Ministry for Primary Industries
Manatū Ahu Matua

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

Version 5

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Version and amendments

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

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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_4) from livestock digestive systems (referred to as enteric CH_4), and nitrous oxide (N_2O) 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.

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

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

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

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

Chapter 11 refers to Prescribed burning of Savannah.

Chapters 12 and 13 contain the references and appendices respectively.

1.1 International climate change agreements

New Zealand is a Party to the United Nations Framework Convention on Climate Change (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 UNFCC, 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_2, N_2O, CH_4, carbon monoxide, hydrofluorocarbons, perfluorocarbons and nitrogen trifluoride. These are calculated across five sectors:

- Energy– (eg, emissions from transport and electricity generation)
- Industrial Processes and Product Use (IPPU) – (eg, 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_2-e conversion metric. (UNFCCC, 2013).

In the *Fourth Assessment Report* for a 100-year time span, CO_2 is set as the reference gas, and has a GWP of 1, while CH_4 and N_2O 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_2-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_4 and N_2O 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_4 and N_2O emissions from each species (Clark *et al*, 2003). This methodology was developed to conform to the IPCC good practice guidelines and 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_2O 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_2 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.

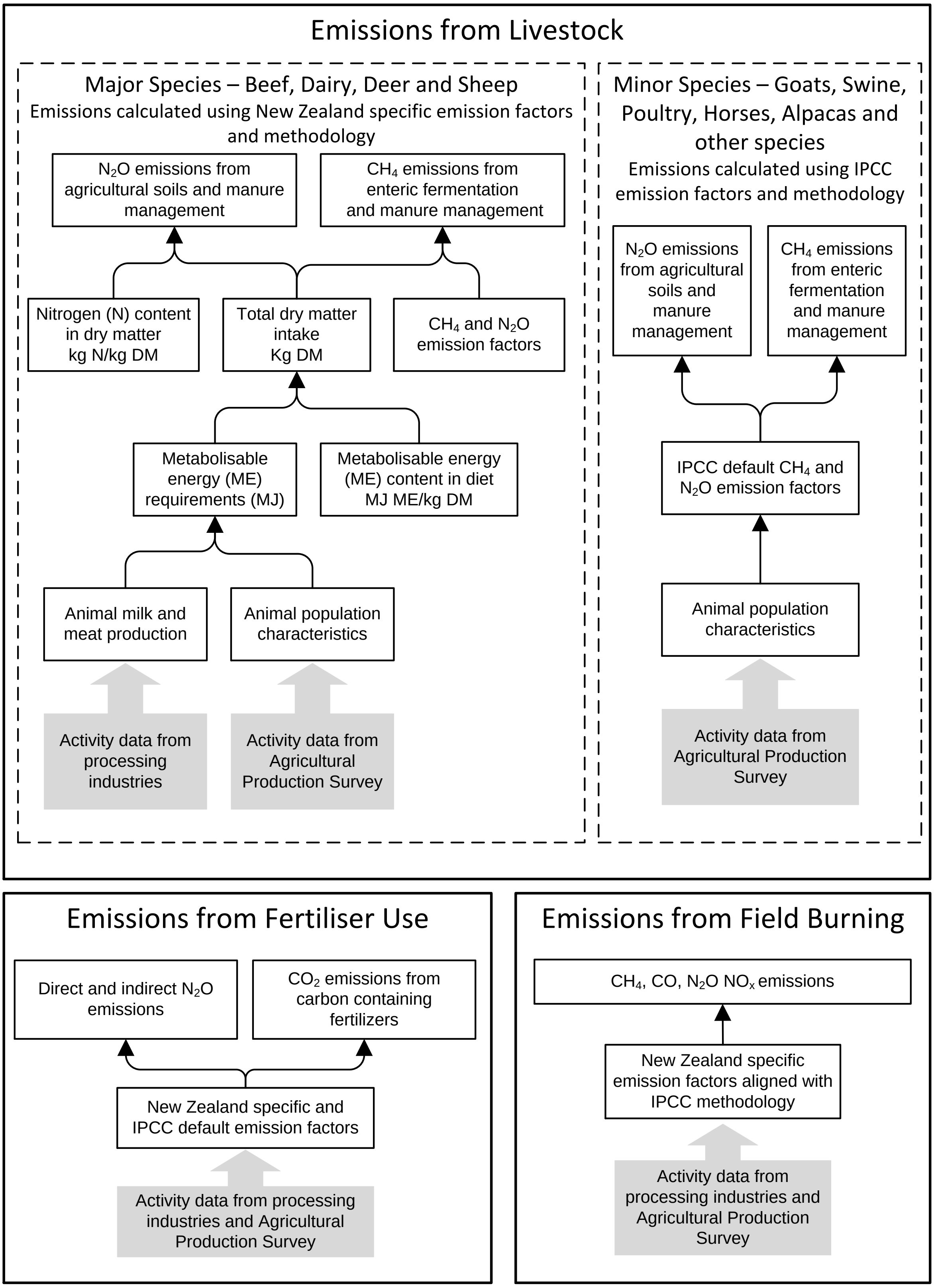
The diagram below outlines how the inventory calculates different emission categories. Livestock emissions from dairy and beef cattle, sheep and deer are calculated by using activity data to calculate the energy and intake requirements of these animals. Methodology specific to New Zealand is then used to calculate the resulting CH_4 and N_2O 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 and 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	AssureQuality
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	AssureQuality

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.

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.

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.

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 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).

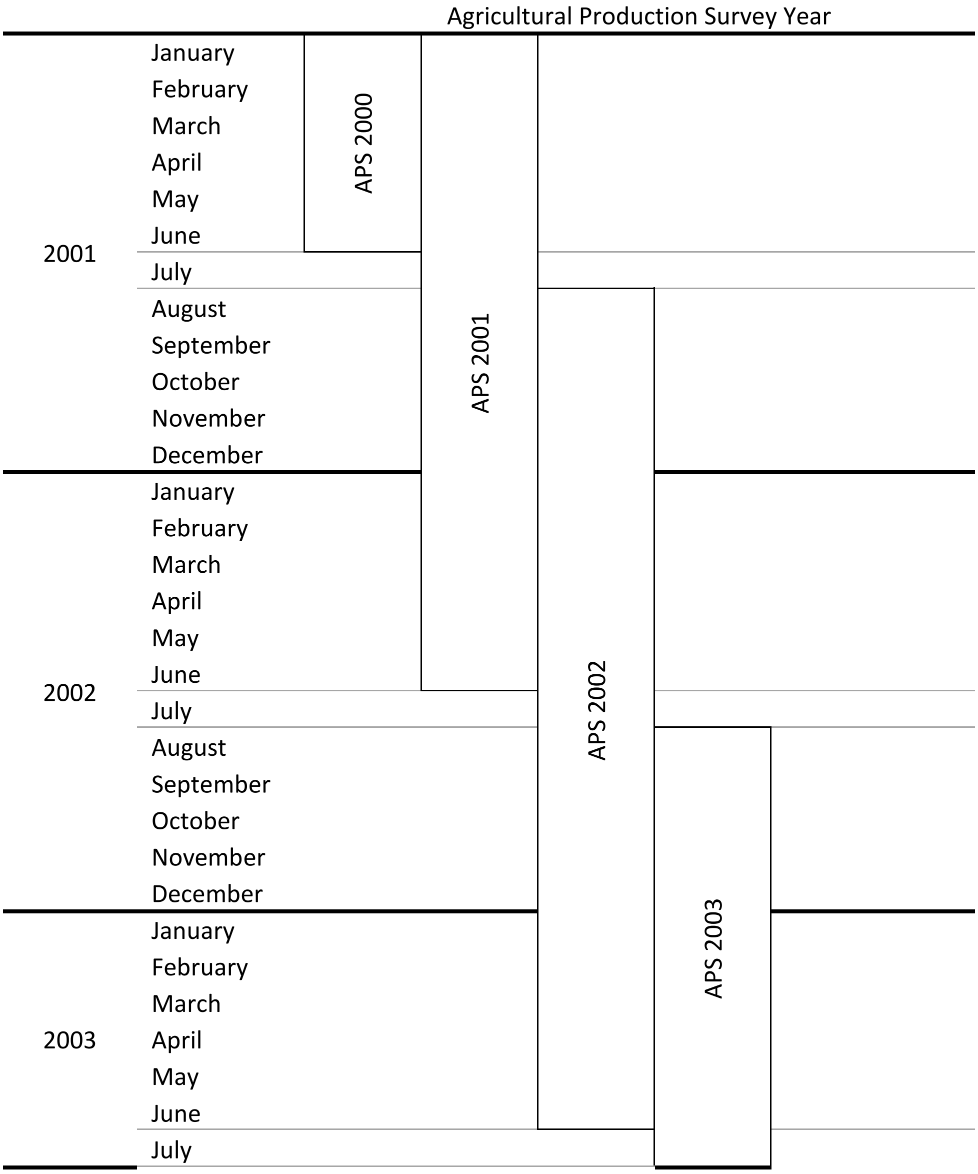
The rest of this chapter explains the equations used to calculate monthly populations for the subcategories of livestock.

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



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 $POPdnmc_t$ are dry cows (as opposed to heifers).

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

$$POPmmc_{aug(t)} = POPdm_t - Dmmc_{aug(t)}$$

Where:

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

$POPdm_t$ = 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)

$$POPmmc_m = POPmmc_{m-1} - Dmmc_{excl.aug(t)}$$

Where:

$POPmmc_m$ = population of mature milking cows in particular month *m*

$POPmmc_{m-1}$ = 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*)

$Dmmc_{jul(t-1)\text{ - }apr(t)}$ = 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*

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

$PDmmc_{aug}$= 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)

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

Where:

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

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

$Dmmc_{jul(t-1)\text{ - }apr(t)}$ = 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)

$$Dmmc_{jul(t-1)-apr(t)} = POPdm_{t-1} \times \left(\frac{DR_{mmc}}{nod_{year}}\right) \times nod_{jul-apr}$$

Where:

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

$POPdm_{t-1}$ = 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)

$$Dmmc_{may(t)-jun(t)} = POPdm_{t} \times \left(\frac{DR_{mmc}}{nod_{year}}\right) \times nod_{jul-apr}$$

Where:

$Dmmc_{may(t)\text{ - }jun(t)}$ = number of mature milking cow deaths, between May and June in year *t*

$POPdm_{t}$ = 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:

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

$POPtotaldairy_t$ = Total number of dairy cows, in milk or calf in year *t* (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)

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

Where:

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

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

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

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

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 on 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:

$POPbgc1_m$ = population of breeding growing cows aged 0-1 in month *m*

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

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

$$POPbgc1_{june} = 17\% \times POPbmc_{jul} \times \left(1 + \frac{DR_{bgc1}}{nod_{year}} \times nod_{jun}\right)$$

Where:

$POPbgc1_{june}$ = population of breeding growing cows aged 0-1 in June

$POPbmc_{jul}$ = 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)

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

Where:

$POPbgc1_m$ = population of breeding growing cows aged 0-1 in month *m*

$POPbgc1_{m+1}$ = population of breeding growing cows 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_{july} = 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:

$POPbmc_{jul(t)}$ = 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:

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

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

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

nod_{year} = number of days in year

nod_{sep} = number of days in September

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

The 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:

$POPbmc_{june(t)}$ = population of breeding mature cows in June of year *t*

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

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

nod_{year} = number of days in year

nod_{sep} = number of days in September

nod_{june} = 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:

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

$POPbmc_{m-1(t)}$ = population of breeding mature cows in next month m+1and year *t*

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

nod_{year} = number of days in year

nod_{sep} = number of days in September

nod_m = number of days in month m

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)

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

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)

$$POPsh1_{m(t)} = POPsh1_{(m-1)(t)} \times \left(1 - \frac{DR_{sh1}}{nod_{year}} \times nod_{m-1}\right)$$

Where:

$POPsh1_{m(t)}$ = population of slaughter heifers aged 0-1 in month *m* and year *t*

$POPbgc1_{m-1(t)}$ = 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)

$$POPsh1_{june(t)} = POPsh1_{jul(t)} \times \left(1 + \frac{DR_{sh1}}{nod_{year}} \times nod_{jun}\right)$$

Where:

$POPsh1_{june(t)}$ = population of slaughter heifers aged 0-1 in June of year *t*

$POPsh1_{jul(t)}$ = 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)

$$POPsh1_{m(t)} = POPsh1_{m+1(t)} \times \left(1 + \frac{DR_{sh1}}{nod_{year}} \times nod_{m}\right)$$

Where:

$POPsh1_{m}$ = population of slaughter heifers aged 0-1 in month *m* and year *t*

$POPbsh1_{m+1}$ = 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)

$$POPsh2_{jul(t)} = POPheifer_{jul(t)} - POPsh1_{jul(t)}$$

Where:

$POPsh2_{jul(t)}$ = population of slaughter heifers aged 1-2 in July of year *t*

$POPsh1_{jul(t)}$ = population of slaughter heifers aged 0-1 in July of year *t* (calculated in equation 3.35)

$POPheifer_{jul(t)}$ = 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)

$$POPsh2_{m(t)} = POPsh2_{(m-1)(t)} \times \left(1 - \frac{DR_{sh2}}{nod_{year}} \times nod_{m-1}\right)$$

Where:

$POPsh2_{m(t)}$ = population of slaughter heifers aged 1-2 in month *m* and year *t*

$POPsh2_{m-1(t)}$ = population of slaughter heifers aged 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)

$$POPsh2_{june(t)} = POPsh2_{jul(t)} \times \left(1 + \frac{DR_{sh2}}{nod_{year}} \times nod_{jun}\right)$$

Where:

$POPsh2_{june(t)}$ = population of slaughter heifers aged 1-2 in June of year *t*

$POPsh2_{jul(t)}$ = population of slaughter heifers aged 1-2 in July of 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_{jun} = number of days in June

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:

$POPsh2_m$ = population of slaughter heifers aged 1-2 in month *m*

$POPbsh2_{m+1}$ = population of slaughter heifers aged 1-2 in next month *m+1*

DR_{sh1} = 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 = 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:

$POPss1_{jul(t)}$ = population of slaughter steers aged 0-1 in July of year *t*

$Slau_{steer(t)}$ = number of steers 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 (from equation 3.37)

Psc_{steer} = 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:

$POPss1_{m(t)}$ = population of slaughter steers aged 0-1 in month m of year *t*

$POPss1_{m-1(t)}$ = population of slaughter steers aged 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)

$$POPss1_{june(t)} = POPss1_{jul(t)} \times \left(1 + \frac{DR_{ss1}}{nod_{year}} \times nod_{jun}\right)$$

Where:

$POPss1_{june(t)}$ = population of slaughter steers aged 0-1 in June of year *t*

$POPss1_{jul(t)}$ = 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)

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

Where:

$POPss1_{m}$ = population of slaughter steers aged 0-1 in month m

$POPss1_{m+1}$ = 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)

$$POPss2_{jul(t)} = \left(\frac{slau_{steer(t)}}{slau_{beef(t)}} \times slau_{aval(t)}\right) - POPss1_{jul(T)}$$

Where:

$POPss2_{jul(t)}$ = population of slaughter steers aged 1-2 in July

$slau_{steer(t)}$ = number of steers 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)

$POPss1_{jul(t)}$ = 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:

$POPss2_m$ = population of slaughter steers aged 1-2 in month m

$POPss2_{m-1}$ = population of slaughter steers aged aged 1-2 in previous month m-1

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 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:

$POPss2_{june(t)}$ = population of slaughter steers aged 1-2 in June of year *t*

$POPss2_{jul(t)}$ = population of slaughter steers aged 1-2 in July 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 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:

$POPss2_{m(t)}$ = population of slaughter steers aged 1-2 in month m of year *t*

$POPss2_{m+1(t)}$ = 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)

$$POPsb1_{jul(t)} = \frac{slau_{bull(t)}}{slau_{beef(t)}} \times slau_{aval(t)} \times Psc_{bull}$$

Where:

$POPsb1_{jul(t)}$ = 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)

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

Where:

$POPsb1_{m(t)}$ = population of slaughter bulls aged 0-1 in month m of year *t*

$POPsb1_{m-1(t)}$ = population of slaughter bulls aged 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)

$$POPsb1_{june(t)} = POPsb1_{jul(t)} \times \left(1 + \frac{DR_{sb1}}{nod_{year}} \times nod_{jun}\right)$$

Where:

$POPsb1_{june(t)}$ = population of slaughter bulls aged 0-1 in June of year *t*

$POPsb1_{jul(t)}$ = population of slaughter bulls aged 0-1 in July of 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 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:

$POPsb1_{m(t)}$ = population of slaughter bulls aged 0-1 in month m of year *t*

$POPsb1_{m+1(t)}$ = population of slaughter bulls aged 0-1 in next month m+1 of 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 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:

$POPsb2_{m(t)}$ = population of slaughter bulls aged 1-2 in month m of year *t*

$POPsb1_{m(t)}$ = 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:

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

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

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

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

nod_{year} = number of days in year

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

3.3 Sheep population model

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

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

3.3.1 Dry ewes

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

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

3.3.2 Mature breeding ewes

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

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

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_{Sep} = number of days in September

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

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

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:

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

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

$Dmbe_{AT(t)}$ = Annual number of deaths of mature breeding ewes in year *t* (see equation 3.60)

$Dmbe_{Aug+Sep(t)}$ = 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_{Jun} = 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:

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

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

$Dmbe_{AT(t)}$ = Annual number of deaths of mature breeding ewes in year *t* (see equation 3.60)

$Dmbe_{Aug+Sep(t)}$ = 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_{Jun} = number of days in month m

3.3.3 Growing breeding sheep

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

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

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:

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

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

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

nod_{year} = number of days in year

nod_{Jul} = number of days in July

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:

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

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

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

nod_{year} = number of days in year

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

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

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:

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

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

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

nod_{year} = number of days in year

nod_{Jul} = number of days in June

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:

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

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

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

nod_{year} = number of days in year

nod_{Jul} = number of days in June

3.3.4 Growing non-breeding sheep

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

- Dry ewe hogget
- Ram hogget
- Wether hogget

populations found from the APS.

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

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

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

Where:

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

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

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

nod_{year} = number of days in year

nod_{Jul} = number of days in July

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

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

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

Where:

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

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

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

nod_{year} = number of days in year

nod_{Jul} = number of days in July

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

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

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

Where:

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

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

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

nod_{year} = number of days in year

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

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

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

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

Where:

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

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

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

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

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

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

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

nod_{year} = number of days in year

nod_{Jun} = number of days in June

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

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

Where:

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

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

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

nod_{year} = number of days in year

nod_{Jul} = number of days in June

3.3.5 Wethers

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

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:

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

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

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

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

nod_{year} = number of days in year

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

3.3.6 Lambs

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

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

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:

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

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

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

nod_{year} = number of days in year

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

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

Population of lambs in March (Equation 3.78)

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

Where:

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

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

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

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

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

During March the model assumes that some lambs are sent to slaughter. The fraction of lambs that are slaughtered in March (currently set at 0.84) is used to calculate the April population of lambs

Population of lambs in April (Equation 3.79)

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

Where:

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

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

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

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

Where:

$POPrs_m$ = population of rams in month m

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

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

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

nod_{year} = number of days in year

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

3.4 Deer population model

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)[a]. 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)

$$Pds3_{jul(t)} = \frac{1}{8} \times \frac{POPlc7620_{(t)} + POPlc7645_{(t)} + POPlc7648_{(t)}}{POPdeer_{(t)}}$$

Where:

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

$POPlc7620_{(t)}$ = population of deer in line code 7620 in year *t* (from APS)

$POPlc7645_{(t)}$ = population of deer in line code 7645 in year *t* (from APS)

$POPlc7648_{(t)}$ = population of deer in line code 7648 in year *t* (from APS)

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

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

$$Pdsma_{jul(t)} = \frac{7}{8} \times \frac{POPlc7620_{(t)} + POPlc7645_{(t)} + POPlc7648_{(t)}}{POPdeer_{(t)}}$$

Where:

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

$POPlc7620_{(t)}$ = population of deer in line code 7620 in year *t* (from APS)

$POPlc7645_{(t)}$ = population of deer in line code 7645 in year *t* (from APS)

$POPlc7648_{(t)}$ = population of deer in line code 7648 in year *t* (from APS)

[a] See table 30 of Suttie report

POPdeer$_{(t)}$ = 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)

$$POPdh1_{jul(t)} = POPdeer_{(t)} \times Pdh1_{(t)}$$

Where:

POPdh1$_{jul(t)}$ = population of hinds aged 0-1 in July of year *t*

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

Pdht$_{(t)}$ = 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)

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

Where:

POPdh1$_{aug(t)}$ = population of hinds aged 0-1 in August in year *t*

POPdh1$_{jul(t)}$ = population of hinds aged 0-1 in July in year *t*

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

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

PDdh1$_{mar-jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod$_{july}$ = number of days in July

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

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

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

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

Where:

POPdh1$_{m(t)}$ = population of hinds aged 0-1 in month *m* of year *t*

POPdh1$_{m-1(t)}$ = population of hinds aged 0-1 in previous month *m-1* of year *t*

POPdh1$_{jul(t)}$ = population of hinds aged 0-1 in July of year *t*

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

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

PDdh1$_{mar-jul}$ = proportion of annual deaths assumed to occur between March and July (inclusive). Currently assumed to be 65%

nod$_{m-1}$ = number of days in previous month *m-1*

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

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

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)

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

Where:

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

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

$POPdh1_{jul}$ = population of hinds aged 0-1 in subsequent July

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

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

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

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

3.4.2 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:

$POPdh2_{jul(t)}$ = population of hinds aged 1-2 in July of year *t*

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

$Pdh2_{(t)}$ = 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:

$POPdh2_{m(t)}$ = population of hinds aged 1-2 in month *m* of year *t*

$POPdh2_{m-1(t)}$ = population of hinds aged 1-2 in previous month *m-1* of year *t*

$POPdh2_{jul(t)}$ = population of hinds aged 1-2 in July of year *t*

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

$PDdh2_{Jun\text{-}Oct}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 60%

$nod_{Jun\text{-}Oct}$ = number of days between June and October (inclusive, i.e. 153)

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

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:

$POPdh2_{dec(t)}$ = population of hinds aged 1-2 in December of year *t*

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

$POPdh2_{jul(t)}$ = population of hinds aged 1-2 in July of year *t*

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

$PDdh2_{Dec-May}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 10%

$nod_{Dec-May}$ = number of days between December and May (inclusive, i.e. 182)

nod_{Nov} = 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:

$POPdh2_{oct(t)}$ = population of hinds aged 1-2 in October of year *t*

$POPdh2_{nov(t)}$ = population of hinds aged 1-2 in November of year *t*

$POPdh2_{jul(t)}$ = population of hinds aged 1-2 in July of year *t*

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

$PDdh2_{Jun-Oct}$ = 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_{Oct} = 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:

$POPdh2_{nov(t)}$ = population of hinds aged 1-2 in November of year *t*

$POPdh2_{dec(t)}$ = population of hinds aged 1-2 in December of year *t*

$POPdh2_{jul(t)}$ = population of hinds aged 1-2 in July of year *t*

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

$PDdh2_{Nov}$= proportion of annual deaths assumed to occur in November. Currently assumed to be 30%

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:

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

$POPdbh_{m-1}$ = population of breeding hinds in previous month *m-1* of year *t*

$POPdbh_{jul}$ = 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_{m-1} = number of days in previous month *m-1*

In December the breeding hind population is boosted by the movement of the 1-2 hind population into the breeding hind population.

Population of breeding hinds in December (Equation 3.98)

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

Where:

$POPdbh_{Dec(t)}$ = population of breeding hinds in December of year *t*

$POPdbh_{Nov(t)}$ = population of breeding hinds in November 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%)

$PDdbh_{Nov}$ = proportion of annual deaths assumed to occur in November. Currently assumed to be 60%

$POPdh2_{Nov(t)}$ = population of hinds aged 1-2 in November of year *t*

The January and February 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:

$POPdbh_{m}$ = population of breeding hinds in month m

$POPdbh_{m-1}$ = population of breeding hinds in previous month m-1

$POPdbh_{jul}$ = population of breeding hinds in the July immediately prior

DR_{dbh} = Annual death rate of breeding hinds (assumed to be 2%)

$PDdbh_{Dec-May}$ = proportion of annual deaths assumed to occur between June and October (inclusive). Currently assumed to be 10%

$nod_{Dec-May}$ = number of days between June and October (inclusive, i.e. 182)

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

The March to June populations of 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)

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

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 'metabolisible 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).

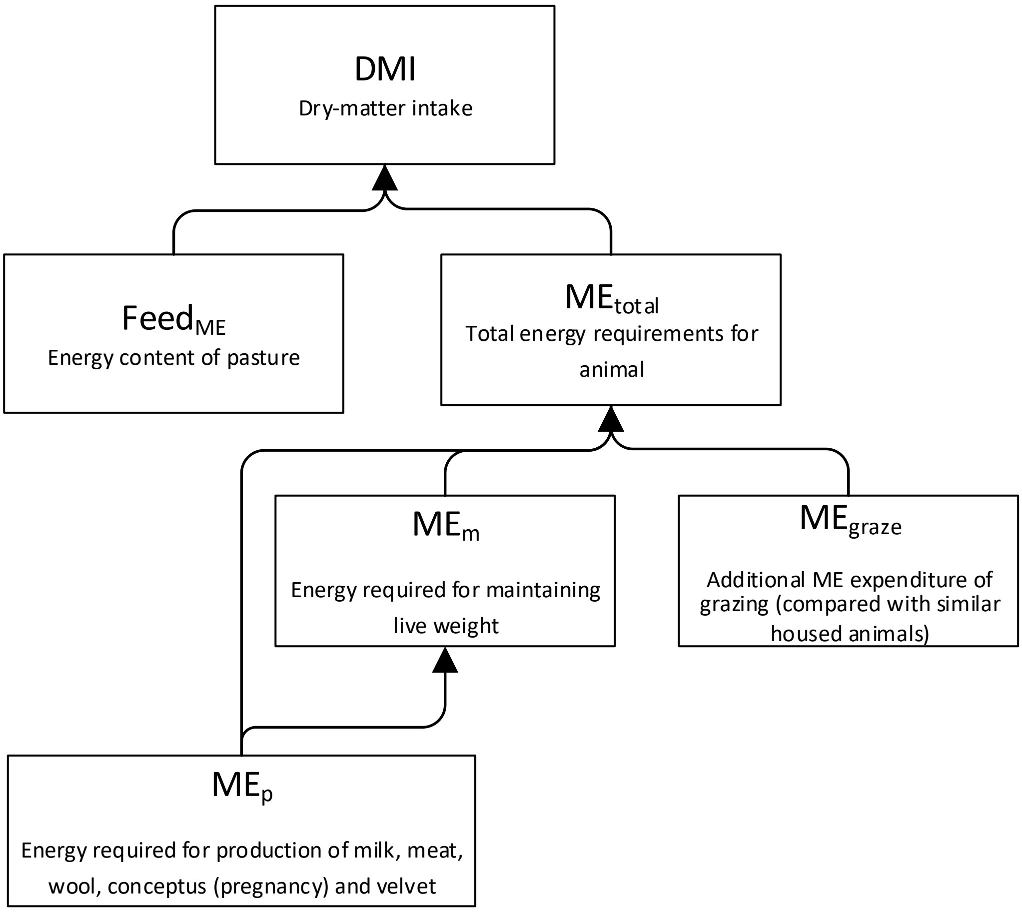
The agricultural inventory model uses data from a range of sources[b] to estimate the ME requirements of New Zealand's livestock population. Although the equations used here and in feeding standards (e.g. CSIRO, 2007) have a sound physiological basis and are based on measurements from several animal species in a range of physiological states (growing, lactating, pregnant, etc.) it is important to appreciate that variation (associated with diet, breed, species and their interactions) exists within species. The results of any ME calculations therefore should be regarded as estimates.

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[c]. 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)

[c] The IPCC Tier 2 energy requirements model is based on 'net energy, NE' whereas the New Zealand approach (using the Australian Feeding Standards algorithms) uses 'metabolisable energy, ME'. Net energy relates to metabolisable energy as follows: NE = ME – energy lost by the animal as heat (Lassey, 2007, figure 2).

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 metabolisible energy required per day for an average animal representing specified categories (MJ/d)

$Feed_{ME}$ = energy content of feed intake or the metabolisible 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 metabolisible energy requirements of an animal (ME_{total}) is the sum of four components:

- ME_m: ME for maintenance (MJ/d).
- ME_p: ME required for production, in the form of wool, meat (live weight gain), milk or velvet (MJ/d)
- ME_{graze}: additional ME expenditure associated with outdoor production systems (walking and grazing) compared with similar animals in confined conditions (MJ/d).
- ME_c: ME required for gestation or growth of the conceptus at any given time during pregnancy (MJ/d)

Total metabolisible 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 = Metabolisible energy required for gestation or growth of the conceptus (MJ/d)

ME_m is the amount of energy required to maintain the animal[d]. 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).

[d] 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_p = ME required for production (MJ/d)

The parameter k_m is the efficiency of the use of ME, and is calculated by using the following equations (CSIRO, 2007):

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 metabolisible to gross energy for pasture, Q_m (Equation 4.5)

$$Q_m = \frac{Feed_{ME}}{Feed_{GE}}$$

Where:

Qm = ratio of feed ME to GE concentration of pasture.

$Feed_{ME}$ = ME content of feed (monthly values by species available in appendix 3 and 9 (MJ/kg)

$Feed_{GE}$ = gross energy per kilogram of dry matter for feed, assumed to be 18.4 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 18.4 MJ GE/kg DM) depending on the animal species and time of year.

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_p component for dairy cattle is made up of the following components, which are also specified in equations 4.6 to 4.20:

- ME_l: ME required for milk production (MJ/d)
- ME_g: ME required for live weight gain (growth) (MJ/d)

metabolisible 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_g), while milking cows produce milk (ME_l) and calves (gestation – ME_c)

4.3.3.1 Metabolisable energy requirements for milk production

The energy requirements for milk production (ME_l) are calculated using methodology developed the United Kingdom's Energy & Protein Requirements of Ruminants Agricultural and Food Research Council (AFRC; 1993). The following equation is used to calculate ME_l:

Metabolisible energy requirements for milk production (Equation 4.7)

$$ME_l = \frac{Y \times MILK_{GE}}{k_l}$$

Where:

ME_l = Metabolisible energy required for milk production (MJ/d)

Y = Daily milk yield per milking cow (kg/d)

$MILK_{GE}$ = Gross energy content of milk (MJ/kg)

k_l = Efficiency of use of ME for milk production, or the factor used to measure how efficiently ME is used by a dairy cow to produce milk (see equation 4.10)

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). 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_m = National aggregate annual milk yield (kg)

mp_{month} = Milk produced in a given month as a proportion of total annual milk produced (appendix 4)

$P_{milkingcow}$ = population of mature milking cows in a given month

D_{month} = number of days in given month

To determine the gross energy content of milk ($MILK_{GE}$), the average fat and protein concentrations of this milk are required, along with the following AFRC (1993) equation:

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 Metabolisible energy requirements for change in live weight

In order to predict the energy required for a change in live weight of a dairy cow, a set of equations taken from the ARC (1980) are utilized for:

- non-lactating animals (Breeding bulls and growing females less than two years);
- milking cows and heifers

4.3.3.2.1 Live weight gain for non-lactating animals

Metabolisable energy requirements for live weight gain in non-lactating animals (Equation 4.11):

$$ME_g = \frac{(6.7 + R) + \frac{20.3 - R}{1 + e^{-6(P_{lw} - 0.4)}}}{k_{gnl}} \times LWG \times 0.92$$

Where:

ME_g = Energy required for live weight gain (MJ/d)

R =An adjustment for rate of change in live weight

LWG = Live weight gain in kg/day

P_{lw} = ratio of current live weight (LW) to a standard reference weight (SRW) of a mature animal

k_{gnl} = Net efficiency of dietary metabolisable energy conversion to live weight gain for non-lactating animals

A number of variables in this equation require additional calculations, which are set out below. The variable R is used to adjust for the rate of gain or loss of live weight. The calculation of R requires information on the change in empty body weight (EBC) or the body weight minus weight of gut contents, and standard reference weight (SRW) of a mature animal. SRW values are fixed at values determined by the CSIRO (1990):

- 550 kg for females
- 770 kg for bulls

LWG measures the daily live weight gain of an animal. P_{lw} is the ratio of current live weight (C_{lw}) to a standard reference weight (SRW) of a mature animal. Annual information on current live weight is provided in appendix 1.

k_{gnl} is a conversion factor that used to measure how efficiently ME is used by a dairy cow for weight gain (see equation 4.17).

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)

$$k_{gnl} = 0.042 \times Feed_{me} + 0.006$$

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)

$Feed_{ME}$ = Metabolisible energy content of feed (MJ/kg)

The calculation of live weight and live weight gain (LWG) for the different animal species is outlined in section 4.7. LWG is assumed to be zero for adult cows (milking cows and heifers, breeding bulls)

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_g 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_g = Net efficiency of dietary metabolisable energy conversion to live weight gain

The variables neclw and kg require additional calculations and inputs such as body condition score (cs) and kl. The body condition score is a visual assessment of an animal's body fat reserves, and is assumed to be 6 for dairy cattle. k_l measures how efficiently ME is used by a dairy cow to produce milk and is also discussed in section 4.3.3.1 (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_g = Net efficiency of dietary metabolisable energy conversion to live weight gain

k_l = Net efficiency of dietary metabolisable energy conversion for milk production (see section 4.3.3.1)

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_c = Metabolisible energy required for gestation or growth of the conceptus (MJ/d)

LW_C = Calf birth weight (kg).

E_t = Energy required for the gravid uterus in utero (MJ/d)

prg = Number of days the cow has been pregnant (see Appendix 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)

$$ME_{graze} = \frac{\left(\left(C \times DMI(0.9 - DMD) \times \left(ME_m + ME_p - Z_1\right)\right) + 0.05 \times \frac{T \times Feed_{ME}}{GF + 3}\right)W}{k_m \times Feed_{ME} - C \times W \times (0.9 - DMD)}$$

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 metabolisible 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).

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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_l 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 × $Feed_{ME}$ + 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 metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk

$Feed_{ME}$ = metabolisible 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 metabolisible energy requirements for dairy

The equations outlined in section 4.3 are used to determine the total metabolisible energy (ME_{total}) requirements for each class of dairy cattle. This figure can then be used to calculate Dry Matter Intake (DMI) using the equation in section 4.1.1 (equation 4.1), which is ultimately used to calculate emissions.

4.4 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 metabolisible energy requirements of animal (MJ/d)

ME_m = Metabolisible energy required for maintenance (MJ/d)

ME_l =Metabolisible energy required for milk production (MJ/d)

ME_c =Metabolisible energy required for gestation (MJ/d)

ME_g =Metabolisible energy required for live weight gain (growth) (MJ/d)

ME_{graze} = Additional metabolisable energy expenditure of grazing (MJ/d)

Z_1 = Energy contained in the milk diet of young animals (MJ/d)

4.4.2 Metabolisible energy required for maintenance

As for dairy cattle, equation (4.3) is used to determine maintenance energy requirements for beef cattle. Information on live weight (W) and age (A) used in this equation are contained in appendix 8 and 2, respectively. Values of 1.4 for *K* and 1.15 for S are used for beef cattle, which is the same as dairy cattle. Information on pasture ME content ($Feed_{ME}$, 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_l for dairy cattle, which are:

- Fat content of milk (F)
- Protein content of milk (P)
- Gross energy content of milk ($MILK_{GE}$)
- Efficiency of metabolisible energy used for milk production (k_l)
- Number of days in a given month (D_{month})

The remaining parameters (listed below) use different values (compared to dairy cattle) to calculate milk production energy requirements for beef cattle:

- Daily milk yield per breeding beef cow (Y)
- Proportion of total annual milk produced by beef cattle in a given month (mp_{month})
- Ratio of pasture ME concentration to the gross energy concentration of pasture (Q_m). The inventory assumes that beef cattle consume pasture with a different metabolisible energy content ($PAST_{ME}$). $PAST_{ME}$ values are provided in appendix 9.
- Population of breeding beef cows in a given month ($P_{milkingcow}$)

The inventory model assumes that a breeding beef cow produces 824 kilograms of milk per year (appendix 8). This can be used to calculate the daily milk yield per breeding beef cow (Y).

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_m = Annual milk yield per breeding beef cow (assumed to be 824 kg)

mp_{month} = Milk produced in a given month as a proportion of total annual milk produced (see appendix 4)

D_{month} = number of days in given month

Information on milk fat (F) and milk protein (P) in these equations is provided in appendix 8. Information on the fraction of total annual milk produced in a given month (mp_{month}) is contained in appendix 4.

4.4.3.2 Energy requirements for change in live weight

The equations used to calculate ME_g (energy required for live weight gain) for beef cattle are identical to those used to calculate ME_g for dairy cattle (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_g for the following classes of beef cattle:

- Growing cows 0 – 1 years
- Growing cows 1 – 2 years
- Breeding Bulls – mixed age
- Slaughter heifers 0 – 1 years
- Slaughter heifers 1 - 2 years
- Slaughter steers 0 – 1 years
- Slaughter steers 1 - 2 years
- Slaughter Bulls 0 - 1 years

- Slaughter Bulls 1 – 2 years

The equations in section *4.3.3.3.2 live weight gain for growing lactating animals* are used to calculate MEg for the following classes of beef cattle:

- Breeding growing cows 2 – 3 years
- Breeding mature cows

Data on live weight is calculated using data provided by MPI. A linear trend is used to estimate live weight for growing beef cattle, 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_{graze} for dairy cattle, which are:

- Additional energy for eating that grazing animals require compared to housed animals (C)
- Availability of green forage (GF)
- Efficiency of utilisation for maintenance (km)

The remaining parameters (listed below) use different values (compared to dairy cattle) to calculate grazing energy requirements for beef cattle:

- Terrain factor (T) A value of 1.5 is used, reflecting undulating pasturelands
- Dry matter intake (DMI). Different values of DMI are calculated for beef cattle, using the iteration methodology outlined in section 4.3.4.
- 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 metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a dairy cow to produce milk (see equation 4.23)

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)

α_{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 metabolisible energy (ME_{total}) requirements for each class of beef cattle. This figure can then be used to calculate Dry Matter Intake (DMI) using the equation in section 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, $ME_p = ME_l + ME_g + ME_{wool}$.

Immediately after birth lambs obtain most of their energy from milk, therefore an energy discount is required to cover the months when the lamb obtains some of its energy from milk. Again, this is achieved by subtracting a term, Z_1, in the calculations for the total ME requirements.

Each subcategory of sheep animal and the specific ME components used in the calculation of total ME requirements for each subcategory are outlined in Table 4.

Table 4.3: Equations for the total ME requirements for each subcategory of sheep

Sheep subcategories	Equation
1. Dry ewes	$ME_{total} = ME_m + ME_{wool} + ME_{graze}$
2. Mature Breeding ewes	$ME_{total} = ME_m + ME_l + ME_c + ME_{wool} + ME_{graze}$
3. Growing breeding sheep	$ME_{total} = ME_m + ME_l + ME_c + ME_g + ME_{wool} + ME_{graze}$
4. Growing non-breeding sheep	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze}$
5. Wethers	$ME_{total} = ME_m + ME_{wool} + ME_{graze}$
6. Lambs	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze} - z_l$
7. Rams	$ME_{total} = ME_m + ME_g + ME_{wool} + ME_{graze}$

4.5.1 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_c = ME required for gestation (MJ/d)

W_l = lamb birth weight (kg)

E_t = Energy required for the “gravid foetus” in utero (MJ)

prg = Number of days the ewe has been pregnant (see Appendix 5)

k_c = 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):

$$E_t = 10 \times (3.322 - 4.979 \times e^{-0.00643prg})$$

Values for coefficients used in the calculation of the term E_t are adopted from the ARC (ARC, 1980) where they were determined for a lamb with a birth weight of 4.0 kg at 147 days of gestation. A summary of the net requirements for gestation can be found in the CSIRO report (CSIRO, 1990). For the calculation of the New Zealand Inventory, lamb birth weight is assumed to be 9% of ewe live weight (see Appendix 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.

Metabolisible 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 = Metabolisible 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 metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk (see equation 4.31)

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 metabolisible 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 metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a sheep to produce milk (see equation 4.31)

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)

$$k_g = 0.042 \times Feed_{ME} + 0.006$$

Where:

k_g = Net efficiency of dietary ME conversion to live weight gain

$Feed_{me}$ = 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).

Metabolisible 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)

Metabolisible 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 metabolisible 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	$ME_{total} = ME_m + ME_g - z_l$
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):

$$ME_g = \frac{(6.7 + R) + \dfrac{20.3 - R}{1 + e^{-6(P_{lw} - 0.4)}}}{k_{gnl}} \times LWG \times 0.92$$

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 19th of November. For the next 120 days, it is assumed that breeding hinds produce milk for these young deer. The daily energy required to do this (ME_l) is calculated using the equation below.

Metabolisible 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 = Metabolisible energy required for milk production (MJ/d)

Y_{deerm} = annual milk yield per breeding hind (assumed to be 204 kilograms per deer per year) (see appendix 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 metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a breeding hind to produce milk. Currently set to 0.64 (Moe *et al.,* 1971)

For 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_l) 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 metabolisible energy for milk production, or the factor used to measure how efficiently ME is used by a breeding hind to produce milk. Currently set to 0.64 (Moe *et al.,* 1971)

For other months of the year z_1 is assumed to be zero.

4.6.6 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	0.2
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 1st of September to the 4th of November. During this period 0.5 mejajoules of ME is required each day to produce velvet (Suttie, 2012).

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 ($Feed_{ME}$) 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 $Feed_{ME}$ 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	55%	uses data in report by Suttie (2012)	0	9%
	Hinds 0-1	Slaughter	19-Nov	NA	NA		Calculated monthly	Calculated	NA
	Hinds 1-2	Slaughter	NA	466	28-Feb		Calculated monthly	Calculated	NA
	Stags 0-1	Slaughter	19-Nov	466 or 629	NA		Calculated monthly	Calculated	10%
	Stags 1-2	Slaughter	NA	466 or 629	28-Feb		Calculated monthly	Calculated	NA
	Stags 2-3	Slaughter	NA	629	NA		Calculated monthly	Calculated	NA
	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

				live weight as a proportion of adult weight		
Month	Class	days since birth (start of month)	days since birth (end of month)	start of month	month average	end of month
August (birth)	Growing heifers 0-1	0	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 $weight_{mmc,y}$ = mature weight of milking cows in year *y* (from activity data – see section 4.7.1.2)

Days to $maturity_{gh}$ = 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)

$$LWbbmc_y = \left(\frac{\left(TOTcarcwgt_{cattle,y} - (LWmmc_y \times KO_{DC}) \times \left(Ncow_{slaughtered,y} - (RR_{Beef} \times Nbeef_{Bcow,y})\right)\right)}{Nbeef_{cow} \times RR_{Beef}}\right) \Big/ KO_{DC}$$

Where:

$LWbbmc_y$= live weight of breeding mature beef cows, for a particular year *y* ending in June (kg)

$TOTcarcwgt_{cattle,y}$ = total carcass weight of all dairy and beef cattle sent to slaughter, for a particular year *y* ending in June (kg). Data provided by Statistics New Zealand

$LWmmc_y$ = live weight of mature milking dairy cows in year *y*, in kilograms (see section 4.7.1.2)

KO_{DC} = killing out percentage for dairy cows (currently set at 42%)

$Ncow_{slaughtered,y}$ = Number of dairy and beef cows slaughtered, for a particular year ending in June (data provided by Statistics New Zealand)

RR_{Beef} = beef cow replacement rate, currently set at 17%

$Nbeef_{Bcow,y}$ = number of beef breeding cows, for a particular year ending in June. Data provided by Statistics New Zealand (line codes 7056 and 7057)

4.7.2.3 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 20th 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)

$$LWbbgc_{m,y} = Birth\ weight_{bbgc,y} + \left(\frac{AgeMOM_{bbgc,m}}{days\ to\ maturity_{bbgc}}\right) \times \left(LWbbmc_y - Birth\ weight_{bbgc,y}\right)$$

Where:

$LWbbgc_{m,y}$ = live weight of breeding growing cows in month *m*, year *y* (kg)

$Birth\ weight_{bbgc,y}$ = birth weight of breeding growing cows in year *y* (equal to 9% of breeding mature cow live weight) (kg)

$AgeMOM_{bbgc,m}$ = age (in days) of breeding growing cows at the middle of month *m*

$Days\ to\ maturity_{bbgc}$ = number of days from birth to slaughter for breeding growing cows (currently set at 1095)

$LWbbmc_y$= live weight of breeding mature beef cows, for a particular year ending in June (kg)

Live weight gain for breeding growing cows (Equation 4.46)

$$LWGbbgc_y = \frac{LWbbmc_y - Birth\ weight_{bbgc,y}}{days\ to\ maturity_{bbgc}}$$

Where:

$LWGbbgc_{m,y}$ = live weight gain of breeding growing cows in year y (kg)

$LWbbmc_{y}$= live weight of breeding mature beef cows, for a particular year ending in June (kg)

Birth $weight_{bbgc,y}$ = birth weight of breeding growing cows in year y (equal to 9% of breeding mature cow live weight) (kg)

Days to $maturity_{bbgc}$ = number of days from birth to slaughter for breeding growing cows (currently set at 1095)

4.7.2.4 Slaughter bulls, slaughter heifers and slaughter steers

Slaughter bulls, slaughter heifers and slaughter steers are raised over a period of two years from birth (20th 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)

$$LWbslaugher_{x,m,y} = Birth\ weight_{bslaughter,x,y} + \left(\frac{AgeMOM_{bslaughter,m}}{days\ to\ slaughter_{bslaughter,x}}\right) \times \left(LWbslaughter_{at\ slaughter,x,y} - Birth\ weight_{bslaughter,x,y}\right)$$

Where:

$LWbslaughter_{x,m,y}$ = live weight in kilograms of beef slaughter animals in year *y*, for animal type *x* (either slaughter bulls, slaughter heifers and slaughter steers)

Birth $weight_{bslaughter,x,y}$ = birth weight in kilograms of beef slaughter animals in year *y*, for animal type *x* (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.

$AgeMOM_{bslaughter,x,m}$ = 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 $slaughter_{bslaughter}$ = number of days from birth to slaughter for all beef slaughter animals (currently set at 730)

$LWbslaughter_{at\ slaughter,x,y}$ = 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)

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:

$LWbslaughter_{at\ slaughter,x,y}$ = 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)

$$LWGbslaugher_{x,y} = \frac{LWbslaughter_{at\ slaughter,x,,y} - Birth\ weight_{bslaughter,x,y}}{days\ to\ slaughter_{bslaughter,x}}$$

Where:

$LWGbslaughter_{x,y}$ = live weight gain in kilograms per day, of beef slaughter animals in year *y*, for animal type *x* (either slaughter bulls, slaughter heifers and slaughter steers)

$LWbslaughter_{at\ slaughter,x,y}$ = 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)

$$LWas_y = \frac{Carcass\ weight_{as,y}}{KO_{as}}$$

Where:

$LWas_y$= 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 11th of September each year and are grown for two slaughter dates (28th February after 171 days, and 31 August after a further 184 days). 84% of lambs are slaughtered at the first slaughter date.

Average lamb slaughter weight data (for each year ending June) is gathered from Statistics New Zealand and this is used (along with an assumed killing out percentage of 45%) to calculate the lamb live weight at the date of first slaughter (see equation 4.54). 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 1st of March to the 31st 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)

$$\begin{aligned} LWlamb_{m,y} &\\ &= Birth\ weight_{lamb,y} + \left(\frac{AgeMOM_{lamb,m}}{days\ to\ 1st\ Slaughter_{lamb}}\right) \\ &\times \left(LW1stSlaughter_{lamb,y} - Birth\ weight_{lamb,y}\right) \end{aligned}$$

Where:

$LWlamb_{m,y}$ = live weight of lambs in month *m*, year *y*, from September to February (kg)

Birth $weight_{lamb,y}$ = birth weight of lambs in year *y* (equal to 9% of whethers, dry ewes, and mature breeding ewe live weight) (kg)

$AgeMOM_{lamb,m}$ = age (in days) of lambs at the middle of month *m*

Days to 1st $Slaughter_{lamb}$ = number of days from birth to slaughter for lambs (currently set at 171)

$LW1stSlaughter_{lamb,y}$ = live weight of lambs at first slaughter in year *y* (kg) (equation 4.54)

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:

$LWlamb_{m,y}$ = live weight of lambs in month *m*, year *y*, from March to August (kg)

$LWlamb_{m,y}$ = live weight of lambs in previous month *m* and year *y* (kg)

nod_m = number of days in month *m*

$LWG_{lamb,2nd,y}$ = live weight gain of lambs between March and August following first slaughter in year *y*

Lamb live weight at first slaughter (Equation 4.54)

$$LW1stSlaughter_{lamb,y} = \frac{Carcass\ weight_{lamb,y}}{KO_{lamb}}$$

Where:

$LW1stSlaughter_{lamb,y}$ = live weight of lambs at first slaughter (28 February) in year *y* (kg)

$Carcass\ weight_{lamb,y}$ = average carcass weight of lambs for year *y* ending in June (kg). Data from Statistics New Zealand

KO_{lamb} = killing out percentage for lambs. Currently set at 45%

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:

$LWG_{lamb,1st,y}$ = live weight gain of lambs in period before first slaughter in year *y* (kg per day)

$LW1stSlaughter_{lamb,y}$ = live weight of lambs at first slaughter (28 February) in year *y* (kg) (equation 4.54)

$Birth\ weight_{lamb,y}$ = birth weight of lambs in year *y* (equal to 9% of whethers, dry ewes, and mature breeding ewe live weight) (kg)

Days to 1^{st} $Slaughter_{lamb}$ = 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:

$LWG_{lamb,2st,y}$ = live weight gain of lambs in period before after first slaughter in year *y* (kg per day)

$LWG_{lamb,1st,y}$ = live weight gain of lambs in period before first slaughter in year *y* (kg per day)

4.7.3.4 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)

$$LWsg_{m,y} = LWlamb_{march,y} + \left(\frac{nod_{m,since\ March}}{365}\left(LWas_y - LWlamb_{march,y}\right)\right)$$

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 19th 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

$baselineLW_{hind,y}$ = 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)

$$LWhind_{birth\ to\ 1st\ slaughter,m,y} = \left(\frac{AgeMOM_{hind,m,y}}{days\ to\ 1st\ Slaughter_{hind}} \times \left(LWhind_{at\ 1st\ slaughter,m,y} - Birth\ weight_{hind,y}\right)\right)$$

Where:

$LWhind_{birth\ to\ 1st\ slaughter,m,y}$ = live weight of growing hinds for a particular year *y* and month m, for the first 466 days of their life

$AgeMOM_{hind,m,y}$ = age (in days) of growing hinds at the middle of month *m* in year *y*

days to 1^{st} $slaughter_{hind}$ = number of days between birth and first slaughter for growing hinds (466)

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg) (equation 4.61)

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)

$$LWhind_{at\ 1st\ slaughter,y} = \frac{Carcass\ weight_{hind,y}}{KO_{hind}}$$

Where:

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg).

Carcass $weight_{hind,y}$ = average carcass weight of hinds for year *y* ending in June (kg). Data supplied by Deer Industry New Zealand

KO_{hind} = killing out percentage for hinds. Currently set at 55%

The live weight of hinds at birth is assumed to be 9% of the mature breeding hind weight.

Live weight of hinds at birth (Equation 4.62)

$$Birth\ weight_{hind,y} = 9\% \times LWbh_y$$

Where:

Birth $weight_{hind,y}$ = live weight of hinds at birth in year *y* (kg)

$LWbh_y$= live weight of breeding hinds for a particular year *y* ending in June (kg) (equation 4.59)

Live weight gain for growing hinds from birth to first slaughter (Equation 4.63)

$$LWGhind_{birth\ to\ first\ slaughter,y} = \frac{LWhind_{at\ 1st\ slaughter,y} - Birth\ weight_{hind,y}}{days\ to\ 1st\ Slaughter_{hind}}$$

Where:

$LWGhind_{birth\ to\ first\ slaughter,y}$ = live weight gain of growing hinds from birth to first slaughter in year y (kg per day)

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg) (equation 4.61)

Birth $weight_{hind,y}$ = live weight of hinds at birth in year *y* (kg) (equation 4.62)

days to 1st $slaughter_{hind}$ = number of days between birth and first slaughter for growing hinds (466)

4.7.4.3 Hinds from first slaughter to maturity

From the 28th of February, the live weight of hinds older than the age of one but younger than two (when they become mature breeding hinds) can be calculated using the formula below.

Monthly live weight for growing hinds, from first slaughter to maturity (Equation 4.64)

$$LWhind_{1st\ slaughter\ to\ mature,m,y} = \left(\frac{AgeMOM_{hind,m,y} - days\ to\ 1st\ Slaughter_{hind}}{days\ to\ maturity_{hind}} \times \left(LWbh_y - LWhind_{at\ 1st\ slaughter,m,y}\right)\right)$$

Where:

$LWhind_{1st\ slaughter\ to\ maturity,m,y}$ = live weight of growing hinds for a particular year *y* and month *m*, from 466 days of age to maturity

$AgeMOM_{hind,m,y}$ = age (in days) of growing hinds at the middle of month *m* in year *y*

days to 1st $slaughter_{hind}$ = number of days between birth and first slaughter for growing hinds (466)

days to $maturity_{hind}$ = number of days between first slaughter and maturity for growing hinds (306)

$LWbh_y$= live weight of breeding hinds for a particular year *y* ending in June (kg) (equation 4.59)

$LWhind_{at\ 1st\ slaughter,y}$ = 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)

$$LWGhind_{1st\ slaughter\ to\ maturity,y} = \frac{LWbh_y - LWhind_{at\ 1st\ slaughter,m,y}}{days\ to\ maturity_{hind}}$$

Where:

$LWGhind_{slaughter\ to\ maturity,y}$ = live weight gain of growing hinds from first slaughter to maturity in year *y* (kg per day)

$LWbh_y$= live weight of breeding hinds for a particular year *y* ending in June (kg) (equation 4.59)

$LWhind_{at\ 1st\ slaughter,y}$ = live weight of hinds for a particular year *y* at slaughter after 466 days (kg) (equation 4.61)

days to $maturity_{hind}$ = 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)

$$LWstag_{birth\ to\ 1st\ slaughter,m,y} = \left(\frac{AgeMOM_{stag,m,y}}{days\ to\ 1st\ Slaughter_{stag}} \times \left(LWstag_{at\ 1st\ slaughter,m,y} - Birth\ weight_{stag,y}\right)\right)$$

Where:

$LWstag_{birth\ to\ 1st\ slaughter,m,y}$ = live weight of growing stags for a particular year *y* and month m, for the first 466 days of their life

$AgeMOM_{stag,m,y}$ = age (in days) of growing stags at the middle of month *m* in year *y*

days to 1^{st} $slaughter_{stag}$ = number of days between birth and first slaughter for growing stag (466)

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year *y* at slaughter after 466 days (kg) (equation 4.67)

Birth $weight_{stag,y}$ = live weight of stags at birth in year *y* (kg) (equation 4.68)

Live weight for growing stags at first slaughter (Equation 4.67)

$$LWstag_{at\ 1st\ slaughter,y} = \frac{Carcass\ weight_{stag,y}}{KO_{stag}}$$

Where:

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year *y* at slaughter after 466 days (kg).

Carcass $weight_{stag,y}$ = average carcass weight of stags for year *y* ending in June (kg). Data supplied by Deer Industry New Zealand

KO_{stag} = killing out percentage for stags. Currently set at 55%

The live weight of stags at birth is assumed to be 10% of the mature breeding hind weight.

Live weight of stags at birth (Equation 4.68)

$$Birth\ weight_{stag,y} = 10\% \times LWbh_y$$

Where:

Birth $weight_{stag,y}$ = live weight of stags at birth in year *y* (kg)

$LWbh_y$= live weight of breeding hinds for a particular year *y* ending in June (kg) (equation 4.59)

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:

$LWGstag_{birth\ to\ first\ slaughter,y}$ = live weight gain of growing stags from birth to first slaughter in year *y* (kg per day)

$LWstag_{at\ 1st\ slaughter,y}$ = live weight of stags for a particular year *y* at slaughter after 466 days (kg) (equation 4.67

Birth $weight_{stag,y}$ = live weight of stags at birth in year *y* (kg) (equation 4.68)

days to 1^{st} $slaughter_{stag}$ = number of days between birth and first slaughter for growing stags (466)

4.7.4.5 Stags from first slaughter to maturity

From the 28th 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)

$$LWstag_{1st\ slaughter\ to\ three,m,y} = \left(\frac{AgeMOM_{stag,m,y} - days\ to\ 1st\ Slaughter_{stag}}{days\ to\ maturity_{stag}} \times \left(LWstag_{age\ three,y} - LWstag_{at\ 1st\ slaughter,m,y}\right)\right)$$

Where:

$LWstag_{1st\ slaughter\ to\ three,m,y}$ = live weight of stags for a particular year *y* and month *m*, from 466 days of age to three years of age

$AgeMOM_{stag,m,y}$ = age (in days) of stags at the middle of month *m* in year *y*

days to 1^{st} $slaughter_{stag}$ = number of days between birth and first slaughter for stags (466)

days to $maturity_{stag}$ = number of days between first slaughter and age three for stags (671)

$LWstag_{age\ three,y}$= live weight of stags at age three for a particular year *y* ending in June (kg) (equation 4.71)

$LWstag_{at\ 1st\ slaughter,y}$ = 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

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. Nitrogen excretion (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.

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.

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.

This chapter outlines the equations and parameters that are used to calculate N_{ex} for dairy, beef, sheep, deer and 'minor' species.

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_{rm} = 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 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):

$$N_f = -4.623 + (Feed_N \times 100 \times 1.970) + (DMI \times 7.890)$$

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)

5.2 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 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.

5.3 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_{rm} = nitrogen secreted in milk per animal (kg N/day)

N_{lwg} = nitrogen retained in live weight gain per animal (kg N/day)

N_{wool} = nitrogen retained in wool growth per animal (kg N/day)

5.3.1 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):

$$z_{3lamb} = \frac{Y_{sheepm}}{d_{srm} \times P_{lamb}} \times \frac{P_{mp}}{6.25}$$

Where:

Z_{3lamb} = nitrogen intake through milk per animal (kg of nitrogen per day)

Y_{sheepm} = annual milk yield per sheep (kilograms per sheep per year)

P_{lamb} = annual lambing percentage rate (see appendix 12)

d_{srm} = number of days young lambs receive milk (assumed to be 122)

P_{mp} = protein content of sheep milk (value currently used is 0.06 grams of protein per gram of milk)

The first fraction in the above equation is used to calculate the daily milk intake for lambs, while the second fraction calculates the nitrogen content of this milk. The value of 6.25 is used because of the assumption that 6.25 tonnes of protein contains 1 tonne of nitrogen (Pierce & Haenisch, 1947).

For September to 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):

$$N_i = (DMI \times Feed_N) + z_{3lamb}$$

Where:

N_i = Nitrogen intake per animal (kg of nitrogen per day)

DMI = dry matter intake per animal (kg/day see Section 4.1.1)

$Feed_N$ = Nitrogen content of feed consumed by sheep, expressed as a proportion of DMI (see appendix 19)

Z_{3lamb} = 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, whethers, lambs and rams) produce no milk so N_{rm} is assumed to be zero for all 12 months of the year for these sheep subcategories.

5.3.3 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):

$$Wool_{lamb,daily} = \frac{totwool_{lamb,m}/nod_m}{POPls_m}$$

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):

$$totWool_{sheep,m} = POPsheep_m \times F_{greasy} \times \left(\frac{nod_m}{nod_y} \times 12\right) \times \left(\frac{natWool_{greasy}}{natWool_{unadj,greasy}}\right)$$

Where:

$totwool_{sheep,m}$ = Amount of wool produced by all adult sheep in month *m* (kg)

$POPsheep_m$ = Adult sheep population in month *m*

F_{greasy} = inital 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):

$$totWool_{lamb,m} = POPls_m \times F_{greasy} \times \left(\frac{nod_m}{nod_y} \times 12\right) \times \left(\frac{natWool_{greasy}}{natWool_{unadj,greasy}}\right) \times Awool_{lamb}$$

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)

$Awool_{lamb}$ = 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):

$$\begin{aligned} natWool_{unadj,greasy} &= \left(\sum_{month}\left(F_{greasy} \times \left(\frac{nod_m}{nod_y} \times 12\right) POPls_m \times Awool_{lamb}\right)\right) \\ &+ \left(\sum_{month}\left(F_{greasy} \times \left(\frac{nod_m}{nod_y} \times 12\right) POPsheep_m \times\right)\right) \end{aligned}$$

Where:

$natWool_{unadj,greasy}$ = calculated total annual greasy wool production (assuming fixed greasy fleece weight of 5kg)

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)

$POPls_m$ = lamb population in month *m*

$Awool_{lamb}$ = factor used to adjust for the slower wool growth of lambs compared to adult sheep (currently equal to 0.5)

$POPsheep_m$ = 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_{wool}). This value is constant over the course of the year, although N_{wool} for lambs will be half of the N_{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):

$$N_{wool} = Wool_{sheep,daily} \times wool_{Ncontent}$$

Where:

N_{wool} = Amount of nitrogen retained in wool per animal (kg of nitrogen per day)

$Wool_{sheep,daily}$ = Amount of wool produced per adult sheep per day (kg)

$Wool_{Ncontent}$ = Proportion of nitrogen content of wool (assumed to be 0.134)

Nitrogen retained in wool produced by lambs (Equation 5.22):

$$N_{wool} = Wool_{lamb,daily} \times wool_{Ncontent}$$

Where:

N_{wool} = Amount of nitrogen retained in wool per animal (kg of nitrogen per day)

$Wool_{sheep,daily}$ = Amount of wool produced per lamb per day (kg)

$Wool_{Ncontent}$ = 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_{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):

$$N_{lwg} = LWG \times \frac{N_{bt,sheep}}{100}$$

Where:

N_{lwg} = Amount of nitrogen retained in animal tissues through liveweight gain per animal (kg N per day)

LWG = live weight gain per animal (kilograms/day, see section 4.7 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):

$$N_f = 2.230 + (N_i \times 0.299) + ([Feed_N \times 100]^2 \times -0.237)$$

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)

5.4 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 1st of September to the 4th of November. The nitrogen retained through the production of this velvet is accounted for with the following calculation. It is assumed that in this period velvet growth occurs at a constant rate.

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.

5.5 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 8).

Table 5.1: Default values for nitrogen excreted (N_{ex})

Species	N_{ex} (kg/head/year)	Reference
Goats	10.6 for 1990 12.1 for 2009 12.0 for 2013	Lassey, 2011
Swine	10.8 for 2009 11.05 for 2013	Hill, 2012
Horses	25.0	2006 IPCC default - Table 10.19
Mules and asses	25.0	2006 IPCC default – Table 10.19
Poultry - broilers	0.39	Fick *et al*., 2011
Poultry - layers	0.42	Fick *et al*., 2011
Other Poultry (including ducks, turkeys, emus, and ostriches)	0.60	2006 IPCC –Table 10.19
Alpaca	12.6	2006 IPCC –Table 10.19

5.5.1 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 kilograms of nitrogen per animal per year) and 2009 (12.1 kilograms of nitrogen per animal per year), 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 assumption that the dairy goat population is changing in a linear fashion (see equation 5.30)

Annual dairy goat population (Equation 5.30):

$$POPgoat_{dairy,y} = POPgoat_{dairy,y-1} + \frac{POPgoat_{dairy,2009} - POPgoat_{dairy,1990}}{19}$$

Where:

$POPgoat_{dairy,y}$ = Milking goat population in year *y*

$POPgoat_{dairy,y-1}$ = Milking goat population in previous year *y-1*

$POPgoat_{dairy,2009}$ = Milking goat population in 2009 (set at 28,954)

$POPgoat_{dairy,1990}$ = Milking goat population in 1900 (set at 37,426)

Proportion of milking goats in total goat population (Equation 5.31):

$$Pgoat_{milk,y} = \frac{POPgoat_{dairy,y}}{POPgoat_{tot,y}}$$

Where:

$Pgoat_{milk,y}$ = Proportion of milking goats in total goat population in year y

$POPgoat_{dairy,y}$ = Milking goat population in year *y*

$POPgoat_{tot,y}$ = Total goat population in year *y* (from Agricultural Production Survey)

Annual nitrogen excretion for goats (Equation 5.32):

$$N_{ex,goat,y} = N_{ex,goat,y-1} + \left(\frac{Pgoat_{milk,y} - Pgoat_{milk,y-1}}{Pgoat_{milk,2009} - Pgoat_{milk,1990}}\right) \times \left(N_{ex,goat,2009} - N_{ex,goat,1990}\right)$$

Where:

$N_{ex,goat,y}$ = Annual nitrogen excretion per goat in year *y* (kg N per year)

$N_{ex,goat,y-1}$ = Annual nitrogen excretion per goat in previous year *y-1* (kg N per year)

$Pgoat_{milk,y}$ = Proportion of milking goats in total goat population in year y

$Pgoat_{milk,y-1}$ = Proportion of milking goats in total goat population in previous year y

$Pgoat_{milk,2009}$ = Proportion of milking goats in total goat population in 2009 (set at 0.3521)

$Pgoat_{milk,1990}$ = Proportion of milking goats in total goat population in 1990 (set at 0.0352)

$N_{ex,goat,2009}$ = 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). The calculation of N_{ex} rates for goats assumes that the dairy goat population has remained static over time, while the rest of the goat population has declined.

5.5.2 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.

5.5.3 Horses, mules and asses

New Zealand uses IPCC (2006) default N_{ex} values (listed in Table 8) for horses, mules and asses.

5.5.4 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 5.33):

$$N_{ex,alpaca} = \frac{\sum_{class}\sum_{month}\left(N_{ex,sheep,c,1990} \times nod_m \times POPs_{c,m,1990}\right)}{POPsheep_{1990}}$$

Where:

$N_{ex,alpaca}$ = Annual nitrogen excretion per alpaca (kilograms of nitrogen per year)

$N_{ex,sheep,c,1990}$ = Nitrogen excretion per sheep in subcategory c in 1990, calculated using equation 5.12, 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

$POPsheep_{1990}$ = total sheep population in 1990 (from Statistics New Zealand)

class refers to the different categories of sheep used in the inventory

month refers to the twelve months of the calendar year.

5.5.5 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 5.34):

$$N_{ex,swine,y} = \frac{Aveslauweight_{swine,y}}{Aveslauweight_{swine,2010}} \times N_{ex,swine,2010}$$

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 5.35):

$$Aveslauweight_{swine,y} = \frac{totslauweight_{swine,y}}{SlauNum_{swine,y}}$$

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

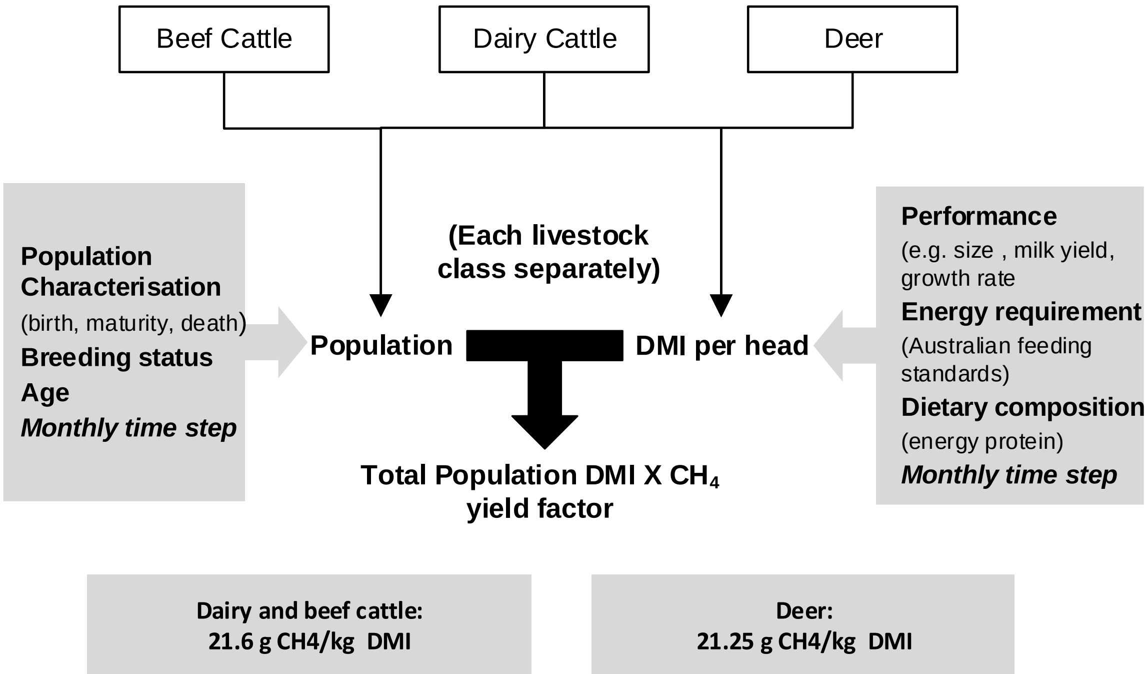
6 Methane emissions from enteric fermentation

Methane (CH_4) is a by-product of fermentation in ruminants and some non-ruminant animals such as swine and horses. Within the agricultural sector, ruminants are the largest source of the enteric release of CH_4, which accompanies feed degradation in the rumen. The amount of CH_4 released depends largely on total DMI, which itself depends on the type, age and weight of the animal, the quality, composition and quantity of feed, and the energy expenditure of the animal.

Enteric methane (EM) production from cattle (dairy and beef), sheep and deer was identified as a key source of greenhouse gas emissions for New Zealand through Intergovernmental Panel on Climate Change (IPCC) Tier 1 calculations. Therefore, a New Zealand-specific Tier 2 methodology developed by Clark *et al.* (2003) is used to calculate these CH_4 sources. This country-specific tier 2 methodology takes into account the unique characteristics of New Zealand livestock farming (see section 1.3)

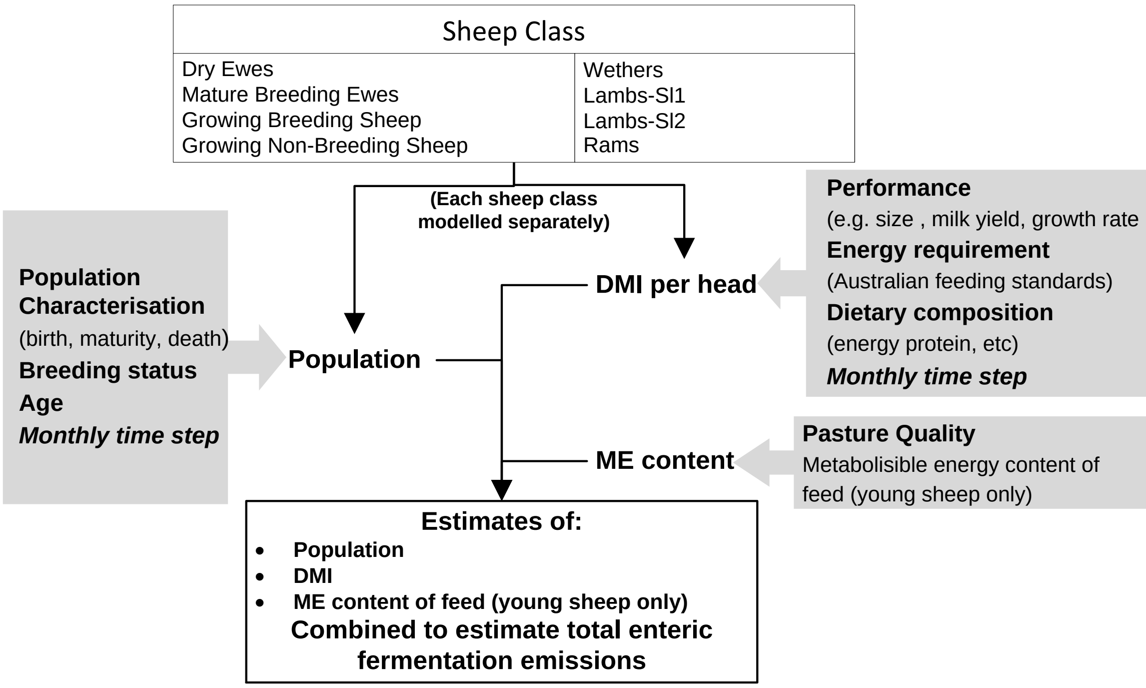
For cattle and deer, enteric CH_4 emissions for a single animal per day is calculated by multiplying estimated daily DMI (calculated using the methods described in chapter 4 of this document) by a CH_4 yield factor. Population estimates (calculated using the methods described in chapter 3 of this document) are used to get an aggregate annual estimate of enteric CH_4 emissions for dairy cattle, beef cattle and deer. A more complex methodology is used to estimate enteric CH_4 emissions for sheep, which is described in section 6.3.

Figure 6.1: Schematic diagram of how New Zealand's emissions from enteric fermentation for cattle and deer are calculated



Note: GEI is the gross energy intake and DMI is the dry-matter intake.

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).



Young sheep (less than one year old)	**Older sheep (greater than one year old)**
CH4 = $\frac{11.705}{1000} e^{0.05 \times ME} DMI^{0.734}$	**CH4 =** $\frac{21.977}{1000} DMI^{0.765}$

Since 1996 CH_4 has been measured in New Zealand from grazing cattle and sheep using the SF_6 tracer technique (Lassey *et al.*, 1997; Ulyatt *et al.*, 1999, 2002a, 2002b, 2005). Since 2008 CH_4 has been measured from cattle and sheep fed cut pasture in respiration chambers (Swainson *et al*., 2016; Jonker *et al*., 2017). New Zealand now has one of the largest datasets in the world of CH_4 emissions determined using the SF_6 technique and respiration chambers on ruminants fed fresh pasture.

Published and unpublished data were used to derive New Zealand-specific enteric methane yield values and equations for cattle (Clark *et al.,* 2003) and sheep (Swainson, Muetzel and Clark, 2016). Assumptions have been made for beef cattle (assumed to have the same yield value as dairy cattle) and deer (explained in section 6.4) (Clark *et al.,* 2003).

6.1 Dairy

The daily production of enteric methane ($CH_{4\text{-enteric-cattle}}$ in equation 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:

$CH_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg), for a particular subcategory of cattle (subcategories as defined in table 4.1 in section 4.3.1)

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_4/kg intake) per unit of intake and is derived from experiments on New Zealand dairy cows. It equates to a loss of 6.5% of gross energy assuming that the feed has a gross energy concentration of 18.45 MJ/kg DM and gross energy of methane (enthalpy of combustion) is 55.6 MJ/kg CH_4[e].

Dairy calves are fed on milk for the first two months of their life (August and September) and it is assumed that they produce no methane during this period. $CH_{4\text{-enteric-cattle}}$ is set to zero for dairy calves during these months.

As stated in section 4.3, 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)

$$dairyCH_{4-enteric} = \sum_{region}\sum_{month}\sum_{class} POPdairy_{c,m,r} \times nod_m \times CH_{4-enteric-cattle}$$

Where:

$dairyCH_{4\text{-enteric}}$ = annual enteric methane emissions for all dairy cattle (kg)

$POPdairy_{c,m,r}$ = population of dairy animals in subcategory *c*, month *m* and region *r*

nod_m = number of days in month *m*

$CH_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of dairy cattle (e.g. mature milking cows, breeding bulls…) in a particular month and region (equation 6.1)

class refers to the different categories of dairy cattle used in the inventory (as defined in table 4.1 in section 4.3.1)

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. $CH_{4\text{-enteric-cattle}}$ is set to zero for beef calves during these months.

The annual enteric methane emissions for beef cattle for all subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for each month and subcategory of beef cattle (see appendix 2).

Annual enteric methane emissions in the beef sector (Equation 6.3)

$$beefCH_{4-enteric} = \sum_{month}\sum_{class} POPbeef_{c,m} \times nod_m \times CH_{4-enteric-cattle}$$

Where:

[e] That is, the methane loss (as a percentage of gross energy) = 21.6/18.45 x 0.0556 x 100% = 6.5%

$beefCH_{4\text{-enteric}}$ = annual enteric methane emissions for all beef cattle (kg)

$POPbeef_{c,m,r}$ = population of beef animals in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of beef cattle (e.g. slaughter heifers 0-1, breeding mature cows…) in a particular month (equation 6.1)

class refers to the different categories of beef cattle used in the inventory (as defined in table 4.2, 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. $CH_{4\text{-enteric-sheep}<1}$ 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)[f]

$$CH_{4-enteric,sheep<1} = \frac{11.705}{1000} \times e^{0.05 \times Feed_{ME}} \times DMI^{0.734}$$

Where:

$CH_{4\text{-enteric,sheep}<1}$ = enteric methane emissions per animal per day (kg), for sheep less than one year of age (e.g. lambs), but older than 2 months

$Feed_{ME}$ = metabolisible 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)[g]

$$CH_{4-enteric,sheep>1} = \frac{21.977}{1000} \times DMI^{0.765}$$

Where:

$CH_{4\text{-enteric,sheep}>1}$ = enteric methane emissions per animal per day (kg), for a particular subcategory sheep greater than one year of age (e.g. dry ewes, mature breeding ewes, growing breeding sheep, growing non-breeding sheep, wethers, lambs, rams)

DMI = dry matter intake (kg per animal per day) (see section 4.1.1)

The above equations are based on Swainson, Muetzel and Clark (2016). This paper analysed a large dataset of recent experiments in New Zealand where methane emissions from sheep, fed cutpasture of varying amounts and quality, were measured in respiration chambers. The meta-analysis confirmed that DMI has the largest influence on CH4 emissions, and also found that pasture quality (as measured by

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[f] The equation displayed here is a re-arranged form of the equation displayed in Swainson, Muetzel and Clark (2016):

$Ln(CH_4) = 0.734 \times ln(DMI) + 0.05 \times ME + 2.46$

[g] The equation displayed here is a re-arranged form of the equation displayed in Swainson, Muetzel and Clark (2016):

$Ln(CH_4) = 0.765 \times ln(DMI) + 3.09$

metabolisable energy content) had a small but statistically significant effect on emissions from sheep younger than one year of age.

The paper concluded that two log-transformed equations (one for sheep younger than one year of age, and one for sheep older than one year of age) provided the best fit for the data and recommended that these equations be used in the national inventory (Swainson, Muetzel and Clark, 2016).

The annual methane emissions from all sheep (kt/yr) can be calculated using 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:

$totalCH_{4\text{-enteric,sheep}<1}$ = annual enteric methane emissions for all sheep less than one year old (kg)

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

nod_m = number of days in month *m*

$CH_{4\text{-enteric-sheep}<1}$ = enteric methane emissions per lamb per day (kg) in a particular month *m* (equation 6.4)

month refers to the twelve months of the calendar year.

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:

$totalCH_{4\text{-enteric,sheep}>1}$ = annual enteric methane emissions for all sheep greater than one year old (kg)

$POPsheep_{c,m}$ = population of sheep (greater than one year old) in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4\text{-enteric-sheep}>1}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of sheep (e.g. dry ewes, mature breeding ewes…) in a particular month *m* (equation 6.5)

class refers to the different subcategories of sheep used in the inventory

month refers to the twelve months of the calendar year.

Annual enteric methane emissions for all sheep (Equation 6.8)

$$totalsheepCH_{4-enteric} = totalCH_{4-enteric,sheep>1} + totalCH_{4-enteric,sheep<1}$$

Where:

$totalsheepCH_{4\text{-enteric}}$ = annual enteric methane emissions for all sheep (kg)

$totalCH_{4\text{-enteric,sheep}>1}$ = annual enteric methane emissions for all sheep greater than one year old (kg) (equation 6.6) totalCH$_{4\text{-enteric,sheep<1}}$ = annual enteric methane emissions for all sheep less than one year old (kg) (equation 6.7)

6.4 Deer

The per-animal production of enteric methane for deer is calculated using the same equation (x, in section 6.1) used for dairy cattle. However, the methane conversion rate (MCR) is set to 21.25 grams of methane per kg of DMI. The MCR value for deer is the average of the MCR value currently used for cattle (21.6 grams of CH_4 per kg of DMI) and the (now defunct) MCR value used for adult sheep until 2016 (20.9) (Clark, 2003).

DMI is calculated using deer-specific energy requirement values (set out in section 4.6) and the DMI equation in section 4.1.1.

Daily enteric methane emissions per animal – deer (Equation 6.9)

$$CH_{4-enteric-deer} = DMI \times \frac{MCR}{1000}$$

Where:

CH$_{4\text{-enteric-cattle}}$ = enteric methane emissions per animal per day (kg), for a particular subcategory of deer (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$_{4\text{-enteric-deer}}$ is set to zero for newborn hinds and stags during these months

The annual enteric methane emissions for the deer population for all subcategories can be calculated using the formula below. This formula aggregates the daily methane emissions for each month and subcategory of deer (see appendix 2).

Annual enteric methane emissions in the deer sector (Equation 6.10)

$$deerCH_{4-enteric} = \sum_{month}\sum_{class} POPdeer_{c,m} \times nod_m \times CH_{4-enteric-deer}$$

Where:

deerCH$_{4\text{-enteric}}$ = annual enteric methane emissions for all deer (kg)

POPdeer$_{c,m}$ = population of deer animals in subcategory *c*, in month *m*

nod$_m$ = number of days in month *m*

CH$_{4\text{-enteric-deer}}$ = enteric methane emissions per animal per day (kg) for a particular subcategory of deer (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_4/head/year)	Reference
Goats	7.4 (for 1990) 8.5 (for 2009)	Lassey (2011) Lassey (2011)
Swine	1.06	Hill (2012)
Horses	18.0	IPCC default - Table 10.10 *2006 IPCC guidelines*
Mules and asses	10.0	IPCC default - Table 10.10 *2006 IPCC guidelines*
Poultry (eg geese, guinea fowl, emus, ostriches etc)	Not estimated	IPCC default - *Table 10.10* *2006 IPCC guidelines*
Alpaca	8.0	IPCC default - *Table 10.10* *2006 IPCC guidelines*

IPCC default emission factors are used for horses, mules and asses and alpaca while New Zealand-derived values are used for goats and swine. These minor species comprised 0.15 per cent of total enteric CH_4 emissions in 2015. For each minor livestock species, the emission factors are multiplied by the species population (Appendix 16) to obtain the total methane emissions.

6.5.1 Goats

New Zealand specific enteric fermentation emission factors of:

- 7.4 kg CH_4/head/year for 1990
- 8.5 kg CH_4/ head/year for 2009

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 interpolated based on the assumption that the dairy goat population has remained relatively constant over time, while the rest of the goat population has changed.

These factors are multiplied by goat population data to obtain the total CH_4 emissions produced by goats from enteric fermentation for a given inventory year. This calculation is similar to the equation used to calculate nitrogen excretion for goats (equation 205, section 5.5.1).

Annual enteric fermentation for goats (Equation 6.11):

$$CH_{4,goat,y} = CH_{4,goat,y-1} + \left(\frac{Pgoat_{milk,y} - Pgoat_{milk,y-1}}{Pgoat_{milk,2009} - Pgoat_{milk,1990}}\right) \times \left(CH_{4,goat,2009} - CH_{4,goat,1990}\right)$$

Where:

$CH_{4,goat,y}$ = Annual enteric fermentation per goat in year *y* (kilograms of methane per year)

$CH_{4,goat,y-1}$ = Annual enteric fermentation per goat in previous year *y-1* (kilograms of methane per year)

$Pgoat_{milk,y}$ = Proportion of milking goats in total goat population in year y (see equation 5.31, section 5.5.1)

$Pgoat_{milk,y-1}$ = Proportion of milking goats in total goat population in previous year *y* (see equation 5.31, section 5.5.1)

$Pgoat_{milk,2009}$ = Proportion of milking goats in total goat population in 2009 (set at 0.3521)

$Pgoat_{milk,1990}$ = Proportion of milking goats in total goat population in 1990 (set at 0.0352)

$CH_{4,goat,2009}$ = Annual enteric fermentation per goat in 2009 (set at 7.4 kilograms of methane per year)

$CH_{4,goat,1990}$ = Annual enteric fermentation per goat in 1990 (set at 8.5 kilograms of methane per year)

6.5.2 Swine

New Zealand uses a country specific emission factor of 1.06 kg CH_4/head/year, which is lower than the IPCC default of 1.5 kg CH_4/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_4 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_4 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_4 emissions produced by mules and asses from enteric fermentation for a given inventory year.

6.5.5 Poultry

New Zealand does not estimate emissions from enteric fermentation of poultry because there is no IPCC 2006 methodology to estimate emissions from this category (Table 9).

6.5.6 Alpacas

The IPCC default value from the IPCC 2006 guidelines (IPCC, 2006) is based on a study carried out in New Zealand (Table 9). In the absence of further work carried out on alpacas in New Zealand this value has been used but is yet to be taken on as a country specific value.

This value is multiplied by population data to obtain the total CH_4 emissions produced by alpacas from enteric fermentation for a given inventory year.

7 Methane and nitrous oxide from manure management

This chapter discusses how emissions from manure management are estimated. The manure management component of the inventory includes methane and nitrous oxide emissions related to the handling and decomposition of livestock manure.

Manure management 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_4. The amount of CH_4 emissions depends on:

- the amount of manure produced
- the amount of faecal dry matter (FDM) contained in the manure
- the amount of manure that decomposes anaerobically (i.e., how the manure is stored).

Sections 7.1.1 to 7.1.4 describe how CH4 manure management emissions are estimated for the four major livestock species. For this tier 2 methodology, calculations of faecal dry matter (FDM) are used.

Based on research performed by Ulyatt (2002a, 2002b), faecal dry matter output (FDM, kg DM/head/day) is calculated for each of the four major livestock categories (dairy cattle, non-dairy cattle, sheep and deer) and subcategory (as described in Chapter 4 in tables 4.1, 4.1 4.3, and 4.4) from the following equation:

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_{4AL}). This equation only applies to mature milking cows.

Calculation of methane from anaerobic lagoons for dairy cattle (Equation 7.2)

$$CH_{4AL-dairy} = FDM \times (1 - ASH) \times B_0 \times 0.67 \times MCF \times MS_{AL,CH4,y}$$

Where:

$CH_{4AL\text{-}dairy}$ = amount of methane produced per dairy animal from anaerobic lagoons per day (kg)

FDM = kilograms of faecal dry matter per animal per day

ASH = Ash content of manure, assumed to be 0.08 (IPCC default value)

B_0 = Maximum methane-producing capacity of manure, 0.24 (IPCC, 2006)

MCF = Methane conversion factor, 0.74 (IPCC, 2006)

$MS_{AL,CH4,y}$ = fraction of total annual dairy manure excreted in anaerobic lagoons in year *y*. Table 7.1 shows the value for each year for mature milking cows which for 2017 was equal to 8.5%. For all other animal classes, this is set to 0%.

The 0.67 value in this equation represents the conversion factor used to convert cubic metres of CH_4 to kilograms of CH_4[h]. The value used for B_0 is the IPCC Oceania default value which was verified by Pratt *et al.,* 2012). The value for MCF is the IPCC default value for uncovered anaerobic lagoon at an annual temperature of 15ºC which was also verified by Pratt *et al.,* 2012).

Table 7.1 shows the annual proportion of mature milking cattle manure distributed between managed manure systems i.e. anaerobic lagoons, and directly onto pasture. The second column, $MS_{AL,CH4}$ represents the proportion of mature milking cattle excreta that is deposited specifically to anaerobic lagoons ($MS_{AL,CH4,y}$). The third column presents the remaining proportion of mature milking cattle manure that is not deposited in anaerobic lagoons, i.e. the proportion which is deposited directly on pasture (MS_{PRP}).

Year	$Trends_{project}$ 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%

[h] 1mol of CH4 at NTP = 24.0548L and 16.044g. Thus 1m3 CH4 =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; Saggar *et al.,* 2003)

The methane yield value of 0.00098198 kg CH_4/kg FDM was determined from studies by Sherlock *et al* (2003) and Saggar *et al.* (2003). For more details on this calculation see table 7.1 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)

$$dairyCH_{4-AL} = \sum_{region}\sum_{month}\sum_{class}\left(POPmmc_{m,r} \times nod_m \times CH_{4AL-dairy,m,r}\right)$$

Where:

$dairyCH_{4-AL}$ = annual manure management methane emissions from anaerobic lagoons for all dairy cattle (kg)

$POPmmc_{m,r}$ = population of mature milking cows in month *m* and region *r*

nod_m = number of days in month *m*

$CH_{4AL-dairy,m}$ = 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)

$$dairyCH_{4-PRP} = \sum_{region}\sum_{month}\sum_{class}\left(POPdairy_{c,m,r} \times nod_m \times CH_{4PRP-dairy,m,r}\right)$$

Where:

$dairyCH_{4\text{-}PRP}$ = annual manure management methane emissions from pasture range and paddock for all dairy cattle (kg)

$POPdairyc_{c,m,r}$ = population of dairy animals in subcategory *c*, month *m* and region *r*

nod_m = number of days in month *m*

$CH_{4PRP\text{-}dairy}$ = amount of methane produced per dairy animal per day from FDM deposited onto pasture in month *m* and region *r* (kg)

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of section 4.3)

Annual manure management methane emissions in the dairy sector (Equation 7.6)

$$dairyCH_{4-mm} = dairyCH_{4-AL} + dairyCH_{4-PRP}$$

Where:

$dairyCH_{4\text{-}mm}$ = annual manure management methane emissions for all dairy cattle (kg)

$dairyCH_{4\text{-}AL}$ = annual manure management methane emissions from anaerobic lagoons for all dairy cattle (kg)

$dairyCH_{4\text{-}PRP}$ = annual manure management methane emissions from pasture range and paddock for all dairy cattle (kg)

7.1.2 Beef

For beef cattle, 100% of FDM is spread onto pasture. Methane emissions from manure management are calculated for all subcategories of beef cattle using the following equation.

Calculation of methane emissions from FDM deposited onto pasture for beef cattle (Equation 7.7)

$$CH_{4PRP-beef} = FDM \times Y_m$$

Where:

$CH_{4PRP\text{-}beef}$ = amount of methane produced per beef animal per day from FDM deposited on pasture (kg/day)

FDM = kilograms of faecal dry matter per animal per day

Y_m = Methane yield value, currently set at 0.00098198 kg CH_4/kg FDM

The methane yield value of 0.00098198 kg CH_4/kg FDM was determined from trials by Sherlock *et al* (2003) and Saggar *et al* (2003). For more details on this calculation see table 7.1 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)

$$beefCH_{4-mm} = \sum_{month}\sum_{class}\left(POPbeef_{c,m} \times nod_m \times CH_{4PRP-beef}\right)$$

Where:

$beefCH_{4-mm}$ = annual manure management methane emissions for all beef cattle (kg)

$POPbeef_{c,m}$ = population of beef animals in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4PRP-beef}$ = 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_4/kg FDM was determined from a study by Carran *et al* (2003). FDM is calculated using equation 7.1 (section 7.1), using sheep-specific values for DMI (calculated in equation 4.1, section 4.1.1) and DMD (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)

$$sheepCH_{4-mm} = \sum_{month}\sum_{class}\left(POPsheep_{c,m} \times nod_m \times CH_{4PRP-sheep}\right)$$

Where:

$sheepCH_{4-mm}$ = annual manure management methane emissions for all sheep (kg)

$POPsheep_{c,m}$ = population of sheep in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4PRP\text{-}sheep}$ = 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:

$CH_{4PRP\text{-}deer}$ = 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 Ym for cattle. The last two rows in the above figure represent the high and low measurement values from the study by Carran *et al* (2003)[i].

[i] Data from the full set of measurements by Carran are on table 1, page 8 of Carran et al. (2003). The average of these five values are used as the Y_{msheep} (manure management methane sheep yield) value

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)

$$deerCH_{4-mm} = \sum_{month} \sum_{class} \left(POPdeer_{c,m} \times nod_m \times CH_{4PRP-deer} \right)$$

Where:

$deerCH_{4-mm}$ = annual manure management methane emissions for all deer (kg)

$POPdeer_{c,m}$ = population of deer in subcategory *c*, in month *m*

nod_m = number of days in month *m*

$CH_{4PRP-deer}$ = 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)

$$minorCH_{4-mm-c} = MEF_c \times POPminor_c$$

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)

$POPminor_c$ = population of minor livestock species *c* (from APS)

Values of MEF_c for a particular livestock species can be found in table 7.1, 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_4 emissions from manure management for alpacas. Therefore, this was calculated by assuming a default CH_4 emission from manure management value for alpacas for all years that is equal to the per head value of the average sheep in 1990 (i.e. total sheep emissions/total sheep population). The alpaca emission factor is not indexed to sheep over time because there is no data to support that alpacas had the same level of productivity increases that have been seen in sheep.

Table 7.1: Manure management emission factors for Tier 1 calculations for methane from manure management from non - key source livestock species

Species	Methane (kg CH_4/head/year)	Reference
Goats	0.20	Table 10.15 2006 IPCC guidelines
Swine	5.94	Hill, 2012
Horse	2.34	Table 10.15 2006 IPCC guidelines
Mules and asses	1.1	Table 10.15 Revised 2006 IPCC guidelines
Broilers	0.022	Fick *et al*., 2011
Layers	0.016	Fick *et al*., 2011
Other poultry (eg geese, guinea fowl, emus, ostriches etc)	0.117	Fick *et al*., 2011
Alpaca	0.091	New Zealand specific value assumed to be the same as sheep in1990

7.2 Nitrous oxide

In New Zealand, dairy cattle, poultry and swine are the only livestock categories that use waste management systems other than *pasture range and paddock*, and are the only sources of nitrous oxide (N_2O) emissions from manure management. These emissions can be classified as either direct (generated by nitrification and denitrification of nitrogen contained in manure (IPCC, 2006) or indirect (from volatilised or leached N).

Nitrous oxide emissions from manure deposited directly onto pasture (*Pasture Range and Paddock,* or PR&P) are reported in the *Agricultural Soils* section of the inventory, and are explained further in chapter 8.

7.2.1 Direct nitrous oxide emissions

Direct N_2O emissions from livestock are determined by the amount of nitrogen excreted from an animal as well as the emissions produced by the manure management system that the animal manures are stored in, including the unmanaged direct deposition on pastureland. The proportion of manure from each livestock species in each animal manure management system (MMS) is detailed in Appendix 17.

To calculate emissions for this category, the total N_{ex} from each livestock species for each MMS is summed and the system-specific emission factor is applied.

7.2.1.1 Dairy

A small proportion of dairy manure is managed in anaerobic lagoons (see table 7.1 in section 7.1.1 and appendix 18). The IPCC (2006) Guidelines note that the production of emissions of direct N2O from managed manure requires aerobic conditions for the formation of oxidised forms of N, but assumes that negligible direct N_2O emissions occur during storage in anaerobic lagoons (IPCC, 2006, table 10.21). Based on this the emission factor for N_2O emissions from waste in anaerobic lagoons (EF_{3AL}) is set to zero, and it is assumed that there are no direct nitrous oxide emissions from manure management for dairy cattle.

Direct N_2O emissions from stored effluent spread onto agricultural land are reported under the *Agricultural Soils* category (Organic nitrogen fertilisers (CRF 3.D.1.2)).

7.2.1.2 Swine

Waste from swine is distributed across 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 N2O manure management emission factor	Value of direct N2O manure management emission factor used in inventory	Proportion of managed manure which volatilises as NH_3 and NO_x
Anaerobic lagoon	20.5	EF_{3AL}	0	$Frac_{GasMS(AL\_swine)}$=0.40
Daily spread	25.7	$EF_{3DailyS}$	0	$Frac_{GasMS(DS\_swine)}$=0.07
Pasture range and paddock	8.9	(calculated in agricultural soils chapter)		
Solid storage and drylot	42.5	EF_{3SSD}	0.02	$Frac_{GasMS(SS\&D\_swine)}$=0.3
Other management systems	2.4	EF_{3OTHER}	0.005	$Frac_{GasMS(other\_swine)}$ =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:

$mmN_2O_{Direct,swine,y}$ = annual direct nitrous oxide emissions from manure management per pig in year *y* (kilograms of nitrous oxide per year)

$N_{ex,swine,y}$ = Annual nitrogen excretion per pig in year *y* (kilograms of nitrogen per year)

$Pmms_{swine,x}$ = Proportion of swine waste deposited in manure management system *x* (see table 7.2 above)

$EF_{3,x}$ = direct N_2O 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_2O emissions from waste in anaerobic lagoons (EF_{3AL}) is set to zero, and it is assumed that there are no direct nitrous oxide emissions from manure management for swine. Direct N2O 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_2O emissions from swine.

Total direct manure management nitrous oxide emissions from swine (Equation 7.15)

$$totmmN_2O_{Direct,swine,y} = mmN_2O_{Direct,swine,y} \times POPswine_y$$

Where:

$totmmN_2O_{Direct,swine,y}$ = annual direct nitrous oxide emissions from manure management for all swine in year *y* (kilograms of nitrous oxide per year)

$mmN_2O_{Direct,swine,y}$ = annual direct nitrous oxide emissions from manure management per pig in year *y* (kilograms of nitrous oxide per year)

$POPswine_y$ = swine population in year *y*

7.2.1.3 Poultry

Direct N2O 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_2O 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_2O 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)

$$\begin{aligned} totmmN_2O_{Direct,poultry,y} \\ &= \left(mmN_2O_{Direct,broiler,y} \times POPpoultry_{broiler,y}\right) \\ &+ \left(mmN_2O_{Direct,layer,y} \times POPpoultry_{layer,y}\right) \\ &+ \left(mmN_2O_{Direct,other,y} \times POPpoultry_{other,y}\right) \end{aligned}$$

Where:

$totmmN_2O_{Direct,poultry,y}$ = annual direct nitrous oxide emissions from manure management for all poultry in year *y* (kilograms of nitrous oxide per year)

$mmN_2O_{Direct,broiler}$ = annual direct nitrous oxide emissions from manure management per broiler chicken (kilograms of nitrous oxide per year)

$POPpoultry_{broiler,y}$ = broiler population in year *y* (from APS)

$mmN_2O_{Direct,layer}$ = annual direct nitrous oxide emissions from manure management per layer hen (kilograms of nitrous oxide per year)

$POPpoultry_{layer,y}$ = layer population in year *y* (from APS)

$mmN_2O_{Direct,other}$ = annual direct nitrous oxide emissions from manure management per poultry animal classified as *other* (kilograms of nitrous oxide per year)

$POPpoultry_{other,y}$ = population of other poultry in year *y* (from APS)

7.2.2 Indirect nitrous oxide emissions

Indirect N_2O emissions from manure management result from diffusion of nitrogen (N) into the surrounding air (volatilisation) and water (leaching and runoff). This N can then subsequently be emitted as N_2O. New Zealand uses the IPPC (2006) Tier 1 methodology for calculating indirect N_2O emissions resulting from N volatilisation from manure management systems.

The IPCC (2006) guidelines provides methodology for estimating leaching and runoff for solid storage and feedlots. 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_2O emissions from manure deposited directly onto pasture (*Pasture Range and Paddock,* or PR&P) are reported in the *Agricultural Soils* section of the inventory, and are explained further in chapter 8.

7.2.2.1 Dairy

A proportion of dairy manure stored in anaerobic lagoons volatilises into NH_3 and NO_x, which is later emitted as N_2O. As mentioned earlier, only mature milking cows (lactating cattle) deposit part (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_2O 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)

$$mmN_2O_{indirect,dairy,m,R} = N_{ex,m,R,mm} \times MS_{AL,N2O} \times EF_4 \times Frac_{GasMS(AL_{dairy})} \times \frac{44}{28}$$

Where:

$mmN_2O_{indirect,dairy,m,R}$ = indirect nitrous oxide emissions from manure management per milking cow per day in month *m* and region *R* (kilograms of nitrous oxide per day)

$N_{ex,m,R,mm}$ = nitrogen excretion per mature milking cow in month *m* and region *R* (kilograms of nitrogen per day – see section 5.1)

$MS_{AL,N2O,y}$ = fraction of total annual dairy manure excreted in anaerobic lagoons in year y, see table 7.1 for annual values.

EF_4 = Emission factor for N_2O emissions from volatilisation. The IPCC (2006) default value of 0.01 kg N_2O-N/(kg NH_3-N + NO_x-N volatilised) is used

$Frac_{GasMS(AL\_dairy)}$ = proportion of managed manure which volatilises as NH_3 and NO_x 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 N2O 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 N2O 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)

$$totmmN_2O_{indirect,swine,y} = mmN_2O_{indirect,swine,y} \times POPswine_y$$

Where:

$totmmN_2O_{indirect,swine,y}$ = annual indirect nitrous oxide emissions from manure management for all swine in year *y* (kilograms of nitrous oxide per year)

$mmN_2O_{indirect,swine,y}$ = annual indirect nitrous oxide emissions from manure management per pig in year *y* (kilograms of nitrous oxide per year)

$POPswine_y$ = swine population in year *y*

7.2.2.3 Poultry

Indirect N2O manure management emissions from poultry are calculated using different parameters for Broilers, Layers and Other poultry.

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)

$$totmmN_2O_{indirect,poultry,y} = \left(mmN_2O_{indirect,broiler,y} \times POPpoultry_{broiler,y}\right) + \left(mmN_2O_{indirect,layer,y} \times POPpoultry_{layer,y}\right) + \left(mmN_2O_{indirect,other,y} \times POPpoultry_{other,y}\right)$$

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 management system	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_2O emissions from agricultural soils, from both direct and indirect pathways (see figure 5.5.1). Direct N_2O emissions come directly from the soils to which nitrogen has been added or released. Indirect emissions come from the volatilisation (evaporation or sublimation) of nitrogen from the land. A fraction of this volatilised nitrogen returns to the ground during rainfall and is then re-emitted as N_2O. Indirect emissions also arise from leaching and runoff of nitrogen (IPCC, 2006).

New Zealand uses a combination of default and country-specific emission factors and parameters to calculate N_2O emissions from agricultural soils.

N_2O-N[j] emissions are calculated for each source and then converted to N_2O emissions for reporting purposes by multiplying by 44/28. Nitrous oxide emissions for each source are then added together to produce the total amount of direct N_2O emissions from Agricultural soils.

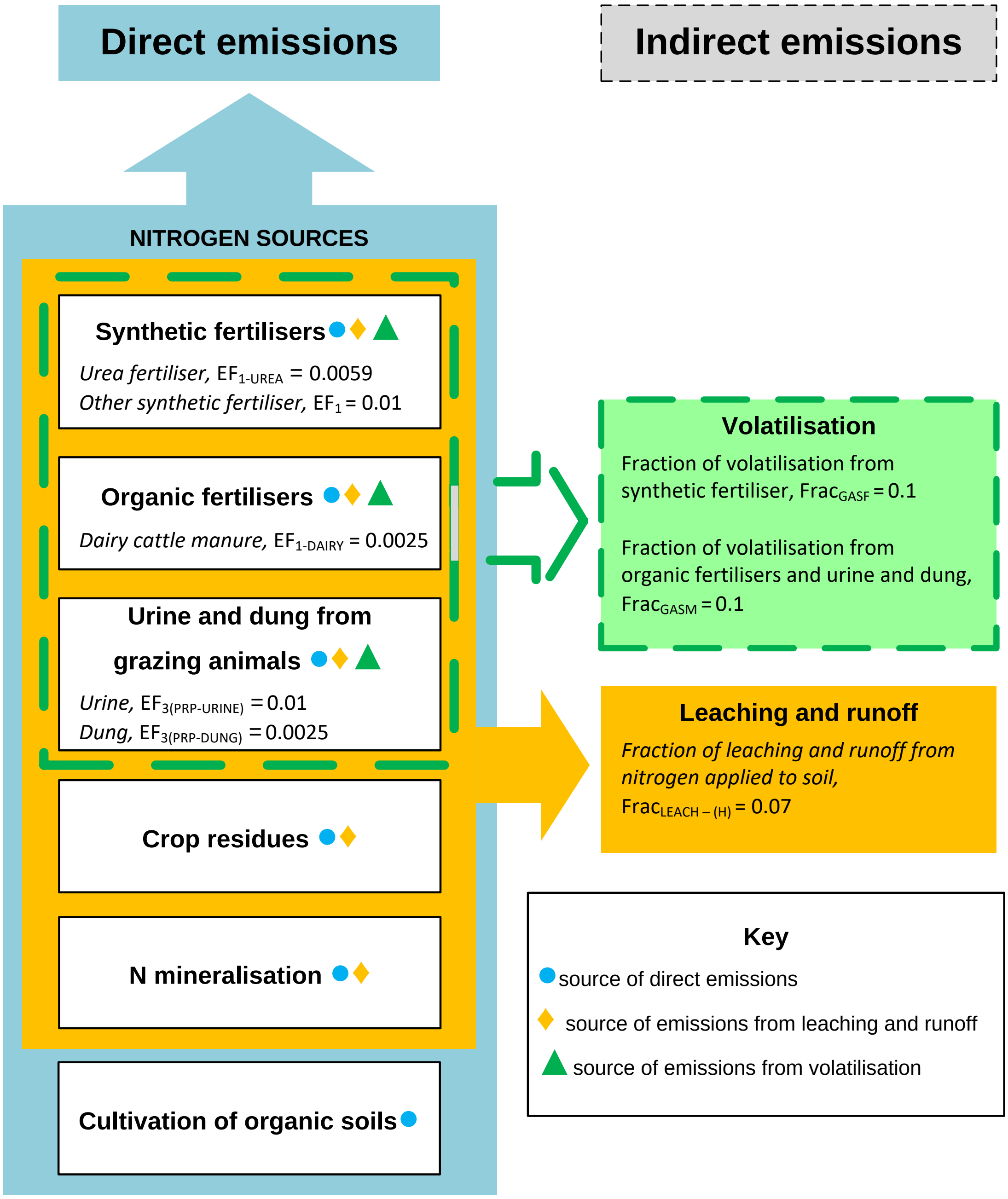
Figure 8.1 shows that there are six main sources of direct and indirect N_2O emissions from *Agricultural Soils*:

- Synthetic fertilisers
- Organic fertilisers
- Urine and dung from grazing animals
- Crop residues
- Nitrogen mineralisation
- Cultivation of organic soils

All six of these sources generate direct N2O emissions, but only the first five generate indirect emissions from leaching and runoff. Only the first three sources listed here generate emissions from volatilisation.

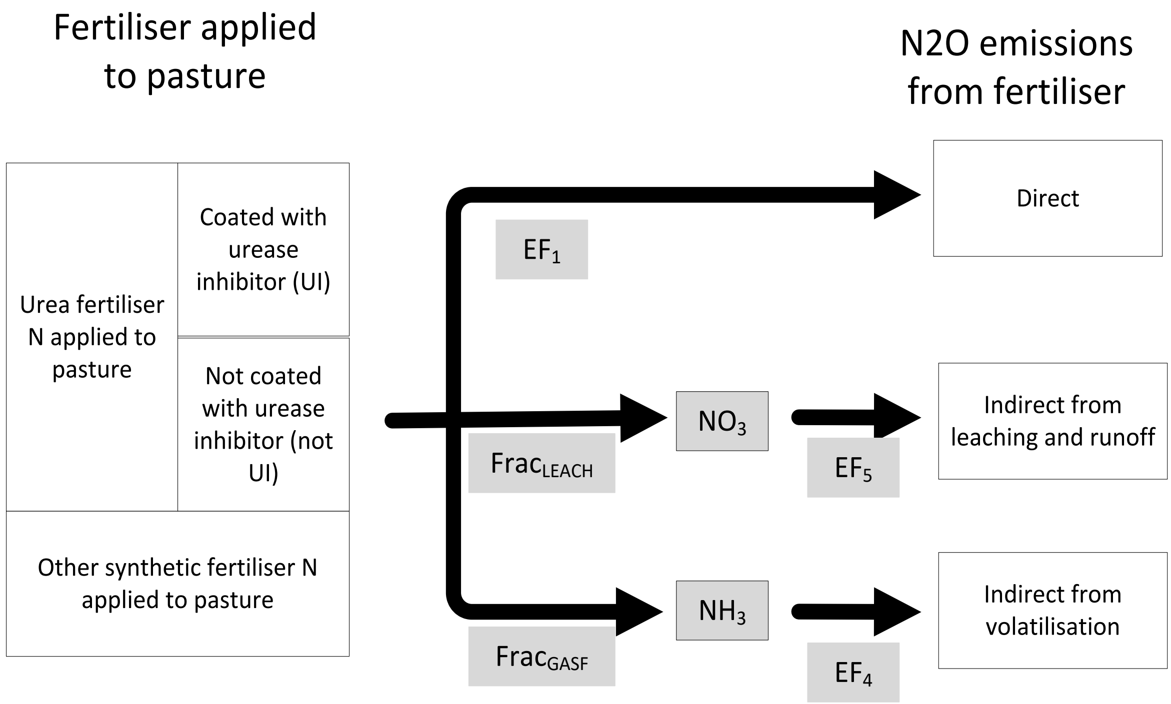
[j] N_2O-N refers to the mass of nitrogen in molecules of N_2O.

Figure 8.1: Sources of nitrous oxide emissions from agricultural soils



The next two figures more detail on the generation of emissions from two of these sources. Figure 8.2 shows the pathways in which nitrous oxide can be formed from the application of nitrogen fertiliser.

Figure 8.2: Flow chart depicting direct and indirect sources of N_2O from fertiliser usage in New Zealand agriculture



Currently used values:

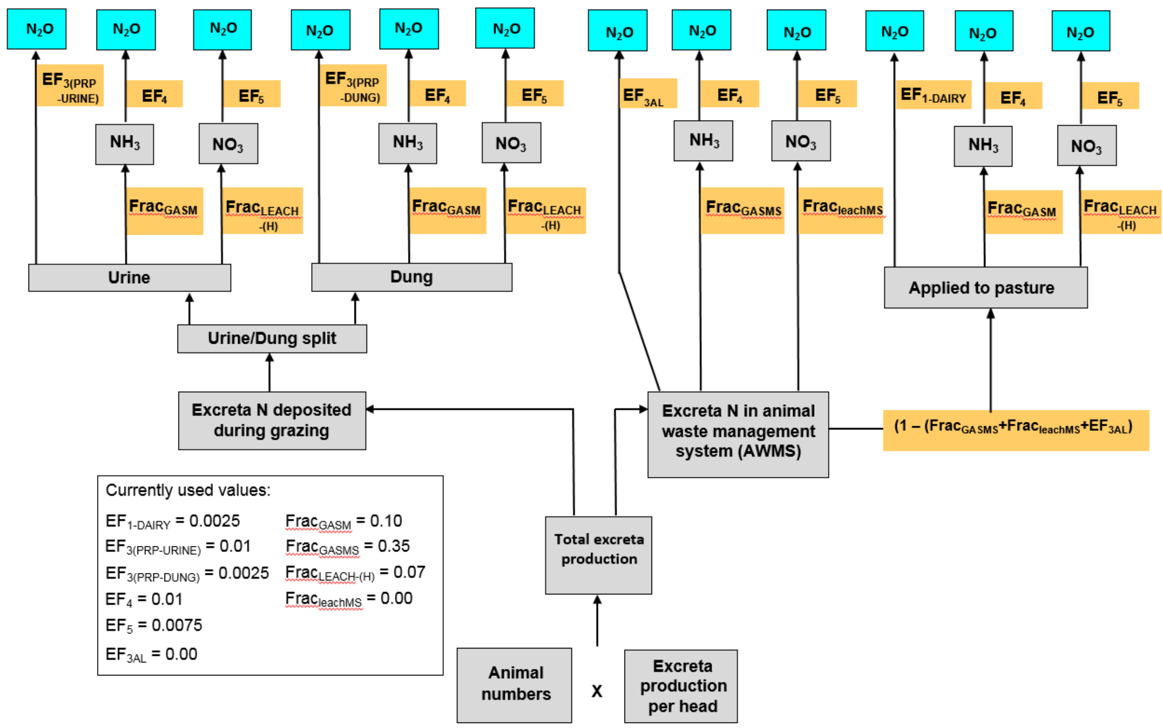
$EF_{1(other)}$ = 0.01
$EF_{1(urea)}$ = 0.0059
EF_4 = 0.01
EF_5 = 0.0075

$Frac_{GASF(UI\ coated)}$ = 0.055
$Frac_{GASF(not\ UI\ coated)}$ = 0.1

Figure 8.3 shows the pathways that lead to N_2O from livestock manure. The majority of the nitrogen excreted follows the left hand pathway and is deposited on pasture. This includes almost all nitrogen from dairy cattle (95%) and all nitrogen from beef cattle, sheep, deer, horses, goats and alpaca. A small portion of nitrogen from swine and poultry is also deposited onto pasture, the rest entering other manure management systems. The pathway on the right of the diagram shows the nitrogen entering manure management systems.

The amount of nitrogen excreted from dairy cattle, beef cattle, sheep, deer and other animal species are determined in Section 5. The nitrogen excreted from goats, horses, alpaca, swine and poultry are as detailed in Table 5.1. Full details of proportions of nitrogen in each animal manure management system (MMS) for all livestock species are summarised in Appendix 17.

Figure 8.3: Flow chart of the current IPCC national N_2O inventory methodology showing N_2O emissions from cattle, sheep and deer excreta for pastoral agriculture in NZ.



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 N2O 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_2O emissions from generic nitrogen source (Equation 8.1):

$$N_2Odirect_N = \frac{44}{28} \times N \times EF$$

Where:

$N_2Odirect_{N,t}$ = Direct N_2O emissions from nitrogen applied to soil (kg N_2O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N = amount of nitrogen applied to soils (kg N); (see Appendix 20)

EF = Emission factor, or the proportion of nitrogen input to soil that is directly emitted as N_2O (kg (N_2O-N)/kg (N applied)

The emission factor can either be EF_1 or EF_3 depending on the nitrogen source.

8.1.1 Synthetic fertiliser application

Emissions from nitrogen from synthetic fertiliser are a relatively small proportion of total N_2O emissions, but have grown significantly over the past two decades. The majority of synthetic nitrogen fertiliser used in New Zealand is urea fertiliser which is mostly applied to dairy pasture land to increase pasture growth during spring and autumn. As shown in Figure 2 there are three main routes in which nitrogen from synthetic fertiliser can be emitted in the form of nitrous oxide. The majority of emissions arises from the direct conversion of nitrogen to N_2O, (explained in this section). There are also two indirect routes that result in nitrous oxide from synthetic fertiliser. These routes are leaching from the soil, and volatilisation of nitrogen into ammonia and NO_X (explained in further sections below).

The Fertiliser Association of New Zealand provides data on the use of 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_2O emissions from synthetic fertiliser (Equation 8.2):

$$N_2Odirect_{SN,t} = \frac{44}{28} \times \left(\left(F_{SN(UREA),t} \times EF_{1(UREA)} \right) + \left(F_{SN(OTHER),t} \times EF_1 \right) \right)$$

Where:

$N_2Odirect_{SN,t}$ = Direct N_2O emissions from synthetic nitrogen fertiliser in year *t* (kilograms per year)

$F_{SN(UREA),t}$ = the total nitrogen amount of urea fertiliser applied to soils in year *t* (kg N/yr); (see Appendix 20)

$EF_{1\ (urea)}$ = the proportion of direct N_2O 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_2O emissions from nitrogen input to the soil (0.01). Proportion of nitrogen input to soil that is directly emitted (kg (N_2O-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_2O emissions from organic nitrogen fertiliser for dairy cattle (Equation 8.3):

$$N_2Odirect_{ON,dairy,t} = \frac{44}{28} \left(F_{AM(dairy),t} \times \left(1 - Frac_{GasAM(AL_{Dairy})} \right) \times EF_{1(DAIRY)} \right)$$

Where:

$N_2Odirect_{ON,dairy,t}$ = direct annual N2O emissions from organic nitrogen fertilisers for dairy cattle in year *t* (kg per year)

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year *t* (kg per year)

$Frac_{GasAM(AL\text{-}Dairy)}$ = fraction of nitrogen lost due to volatilisation (currently set at 0.35, as per IPCC (2006) guidelines

$EF_{1(DAIRY)}$ is the proportion of direct N_2O emissions from animal manure (dairy cattle) applied to soils, set at 0.0025 from van der Weerden et al (2016)

Total amount of dairy animal manure nitrogen applied to soils (Equation 8.4)

$$F_{AM(dairy),t} = \sum_{class} \sum_{region} \sum_{month} \left(N_{ex,c,m,R} \times nod_m \times POPdairy_{c,m,r}\right) \times MS_{AL,N2O}$$

Where:

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year t (kg per year)

$N_{ex,x,m,R}$ = daily nitrogen excretion per dairy cow of class c in month m and region R (kilograms of nitrogen per day – see section 5.1, equation 5.1)

$MS_{AL,N2O}$ = 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

$POPdairyc_{c,m,r}$ = population of dairy animals in subcategory *c*, month *m* and region *r*

class refers to the different categories of dairy cattle populations used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of section 4.3)

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 N2O emissions from organic nitrogen fertiliser for swine (Equation 8.5):

$$N_2Odirect_{ON,swine,t} = EF_1 \times \frac{44}{28}\left(\sum_{x}\left(N_{ex,swine,t} \times Pmms_{swine,x} \times \left(1 - Frac_{GasAM(x,swine)}\right)\right)\right)$$

Where:

$N_2Odirect_{ON,swine,t}$ = total direct annual N2O 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)

$Pmms_{swine,x}$ = 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)

$POPswine_t$ = swine population in year *t* (from APS)

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

The fraction 44/28 is used to convert nitrogen to nitrous oxide.

8.1.2.3 Direct organic nitrogen fertiliser emissions for poultry

Direct N2O 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)

$$N_2Odirect_{ON,broiler,t} = N_{ex,broiler} \times Pmms_{broiler,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_1 \times \frac{44}{28} \times POPbroiler_t$$

Where:

$N_2Odirect_{ON,broiler,t}$ = total direct annual N2O 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)

$POPbroiler_t$ = Broiler population in year t (from APS)

Direct organic nitrogen fertiliser emissions from layers (Equation 8.7)

$$N_2Odirect_{ON,layer,t} = N_{ex,layer} \times Pmms_{layer,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_1 \times \frac{44}{28} \times POPlayer_t$$

Where:

$N_2Odirect_{ON,layer,t}$ = total direct annual N_2O emissions from organic nitrogen fertilisers for layer chicken (kg per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer chicken (set at 0.42 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{layer,other}$ = 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)

$$N_2Odirect_{ON,other,t} = N_{ex,other} \times Pmms_{other,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_1 \times \frac{44}{28} \times POPotherpoultry_t$$

Where:

$N_2Odirect_{ON,other,t}$ = total direct annual N_2O emissions from organic nitrogen fertilisers for other poultry in year t (kg per year)

$N_{ex,other}$ = Annual nitrogen excretion per 'other' chicken (set at 0.6 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{other,other}$ = 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)

$POPotherpoultry_t$ = Other poultry population in year t (from APS)

The results from the above three equations can be summed together to get an estimate of total direct annual N_2O emissions from organic nitrogen fertilisers for all poultry.

8.1.3 Urine and dung deposited by grazing animals

This section explains how direct N2O 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.

8.1.3.1 Dairy

For dairy cattle, the following equations are used to determine N_2O emissions separately from urine and dung.

Direct N_2O emissions from dairy urine (Equation 8.9):

$$N_2Odirect_{U,Dairy,t} = \frac{44}{28} EF_{3(PRP-URINE)} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Odirect_{U,dairy,t}$ = direct annual N2O emissions from urine deposited by dairy cattle during grazing (kg of N_2O per year)

$EF_{3(PRP-URINE)}$ = 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)

$MS_{dairy,PRP}$ = proportion of manure excreted on pasture by dairy cattle overall,

$N_{u,c,m,R}$ = 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)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of section 4.3)

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

Direct N_2O emissions from dairy dung (Equation 8.10):

$$N_2Odirect_{D,Dairy,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Odirect_{D,dairy,t}$ = direct annual N2O emissions from dung deposited by dairy cattle during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}Dung)}$ = emission factor for dung from grazing animals in pasture, range and paddock. Currently set at 0.0025 (Luo et al, 2009)

$MS_{dairy,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by dairy cattle overall. Assumed to be 95%

$N_{f,c,m,R}$ = 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)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of section 4.3)

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. These equations are effectively identical to the equations in section 8.1.3.1.

Direct N_2O emissions from beef urine (Equation 8.11):

$$N_2Odirect_{U,beef,t} = \frac{44}{28} \times EF_{3(PRP-URINE)} \times MS_{beef,PRP} \times \left(\sum_{class} \sum_{month} N_{u,c,m} \times POPbeef_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{U,beef,t}$ = direct annual N2O emissions from urine deposited by beef cattle during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}URINE)}$ = emission factor for urine from grazing animals in pasture, range and paddock. Currently set at 0.01 (Carran *et al*., 1995; Muller *et al*., 1995; de Klein *et al*., 2003)

$MS_{beef,PRP}$ = 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

$POPbeef_{c,m,R}$ = 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 urine by all beef cattle in a given year.

Direct N_2O emissions from beef dung (Equation 8.12):

$$N_2Odirect_{D,Beef,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{beef,PRP} \times \left(\sum_{class} \sum_{month} N_{f,c,m} \times POPbeef_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{D,beef,t}$ = direct annual N2O emissions from dung deposited by beef cattle during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}Dung)}$ = emission factor for dung from grazing animals in pasture, range and paddock. Currently set at 0.0025 (Luo et al, 2009)

$MS_{beef,PRP}$ = 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

$POPbeef_{c,m}$ = population of beef animals in subcategory *c* and month *m*

nod_m = number of days in month *m*

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all beef cattle in a given year.

8.1.3.3 Sheep

Direct N_2O emissions from sheep urine and dung are calculated using the same equations in section 8.1.3.2, but with the beef inputs replaced by sheep inputs. It is assumed that 100% of sheep urine and dung is spread onto pasture.

Direct N_2O emissions from sheep urine (Equation 8.13):

$$N_2Odirect_{U,sheep,t} = \frac{44}{28} \times EF_{3(PRP-URINE)} \times MS_{sheep,PRP} \times \left(\sum_{class} \sum_{month} N_{u,c,m} \times POPsheep_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{U,sheep,t}$ = direct annual N2O emissions from urine deposited by sheep during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}URINE)}$ = emission factor for urine from grazing animals in pasture, range and paddock. Currently set at 0.01 (Carran *et al*., 1995; Muller *et al*., 1995; de Klein *et al*., 2003)

$MS_{sheep,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by sheep overall. Assumed to be 100%.

$N_{u,c,m}$ = Amount of nitrogen excreted in urine per animal for sheep animal class *c*, in month *m* (kg of nitrogen per day). See section 5.3.5

$POPsheep_{c,m,R}$ = population of sheep animals in subcategory *c* and month *m*

nod_m = number of days in month *m*

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 urine by all sheep in a given year.

Direct N_2O emissions from sheep dung (Equation 8.14):

$$N_2Odirect_{D,Sheep,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{sheep,PRP} \times \left(\sum_{class} \sum_{month} N_{f,c,m} \times POPsheep_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{D,sheep,t}$ = direct annual N2O emissions from dung deposited by sheep during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}Dung)}$ = emission factor for dung from grazing animals in pasture, range and paddock. Currently set at 0.0025 (Luo et al, 2009)

$MS_{sheep,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by sheep overall. Assumed to be 100%.

$N_{f,c,m}$ = Amount of nitrogen excreted in faeces per animal for sheep animal class *c*, and month *m* (kg of nitrogen per day). See section 5.3.5

$POPsheep_{c,m}$ = population of sheep animals in subcategory *c*, month *m*

nod_m = number of days in month *m*

class refers to the different categories of sheep used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all sheep in a given year.

8.1.3.4 Deer

Direct N_2O emissions from deer urine and dung are calculated using the same equations in section 8.1.3.2 and section 8.1.3.3, but with the beef and sheep inputs replaced by deer inputs. It is assumed that 100% of deer urine and dung is spread onto pasture.

Direct N_2O emissions from deer urine (Equation 8.15):

$$N_2Odirect_{U,deer,t} = \frac{44}{28} \times EF_{3(PRP-URINE)} \times MS_{deer,PRP} \times \left(\sum_{class} \sum_{month} N_{u,c,m} \times POPdeer_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{U,deer,t}$ = direct annual N2O emissions from urine deposited by deer during grazing (kg of N_2O per year)

$EF_{3(PRP\text{-}URINE)}$ = emission factor for urine from grazing animals in pasture, range and paddock. Currently set at 0.01 (Carran *et al*., 1995; Muller *et al*., 1995; de Klein *et al*., 2003)

$MS_{deer,PRP}$ = proportion of manure excreted directly onto pasture, range and paddock by deer overall. Assumed to be 100%.

$N_{u,c,m}$ = Amount of nitrogen excreted in urine per animal for deer animal class *c*, in month *m* (kg of nitrogen per day). See section 5.4.5

$POPdeer_{c,m,R}$ = population of deer animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

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 urine by all deer in a given year.

Direct N_2O emissions from deer dung (Equation 8.16):

$$N_2Odirect_{D,deer,t} = \frac{44}{28} \times EF_{3(PRP-Dung)} \times MS_{deer,PRP} \times \left(\sum_{class} \sum_{month} N_{f,c,m} \times POPdeer_{c,m} \times nod_m \right)$$

Where:

$N_2Odirect_{D,deer,t}$ = direct annual N2O emissions from dung deposited by deer 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 set at 0.0025 (Luo et al, 2009)

$MS_{deer,PRP}$ = 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

$POPdeer_{c,m}$ = population of deer animals in subcategory *c*, month *m*

nod_m = number of days in month *m*

class refers to the different categories of deer used in the inventory

month refers to the twelve months of the calendar year.

In the above equation, the section in brackets is used to calculate the total amount of nitrogen excreted in dung by all deer in a given year.

8.1.3.5 Minor livestock

For minor livestock species, the direct N2O emissions from urine and dung deposited onto pasture are not separated into the urine and dung components. This section shows how direct N2O emissions from urine and dung deposited on pasture are calculated for these animal species.

Nitrous oxide from these minor species is not calculated separately for dung and urine and therefore the one emission factor, $EF_{3PRP-URINE}$, is used.

8.1.3.5.1 Poultry

Direct N2O 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):

$$N_2Odirect_{UD,poultry,t} = \frac{44}{28} \times EF_{3(PRP-URINE)} \times \sum_x \left(N_{ex,x,t} \times POPminorpoultry_{x,t} \times MS_{x,PRP}\right)$$

Where:

$N_2Odirect_{UD,x,t}$ = direct annual N2O 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)

$EF_{3(PRP-URINE)}$ = 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)

$N_{ex,x,t}$= 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

$POPpoultry_{x,t}$ = population of poultry type *x* in year *t* (from APS)

$MS_{x,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by poultry type *x*. Assumed to be 4.9% for broilers, 5.8% for layers and 3% for other poultry (Appendix 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 N2O emissions from urine and dung deposited on pasture by swine are calculated using the following equation.

Direct N_2O emissions from urine and dung for swine (Equation 8.18):

$$N_2Odirect_{UD,swine,t} = \frac{44}{28} \times EF_{3(PRP-URINE)} \times N_{ex,swine,t} \times POPswine_t \times MS_{swine,PRP}$$

Where:

$N_2Odirect_{UD,swine,t}$ = direct annual N2O emissions from urine and dung deposited by swine during grazing in year *t* (kg of N_2O per year)

$EF_{3(PRP\text{-}URINE)}$ = 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)

$N_{ex,x,t}$= 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

$POPswine_t$ = population of swine in year *t* (from APS)

$MS_{swine,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by swine. Assumed to be 9% (Hill *et al*., 2011).

8.1.3.5.3 Goats, horses, alpaca, llamas, mules and asses

For these animals, it is assumed that all manure is excreted directly onto pasture. This means that direct N_2O emissions from urine and dung can be calculated from the following equation.

Direct N_2O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses (Equation 8.19):

$$N_2Odirect_{UD,x,t} = \frac{44}{28} \times EF_{3(PRP-URINE)} \times N_{ex,x,t} \times POPminor_{x,t}$$

Where:

$N_2Odirect_{UD,x,t}$ = direct annual N2O emissions from urine and dung deposited by animal type *x* (i.e. goats, horses…) during grazing in year *t* (kg of N_2O per year)

$EF_{3(PRP\text{-}URINE)}$ = 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)

$N_{ex,x,t}$= Annual nitrogen excretion per animal in year *t*, for animal type *x* (kg of nitrogen per year). See section 5.5 (nitrogen excretion, other livestock sources)

$POPminor_x$ = population of animal type *x* in year *t* (from APS)

Specific values of N_{ex} for the different animal categories are outlined in sections 5.5.1 (goats), 5.5.3 (horses, mules and asses) and 5.5.4 (alpacas).

8.1.3.6 Nitrification inhibitor dicyandiamide

A methodology has been developed to incorporate the nitrification inhibitor dicyandiamide (DCD), an N_2O mitigation technology, into the inventory. The N_2O emissions reported in the *Agricultural soils* category take into account the use of nitrification inhibitors on dairy farms using the methodology described in Clough *et al*. (2008). Greenhouse gas mitigation estimates from DCD are reported in the inventory only up until 2012, because it was no longer used after this time. Sales were suspended due to the detection of low levels of DCD residues in milk.

Research has shown that DCD reduces N_2O emissions and nitrate (NO_3^-) leaching in pastoral grassland systems grazed by ruminant animals. The inventory methodology incorporates DCD use by modifying the emission factors $EF_{3(PRP)}$ and the parameter $Frac_{LEACH}$. These were modified based on comprehensive field-based research that showed significant reductions in direct and indirect N_2O emissions and NO_3^- leaching where the DCD was applied. It was determined that, on a national basis, reductions in $EF_{3(PRP)}$ and $Frac_{LEACH}$ of 67 per cent and 53 per cent respectively could be made (Clough *et al*., 2008).

There has been some research into the effect of the inhibitor on dung ($EF_{3(PRP-DUNG)}$); 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 N2O emissions from dairy urine deposited on pasture

B. Indirect N2O 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):

$$DCD\ weighting\ factor = \left(1 - \left(reduction\ in\ EF_{3(PRP-URINE)} \times \frac{DCD\ area\ treated}{Total\ area\ of\ dairy}\right)\right)$$

Where:

DCD weighting factor = amount that $EF_{3(PRP-URINE)}$ (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 EF3 for dairy, accounting for the use of DCD, for May to September (Equation 8.21):

Where:

$$EF_{3(PRP-URINE),DCD} = EF_{3(PRP-URINE)} \times DCD\ weighting\ factor$$

$EF_{3(PRP-URINE),DCD}$ = 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 $N_2Odirect_{U,dairy,t}$ (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 $EF_{3(PRP\text{-}URINE),DCD}$ for these years would be equal to $EF_{3(PRP\text{-}URINE)}$.

It was assumed that the inhibitor was applied to pastures based on good management practice to maximise N_2O emission reductions. This is an application rate of 10 kilograms of DCD per hectare, applied twice per year in autumn and early spring within seven days of the application of animal excreta. 'Good practice' application methods of DCD can be by slurry or DCD-coated granules.

8.1.4 Nitrous oxide from crop residues returned to soils

This section of the inventory includes emissions from:

- nitrogen added to soils by above and below-ground crop residue (including residue left behind after crop burning), and
- nitrogen added to soils as a result of mineralisation of forages during pasture renewal

Crop residues are materials left in an agricultural field or orchard after the crop has been harvested. Pasture renewal is the destruction of low quality pasture followed by the sowing of improved pasture species and/or varieties, and is promoted as a simple method to increase farm productivity. As these crop residues and pastures decay or are destroyed, the nitrogen in these plant materials are released into the surrounding soil and result in direct and indirect N_2O emissions. Both of these emission sources include N-fixing and non-N-fixing crop species.

The methodology for calculating direct emissions from agricultural residue that is burnt is outlined in section 9 of this document.

The activity data required to estimate direct agricultural soils emissions from crop residues and pasture renewal is supplied by Statistics New Zealand from their agricultural production survey and includes data on the amount of different crops grown. The country-specific value for $Frac_{BURN}$ was derived from Statistics New Zealand data and farm surveys (Thomas *et al.,* 2011). The parameters used to estimate the N added by both above- and below-ground crop residues were compiled from published and unpublished reports from New Zealand-grown crops (Cichota et al*.,* 2010) and typical values derived by OVERSEER® nutrient budget model for New Zealand. The OVEERSEER® model provides average estimates of nitrogen pathways for a range of pastoral, arable and horticultural systems (Wheeler et al*.,* 2003; see also http://www.overseer.org.nz).

8.1.4.1 Nitrogen from crop residue

The non-nitrogen fixing crops grown in New Zealand are:

- barley,
- wheat,
- oats,
- potatoes,
- maize grain,
- brassica seeds,
- herbage seeds,
- onions,
- squash and
- sweet corn.

The nitrogen-fixing crops grown in New Zealand are:

- legumes,
- peas (fresh and processed),
- seed peas,
- lentils

The annual tonnage of most non-nitrogen fixing crops in New Zealand is supplied by Statistics New Zealand from its Agricultural Production Survey. Additional information is provided by PotatoesNZ and information on seed crops from AsureQuality (Thomas *et al.,* 2010). The tonnage of nitrogen fixing crops is supplied by Statistics New Zealand from it Agricultural Production census and survey (i.e. lentils and legumes) and HortNZ (peas). A country-specific methodology (Thomas *et al.,* 2008) is used to calculate emissions from nitrogen fixing crops (kt (N)/yr). Most of the specific parameters used to calculate above ground and below ground crop nitrogen returned to soils (AGN and BGN) are outlined by Thomas et al (2011).

Direct N_2O emissions from decay of crop residue (Equation 8.22):

$$N_2Odirect_{CR,t} = \frac{44}{28} \times EF_1 \times \sum_c \left(AG_{N,c} + BG_{N,x}\right)$$

Where:

$N_2Odirect_{CR,t}$ = direct annual N2O emissions from crop residues (kg of N_2O per year)

EF_1 = the proportion of direct N_2O emissions from nitrogen input to the soil (0.01).

$AG_{N,c}$ = Amount of above-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year) (see equation 8.23)

$BG_{N,c}$ = 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):

$$AG_{N,c} = DMF_c \times \left(\frac{Prod_c}{HI_c} - Prod_c\right) \times \left(1 - Frac_{burn} - Frac_{remove,c}\right) \times N_{AG,c}$$

Where:

$AG_{N,c}$ = Amount of above-ground nitrogen returned to soils per year through incorporation of crop residues for crop type *c* (kilograms of nitrogen per year)

DMF_c = Dry matter factor, used to convert total production to dry matter crop production for crop type *c* (see table 8.1 for values)

$Prod_c$ = Annual production of crop type, *c* (kg/yr) see Appendix 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):

$$Frac_{burn,c} = \frac{AG_{BURN,c}}{AGresd_c}$$

Where:

$Frac_{burn,c}$ = fraction of above-ground biomass burned for crop type *c* (barley, oats or wheat)

$AG_{BURN,c}$ = Biomass of crop burnt (tonnes per year) for crop type *c* (i.e. barley, oats or wheat) (see equation 9.9, section 9.2)

$AGresd_c$ = Above-ground residue for crop *c* (tonnes of dry matter per year) (see equation 9.10, section 9.2)

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)	NAG	NBG	Dry Matter factor (DMF)
Wheat	0.46	0.005	0.009	0.86
Barley	0.46	0.005	0.009	0.86
Oats	0.3	0.005	0.009	0.86
Maize grain	0.5	0.007	0.007	0.86
Field Seed peas	0.5	0.02	0.015	0.21
Lentils	0.5	0.02	0.015	0.86
Peas fresh and process	0.45	0.03	0.015	0.86
Potatoes	0.9	0.02	0.01	0.22
Onions	0.8	0.02	0.01	0.11
Sweet corn	0.55	0.009	0.007	0.24
Squash	0.8	0.02	0.01	0.2
Herbage seeds	0.11	0.015	0.01	0.85
Legume seeds	0.09	0.04	0.01	0.85
Brassica seeds	0.2	0.011	0.0081	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 N2O emissions from these pastures separately with the following equations:

Direct N_2O emissions from pasture renewal (Equation 8.26):

$$N_2Odirect_{Renew,t} = \frac{44}{28} \times EF_1 \times \sum_p F_{CR-Renew,p,t}$$

Where:

$N_2Odirect_{renew,t}$ = Direct N_2O emissions from pasture renewal in year *t* (kilograms per year)

EF_1 = the proportion of direct N_2O emissions from nitrogen input to the soil (0.01 kg (N_2O-N)/kg (N applied). See Appendix 18.

$F_{CR\text{-}Renew,p,t}$ = 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 ($F_{CR\text{-}Renew,x}$) can be calculated from the equation below.

Nitrogen in residues from pasture renewal (Equation 8.27):

$$F_{CR-Renew,p,t} = Area_{p,t} \times Freq_{renew,p,t} \times \left(\left(R_{AG,p} \times N_{AG} \times \left(1 - Frac_{remove,p}\right)\right) + \left(R_{BG,p} + N_{BG}\right)\right)$$

Where:

$F_{CR\text{-}Renew,p,t}$ = 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)

$$N_2Odirect_{FSOM,t} = \frac{44}{28} \times EF_1 \times F_{SOM}$$

Where:

$N_2Odirect_{FSOM,t}$ = Direct N_2O emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils in year *t* (kilograms per year)

EF_1 = the proportion of direct N_2O emissions from nitrogen input to the soil (0.01).

F_{SOM} = amount of nitrogen mineralised from loss of soil organic matter in mineral soils through land management for *cropland remaining cropland* (kg) (see equation 8.29)

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 amount of managed cultivated organic soils in New Zealand is 160,385 ha. Dresser *et al*. (2011) determined that 5 percent of organic soils (plus mineral soils with a peaty layer) under agricultural pasture are cultivated on an annual basis (Kelliher *et al*., 2002). This results in 8,019 hectares of “organic agricultural soils” being cultivated annually.

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)

$$N_2Odirect_{OAS-C,t} = \frac{44}{28} \times EF_2 \times Area_{OAS-C}$$

Where:

$N_2Odirect_{OAS-C,t}$ = Direct N_2O emissions from the cultivation of organic soils (kilograms per year)

EF_2 = emission factor for direct emissions from organic soil mineralisation due to cultivation (8 kilograms of N_2O per hectare)

$Area_{OAS-C}$ = Area of organic agricultural soils cultivated annually (currently set at 8019 ha)

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):

$$N_2Oindirect, leaching_N = \frac{44}{28} \times N \times EF_5 \times Frac_{leach}$$

Where:

$N_2Oindirect,leaching_N$ = Indirect leaching and run-off N_2O emissions from nitrogen applied to soil (kg N_2O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N = amount of nitrogen applied to soils (kg N); (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)

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

8.2.1 Synthetic fertiliser application

The following equation is used to calculate indirect leaching and runoff N_2O emissions from synthetic nitrogen fertiliser.

Indirect leaching and run-off N_2O emissions from synthetic fertiliser (Equation 8.32):

$$N_2Oindirect, leaching_{SN,t} = \frac{44}{28} \times F_{SN,t} \times EF_5 \times Frac_{leach}$$

Where:

$N_2Oindirect,leaching_{SN,t}$ = indirect leaching and run-off N_2O emissions from synthetic nitrogen fertiliser in year *t* (kilograms per year)

$F_{SN,t}$ = the total nitrogen amount of all synthetic fertiliser applied to soils in year *t* (kg N/yr); (see Appendix 20)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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_2O emissions from the other sources of indirect leaching and runoff emissions.

8.2.2 Organic nitrogen fertilisers

In New Zealand, emissions from *Organic nitrogen fertilisers* are solely from animal manure that is spread on pasture after collection in manure management systems. In New Zealand, this only occurs for dairy cattle, swine and poultry. Additional information on organic nitrogen fertilisers are contained in section 8.1.2.

8.2.2.1 Indirect leaching and runoff organic nitrogen fertiliser emissions for dairy

Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for dairy cattle (Equation 8.33):

$$N_2Oindirect, leaching_{ON,dairy,t} = \frac{44}{28} \times F_{AM(dairy),t} \times Frac_{leach} \times EF_5$$

Where:

$N_2Oindirect,leaching_{ON,dairy,t}$ = indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for all dairy cattle in year *t* (kg per year)

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year *t* (kg per year). See equation 8.4, section 8.1.2.1

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

EF_5 = N_2O 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_2O emissions from organic nitrogen fertiliser for swine (Equation 8.34):

$$N_2Oindirect, leaching_{ON,swine,t} = EF_5 \times Frac_{leach} \times \frac{44}{28}\left(\sum_x \left(N_{ex,swine,t} \times Pmms_{swine,x} \times \left(1 - Frac_{GasAM(x,swine)}\right) \times POPswine_t\right)\right)$$

Where:

$N_2Oindirect,leaching_{ON,swine,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for swine (kg per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (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 11, 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 11, section 7.2.1.2 for values)

$POPswine_t$ = swine population in year t (from APS)

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

8.2.2.3 Indirect leaching and runoff organic nitrogen fertiliser emissions for poultry

Indirect leaching and runoff N_2O organic nitrogen fertiliser emissions from poultry are calculated using parameters for broilers, layers and other poultry. Some of these parameters are different and some are the same.

Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for broilers (Equation 8.35)

$$N_2Oindirect, leaching_{ON,broiler,t} = N_{ex,broiler} \times Pmms_{broiler,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_5 \times Frac_{leach} \times \frac{44}{28} \times POPbroiler_t$$

Where:

$N_2Oindirect,leaching_{ON,broiler,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for broiler chicken in year *t* (kg per year)

$N_{ex,broiler}$ = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{broiler,other}$ = 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_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$POPbroiler_t$ = Broiler population in year t (from APS)

Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for layers (Equation 8.36)

$$N_2Oindirect, leaching_{ON,layer,t} = N_{ex,layer} \times Pmms_{layer,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_5 \times Frac_{leach} \times \frac{44}{28} \times POPlayer_t$$

Where:

$N_2Oindirect,leaching_{ON,layer,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for layer chicken in year *t* (kg per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer chicken (set at 0.42 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{layer,other}$ = 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_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$POPlayer_t$ = Layer population in year t (from APS)

Indirect leaching and run-off N_2O emissions from organic nitrogen fertiliser for other poultry (Equation 8.37)

$$N_2Oindirect, leaching_{ON,other,t} = N_{ex,other} \times Pmms_{other,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_5 \times Frac_{leach} \times \frac{44}{28} \times POPotherpoultry_t$$

Where:

$N_2Oindirect,leaching_{ON,other,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for other poultry in year *t* (kg per year)

$N_{ex,other}$ = Annual nitrogen excretion per ‘other’ chicken (set at 0.6 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{other,other}$ = 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_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$POPotherpoultry_t$ = Other poultry population in year t (from APS)

The results from the above three equations can be summed together to get an estimate of total indirect leaching and runoff N_2O emissions from organic nitrogen fertilisers for all poultry per year.

8.2.3 Urine and dung deposited by grazing animals

This section explains how indirect leaching and runoff N2O emissions from urine and dung deposited on pasture are calculated.

8.2.3.1 Dairy

For dairy cattle, the following equations are used to determine N_2O emissions separately from urine and dung.

Indirect leaching and runoff N_2O emissions from dairy urine (Equation 8.38):

$$N_2Oindirect, leaching_{U,dairy,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,leaching_{U,dairy,t}$ = annual indirect leaching and runoff N_2O emissions from urine deposited by dairy cattle during grazing (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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. 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)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of section 4.3)

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_2O emissions from dairy dung (Equation 8.39):

$$N_2Oindirect, leaching_{D,Dairy,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,leaching_{D,dairy,t}$ = annual indirect leaching and runoff N_2O emissions from dung deposited by dairy cattle during grazing (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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. Assumed to be 95%

$N_{f,c,m,R}$ = 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)

$POPdairyc_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month *m*

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of section 4.3)

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, Fracleach, 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):

$$N_2Oindirect, leaching_{U,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,u,c,m} \times POPx_{c,m} \times nod_m \right)$$

Indirect leaching and runoff N_2O emissions from dung, for animal species x (Equation 8.41):

$$N_2Oindirect, leaching_{D,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,f,c,m} \times POPx_{c,m} \times nod_m \right)$$

Where:

$N_2Oindirect,leaching_{U,x,t}$ = annual indirect leaching and runoff N_2O emissions from urine deposited by animal species *x* during grazing (kg of N_2O per year)

$N_2Oindirect,leaching_{D,x,t}$ = annual indirect leaching and runoff N_2O emissions from dung deposited by animal species *x* during grazing (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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

$POPx_{c,m,R}$ = population of animal species *x* in subcategory *c* and month *m*

nod_m = number of days in month *m*

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

x refers to the different animal species, either sheep, beef cattle or deer (but not dairy cattle)

In these equations, the section in brackets is used to calculate the total amount of nitrogen excreted in urine and dung by all animals in a particular category (i.e. sheep, beef cattle or deer) in a given year.

8.2.3.3 Nitrification inhibitor dicyandiamide

DCD was used in New Zealand's pastoral farming system for dairy between 2007 and 2012, and affects indirect leaching emissions from urine and dung. The inventory accounts for the use of DCD by using the methodology described in Clough et al. (2008).

The use of DCD reduces N2O emissions and nitrate (NO3–) 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):

$$DCD\ weighting\ factor_{Fracleach} = \left(1 - \left(\%\ reduction\ in\ Frac_{leach} \times \frac{DCD\ area\ treated}{Total\ area\ of\ dairy}\right)\right)$$

Where:

$DCD\ weighting\ factor_{Fracleach}$ = amount that $Frac_{leach}$ (see equation x) needs to be multiplied by to account for the effect of DCD between 2007 and 2012

% reduction in $Frac_{leach}$ = percentage amount by which $Frac_{leach}$ is lower following use of DCD. Currently set at 53% (Clough et al., 2008).

DCD area treated = area of dairy land treated with DCD per year between 2007 and 2012 (from APS)

Total area of dairy = total effective dairy area per year (from APS)

In the years before 2007, and after 2012, DCD was not used in New Zealand, so the DCD weighting factor for these years would be set at 1.

The appropriate weighting factor is then used as an additional multiplier in the current methodology for calculating indirect and direct dairy emissions of N_2O from grazed pastures.

Calculating $Frac_{leach}$ for dairy, accounting for the use of DCD, for May to September (Equation 8.42):

Where:

$$Frac_{leach,DCD} = Frac_{leach} \times DCD\ weighting\ factor_{Fracleach}$$

$Frac_{leach,DCD}$ = fraction of leaching and runoff from nitrogen in urine applied to soil by dairy cattle between May and September, after accounting for the effects of DCD use.

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (see Appendix 18)

$DCD\ weighting\ factor_{Fracleach}$ = 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_2O emission reductions. This is an application rate of 10 kilograms per hectare, applied twice per year in autumn and early spring within seven days of the application of animal excreta. 'Good practice' application methods of DCD can be by slurry or DCD-coated granules

8.2.3.4 Minor livestock

For minor livestock species, the indirect N2O 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 N2O emissions for these species are calculated

8.2.3.4.1 Poultry

Indirect N2O 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_2O emissions from urine and dung for poultry (Equation 8.43):

$$N_2Oindirect, leaching_{UD,poultry,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times \sum_x \left(N_{ex,x,t} \times POPpoultry_{x,t} \times MS_{x,PRP}\right)$$

Where:

$N_2Oindirect,leaching_{UD,x,t}$ = indirect N2O emissions from leaching and run-off from urine and dung deposited by poultry type x (i.e. broilers, layers, and other poultry) during grazing in year t (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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

$POPpoultry_{x,t}$ = population of poultry type *x* in year *t* (from APS)

$MS_{x,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by poultry type x. Assumed to be 4.9% for broilers, 5.8% for layers and 3% for other poultry.

The $MS_{x,PRP}$ values for broilers and layers were determined from a study by Fick et al (2011) while the $MS_{x,PRP}$ value for other poultry is taken from the IPCC 1996 guidelines.

8.2.3.4.2 Swine

Indirect N2O emissions (from leaching and run-off) from urine and dung deposited on pasture by swine are calculated using the following equation.

Indirect leaching and run-off N_2O emissions from urine and dung for swine (Equation 8.44):

$$N_2Oindirect, leaching_{UD,swine,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times N_{ex,swine,t} \times POPswine_t \times MS_{swine,PRP}$$

Where:

$N_2Oindirect,leaching_{UD,swine,t}$ = indirect N2O emissions from leaching and run-off from urine and dung deposited by swine during grazing in year t (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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

$POPswine_t$ = population of swine in year *t* (from APS)

$MS_{swine,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by swine. Assumed to be 9% (Hill et al., 2011).

8.2.3.4.3 Goats, horses, alpaca, llamas, mules and asses

For these animals, it is assumed that all manure is excreted directly onto pasture. This means that indirect N_2O emissions (from leaching and run-off) from urine and dung can be calculated from the following equation.

Indirect leaching and run-off N_2O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses (Equation 8.45):

$$N_2Oindirect, leaching_{UD,x,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times N_{ex,x,t} \times POPminor_{x,t}$$

Where:

$N_2Oindirect,leaching_{UD,x,t}$ = indirect N2O emissions from leaching and run-off from urine and dung deposited by animal type x (i.e. goats, horses…) during grazing in year t (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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 5.5 (nitrogen excretion, other livestock sources)

$POPminor_x$ = population of animal type x in year t (from APS)

Specific values of N_{ex} for the different animal categories are outlined in sections 5.5.1 (goats), 5.5.3 (horses, mules and asses) and 5.5.4 (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

Indirect N_2O emissions from decay of crop residue (Equation 8.46):

$$N_2Oindirect_{CR,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times \sum_c \left(AG_{N,c} + BG_{N,c}\right)$$

Where:

$N_2Oindirect_{CR,t}$ = indirect annual N2O emissions from crop residues (kg of N_2O per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (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):

$$N_2Oindirect_{Renew,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times \sum_p F_{CR-Renew,p,t}$$

Where:

$N_2Oindirect_{renew,t}$ = indirect N_2O emissions from pasture renewal in year *t* (kilograms per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all 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 N2O 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)

$$N_2Oindirect_{FSOM,t} = \frac{44}{28} \times EF_5 \times Frac_{leach} \times F_{SOM}$$

Where:

$N_2Oindirect_{FSOM,t}$ = indirect N_2O emissions from nitrogen mineralisation due to the loss of soil organic matter in mineral soils in year t (kilograms per year)

EF_5 = N_2O emission factor for leaching and runoff (0.0075) (see Figure 8.3 and Appendix 18).

$Frac_{leach}$ = fraction of leaching and runoff from all nitrogen applied to soil. Currently set at 0.07 (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_2O emissions associated with nitrogen volatilisation from soils

Nitrogen can be volatised as ammonia or NO_X (reactive oxides of nitrogen) before it is later returned to the soil by wet or dry deposition to be again a candidate for conversion to nitrous oxide. This is another indirect pathway for N_2O production (in addition to leaching and runoff).

In the New Zealand Inventory, there are three sources of indirect agricultural soils emissions from volatilisation:

- Synthetic nitrogen fertiliser
- Organic fertiliser
- Urine and dung from grazing animals

Emissions from each of these sources are discussed in turn.

The basic form of the equation used to calculate indirect volatilisation emissions is below:

Indirect volatilisation N_2O emissions from generic nitrogen source (Equation 8.49):

$$N_2Oindirect, volatilisation_N = \frac{44}{28} \times N \times EF_4 \times Frac_{GAS}$$

Where:

$N_2Oindirect,volatilisation_N$ = Indirect volatilisation N_2O emissions from nitrogen applied to soil (kg N_2O)

44/28 = molecular conversion factor, used to convert nitrogen to nitrous oxide

N = amount of nitrogen applied to soils (kg N); (see Appendix 20)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$Frac_{GAS}$ = fraction of nitrogen applied to soil emitted as NOx or NH3.

The parameter $Frac_{GAS}$ can either be $Frac_{GASF}$ or $Frac_{GasAM}$ depending on the type or source of nitrogen applied to the soil.

8.3.1 Synthetic fertiliser application and urease inhibitor

Some of the nitrogen fertiliser sold in New Zealand is coated with a substance called urease inhibitor (UI). Urease inhibitors restrict the action of the enzyme urease, which is a catalyst for the volatilisation of the nitrogen into ammonia gas.

The application of all nitrogen fertiliser leads to indirect N2O emissions from volatilisation[k], but urease inhibitor coated fertiliser (when used instead of non-UI coated fertiliser) can be regarded as a mitigation option as it leads to lower N2O emissions.

Research from Saggar et al. (2013) has quantified the mitigation effect of urease inhibitor, which is included in New Zealand's Agriculture inventory by adjusting the value of the $Frac_{GASF}$ parameter from 0.1 to 0.055 when urease inhibitor is used.

The equations used to estimate indirect N2O emissions from volatilisation (by UI and non-UI coated fertiliser) are below.

Indirect volatilisation N_2O emissions from synthetic fertiliser coated with urease inhibitor (Equation 8.50):

$$N_2Oindirect, volatilisation_{SN,UI,t} = \frac{44}{28} \times F_{SN,UI,t} \times EF_4 \times Frac_{GASF,UI}$$

[k] in addition to direct N2O emissions (see section 8.1.1) and indirect leaching N2O emissions (see section 8.2.1)

Indirect volatilisation N_2O emissions from synthetic fertiliser NOT coated with urease inhibitor (Equation 8.51):

$$N_2Oindirect, volatilisation_{SN,no\ UI,t} = \frac{44}{28} \times F_{SN,no\ UI,t} \times EF_4 \times Frac_{GASF}$$

Where:

$N_2Oindirect,volatilisation_{SN,UI,t}$ = indirect volatilisation N_2O emissions from UI coated synthetic nitrogen fertiliser in year *t* (kilograms per year)

$N_2Oindirect,volatilisation_{SN,no\ UI,t}$ = indirect volatilisation N_2O emissions from synthetic nitrogen fertiliser NOT coated with UI in year *t* (kilograms per year)

$F_{SN,UI,t}$ = nitrogen amount of all UI coated synthetic fertiliser applied to soils in year *t* (kg N/yr)

$F_{SN,no\ UI,t}$ = nitrogen amount of synthetic fertiliser NOT coated with UI applied to soils in year *t* (kg N/yr)

EF_4 = N_2O emission factor for indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 18).

$Frac_{GASF,UI}$ = fraction of UI coated synthetic fertiliser emitted as NOx or NH3. Currently set at 0.055 (see Appendix 18)

$Frac_{GASF}$ = fraction of synthetic fertiliser NOT coated with UI emitted as NOx or NH3. 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):

$$N_2Oindirect, volatilisation_{ON,dairy,t} = \frac{44}{28} \times F_{AM(dairy),t} \times Frac_{GASam} \times EF_4$$

Where:

$N_2Oindirect,volatilisation_{ON,dairy,t}$ = indirect volatilisation N_2O emissions from organic nitrogen fertilisers for all dairy cattle in year *t* (kg per year)

$F_{AM(dairy),t}$ = Total amount of dairy cattle manure nitrogen applied to soils from manure management systems (anaerobic lagoons) in year *t* (kg per year). See equation 8.4, section 8.1.2.1.

$Frac_{GASam}$ = 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 volatising 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):

$$N_2Oindirect, volatilisation_{ON,swine,t} = EF_4 \times Frac_{GASam} \times \frac{44}{28}\left(\sum_x \left(N_{ex,swine,t} \times Pmms_{swine,x} \times \left(1 - Frac_{GasAM(x,swine)}\right) \times POPswine_t\right)\right)$$

Where:

$N_2Oindirect,volatilisation_{ON,swine,t}$ = total annual indirect volatilisation N_2O emissions from organic nitrogen fertilisers for swine (kg per year)

EF_4 = N_2O emission factor indirect emissions from volatising nitrogen (0.01) (see Figure 8.3 and Appendix 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)

$POPswine_t$ = swine population in year t (from APS)

x refers to the different manure management systems used for swine (e.g. anaerobic lagoon, daily spread…)

8.3.2.3 Indirect volatilisation organic nitrogen fertiliser emissions for poultry

Indirect N2O emissions from the volatilisation of organic nitrogen fertiliser from poultry are calculated using parameters for broilers, layers and other poultry. Some of these parameters are different and some are the same.

Indirect volatilisation N_2O emissions from organic nitrogen fertiliser for broilers (Equation 8.54):

$$N_2Oindirect, volatilisation_{ON,broiler,t} = N_{ex,broiler} \times Pmms_{broiler,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POPbroiler_t$$

Where:

$N_2Oindirect,volatilisation_{ON,broiler,t}$ = total annual indirect volatilisation N_2O emissions from organic nitrogen fertilisers for broiler chicken (kg per year)

$N_{ex,broiler}$ = Annual nitrogen excretion per broiler chicken (set at 0.39 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{broiler,other}$ = 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 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)

$POPbroiler_t$ = Broiler population in year t (from APS)

Indirect volatilisation N_2O emissions from organic nitrogen fertiliser for layers (Equation 8.55):

$$N_2Oindirect, volatilisation_{ON,layer,t} = N_{ex,layer} \times Pmms_{layer,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POPlayer_t$$

Where:

$N_2Oindirect,volatilisation_{ON,layer,t}$ = total annual indirect volatilisation N_2O emissions from organic nitrogen fertilisers for layer chicken (kg per year)

$N_{ex,layer}$ = Annual nitrogen excretion per layer chicken (set at 0.42 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{layer,other}$ = 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 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)

$POPlayer_t$ = Layer population in year *t* (from APS)

Indirect volatilisation N_2O emissions from organic nitrogen fertiliser for other poultry (Equation 8.56):

$$N_2Oindirect, volatilisation_{ON,other,t} = N_{ex,other} \times Pmms_{other,other} \times \left(1 - Frac_{GasAM,poultry}\right) \times EF_4 \times Frac_{GASam} \times \frac{44}{28} \times POPotherpoultry_t$$

Where:

$N_2Oindirect,leaching_{ON,other,t}$ = total annual indirect leaching and run-off N_2O emissions from organic nitrogen fertilisers for other poultry in year t (kg per year)

$N_{ex,other}$ = Annual nitrogen excretion per ‘other’ chicken (set at 0.6 kilograms of nitrogen per year – see section 5.5.2)

$Pmms_{other,other}$ = 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)

$POPotherpoultry_t$ = Other poultry population in year t (from APS)

The results from the above three equations can be summed together to get an estimate of total indirect leaching and runoff N_2O emissions from organic nitrogen fertilisers for all poultry per year.

8.3.3 Urine and dung deposited by grazing animals

This section explains how indirect volatilisation N_2O emissions from urine and dung deposited on pasture are calculated.

8.3.3.1 Dairy

For dairy cattle, the following equations are used to determine indirect N_2O emissions due to volatilisation separately from urine and dung.

Indirect volatilisation N_2O emissions from dairy urine (Equation 8.57):

$$N_2Oindirect, volatilisation_{U,dairy,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{u,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,volatilisation_{U,dairy,t}$ = annual indirect volatilisation N_2O emissions from urine deposited by dairy cattle during grazing (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 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)

$POPdairy_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month m

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see the beginning of section 4.3)

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):

$$N_2Oindirect, volatilisation_{D,Dairy,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{dairy,PRP} \times \left(\sum_{class} \sum_{region} \sum_{month} N_{f,c,m,R} \times POPdairy_{c,m,R} \times nod_m \right)$$

Where:

$N_2Oindirect,volatilisation_{D,dairy,t}$ = annual indirect volatilisation N_2O emissions from dung deposited by dairy cattle during grazing (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 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).

$N_{f,c,m,R}$ = 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)

$POPdairy_{c,m,R}$ = population of dairy animals in subcategory *c*, month *m* and region *R*

nod_m = number of days in month m

class refers to the different categories of dairy cattle used in the inventory

month refers to the twelve months of the calendar year.

region refers to the regions used in the dairy inventory (see section 4.3)

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 NOx or NH3.

Indirect volatilisation N_2O emissions from urine, for animal species x (Equation 8.59):

$$N_2Oindirect, volatilisation_{U,x,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,u,c,m} \times POPx_{c,m} \times nod_m \right)$$

Indirect volatilisation N_2O emissions from dung, for animal species x (Equation 8.60):

$$N_2Oindirect, volatilisation_{D,x,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times MS_{x,PRP} \times \left(\sum_{class} \sum_{month} N_{x,f,c,m} \times POPx_{c,m} \times nod_m \right)$$

Where:

$N_2Oindirect,volatilisation_{U,x,t}$ = annual indirect volatilisation N_2O emissions from urine deposited by animal species x during grazing (kg of N_2O per year)

$N_2Oindirect,volatilisation_{D,x,t}$ = annual indirect volatilisation N_2O emissions from dung deposited by animal species x during grazing (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 18)

EF_4 = N_2O emission factor for indirect emissions from volatising 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

$POPx_{c,m,R}$ = population of animal species *x* in subcategory *c* and month *m*

nod_m = number of days in month *m*

class refers to the different categories of beef cattle used in the inventory

month refers to the twelve months of the calendar year.

x refers to the different animal species, either sheep, beef cattle or deer (but not dairy cattle)

In these equations, the section in brackets is used to calculate the total amount of nitrogen excreted in urine and dung by all beef cattle, sheep or deer in a given year.

8.3.3.3 Minor livestock

This section shows how indirect volatilisation N2O emissions for minor livestock species are calculated. These equations are effectively identical to the equations in section 8.2.3.4, although the emission factor EF_4 is used instead of EF_5, and $Frac_{GASam}$ is used instead of $Frac_{leach}$.

8.3.3.3.1 Poultry

Indirect N2O emissions (from volatilisation) from urine and dung deposited on pasture by poultry are calculated by using different parameters for broilers, layers and other poultry.

Indirect volatilisation N_2O emissions from urine and dung for poultry (Equation 8.61):

$$N_2Oindirect, volatilisation_{UD,poultry,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times \sum_x \left(N_{ex,x,t} \times POPpoultry_{x,t} \times MS_{x,PRP}\right)$$

Where:

$N_2Oindirect,volatilisation_{UD,poultry,x,t}$ = indirect N2O emissions from volatilisation from urine and dung deposited by poultry type x (i.e. broilers, layers, and other poultry) during grazing in year t (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 18)

EF_4 = N_2O emission factor for indirect emissions from volatising 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

$POPpoultry_{x,t}$ = population of poultry type *x* in year *t* (from APS)

$MS_{x,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by poultry type x. Assumed to be 4.9% for broilers, 5.8% for layers and 3% for other poultry.

The $MS_{x,PRP}$ values for broilers and layers were determined from a study by Fick et al (2011) while the $MS_{x,PRP}$ value for other poultry is taken from the IPCC 1996 guidelines.

8.3.3.3.2 Swine

Indirect N2O emissions (from volatilisation) from urine and dung deposited on pasture by swine are calculated using the following equation. This equation is effectively identical to the equation in section 8.2.3.4.2, although the emission factor EF_4 is used instead of EF_5, and $Frac_{GASam}$ is used instead of $Frac_{leach}$.

Indirect volatilisation N_2O emissions from urine and dung for swine (Equation 8.62):

$$N_2Oindirect, volatilisation_{UD,swine,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times N_{ex,swine,t} \times POPswine_t \times MS_{swine,PRP}$$

Where:

$N_2Oindirect,volatilisation_{UD,swine,t}$ = indirect N2O emissions from volatilisation from urine and dung deposited by swine during grazing in year t (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 18)

EF_4 = N_2O emission factor indirect emissions from volatising 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

$POPswine_t$ = population of swine in year *t* (from APS)

$MS_{swine,PRP}$ = proportion of total manure excreted directly onto pasture, range and paddock by swine. Assumed to be 9% (Hill et al., 2011).

8.3.3.3.3 Goats, horses, alpaca, llamas, mules and asses

For these animals, it is assumed that all manure is excreted directly onto pasture. This means that indirect N_2O emissions (from volatilisation) from urine and dung can be calculated from the following equation. This equation is effectively identical to the equation in section 8.2.3.4.3, although the emission factor EF_4 is used instead of EF_5, and $Frac_{GASam}$ is used instead of $Frac_{leach}$.

Indirect volatilisation N_2O emissions from urine and dung, for goats, horses, alpaca, llamas, mules and asses (Equation 8.63):

$$N_2Oindirect, volatilisation_{UD,x,t} = \frac{44}{28} \times EF_4 \times Frac_{GASam} \times N_{ex,x,t} \times POPminor_{x,t}$$

Where:

$N_2Oindirect,volatilisation_{UD,x,t}$ = indirect N2O emissions from volatilisation from urine and dung deposited by animal type x (i.e. goats, horses…) during grazing in year *t* (kg of N_2O per year)

$Frac_{GASam}$ = fraction of nitrogen excretion emitted as NO_x or NH_3. Currently set at 0.1 (see Appendix 18)

EF_4 = N_2O emission factor indirect emissions from volatising 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 5.5 (nitrogen excretion, other livestock sources)

$POPminor_x$ = population of animal type *x* in year t (from APS)

Specific values of N_{ex} for the different animal categories are outlined in sections 5.5.1 (goats), 5.5.3 (horses, mules and asses) and 5.5.4 (alpacas).

9 Field burning of agricultural residues

The burning of crop residues following harvest results in emissions of CH_4, CO, N_2O and NO_x. These emissions are estimated using country-specific parameters, emission factors and methodology which is aligned with the 1996 IPCC methodology (Thomas *et al.,* 2011). Based on industry information, it is assumed that only the residues from barley, oat and wheat crops are burnt.

The calculation of emissions from crop residues uses country-specific data on:

- crop production
- burning statistics, along with
- the proportion of residue actually burnt,
- harvest indices,
- dry matter fractions,
- fraction oxidised
- carbon and nitrogen fractions of the residue.

Country specific values for these parameters are identical to those from the OVERSEER® nutrient budget model for New Zealand (Wheeler *et al.,* 2003) and are the same as those used for estimates of emissions from crop residues (section 8). This provides consistency between the two emissions estimates for crop residue and crop burning.

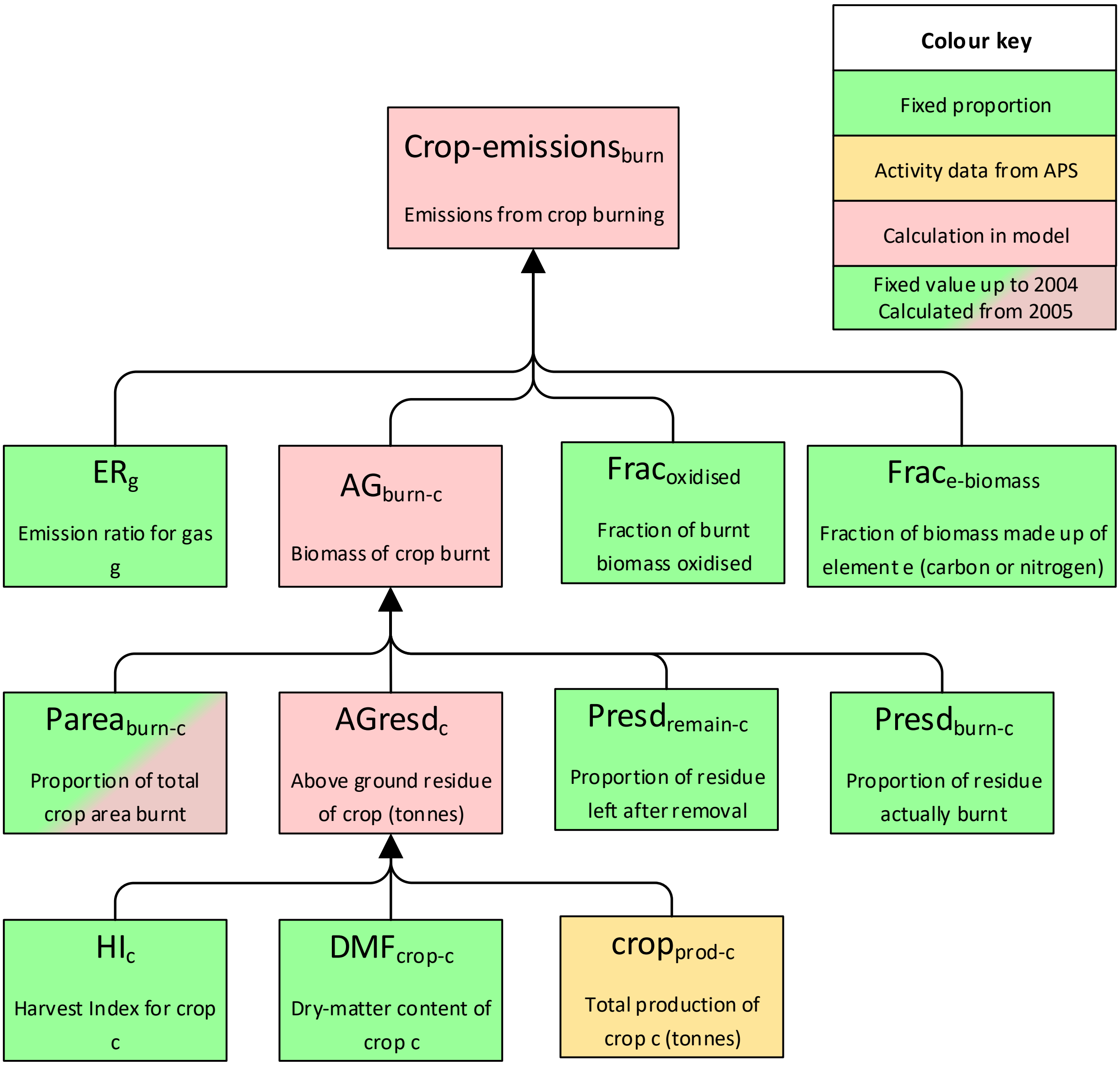
The amount of crop residue burned is estimated from crop production and burning statistics. Country specific data for each crops is then used to calculate the amount of carbon and nitrogen contained in the crop residues

Emissions of CH_4, CO, N_2O and NO_x are estimated by:

- calculating the amount of carbon and nitrogen released and
- multiplying these amounts by various emission ratios.

The diagram below summarises how the different parameters are combined to estimate emissions from crop burning. Statistics New Zealand did not start collecting crop burning area information until 2005. Before 2005, crop burning data is based on farmer survey information (Thomas *et al.,* 2011).

Figure 9.1 Calculation of field burning emissions. Boxes describe activity data, emission factors and calculations required.



9.1 Activity data, parameters and the proportion and areas of crop burning

9.1.1 Activity data

The main activity data sources used to calculate crop burning emissions are:

- Annual production (in tonnes) of barley, oats and wheat crops (from APS)
- Annual area (in hectares) of barley, oats and wheat crops harvested (from APS)
- 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:

$area_{burn\text{-}oats}$ = 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:

$area_{burn\text{-}barley}$ = 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):

$$area_{burn-wheat} = area_{wheat} \times 0.7 \times \left(\frac{area_{burn,total}}{area_{oats} \times 0.5 + area_{barley} \times 0.5 + area_{wheat} \times 0.7}\right)$$

Where:

$area_{burn\text{-}wheat}$ = area of wheat crop burnt (hectares)

$area_{wheat}$ = production area of wheat crop (hectares, from APS)

$area_{burn,total}$ = total area of crop residues burnt (hectares, from APS)

$area_{oats}$ = production area of oat crop (hectares, from APS)

$area_{barley}$ = production area of barley crop (hectares, from APS)

9.1.3 Parameters used in crop burning model

The following tables show the fixed parameters that are used to calculate N_2O, NO_x, CH_4 and CO emissions from crop burning.

Table 9.1: Values used to calculate New Zealand emissions from burning of agricultural residues. Values taken from Thomas *et al.* (2011).

	Barley	Wheat	Oats
Fraction of residue actually burnt (kg above ground residue/kg DM) $Presd_{burn\text{-}C}$	0.7	0.7	0.7
Fraction of above ground residue oxidized (kg oxidized/ kg DM) $Frac_{OXIDISED}$	0.9	0.9	0.9
Fraction of nitrogen in biomass (kg N/ kg DM) $Frac_{N\text{-}BIOMASS}$	0.005	0.005	0.005
Fraction of carbon in biomass (kg C/ kg DM) crop) $Frac_{C\text{-}BIOMASS}$	0.4567	0.4853	0.4567
Dry matter fraction (kg DM/ kg crop	0.86	0.86	0.86

DMF_{crop-C} Harvest Index (see equation x) HI_c	0.46	0.46	0.30

Table 9.2: Emission ratios for agricultural residue burning (Revised IPCC 1996 Guidelines, Table 4-16).

Compound	Emission ratio (kg compound released/kg total compound released during burning)
CH_4	0.005
CO	0.06
N_2O	0.007
NO_x	0.121

9.2 Nitrous oxide field burning emissions

The following equations are used to calculate N_2O emissions from the burning of barley, oats and wheat residues (kt/yr):

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:

$cropN_2O_{BURN}$ = annual nitrous oxide emissions from field burning of barley, oats and wheat (kilotonnes per year)

$N_2O_{BURN-barley}$ = annual nitrous oxide emissions from field burning of barley (kilotonnes per year)

$N_2O_{BURN-oats}$ = annual nitrous oxide emissions from field burning of oats (kilotonnes per year)

$N_2O_{BURN-wheat}$ = 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):

$$N_2O_{BURN-c} = \frac{44}{28} \times AG_{BURN-c} \times Frac_{OXIDISED} \times Frac_{N-BIOMASS} \times ER_{N2O}$$

Where:

N_2O_{BURN-c} = annual nitrous oxide emissions from field burning of crop *c* (i.e. barley, oats or wheat)(kilotonnes per year)

AG_{BURN-c} = Biomass of crop burnt (tonnes per year) for crop type *c* (i.e. barley, oats or wheat)

$Frac_{OXIDISED}$ = Fraction of burnt biomass that is oxidised (currently set at 0.9 for barley, oats and wheat – see Table 9.1).

$Frac_{N-BIOMASS}$ = Fraction of biomass made up of nitrogen, (currently set at 0.005 for barley, oats and wheat– see Table 9.1).

ER_{N2O} = Emission ratio for N_2O (currently set at 0.007 – see table 9.2)

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)

$CH_{4BURN\text{-}barley}$ = annual methane emissions from field burning of barley (kilotonnes per year)

$CH_{4BURN\text{-}oats}$ = annual methane emissions from field burning of oats (kilotonnes per year)

$CH_{4BURN\text{-}wheat}$ = annual methane emissions from field burning of wheat (kilotonnes per year)

Annual methane emissions from field burning by crop type (Equation 9.12)

$$CH_{4_{BURN-c}} = CarbonR_{BURN-c} \times molw_{CH4} \times ER_{CH4}$$

Where:

$CH_{4BURN\text{-}c}$ = annual methane emissions from field burning of crop *c* (i.e. barley, oats or wheat)(kilotonnes per year)

$CarbonR_{BURN\text{-}c}$ = amount of carbon released from burning residues of crop *c*

$molw_{CH4}$ = molecular weight conversion of carbon to methane, (currently set at 16/12).

ER_{CH4} = Emission ratio for methane (currently set at 0.005 – see table 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:

$CarbonR_{BURN\text{-}c}$ = amount of carbon released from burning residues of crop *c*

$AG_{BURN\text{-}c}$ = 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).

$Frac_{c\text{-}BIOMASS}$ = 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)

$CO_{BURN\text{-}barley}$ = annual carbon monoxide emissions from field burning of barley (kilotonnes per year)

$CO_{BURN\text{-}oats}$ = annual carbon monoxide emissions from field burning of oats (kilotonnes per year)

$CO_{BURN\text{-}wheat}$ = 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:

$CO_{BURN\text{-}C}$ = annual carbon monoxide emissions from field burning of crop c (i.e. barley, oats or wheat)(kilotonnes per year)

$CarbonR_{BURN\text{-}C}$ = amount of carbon released from burning residues of crop c (see equation 9.13 in section 9.3)

$molw_{CO}$ = molecular weight conversion of carbon to carbon monoxide, (currently set at 14/6).

ER_{CO} = Emission ratio for carbon monoxide (currently set at 0.06 – see table 13)

9.5 NO_X field burning emissions

NOx refers to nitrogen oxides such as nitric oxide (NO) and nitrogen dioxide (NO_2). Although they are not a greenhouse gases, their emissions have an indirect greenhouse effect. NO_x emissions from field burning can be calculated by using the equations below.

Total NO_x emissions from field burning of all crops (Equation 9.16)

$$cropNO_{X_{BURN}} = NO_{X_{BURN-barley}} + NO_{X_{BURN-oats}} + NO_{X_{BURN-wheat}}$$

Where:

$cropNO_{XBURN}$ = annual NO_x emissions from field burning of barley, oats and wheat (kilotonnes per year)

$NO_{XBURN\text{-}barley}$ = annual NO_x emissions from field burning of barley (kilotonnes per year)

$NO_{XBURN\text{-}oats}$ = annual NO_x emissions from field burning of oats (kilotonnes per year)

$NO_{XBURN\text{-}wheat}$ = annual NO_x emissions from field burning of wheat (kilotonnes per year)

Annual NO_x emissions from field burning by crop type (Equation 9.17)

$$NO_{XBURN-c} = NitrogenR_{BURN-c} \times molw_{CH4} \times ER_{CH4}$$

Where:

$CO_{BURN\text{-}c}$ = annual NO_x emissions from field burning of crop *c* (i.e. barley, oats or wheat)(kilotonnes per year)

$NitrogenR_{BURN\text{-}c}$ = amount of nitrogen released from burning residues of crop *c* (see equation 9.18)

$molw_{CO}$ = molecular weight conversion of nitrogen to NO_x, (uses a value of 46/14).

ER_{NOx} = Emission ratio for NO_x (currently set at 0.06 – see table 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:

$NitrogenR_{BURN\text{-}c}$ = amount of nitrogen released from burning residues of crop *c*

$AG_{BURN\text{-}c}$ = 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).

$Frac_{N\text{-}BIOMASS}$ = 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. Because of gaps in the time-series of this data for 1991 and from 1997-2001, a linear interpolation was used to estimate data on the use of limestone and dolomite for these years. For the remaining years, the equation used to determine carbon dioxide (CO_2) emissions from the application of limestone and dolomite is shown below.

Carbon dioxide emissions from limestone and dolomite application (Equation 10.1)

$$CO_{2lime\&dolomite} = (M_{Lime} \times EF_{Lime} \times molw_{CO2}) + (M_{dolomite} \times EF_{dolomite} \times corr_{CO2})$$

Where:

$CO_{2lime\&dolomite}$ = annual CO_2 emissions from the use of limestone and dolomite (kg CO_2 per year)

M_{Lime} = Total annual amount of calcic limestone applied on farms (kg per year)

EF_{Lime} = Emission factor for calcic limestone (carbonate content of limestone, currently set at 0.12)

$corr_{CO2}$ = molecular weight of CO_2 relative to that for carbon (set at 44/12, or 3.666666)

$M_{dolomite}$ = Total annual amount of dolomite applied on farms (kg per year)

$EF_{dolomite}$ = Emission factor for dolomite (carbonate content of dolomite, currently set at 0.13)

The variable $molw_{CO2}$ is a conversion factor to convert from the mass of C in CO_2, to the total mass of CO_2.

10.2 Urea Application

The use of urea fertilizer, which accounts for the majority of synthetic nitrogen fertilizer used in New Zealand, produces CO_2 emissions following application to soil. The CO_2 is formed from bicarbonate, which is produced when the urea is converted to ammonium via hydrolysis. The CO_2 emissions are estimated using a Tier 1 methodology and equation 11.13 from the IPCC (2006) guidelines, using the default emission factor ($EF_{urea\text{-}carbon)}$ of 0.20. Data on the annual total weight of synthetic N fertilizer applied on farms and the percentage represented as urea is sourced from the Fertiliser Association of New Zealand. This data is also used to calculate N_2O emissions from urea fertilizer as in Section 8. The following equation is used to calculate the CO_2 emissions from the application of urea fertilizer.

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)

$EF_{urea\text{-}carbon}$ = Emission factor for CO_2 emissions from urea after reaction in soil (currently set at 0.2)

$corr_{CO2}$ = molecular weight of CO_2 relative to that for carbon (set at 44/12, or 3.666666)

For this equation it is important to note that M is the *total* weight of urea applied to farms in New Zealand, not just the N or C content.

11 Prescribed burning of savannah

From 1990-2014, New Zealand has reported this Section under New Zealand's Agricultural Greenhouse Gas inventory. As from 2015 onwards it is being reported under the LULUCF Section of New Zealand's Greenhouse Gas inventory.

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13 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_{te}) (% 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

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

Collected from a 12 month study in 2001 – 2002 of 10 dairy farms (Ian Brookes, personal communication).

	Monthly feed Digestibility and ME content											
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Digestibility of feed (kg/kg)	0.8366	0.7945	0.7906	0.8048	0.785	0.7377	0.762	0.7362	0.7436	0.7861	0.8121	0.8022
ME of feed (ME_{con}; MJ ME/kg dry matter)	12.582	11.53	11.686	12.007	11.637	10.817	11.084	10.611	10.69	11.329	11.936	11.655

Appendix 4: Proportion of annual milk yield each month

Month	Dairy	Beef	Sheep	Deer
July	0.008804	0	0	0
August	0.057791	0	0	0
September	0.121324	0.167	0.163934426	0
October	0.150349	0.167	0.254098361	0
November	0.142470	0.167	0.245901639	0.1
December	0.128155	0.167	0.254098361	0.258333333
January	0.110942	0.167	0.081967213	0.258333333
February	0.090041	0.167	0	0.233333333
March	0.085142	0	0	0.15
April	0.065438	0	0	0
May	0.033474	0	0	0
June	0.006069	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.

		Population Data		
June year end	Dairy Cows & Heifers (1 Year and Over) NOT in Milk or in Calf	Dairy Cows & Heifers (1 Year and Over) in Milk or in Calf	Dairy Cattle Total	Dairy Breeding Bulls
1990	86692	2723288	3440815	31174
1991	87695	2641712	3429427	35315
1992	92274	2722939	3467824	30631
1993	86737	2808030	3550140	29642
1994	120070	2994022	3839184	31430
1995	158391	3153230	4089817	31543
1996	182159	3219548	4165098	32401
1997	187824	3319680	4256000	33409
1998	191708	3388320	4344000	34099
1999	170227	3337486	4316409	39657
2000	194584	3505508	4598136	44447
2001	205432	3673531	4879862	49237
2002	221538	3841553	5161589	54027
2003	149190	3928140	5101603	43707
2004	174124	4103318	5152492	44661
2005	212042	4120176	5087176	38536
2006	234880	4137697	5169557	45190
2007	305727	4167121	5260850	53331
2008	335565	4347657	5578440	56466
2009	331428	4606971	5860776	57480
2010	339286	4680096	5915452	57808
2011	403704	4816190	6174503	66448
2012	407820	5009795	6445681	70410
2013	418866	5004634	6483600	75141
2014	483233	5175869	6698326	79572
2015	335790	5056403	6485535	70548
2016	345398	5202467	6618800	69583

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		**491.4920228**	350,496		**383.1271426**	1,055,998		**440.189503**

NZ National dairy cow breeds:	Breakdown of breed types in the National NZ dairy herd (%).	Proportion of dairy breed weights 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_{te}) (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	4.86	3.34	3.26
2015	608.81	470.58	604.72	533.71	600.00	0.50	824.00	4.87	3.34	3.26
2016	599.44	464.31	593.89	558.59	600.00	0.50	824.00	4.88	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 2012 for deer.

	Monthly Digestibility (Decimal)											
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Sheep and beef												
Digestibility of feed	0.738	0.738	0.777	0.777	0.777	0.681	0.681	0.681	0.661	0.661	0.661	0.738
ME of feed	10.8	10.8	11.4	11.4	11.4	9.9	9.9	9.9	9.6	9.6	9.6	10.8
Deer 1990												
Digestibility of feed	0.783	0.764	0.783	0.790	0.781	0.707	0.718	0.706	0.699	0.719	0.731	0.768
ME of feed	11.6	11.1	11.5	11.7	11.5	10.3	10.4	10.2	10.1	10.4	10.7	11.2
Deer 2010												
Digestibility of feed	0.748	0.744	0.778	0.780	0.778	0.687	0.689	0.687	0.669	0.674	0.676	0.744
ME of feed	11.0	10.9	11.4	11.5	11.4	10.0	10.0	10.0	9.7	9.8	9.8	10.9

Sheep and beef data collected from a national survey of 19 beef and sheep farms conducted between March 2001 and February 2002 (Litherland et al., 2002).

Appendix 10: Beef 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	Breeding Cows	Bulls	Total	Heifers	Steers	Bulls
1990	1,355,000	68,751	4,526,056	520,327	804,758	447,345
1991	1,386,418	78,965	4,593,160	376,170	581,095	382,936
1992	1,388,000	76,865	4,670,569	418,723	637,721	434,053
1993	1,418,955	76,907	4,676,497	428,031	649,168	496,351
1994	1,462,787	86,448	4,757,962	425,363	580,125	573,791
1995	1,576,587	91,245	5,047,848	448,888	611,463	556,127
1996	1,616,860	88,052	5,182,508	427,974	708,551	514,929
1997	1,595,548	86,676	4,852,179	492,787	807,203	473,690
1998	1,590,000	88,052	4,806,000	518,288	779,084	370,000
1999	1,443,000	79,911	4,432,000	511,528	781,985	346,601
2000	1,457,413	80,709	4,643,705	454,696	610,419	368,664
2001	1,392,048	80,120	4,594,029	486,969	588,710	486,552
2002	1,326,682	79,531	4,544,354	437,632	544,873	610,512
2003	1,259,190	78,945	4,491,281	401,716	467,291	626,450
2004	1,288,214	80,428	4,626,617	453,700	488,552	640,547
2005	1,263,243	67,548	4,447,400	513,956	583,473	698,050
2006	1,255,255	71,305	4,423,626	509,613	596,501	577,052
2007	1,268,981	71,709	4,439,136	500,590	621,409	531,330
2008	1,195,098	80,424	4,393,617	492,805	607,224	525,898
2009	1,103,603	66,336	4,136,872	500,652	647,770	553,518
2010	1,096,014	78,259	4,100,718	516,472	604,933	485,606
2011	1,117,659	70,383	3,948,520	508,558	616,462	439,024
2012	1,052,822	72,379	3,846,414	480,440	595,519	431,793
2013	1,059,784	78,334	3,734,412	460,527	569,194	445,098
2014	1,019,012	75,214	3,698,522	443404	577346	426003
2015	1,011,914	81,037	3,669,862	454416	573443	435835
2016	981,856	82105	3547228	488372	566632	482586

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 carcases kg	Beef cow replacement rate (%)	Beef cows killed Number	Dairy cattle killed Number	Total weight dairy carcase kg	Total weight beef carcase kg	Av beef cow carcass weight kg	Av beef cow live weight kg
1990	446	581,472	2,723,288	1,386,418	0.42	187	104,113,209	0.17	230,350	351,122	65,798,553	38,314,656	166	390
1991	447	645,694	2,641,712	1,388,000	0.42	188	117,834,423	0.17	235,691	410,003	77,035,679	40,798,744	173	406
1992	449	611,885	2,722,939	1,418,955	0.42	188	113,866,925	0.17	235,960	375,925	70,823,144	43,043,781	182	428
1993	450	590,799	2,808,030	1,462,787	0.42	189	109,557,298	0.17	241,222	349,577	66,042,457	43,514,841	180	423
1994	451	548,110	2,994,022	1,576,587	0.42	189	105,221,126	0.17	248,674	299,436	56,658,927	48,562,199	195	458
1995	452	657,411	3,153,230	1,616,860	0.42	190	123,991,226	0.17	268,020	389,391	73,994,015	49,997,211	187	438
1996	453	738,937	3,219,548	1,595,548	0.42	190	141,028,097	0.17	274,866	464,071	88,323,027	52,705,070	192	450
1997	447	720,733	3,319,680	1,590,000	0.42	188	142,747,668	0.17	271,243	449,490	84,409,180	58,338,488	215	505
1998	455	875,375	3,388,320	1,443,000	0.42	191	71,918,238	0.17	270,300	605,075	15,721,344	56,196,894	208	488
1999	444	749,863	3,337,486	1,457,413	0.42	186	42,945,239	0.17	245,310	504,553	93,997,030	48,948,209	200	468
2000	455	687,825	3,505,508	1,392,048	0.42	191	34,357,518	0.17	247,760	440,065	84,079,830	50,277,688	203	476
2001	460	596,814	3,673,531	1,326,682	0.42	193	21,038,567	0.17	236,648	360,166	69,532,320	51,506,247	218	511
2002	455	674,042	3,841,553	1,259,190	0.42	191	33,117,998	0.17	225,536	448,506	85,685,067	47,432,931	210	494
2003	458	816,993	3,928,140	1,288,214	0.42	193	61,643,304	0.17	214,062	602,931	116,075,385	45,567,919	213	500
2004	457	853,640	4,103,318	1,263,243	0.42	192	69,172,543	0.17	218,996	634,644	121,845,926	47,326,617	216	507
2005	455	795,344	4,120,176	1,255,255	0.42	191	58,599,700	0.17	214,751	580,593	111,036,610	47,563,090	221	520
2006	455	668,020	4,137,697	1,268,981	0.42	191	36,453,282	0.17	213,393	454,627	86,783,681	49,669,601	233	546
2007	444	709,163	4,167,121	1,195,098	0.42	187	44,305,545	0.17	215,727	493,436	92,082,002	52,223,543	242	568
2008	455	642,858	4,347,657	1,103,603	0.42	191	30,105,840	0.17	203,167	439,691	83,936,661	46,169,179	227	533
2009	446	837,919	4,606,971	1,096,014	0.42	187	66,708,922	0.17	187,613	650,306	121,795,102	44,913,820	239	562
2010	458	826,812	4,680,096	1,117,659	0.42	193	65,000,115	0.17	186,322	640,490	123,320,833	41,679,282	224	525
2011	453	869,841	4,816,190	1,052,822	0.42	190	171,962,939	0.17	190,002	679,839	29,223,208	42,739,731	225	528
2012	463	742,864	5,009,795	1,059,784	0.42	194	52,511,600	0.17	178,980	563,884	109,567,081	42,944,519	240	563
2013	458	925,345	5,004,634	1,019,012	0.42	192	83,748,092	0.17	180,163	745,182	143,264,550	40,483,542	225	527
2014	458	910,092	5,175,869	1,011,914	0.42	192	81,208,065	0.17	173,232	736,860	141,821,764	39,386,301	227	534
2015	452	1,089,436	5,056,403	981,856	0.42	190	15,207,216	0.17	172,025	917,411	174,272,380	40,934,836	238	559
2016	448	1,155,295	5,202,467	953,618	0.42	188	25,281,812	0.17	230,350	351,122	65,798,553	38,314,656	166	390

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_{te}) (kg(N)/100 kg (live weight))	Nitrogen in wool (kg N/kg wool)	Lambing Percentage rate	National wool yield (kg/yr)
1990	51.0	71.3	29.9	0.05	5	103	8	2.6	0.134	0.975	341,000,000
1991	52.3	73.2	31.4	0.05	5	103	8	2.6	0.134	0.941	309,000,000
1992	52.9	74.0	32.2	0.05	5	103	8	2.6	0.134	0.965	305,300,000
1993	53.0	74.2	32.6	0.05	5	103	8	2.6	0.134	0.972	295,900,000
1994	52.6	73.6	34.2	0.05	5	103	8	2.6	0.134	0.911	255,500,000
1995	54.3	76.0	34.0	0.05	5	103	8	2.6	0.134	0.989	284,000,000
1996	52.6	73.6	32.4	0.05	5	103	8	2.6	0.134	1.035	288,600,000
1997	53.4	74.8	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

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	685,000	40,453,000	1,247,000	1,643,000	8,938,000	732,000	2,393,000	1,761,000	39,997,000	57,852,000
1991	666,000	36,631,000	1,213,000	3,202,000	8,696,000	712,000	2,329,000	1,713,000	40,616,000	55,162,000
1992	641,000	36,684,000	795,000	1,715,000	8,024,000	698,000	2,325,000	1,688,000	38,716,000	52,568,000
1993	575,000	35,375,000	707,000	1,263,000	7,967,000	668,000	2,142,000	1,602,000	34,991,000	50,298,000
1994	541,000	34,438,000	768,000	1,316,000	8,319,000	608,000	2,107,000	1,275,000	36,244,000	49,466,000
1995	516,000	33,693,000	849,000	1,306,000	8,269,000	579,000	2,160,000	1,246,000	37,018,000	48,816,000
1996	502,000	33,447,000	520,000	945,000	7,956,000	651,000	2,196,000	1,179,000	35,149,000	47,394,000
1997	350,000	33,021,000	242,000	1,891,000	8,882,000	418,000	1,412,000	618,000	37,426,000	46,834,000
1998	345,000	32,355,000	238,000	1,861,000	8,748,000	412,000	1,389,000	608,000	38,521,000	45,956,000
1999	768,000	30,364,000	530,000	1,869,000	6,787,000	917,000	3,092,000	1,353,000	34,854,000	45,680,000
2000	476,000	30,646,000	329,000	2,570,000	6,295,000	569,000	1,919,000	839,000	34,840,000	43,644,000
2001	454,000	29,217,000	313,000	2,450,000	6,002,000	542,000	1,829,000	800,000	35,748,000	41,608,000
2002	434,000	26,785,000	381,000	2,374,000	5,684,000	707,000	2,385,000	822,000	32,647,000	39,572,000
2003	421,000	27,087,000	291,000	2,272,000	5,564,000	726,000	2,450,000	742,000	33,247,000	39,552,000
2004	399,000	26,742,000	301,000	2,662,000	5,365,000	707,000	2,366,000	728,000	31,854,000	39,271,000
2005	382,000	26,419,000	237,000	3,130,000	5,851,000	748,000	2,505,000	607,000	33,226,000	39,880,000
2006	385,000	26,905,000	281,000	3,023,000	5,682,000	756,000	2,530,000	521,000	33,810,000	40,082,000
2007	390,000	26,063,000	286,000	2,525,000	5,552,000	718,000	2,403,000	524,000	33,005,000	38,460,000
2008	345,000	23,486,000	311,000	1,470,000	4,966,000	687,000	2,301,000	522,000	31,020,000	34,088,000
2009	348,000	22,214,000	224,000	1,821,000	4,668,000	611,000	2,045,000	453,000	27,888,000	32,384,000
2010	313,000	21,794,000	224,000	2,077,000	4,835,000	676,000	2,261,000	383,000	28,152,000	32,563,000
2011	316,000	20,485,000	339,000	2,016,000	4,650,000	670,000	2,244,000	412,000	24,967,000	31,132,000
2012	295,000	20,411,000	320,000	2,381,000	4,619,000	660,000	2,209,000	368,000	25,954,000	31,263,000
2013	302,000	20,233,000	192,000	1,999,000	4,682,000	708,000	2,372,000	299,000	25,967,000	30,787,000
2014	297,000	19,779,000	245,000	2,072,000	4,190,000	672,000	2,248,000	300,000	24,977,000	29,803,000
2015	290,000	19,074,000	314,000	1,750,000	4,562,000	664,000	2,224,000	242,000	25,833,000	29,121,000
2016	271,000	18,137,000	323,000	1,695,000	4,294,000	592,000	1,982,000	290,000	24,570,000	27,584,000

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

Appendix 15: Deer population data

Values are June year end

Year end June	HINDS			STAGS				Total population
	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	numbers
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

Appendix 17: Fraction of manure excreted in each animal manure management system (MMS) - for all livestock species

	Proportion of nitrogen in each management system (MS)							
MMS	**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 *et al.*, 2011	IPCC default table 4-21 1996 IPCC reference manual

Appendix 18: Emission factor and fractions used to determine direct and indirect N_2O emissions from Agricultural soils

Parameter	Emission factor or fraction value	Units	Reference
$Frac_{gasf}$	0.1	kg(NH_3-N + NO_X-N)/kg(N applied)	Sherlock *et al.*, 2008
$Frac_{gasf,UI}$	0.055	kg(NH_3-N + NO_X-N)/kg(N applied)	Saggar *et al.*, (2013)
$Frac_{gasm}$	0.1	kg(NH_3-N + NO_X-N)/kg(N applied)	Sherlock *et al.*, 2008
$Frac_{LEACH-(H)}$	0.07	kg N/kg of fertiliser or manure N	Thomas *et al.*, 2003 & 2005
$Frac_{BURN}$	Crop specific	kg N/kg crop-N	Thomas *et al.*, 2008
$Frac_{RENEW}$	Year specific		Beare *et al.*, 2012; Thomas *et al.*, 2014
$Frac_{REMOVE}$	0	kg N/kg crop-N	Thomas *et al.*, 2014
EF_1	0.01	kg(N_2O-N)/kg(N applied)	Kelliher & de Klein, 2006
$EF1_{urea}$	0.0059	kg(N2O-N)/kg(N applied)	Kelliher *et al.,* 2014
EF_2	8	kg(N_2O-N)/ha/yr	IPCC 2006, Table 11.1
$EF_{3PR\&P\ DUNG}$	0.0025	kg(N_2O-N)/kg(excreted N)	Luo *et al*., 2009
$EF_{3PR\&P}$	0.01	kg(N_2O-N)/kg(excreted N)	Based on Carran *et al*., 1995; Muller *et al*., 1995; de Klein *et al*., 2003; Kelliher *et al*.,
EF_{3AL}	0.001	kg(N_2O-N)/kg(excreted N)	IPCC 2006, pg. 10.52 note in text.
EF_{3SSD}	0.02	kg(N_2O-N)/kg(excreted N)	IPCC 2006, Table 10.21
EF_{3OTHER}	0.005	kg(N_2O-N)/kg(excreted N)	IPCC GPG Table 4.13 (poultry manure without bedding)
$EF_{3poultry}$	0.001	kg(N_2O-N)/kg(excreted N)	Fick *et al*., 2011
EF_4	0.01	kg(N_2O-N/kg(deposited NH_3-N + NO_X-N)	IPCC 2006, Table 11.3
EF_5	0.025	kg(N_2O-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	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Beef	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Sheep	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Deer												
1990	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32
2013	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07

Appendix 20: Nitrogen fertiliser application and yield of nitrogen fixing and other crops

Year	Synthetic fertiliser use (t (N)/yr)	Urease inhibitor use (t N/yr)	Urea use (kg N/yr)	Pea yield (kg/yr)	Field seed peas (kg/yr)	Lentil yield (t/yr)	Barley yield (t/yr)	Wheat yield (t/yr)	Maize yield (t/yr)	Oats yield (t/yr)	Potatoes yield (kg/yr)	Onions (kg/yr)	Sweet corn (kg/yr)	Squash (kg/yr)	Herbage seeds (kg/yr)	Legume seeds (kg/yr)	Brassica seeds (kg/yr)
1990	59,265	0	24,585,917	67,200,000	57,378,000	3,386	434,856	188,04	161,651	78,877	467,866,00	162,240,00	57,960,000	73,540,000	28,492,000	6,732,000	1,062,000
1991	61,694	0	32,520,868	67,200,000	65,064,000	3,386	382,043	180,69	183,388	57,187	456,918,00	168,870,00	63,830,000	80,730,000	28,057,000	9,124,000	1,274,000
1992	70,122	0	32,071,302	67,200,000	75,290,000	5,204	318,787	191,03	163,842	57,625	445,970,00	175,500,00	69,700,000	87,920,000	28,159,000	8,658,000	978,000
1993	104,095	0	44,218,217	67,200,000	63,268,000	5,018	389,523	219,41	133,069	56,793	416,944,00	187,620,00	73,100,000	116,580,00	25,704,000	9,331,000	1,314,000
1994	124,131	0	57,420,471	67,200,000	59,898,000	2,712	395,476	241,85	142,768	57,718	439,840,00	295,740,00	110,520,00	150,180,00	24,439,000	8,347,000	948,000
1995	151,263	0	85,796,763	67,200,000	56,448,000	923	302,804	245,17	160,797	38,735	494,060,00	341,820,00	147,660,00	136,620,00	33,727,000	8,419,000	1,656,000
1996	153,780	0	88,972,714	67,200,000	46,373,000	923	367,181	277,01	209,710	41,217	486,040,00	346,320,00	143,360,00	129,320,00	35,771,000	8,588,000	1,322,000
1997	143,295	0	80,158,542	68,040,000	50,337,000	923	411,000	317,37	193,806	49,065	454,440,00	384,480,00	135,480,00	131,790,00	39,553,000	8,392,000	546,000
1998	155,467	0	102,800,655	87,360,000	66,200,000	940	340,000	302,10	176,148	42,223	478,860,00	384,480,00	135,480,00	131,790,00	42,062,000	6,268,000	2,204,000
1999	166,819	0	139,015,833	95,760,000	52,200,000	0	304,000	320,00	197,000	41,702	560,640,00	384,480,00	135,480,00	140,160,00	39,413,000	5,832,000	1,590,000
2000	189,096	0	143,358,866	100,800,00	64,000,000	0	302,000	326,00	181,000	35,398	504,520,00	422,640,00	127,600,00	134,260,00	28,789,000	4,363,000	1,109,000
2001	248,000	10,443	187,451,505	100,800,00	37,700,000	0	365,000	364,00	177,000	22,394	497,300,00	379,950,00	121,700,00	139,360,00	24,543,000	3,476,000	809,000
2002	309,200	9,200	244,835,138	100,800,00	29,457,000	3,302	440,883	301,49	148,847	34,986	526,080,00	337,260,00	115,800,00	131,200,00	32,504,000	3,990,000	1,302,000
2003	337,400	12,420	272,303,015	87,360,000	31,200,000	2,000	371,837	318,91	197,182	29,934	555,160,00	344,880,00	140,820,00	136,080,00	39,456,000	4,226,000	1,778,000
2004	348,000	23,000	285,437,170	86,643,648	31,911,820	2,000	226,082	255,86	234,248	30,844	567,060,00	320,370,00	141,560,00	168,860,00	43,400,000	4,573,000	2,433,000
2005	350,320	4,600	286,410,270	85,927,296	29,068,000	2,000	302,023	318,94	210,253	25,000	560,720,00	295,860,00	142,300,00	139,620,00	37,141,000	5,554,000	1,952,000
2006	329,700	22,154	264,869,515	76,317,696	22,506,000	2,000	277,020	261,79	227,054	28,478	513,840,00	285,750,00	133,250,00	160,840,00	29,738,000	5,028,000	1,269,000
2007	315,920	14,242	286,221,406	66,708,096	22,053,000	847	335,627	344,43	185,627	27,531	516,320,00	275,640,00	124,200,00	155,480,00	35,159,000	3,578,000	2,279,000
2008	328,157	14,242	276,208,078	77,977,200	20,047,000	1,863	408,730	343,35	205,557	25,463	486,220,00	273,150,00	112,690,00	132,020,00	44,919,000	3,234,000	2,187,000
2009	279,752	22,154	234,542,989	58,998,800	21,201,000	1,445	435,270	403,46	237,844	33,703	501,080,00	270,660,00	101,180,00	136,500,00	43,247,000	4,531,000	2,900,000
2010	332,981	19,325	281,871,447	59,000,000	37,094,000	3,800	308,298	444,89	188,812	47,608	521,440,00	289,590,00	86,170,000	132,920,00	29,812,000	3,671,000	1,851,000
2011	360,284	16,496	311,755,951	59,000,000	32,401,000	4,573	367,958	383,26	210,175	28,466	579,540,00	308,520,00	71,160,000	129,340,00	40,365,000	3,392,000	2,069,000
2012	362,508	21,603	310,020,373	63,000,000	20,148,000	2,865	438,789	488,61	211,231	18,118	521,900,00	343,080,00	93,280,000	136,740,00	44,102,000	3,446,000	2,348,000
2013	366,600	28,162	326,297,077	63,000,000	24,532,000	2,490	416,478	447,79	201,659	28,225	502,135,00	323,560,00	91,951,000	133,382,00	40,003,000	3,773,000	2,438,000
2014	376,890	64,630	320,356,500	66,000,000	28,070,000	1,800	405,747	413,49	237,165	34,741	488,043,20	304,020,00	90,620,000	130,020,00	55,706,000	6,554,000	4,797,000
2015	428,682	61,941	381,526,980	66,500,000	25,353,000	1,637	437,144	413,53	226,278	29,119	445,556,00	284,490,00	89,290,000	126,660,00	41,395,000	4,629,000	3,053,000
2016	432,200	95,400	360,300,000	62,000,000	41,321,000	2,363	364,186	459,34	210,325	46,645	488,120,00	264,960,00	87,960,000	123,300,00	41,334,000	7,026,000	4,137,000

Appendix 21: Forage crops for pasture renewal

Year	Rye-Clover mix (sheep, beef, deer)		Rye-Clover mix (dairy)		Lucerne (dairy, sheep, beef, deer)	
	Area (ha)	Frequency of renewal (%)	Area (ha)	Frequency of renewal (%)	Area (ha)	Frequency of renewal (%)
1990	12,464,774	1.5	1,348,773	5.6	84,000	10
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	-61.08
1991	-80.05
1992	-99.03
1993	-118.01
1994	-136.98
1995	-155.96
1996	-174.93
1997	-194.72
1998	-214.50
1999	-234.28
2000	-254.06
2001	-273.84
2002	-292.82
2003	-311.80
2004	-330.77
2005	-349.75
2006	-368.72
2007	-387.70
2008	-407.32
2009	-426.93
2010	-427.58
2011	-428.22
2012	-428.86
2013	-412.84
2014	-396.82
2015	-380.80
2016	-364.78

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