0 - 1	1
	Stags 1 - 2	1.5
	Stags 2 - 3	2.5
	Mix age breeding stags	4



### Appendix 3: Monthly digestibility of feed and energy concentration of feed for dairy for entire time series

Provided through an analysis of nationally collated data on metabolisable energy, organic matter digestibility, and nitrogen content (Giltrap & McNeill, 2020).

Monthly feed Digestibility and ME content												
Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Digestibility of feed (kg/kg)	0.794	0.811	0.824	0.820	0.770	0.752	0.741	0.711	0.697	0.737	0.753	0.783
ME of feed (ME <sub>con</sub> ; MJ ME/kg dry matter)	11.8	12.1	12.3	12.3	11.3	11.1	10.6	10.3	10.0	10.6	10.8	11.5

### Appendix 4: Proportion of annual milk yield each month

Month	Dairy	Beef	Sheep	Deer
July	0.009	0	0	0
August	0.058	0	0	0
September	0.121	0.167	0.164	0
October	0.150	0.167	0.254	0
November	0.142	0.167	0.246	0.1
December	0.128	0.167	0.254	0.258
January	0.111	0.167	0.082	0.258
February	0.090	0.167	0	0.233
March	0.085	0	0	0.150
April	0.065	0	0	0
May	0.033	0	0	0
June	0.006	0	0	0

**Appendix 5: Cumulative pregnancy of days pregnant used in ME requirement equations**

Month	Dairy	Beef	Sheep	Deer
July	269	220	97	159
August	0	251	128	190
September	0	269	138	220
October	0	0	0	251
November	26	0	0	269
December	57	8	0	0
January	88	39	0	0
February	116	67	0	6
March	147	98	0	37
April	177	128	5	67
May	208	159	36	98
June	238	189	66	128

## Appendix 6: 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	95697	2621378	3302377	29941
1991	86692	2723288	3440815	31174
1992	87695	2641712	3429427	35315
1993	92274	2722939	3467824	30631
1994	86737	2808030	3550140	29642
1995	120070	2994022	3839184	31430
1996	158391	3153230	4089817	31543
1997	182159	3219548	4165098	32401
1998	187824	3319680	4256000	33409
1999	191708	3388320	4344000	34099
2000	170227	3337486	4316409	39657
2001	194584	3505508	4598136	44447
2002	205432	3673531	4879862	49237
2003	221538	3841553	5161589	54027
2004	149190	3928140	5101603	43707
2005	174124	4103318	5152492	44661
2006	212042	4120176	5087176	38536
2007	234880	4137697	5169557	45190
2008	305727	4167121	5260850	53331
2009	335565	4347657	5578440	56466
2010	331428	4606971	5860776	57480
2011	339286	4680096	5915452	57808
2012	403704	4816190	6174503	66448
2013	407820	5009795	6445681	70410
2014	418866	5004634	6483600	75141
2015	483233	5175869	6698326	79572
2016	335790	5056403	6485535	70548
2017	345398	5202467	6618800	69583
2018	414784	5043813	6529811	71079
2019	393144	5010334	6385541	79983

## Appendix 7: 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.

Example for June year end 2010. Data obtained from Dairy NZ Statistics:

Age	Holstein Friesian			Jersey			Holstein Friesian Jersey		
	Number	Weight (kg)	Proportion of weight cows in each age class	Number	Weight (kg)	Proportion of weight per age class	Number	Weight (kg)	Proportion of weight per age class
2	194,511	396.70	80.27743888	66,612	317.44	60.32968502	244,165	370.51	85.66831959
3	166,399	481.17	83.29834938	60,118	366.59	62.8784854	199,394	428.02	80.81892189
4	138,738	515.38	74.3892418	51,013	382.37	55.65210676	152,614	450.81	65.15156027
5	126,665	520.08	68.53523748	47,263	405.77	54.71648039	132,605	467.59	58.71675131
6	99,144	533.40	55.01822684	36,273	409.08	42.3358864	98,832	477.63	44.70191057
7	76,863	525.77	42.0436367	30,031	419.67	35.95792754	79,439	480.15	36.11998872
8	61,636	533.15	34.18778795	22,400	425.37	27.18515475	59,090	486.49	27.22229976
9	46,625	531.37	25.7752578	16,149	424.59	19.56285923	41,953	493.33	19.59915974
10	50,617	531.08	27.96684592	20,637	416.25	24.50855716	47,906	489.15	22.19059118
Total	961,198		<b>491.4920228</b>	350,496		<b>383.1271426</b>	1,055,998		<b>440.189503</b>
NZ National dairy cow breeds:			Breakdown of breed types in the National NZ dairy herd (%).				Proportion of dairy breed live weight per age class from the National dairy herd (kg).		
Holstein Friesian			40.0				196.4		
Jersey			12.4				47.7		
Holstein Friesian Jersey			38.9				171.2		
other			8.7				38.1		
National average dairy cow weight (kg)							453.42		

# Appendix 8: “Final Inputs” worksheet taken from the Beef inputs file for the Tier Two Inventory program

The live weight of mature cow is calculated using dairy cow weights and slaughter weights (Appendix 11). Breeding bull weights are kept constant. All other weights are converted from slaughter weights as collected and reported by MPI. 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). 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 live weight (kg)	Heifer live weight (kg)	Bull live weight (kg)	Milking cow live 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)/ 100kg(milk))	Protein (kg(protein)/ 100kg(milk))	Nitrogen retained in tissue (N <sub>re</sub> ) (kg(N)/ 100kg(live weight))
1990	562.98	411.24	543.84	424.29	600.00	0.50	824.00	4.62	3.34	3.26
1991	563.32	407.83	550.20	390.45	600.00	0.50	824.00	4.66	3.34	3.26
1992	577.87	419.78	565.49	406.34	600.00	0.50	824.00	4.71	3.34	3.26
1993	588.49	423.04	570.10	428.22	600.00	0.50	824.00	4.75	3.34	3.26
1994	584.62	421.88	563.34	423.45	600.00	0.50	824.00	4.75	3.34	3.26
1995	606.26	436.23	589.40	458.31	600.00	0.50	824.00	4.77	3.34	3.26
1996	602.70	437.36	589.08	437.89	600.00	0.50	824.00	4.74	3.34	3.26
1997	593.60	433.89	577.02	450.11	600.00	0.50	824.00	4.71	3.34	3.26
1998	605.48	441.95	612.08	504.88	600.00	0.50	824.00	4.75	3.34	3.26
1999	603.43	439.16	609.57	488.04	600.00	0.50	824.00	4.68	3.34	3.26
2000	589.20	431.42	587.50	468.39	600.00	0.50	824.00	4.63	3.34	3.26
2001	602.67	441.34	600.02	476.36	600.00	0.50	824.00	4.67	3.34	3.26
2002	617.63	441.57	609.63	510.91	600.00	0.50	824.00	4.70	3.34	3.26
2003	612.01	445.61	598.05	493.69	600.00	0.50	824.00	4.69	3.34	3.26
2004	614.04	454.44	608.76	499.70	600.00	0.50	824.00	4.72	3.34	3.26
2005	623.68	458.76	616.06	507.29	600.00	0.50	824.00	4.76	3.34	3.26
2006	622.60	458.41	620.06	519.91	600.00	0.50	824.00	4.77	3.34	3.26
2007	635.52	465.71	628.18	546.39	600.00	0.50	824.00	4.78	3.34	3.26
2008	623.67	461.60	615.15	568.27	600.00	0.50	824.00	4.81	3.34	3.26
2009	607.71	462.91	598.51	533.45	600.00	0.50	824.00	4.76	3.34	3.26
2010	603.08	458.22	599.00	561.96	600.00	0.50	824.00	4.79	3.34	3.26
2011	623.47	474.97	622.28	525.10	600.00	0.50	824.00	4.81	3.34	3.26
2012	608.52	462.35	595.80	528.04	600.00	0.50	824.00	4.81	3.34	3.26
2013	628.08	485.00	615.99	563.24	600.00	0.50	824.00	4.84	3.34	3.26
2014	621.07	480.94	609.66	527.48	600.00	0.50	824.00	4.83	3.34	3.26
2015	608.81	470.58	604.72	533.71	600.00	0.50	824.00	4.86	3.34	3.26
2016	599.44	464.31	593.89	558.59	600.00	0.50	824.00	4.87	3.34	3.26
2017	611.70	468.62	604.65	553.25	600.00	0.50	824.00	4.88	3.34	3.26
2018	625.84	481.21	610.67	566.72	600.00	0.50	824.00	4.89	3.34	3.26
2019	622.66	481.37	602.97	512.65	600.00	0.50	824.00	4.85	3.34	3.26

**Appendix 9: Monthly digestibility of feed (percentage as a decimal) and energy concentration of feed (MJ ME/kg dry matter) for all years in the time series for sheep, beef and deer.**

Average monthly digestibility of feed and energy concentration of feed as determined for sheep and beef for all years, and 1990 and 2010 for deer.

Month	Monthly Digestibility (Decimal)											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
<b>Sheep and beef</b>												
Digestibility of feed	0.736	0.756	0.772	0.767	0.708	0.687	0.674	0.640	0.625	0.670	0.688	0.722
ME of feed	10.8	11.1	11.3	11.3	10.3	10.1	9.6	9.2	9.0	9.6	9.7	10.5
<b>Deer 1990</b>												
Digestibility of feed	0.763	0.781	0.796	0.791	0.737	0.717	0.705	0.673	0.658	0.701	0.718	0.750
ME of feed	11.3	11.6	11.8	11.8	10.8	10.6	10.1	9.7	9.5	10.1	10.2	11.0
<b>Deer 2010</b>												
Digestibility of feed	0.742	0.762	0.777	0.772	0.714	0.694	0.681	0.647	0.632	0.667	0.695	0.728
ME of feed	10.9	11.2	11.4	11.4	10.5	10.2	9.7	9.3	9.1	9.7	9.8	10.6

*Provided through an analysis of nationally collated data on metabolisable energy, organic matter digestibility, and nitrogen content (Giltrap & McNeill, 2020).*

## Appendix 10: 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	APS Population Data			MPI Slaughter Statistics		
	Breeding Cows	Bulls	Total	Heifers	Steers	Bulls
1990	1,386,418	78,965	4,593,160	520,327	804,758	447,345
1991	1,388,000	76,865	4,670,569	376,170	581,095	382,936
1992	1,418,955	76,907	4,676,497	418,723	637,721	434,053
1993	1,462,787	86,448	4,757,962	428,031	649,168	496,351
1994	1,576,587	91,245	5,047,848	425,363	580,125	573,791
1995	1,616,860	88,052	5,182,508	448,888	611,463	556,127
1996	1,595,548	86,676	4,852,179	427,974	708,551	514,929
1997	1,590,000	88,052	4,806,000	492,787	807,203	473,690
1998	1,443,000	79,911	4,432,000	518,288	779,084	370,000
1999	1,457,413	80,709	4,643,705	511,528	781,985	346,601
2000	1,392,048	80,120	4,594,029	454,696	610,419	368,664
2001	1,326,682	79,531	4,544,354	486,969	588,710	486,552
2002	1,259,190	78,945	4,491,281	437,632	544,873	610,512
2003	1,288,214	80,428	4,626,617	401,716	467,291	626,450
2004	1,263,243	67,548	4,447,400	453,700	488,552	640,547
2005	1,255,255	71,305	4,423,626	513,956	583,473	698,050
2006	1,268,981	71,709	4,439,136	509,613	596,501	577,052
2007	1,195,098	80,424	4,393,617	500,590	621,409	531,330
2008	1,103,603	66,336	4,136,872	492,805	607,224	525,898
2009	1,096,014	78,259	4,100,718	500,652	647,770	553,518
2010	1,117,659	70,383	3,948,520	516,472	604,933	485,606
2011	1,052,822	72,379	3,846,414	508,558	616,462	439,024
2012	1,059,784	78,334	3,734,412	480,440	595,519	431,793
2013	1,019,012	75,214	3,698,522	460,527	569,194	445,098
2014	1,011,914	81,037	3,669,862	443,404	577,346	426,003
2015	981,856	82,105	3,547,228	454,416	573,443	435,835
2016	953,618	73,972	3,533,054	488,372	566,632	482,586

2017	976,094	76,302	3,616,091	481,561	525,297	465,016
2018	1,029,149	85,992	3,721,262	478,249	531,140	460,669
2019	1,104,700	87,849	3,889,996	480,967	535,268	537,108



# Appendix 11: Mature beef cow live weight calculation spreadsheet

For further details see Clark (2008).

Year	Dairy cow live weight kg	Cows slaughtered Number	Dairy cows in milk or in calf Number	Beef breeding cows Number	Killing out dairy cows %	Carcass weight of dairy cows kg	Total weight all carcasses kg	Beef cow replacement rate (%)	Beef cows killed Number	Dairy cattle killed Number	Total weight dairy carcass kg	Total weight beef carcass kg	Av beef cow carcass weight kg	Av beef cow live weight kg
1990	446	581,472	2,621,378	1,355,000	0.42	187	104,113,209	0.17	230,350	351,122	65,798,553	38,314,656	166	390
1991	447	645,694	2,723,288	1,386,418	0.42	188	117,834,423	0.17	235,691	410,003	77,035,679	40,798,744	173	406
1992	449	611,885	2,641,712	1,388,000	0.42	188	113,866,925	0.17	235,960	375,925	70,823,144	43,043,781	182	428
1993	450	590,799	2,722,939	1,418,955	0.42	189	109,557,298	0.17	241,222	349,577	66,042,457	43,514,841	180	423
1994	451	548,110	2,808,030	1,462,787	0.42	189	105,221,126	0.17	248,674	299,436	56,658,927	48,562,199	195	458
1995	452	657,411	2,994,022	1,576,587	0.42	190	123,991,226	0.17	268,020	389,391	73,994,015	49,997,211	187	438
1996	453	738,937	3,153,230	1,616,860	0.42	190	141,028,097	0.17	274,866	464,071	88,323,027	52,705,070	192	450
1997	447	720,733	3,219,548	1,595,548	0.42	188	142,747,668	0.17	271,243	449,490	84,409,180	58,338,488	215	505
1998	455	875,375	3,319,680	1,590,000	0.42	191	171,918,238	0.17	270,300	605,075	15,721,344	56,196,894	208	488
1999	444	749,863	3,388,320	1,443,000	0.42	186	142,945,239	0.17	245,310	504,553	93,997,030	48,948,209	200	468
2000	455	687,825	3,337,486	1,457,413	0.42	191	134,357,518	0.17	247,760	440,065	84,079,830	50,277,688	203	476
2001	460	596,814	3,505,508	1,392,048	0.42	193	121,038,567	0.17	236,648	360,166	69,532,320	51,506,247	218	511
2002	455	674,042	3,673,531	1,326,682	0.42	191	133,117,998	0.17	225,536	448,506	85,685,067	47,432,931	210	494
2003	458	816,993	3,841,553	1,259,190	0.42	193	161,643,304	0.17	214,062	602,931	116,075,385	45,567,919	213	500
2004	457	853,640	3,928,140	1,288,214	0.42	192	169,172,543	0.17	218,996	634,644	121,845,926	47,326,617	216	507
2005	455	795,344	4,103,318	1,263,243	0.42	191	158,599,700	0.17	214,751	580,593	111,036,610	47,563,090	221	520
2006	455	668,020	4,120,176	1,255,255	0.42	191	136,453,282	0.17	213,393	454,627	86,783,681	49,669,601	233	546
2007	444	709,163	4,137,697	1,268,981	0.42	187	144,305,545	0.17	215,727	493,436	92,082,002	52,223,543	242	568
2008	455	642,858	4,167,121	1,195,098	0.42	191	130,105,840	0.17	203,167	439,691	83,936,661	46,169,179	227	533
2009	446	837,919	4,347,657	1,103,603	0.42	187	166,708,922	0.17	187,613	650,306	121,795,102	44,913,820	239	562
2010	458	826,812	4,606,971	1,096,014	0.42	193	165,000,115	0.17	186,322	640,490	123,320,833	41,679,282	224	525
2011	453	869,841	4,680,096	1,117,659	0.42	190	171,962,939	0.17	190,002	679,839	29,223,208	42,739,731	225	528
2012	463	742,864	4,816,190	1,052,822	0.42	194	152,511,600	0.17	178,980	563,884	109,567,081	42,944,519	240	563
2013	458	925,345	5,009,795	1,059,784	0.42	192	183,748,092	0.17	180,163	745,182	143,264,550	40,483,542	225	527
2014	458	910,092	5,004,634	1,019,012	0.42	192	181,208,065	0.17	173,232	736,860	141,821,764	39,386,301	227	534
2015	452	1,089,436	5,175,869	1,011,914	0.42	190	215,207,216	0.17	172,025	917,411	174,272,380	40,934,836	238	559
2016	448	1,155,295	5,056,403	981,856	0.42	188	225,281,812	0.17	166,916	988,379	185,942,569	39,339,241	236	553
2017	450	946,801	5,202,467	953,618	0.42	189	187,586,293	0.17	162,115	784,686	148,448,016	39,138,277	241	567
2018	461	1,032,175	5,043,813	976,094	0.42	194	203,916,297	0.17	165,936	866,239	167,677,620	36,238,677	218	513
2019	464	978,818	5,010,334	1,029,149	0.42	195	195,655,439	0.17	174,955	803,863	156,524,765	39,130,674	224	525

## Appendix 12: Final Inputs taken from the sheep inputs file 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	Dry Ewe live weight at slaughter (kg)	Ram live weight at slaughter (kg)	Lamb live weight at slaughter (kg)	Live weight change ram (kg/yr)	Greasy Fleece Weight (kg/yr)	Annual Milk Yield (Kg/yr)	Butterfat (kg(fat)/100kg(milk))	Nitrogen retained in tissue (N <sub>te</sub> ) (kg(N)/100 kg (live weight))	Nitrogen in wool (kg N/kg wool)	Lambing Percentage rate	National wool yield (kg/yr)
1990	49.4	69.1	29.1	0.05	5	103	8	2.6	0.134	0.975	341,000,000
1991	50.9	71.3	30.5	0.05	5	103	8	2.6	0.134	0.941	309,000,000
1992	51.4	71.9	31.3	0.05	5	103	8	2.6	0.134	0.965	305,300,000
1993	51.5	72.1	31.7	0.05	5	103	8	2.6	0.134	0.972	295,900,000
1994	51.0	71.4	33.2	0.05	5	103	8	2.6	0.134	0.911	255,500,000
1995	54.2	75.9	33.9	0.05	5	103	8	2.6	0.134	0.989	284,000,000
1996	52.7	73.8	32.4	0.05	5	103	8	2.6	0.134	1.035	288,600,000
1997	53.5	74.9	33.7	0.05	5	103	8	2.6	0.134	1.004	268,800,000
1998	55.4	77.5	35.1	0.05	5	103	8	2.6	0.134	1.088	274,800,000
1999	56.2	78.7	34.3	0.05	5	103	8	2.6	0.134	1.103	265,800,000
2000	56.5	79.2	34.8	0.05	5	103	8	2.6	0.134	1.019	252,000,000
2001	58.1	81.4	36.5	0.05	5	103	8	2.6	0.134	1.081	257,300,000
2002	59.8	83.8	36.8	0.05	5	103	8	2.6	0.134	1.076	236,700,000
2003	58.2	81.5	37.1	0.05	5	103	8	2.6	0.134	1.031	228,800,000
2004	58.6	82.1	37.4	0.05	5	103	8	2.6	0.134	1.140	227,100,000
2005	60.5	84.7	38.3	0.05	5	103	8	2.6	0.134	1.085	217,700,000
2006	61.8	86.5	38.6	0.05	5	103	8	2.6	0.134	1.130	215,300,000
2007	61.8	86.5	38.3	0.05	5	103	8	2.6	0.134	1.144	224,500,000
2008	60.3	84.4	37.4	0.05	5	103	8	2.6	0.134	1.103	217,600,000
2009	58.3	81.7	36.6	0.05	5	103	8	2.6	0.134	1.085	205,800,000
2010	60.0	84.0	38.7	0.05	5	103	8	2.6	0.134	1.118	157,500,000
2011	61.9	86.7	39.2	0.05	5	103	8	2.6	0.134	1.171	185,800,000
2012	59.6	83.5	39.7	0.05	5	103	8	2.6	0.134	1.046	172,700,000
2013	63.2	88.5	41.1	0.05	5	103	8	2.6	0.134	1.153	164,900,000
2014	62.5	87.5	40.1	0.05	5	103	8	2.6	0.134	1.139	169,900,000
2015	62.9	88.0	40.5	0.05	5	103	8	2.6	0.134	1.123	158,200,000
2016	62.7	87.8	40.3	0.05	5	103	8	2.6	0.134	1.182	154,500,000
2017	62.6	87.6	40.7	0.05	5	103	8	2.6	0.134	1.180	151,600,000
2018	63.8	89.3	41.3	0.05	5	103	8	2.6	0.134	1.215	143,400,000
2019	64.0	89.6	41.0	0.05	5	103	8	2.6	0.134	1.223	141,300,000

### Appendix 13: 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	684,662	40,453,499	1,246,661	1,643,103	8,938,057	732,058	2,393,466	1,760,686	40,616,456	57,852,192
1991	666,113	36,631,076	1,212,886	3,201,837	8,695,902	712,225	2,328,621	1,712,984	38,716,291	55,161,643
1992	640,588	36,684,469	794,574	1,714,532	8,023,500	697,784	2,324,510	1,688,436	34,990,925	52,568,393
1993	575,207	35,374,952	706,605	1,262,702	7,966,586	667,934	2,142,130	1,602,245	36,243,948	50,298,361
1994	541,283	34,437,986	767,898	1,316,284	8,319,053	608,261	2,106,872	1,274,690	37,017,649	49,466,054
1995	516,374	33,692,996	848,541	1,305,607	8,269,253	578,549	2,160,143	1,246,002	35,148,880	48,816,271
1996	501,556	33,446,796	519,786	944,730	7,956,081	650,937	2,195,511	1,178,509	37,426,000	47,393,907
1997	350,402	33,021,000	241,886	1,891,068	8,882,000	418,500	1,411,536	617,609	38,521,000	46,834,000
1998	344,859	32,355,000	238,060	1,861,154	8,748,000	411,880	1,389,208	607,840	34,853,607	45,956,000
1999	767,626	30,364,254	529,901	1,869,499	6,786,549	916,809	3,092,256	1,352,998	34,840,000	45,679,891
2000	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
2001	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
2002	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
2003	420,945	27,086,569	290,583	2,271,780	5,563,982	726,370	2,449,937	741,947	31,853,940	39,552,113
2004	398,788	26,742,440	301,198	2,662,492	5,364,817	706,796	2,366,229	728,378	33,225,836	39,271,137
2005	382,371	26,418,797	236,632	3,130,399	5,850,583	748,380	2,505,446	607,059	33,809,880	39,879,668
2006	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
2007	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
2008	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
2009	348,318	22,214,044	223,869	1,821,217	4,667,610	610,784	2,044,798	452,950	28,152,100	32,383,589
2010	313,444	21,793,694	224,066	2,077,197	4,834,558	675,500	2,261,458	382,694	24,967,363	32,562,612
2011	316,280	20,484,792	339,381	2,015,897	4,650,351	670,229	2,243,808	411,592	25,954,154	31,132,329
2012	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
2013	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
2014	297,419	19,779,205	244,900	2,072,038	4,189,670	671,628	2,248,493	300,047	25,832,974	29,803,402
2015	290,187	19,074,356	313,941	1,750,318	4,561,932	664,272	2,223,868	241,954	24,570,347	29,120,827
2016	271,085	18,137,180	322,511	1,694,888	4,294,238	591,911	1,981,617	290,242	24,102,597	27,583,673
2017	264,731	17,755,322	371,132	1,980,740	4,281,532	602,254	2,016,241	254,258	24,127,372	27,526,537
2018	274,231	17,161,744	379,309	2,018,126	4,264,600	678,974	2,273,086	245,697	24,707,163	27,295,749
2019	273,225	16,845,367	338,699	2,073,458	4,224,674	652,706	2,185,145	228,574	22,745,000	26,821,846

**Appendix 14: Deer inputs**

Year	Hind live weight (kg)	Stag live weight (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	100	133	204	3.71	9	1.94
1991	101	130	204	3.71	9	1.60
1992	105	133	204	3.71	9	1.63
1993	106	142	204	3.71	9	1.94
1994	110	146	204	3.71	9	2.31
1995	105	149	204	3.71	9	2.61
1996	110	156	204	3.71	9	2.85
1997	111	153	204	3.71	9	3.07
1998	118	167	204	3.71	9	2.99
1999	120	160	204	3.71	9	3.37
2000	122	167	204	3.71	9	2.87
2001	125	164	204	3.71	9	3.46
2002	128	159	204	3.71	9	3.22
2003	127	158	204	3.71	9	3.35
2004	129	153	204	3.71	9	2.95
2005	131	159	204	3.71	9	3.80
2006	133	163	204	3.71	9	2.29
2007	135	163	204	3.71	9	3.62
2008	134	160	204	3.71	9	3.16
2009	133	159	204	3.71	9	3.21
2010	135	166	204	3.71	9	3.22
2011	139	163	204	3.71	9	4.00
2012	138	163	204	3.71	9	4.00
2013	140	166	204	3.71	9	4.00
2014	139	165	204	3.71	9	4.00
2015	138	163	204	3.71	9	4.00
2016	138	163	204	3.71	9	4.00
2017	140	164	204	3.71	9	4.00
2018	141	171	204	3.71	9	4.00
2019	142	172	204	3.71	9	4.00

# Appendix 15: Deer population data

Values are June year end

Year end June	HINDS			STAGS				Total population  numbers
	Mixed age breeding	1-2 years old	0-1 years old	Mixed age breeding	0-1 years old	1-2 years old	2-3 years old	
	proportion	proportion	proportion	proportion	proportion	proportion	proportion	
1990	0.44	0.09	0.12	0.11	0.16	0.05	0.02	780,066
1991	0.38	0.07	0.15	0.12	0.19	0.05	0.02	976,290
1992	0.39	0.08	0.13	0.16	0.16	0.05	0.02	1,129,503
1993	0.38	0.08	0.14	0.16	0.15	0.05	0.02	1,135,242
1994	0.38	0.08	0.15	0.16	0.14	0.05	0.02	1,078,479
1995	0.37	0.07	0.16	0.16	0.14	0.05	0.02	1,231,109
1996	0.39	0.08	0.12	0.17	0.15	0.05	0.03	1,178,704
1997	0.41	0.08	0.15	0.14	0.16	0.05	0.02	1,192,138
1998	0.42	0.08	0.16	0.11	0.16	0.05	0.02	1,353,688
1999	0.43	0.09	0.18	0.09	0.17	0.05	0.01	1,515,238
2000	0.44	0.09	0.17	0.09	0.17	0.05	0.01	1,676,788
2001	0.45	0.09	0.16	0.08	0.18	0.05	0.01	1,667,171
2002	0.47	0.09	0.15	0.07	0.18	0.05	0.01	1,657,555
2003	0.45	0.09	0.16	0.08	0.18	0.05	0.01	1,647,938
2004	0.43	0.09	0.19	0.08	0.18	0.05	0.01	1,689,444
2005	0.41	0.12	0.17	0.07	0.17	0.05	0.01	1,756,888
2006	0.41	0.10	0.19	0.07	0.18	0.05	0.01	1,705,084
2007	0.43	0.10	0.17	0.07	0.18	0.04	0.01	1,586,918
2008	0.43	0.09	0.18	0.07	0.18	0.04	0.01	1396023
2009	0.43	0.10	0.17	0.07	0.19	0.04	0.01	1,223,324
2010	0.43	0.10	0.18	0.07	0.17	0.05	0.01	1,145,858
2011	0.42	0.10	0.18	0.07	0.17	0.04	0.01	1,122,695
2012	0.42	0.10	0.18	0.08	0.17	0.03	0.01	1,088,533
2013	0.42	0.10	0.18	0.08	0.18	0.04	0.01	1,060,694
2014	0.42	0.10	0.17	0.08	0.17	0.04	0.01	1,028,382
2015	0.40	0.10	0.17	0.10	0.17	0.04	0.01	958,219
2016	0.41	0.10	0.17	0.10	0.17	0.04	0.01	900,100

**Appendix 16: Population numbers for non-key source livestock categories**

	Goat	Swine	Poultry	Horse	Alpaca and llama	Mules and asses
	(1000s)	(1000s)	(1000s)	(1000s)	(1000s)	(1000s)
1990	1,063	395	8,719	94	0.397	0.141
1991	793	407	8,687	90	0.498	0.141
1992	533	411	8,790	88	0.63	0.141
1993	353	395	9,217	87	0.752	0.141
1994	284	423	9,296	68	0.859	0.141
1995	337	431	10,587	69	1.032	0.141
1996	228	424	11,069	68	1.234	0.141
1997	228	417	10,862	69	1.427	0.141
1998	228	412	11,267	70	1.706	0.141
1999	186	369	11,547	72	2.142	0.141
2000	175	369	11,673	73	2.677	0.141
2001	164	354	12,118	74	3.434	0.141
2002	153	342	12,824	76	4.356	0.141
2003	179	377	13,934	80	6.091	0.141
2004	141	389	14,768	77	7.811	0.141
2005	136	341	15,080	73	10.337	0.141
2006	131	356	14,388	68	12.586	0.141
2007	112	367	14,226	66	14.794	0.141
2008	96	325	14,258	63	15.334	0.141
2009	82	323	13,427	65	15.887	0.141
2010	95	335	13,609	64	15.224	0.141
2011	86	327	13,739	57	14.122	0.141
2012	90	314	14,001	57	14.168	0.141
2013	80	298	14,177	57	14.523	0.141
2014	97	287	15,082	52	15.804	0.141
2015	75	268	15,975	41	8.091	0.141
2016	112	255	17,133	49	8.127	0.141
2017	99	274	17,777	44	9.649	0.141
2018	89	287	17,949	41	8.619	0.141
2019	94	256	18,757	38	10.185	0.141

Appendix 17: Fraction of manure excreted in each animal manure management system (MMS) - for all livestock species

MMS	Proportion of nitrogen in each management system (MS)							
	Dairy	Beef	Sheep	Deer	Goats	Swine	Poultry	Horse
Pasture Range and Paddock	0.95	1.0	1.0	1.0	1.0	0.09	Broilers – 0.049 Layers – 0.058 Other - 0.03	1.0
Anaerobic lagoon	.05					0.21		
Solid storage and dry lot						0.42		
Daily Spread						0.26		
Other management						0.02	Broilers – 0.951 Layers – 0.942 Other - 0.97	
Reference	Ledgard & Brier 2004	Animals graze outside 365 days/annum	Animals graze outside 365 days/annum	Animals graze outside 365 days/annum	IPCC default table 4-21 1996 IPCC reference manual	Hill 2012	Fick <i>et al.</i> , 2011	IPCC default table 4-21 1996 IPCC reference manual

**Appendix 18: Emission factor and fractions used to determine direct and indirect N<sub>2</sub>O emissions from Agricultural soils**

Parameter	Emission factor or fraction value	Units	Reference
<b>Frac<sub>gasf</sub></b>	0.1	kg(NH <sub>3</sub> -N + NO <sub>x</sub> -N)/kg(N applied)	Sherlock <i>et al.</i> , 2008
<b>Frac<sub>gasf,UI</sub></b>	0.055	kg(NH <sub>3</sub> -N + NO <sub>x</sub> -N)/kg(N applied)	Saggar <i>et al.</i> , (2013)
<b>Frac<sub>gasm</sub></b>	0.1	kg(NH <sub>3</sub> -N + NO <sub>x</sub> -N)/kg(N applied)	Sherlock <i>et al.</i> , 2008
<b>Frac<sub>LEACH(SN,ON,U,Renew)</sub></b>	0.07	kg N/kg of fertiliser or manure N	Thomas <i>et al.</i> , 2003 & 2005
<b>Frac<sub>LEACH(CR)</sub></b>	0.1	kg N/kg of fertiliser or manure N	Welten <i>et al.</i> , (2021)
<b>Frac<sub>BURN</sub></b>	Crop specific	kg N/kg crop-N	Thomas <i>et al.</i> , 2008
<b>Frac<sub>RENEW</sub></b>	Year specific		Beare <i>et al.</i> , 2012; Thomas <i>et al.</i> , 2014
<b>Frac<sub>REMOVE</sub></b>	0	kg N/kg crop-N	Thomas <i>et al.</i> , 2014
<b>EF<sub>1</sub></b>	0.01	kg(N <sub>2</sub> O-N)/kg(N applied)	Kelliher & de Klein, 2006
<b>EF<sub>1urea</sub></b>	0.0059	kg(N <sub>2</sub> O-N)/kg(N applied)	Kelliher <i>et al.</i> , 2014
<b>EF<sub>2</sub></b>	8	kg(N <sub>2</sub> O-N)/ha/yr	IPCC 2006, Table 11.1
<b>EF<sub>3PR&amp;P DUNG</sub></b>	0.0012	kg(N <sub>2</sub> O-N)/kg(excreted N)	van der Weerden <i>et al.</i> , 2019
<b>EF<sub>3PR&amp;P</sub></b>	based on slope and livestock category, see table 8.1		
<b>EF<sub>3PR&amp;P MINOR</sub></b>	0.01	kg(N <sub>2</sub> O-N)/kg(excreted N)	Based on Carran <i>et al.</i> , 1995; Muller <i>et al.</i> , 1995; de Klein <i>et al.</i> , 2003; Kelliher <i>et al.</i> , 2003
<b>EF<sub>3AL</sub></b>	0.001	kg(N <sub>2</sub> O-N)/kg(excreted N)	IPCC 2006, pg. 10.52 note in text.
<b>EF<sub>3SSD</sub></b>	0.02	kg(N <sub>2</sub> O-N)/kg(excreted N)	IPCC 2006, Table 10.21
<b>EF<sub>3OTHER</sub></b>	0.005	kg(N <sub>2</sub> O-N)/kg(excreted N)	IPCC GPG Table 4.13 (poultry manure without bedding)
<b>EF<sub>3poultry</sub></b>	0.001	kg(N <sub>2</sub> O-N)/kg(excreted N)	Fick <i>et al.</i> , 2011
<b>EF<sub>4</sub></b>	0.01	kg(N <sub>2</sub> O-N)/kg(deposited NH <sub>3</sub> -N + NO <sub>x</sub> -N)	IPCC 2006, Table 11.3
<b>EF<sub>5</sub></b>	0.025	kg(N <sub>2</sub> O-N)/kg(leached N)	IPCC 2006, Table 11.3



**Appendix 19: Nitrogen content of the diet for dairy, beef, sheep and deer**

Percent Nitrogen in Diet kg(N)/100kg(dietary DM) or tonne(N)/100 tonne(dietary DM)												
Species	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Dairy	3.98	4.09	4.16	3.69	3.23	3.15	3.02	2.86	3.10	3.40	3.57	3.79
Beef & Sheep	3.55	3.65	3.72	3.25	2.80	2.72	2.59	2.43	2.66	2.97	3.13	3.36
<b>Deer</b>												
1990	3.75	3.85	3.92	3.45	3.00	2.92	2.79	2.63	2.86	3.17	3.33	3.56
2010	3.59	3.69	3.76	3.29	2.84	2.76	2.63	2.47	2.70	3.01	3.17	3.40

*Provided through an analysis of nationally collated data on metabolisable energy, organic matter digestibility, and nitrogen content (Giltrap & McNeill, 2020).*

## Appendix 20: Nitrogen fertiliser application and yield of nitrogen fixing and other crops

Year	Synthetic fertiliser use (t N/yr)	Urease inhibito r 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	67,200	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
1991	61,694	0	32,521	67,200	65,064	3,386	382,043	180,690	183,388	57,187	456,918	168,870	63,830	80,730	28,057	9,124	1,274
1992	70,122	0	32,071	67,200	75,290	5,204	318,787	191,039	163,842	57,625	445,970	175,500	69,700	87,920	28,159	8,658	978
1993	104,095	0	44,218	67,200	63,268	5,018	389,523	219,414	133,069	56,793	416,944	187,620	73,100	116,580	25,704	9,331	1,314
1994	124,131	0	57,420	67,200	59,898	2,712	395,476	241,853	142,768	57,718	439,840	295,740	110,520	150,180	24,439	8,347	948
1995	151,263	0	85,797	67,200	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
1996	153,780	0	88,972	67,200	46,373	923	367,181	277,014	209,710	41,217	486,040	346,320	143,360	129,320	35,771	8,588	1,322
1997	143,295	0	80,159	68,040	50,337	923	411,000	317,379	193,806	49,065	454,440	384,480	135,480	131,790	39,553	8,392	546
1998	155,467	0	102,801	87,360	66,200	940	340,000	302,100	176,148	42,223	478,860	384,480	135,480	131,790	42,062	6,268	2,204
1999	166,819	0	139,016	95,760	52,200	0	304,000	320,000	197,000	41,702	560,640	384,480	135,480	140,160	39,413	5,832	1,590
2000	189,096	0	143,359	100,800	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	100,800	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	100,800	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	87,360	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	86,644	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	85,927	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	76,318	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	66,708	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	77,977	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	58,999	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	59,000	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	59,000	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	63,000	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	63,000	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	66,000	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	66,500	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	62,000	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	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	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	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

**Appendix 21: Forage crops for pasture renewal**

Year	<u>Rye-Clover mix (sheep, beef, deer)</u>		<u>Rye-Clover mix (dairy)</u>		<u>Lucerne (dairy, sheep, beef, deer)</u>	
	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
1991	12,375,199	1.5	1,340,139	5.6	87,637	10
1992	12,481,023	1.5	1,359,654	5.6	97,517	10
1993	12,544,768	1.5	1,400,408	5.6	102,714	10
1994	12,014,309	1.5	1,521,398	5.6	106,238	10
1995	11,899,584	1.9	1,620,211	6.1	107,085	10
1996	11,630,514	1.9	1,634,912	6.1	115,095	10
1997	11,346,725	1.9	1,702,290	6.1	114,282	10
1998	11,090,807	1.9	1,741,797	6.1	111,842	10
1999	10,872,953	1.9	1,743,240	6.1	111,111	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	8,684,944	3.0	2,289,094	7.4	132,187	10
2014	8,517,405	3.0	2,382,324	7.4	133,695	10
2015	8,354,734	3.0	2,309,423	7.4	138,056	10
2016	8,170,561	3.0	2,426,790	7.4	148,965	10

**Appendix 22: Loss of soil carbon in mineral soil during cropland management**

Year	Soil carbon loss (tonne)
1990	-61.66
1991	-80.57
1992	-99.48
1993	-118.39
1994	-137.30
1995	-156.21
1996	-175.13
1997	-194.97
1998	-214.81
1999	-234.65
2000	-254.49
2001	-274.34
2002	-293.25
2003	-312.16
2004	-331.07
2005	-349.98
2006	-368.89
2007	-387.81
2008	-407.27
2009	-426.73
2010	-427.28
2011	-427.83
2012	-428.38
2013	-407.33
2014	-386.28
2015	-365.23
2016	-344.19
2017	-323.14
2018	-302.09
2019	-281.04

**Appendix 23: Limestone, dolomite and urea usage**

Year	Limestone (tonne)	Dolomite (tonne)	Urea (kg (N))
1990	802,760	14,367	24,585,917
1991	866,597	15,510	32,520,868
1992	930,435	16,652	32,071,302
1993	1,007,628	18,034	44,218,217
1994	1,107,066	19,814	57,420,471
1995	1,206,504	21,593	85,796,763
1996	1,081,801	19,362	88,972,714
1997	1,191,928	21,333	80,158,542
1998	1,302,056	23,304	102,800,655
1999	1,412,183	25,275	139,015,833
2000	1,522,310	27,246	143,358,866
2001	1,632,438	29,217	187,451,505
2002	1,742,565	31,188	244,835,138
2003	1,536,886	27,506	272,303,015
2004	1,494,224	26,743	285,437,170
2005	1,644,880	29,439	286,410,270
2006	1,374,290	24,596	264,869,515
2007	1,460,817	26,145	286,221,406
2008	1,370,382	16,515	276,208,078
2009	1,614,132	19,894	234,542,989
2010	1,371,608	35,578	281,871,447
2011	1,411,414	28,251	311,755,951
2012	1,517,235	31,734	310,020,373
2013	1,190,855	33,756	326,297,077
2014	1,312,257	30,597	320,356,500
2015	1,190,169	26,419	381,526,980
2016	1,144,648	22,586	360,300,000
2017	1,019,861	22,785	369,000,000
2018	1,097,270	25,294	381,500,000
2019	1,216,694	22,648	358,000,000

**Appendix 24: Area of organic soils (hectares)**

Year	Cropland - annual	Cropland - perennial	Grassland – high producing	Grassland – low producing	Grassland – with woody biomass	Total Area
1990	7428	2235	127673	29964	4553	171853
1991	7449	2259	128739	28988	4536	171970
1992	7469	2283	129785	27983	4504	172024
1993	7490	2307	130824	26968	4468	172057
1994	7511	2330	131844	25922	4416	172023
1995	7532	2354	132877	24896	4375	172033
1996	7552	2378	133904	23863	4329	172026
1997	7573	2402	134944	22883	4301	172103
1998	7593	2427	135991	21914	4278	172203
1999	7613	2452	137044	20954	4260	172322
2000	7634	2477	138108	20000	4246	172464
2001	7654	2502	139173	19049	4234	172612
2002	7675	2525	140241	18068	4216	172726
2003	7697	2549	141318	17090	4200	172854
2004	7719	2573	142410	16120	4189	173010
2005	7741	2597	143523	15157	4179	173196
2006	7764	2620	144647	14196	4172	173400
2007	7787	2644	145792	13239	4168	173630
2008	7789	2648	146036	13167	4142	173782
2009	7791	2652	146287	13096	4116	173943
2010	7793	2656	146532	13027	4095	174104
2011	7795	2660	146777	12952	4070	174253
2012	7797	2664	147029	12879	4045	174413
2013	7798	2663	147043	12886	4010	174400
2014	7809	2663	147065	12916	3999	174453
2015	7811	2663	147076	12929	3963	174443
2016	7811	2664	147104	12929	3930	174438
2017	7811	2664	147092	12932	3906	174405
2018	7811	2664	147081	12935	3880	174370
2019	7811	2663	147069	12938	3820	174302

*This area is updated annually by the Ministry for the Environment*