OVERSEER® Technical Manual

Technical Manual for the description of the OVERSEER® Nutrient Budgets engine

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Calculation of methane emissions

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Preface

OVERSEER® Nutrient Budgets

OVERSEER® Nutrient Budgets (OVERSEER) is a strategic management tool that supports optimal nutrient use on farm for increased profitability and managing within environmental limits.

OVERSEER provides users with information to examine the impact of nutrient use and flows within a farm and off-farm losses of nutrients and greenhouse gases. An OVERSEER nutrient budget takes into account inputs and outputs and the key internal recycling of nutrients around the farm.

See the OVERSEER website for more detailed information: http://www.overseer.org.nz

This technical manual

OVERSEER is made up of a user interface and an engine. These two components work together to enable users to generate nutrient budget reports. The Technical Manual provides details of the calculation methods used in the OVERSEER engine.

The OVERSEER engine is based on extensive published scientific research. Technical information about the model's development and use can be found in a growing number of conference proceedings and peer-reviewed papers. Given the ongoing upgrades many of the earlier papers no longer reflect the current version.

The Technical Manual chapters provide detailed descriptions of the methods used in the OVERSEER engine's main sub-models. The Technical Manual sets out the underlying principles and sources of data used to build the model engine. It is a description of the model as implemented, and hence references may not now be the most appropriate or cover the range of data of information currently available, or may not necessarily be the most up to date. If the source of some information and/or assumptions is not known or could not be found, this is acknowledged.

The chapters will continually be updated to reflect the current version.

If readers have feedback or further technical information that they consider could contribute to the future development of the model, please provide feedback via the website http://www.overseer.org.nz.

Scientific contribution to model development:

OVERSEER is a farm systems model covering a wide range of science disciplines. Since the model's inception, a large number of researchers from many disciplines and organisations have contributed to its development.

Researchers contributing significantly to the methane emissions component of the model described in this report include:

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Calculation of methane emissions

1. Introduction

1.1. Background

This chapter documents the methods for calculating methane emissions within OVERSEER® Nutrient Budgets engine (OVERSEER). Methane emissions are reported as part of the greenhouse gas emission reports. On pastoral farms, methane emissions are the largest contributor to greenhouse gas emissions. In contrast, on non-pastoral farms, methane emissions are usually minor.

This document should be read in conjunction with other reports making up the technical manual. In particular, calculation of methane emissions are dependent on estimation of animal ME requirements, dry matter intake, dung production and effluent management system. The relationship between the main reports and estimation of methane emissions, and methane emissions and greenhouse gas reporting is shown schematically in Figure 1.

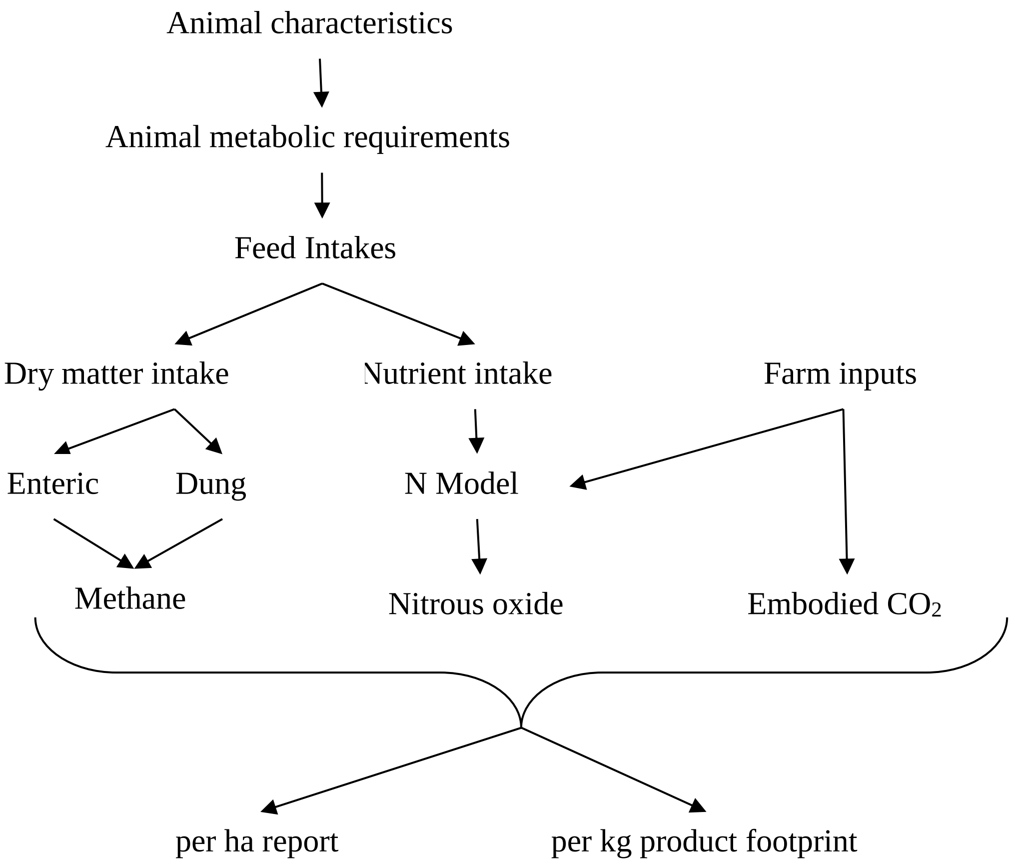

Figure 1. Relationship between main reports within the technical manual and estimation of methane emissions.

The sources of methane emissions have been separated into enteric and excreta dung. Emissions from excreted dung have been further separated into emissions from dung deposited on pasture, raceways, dairy sheds and feed pads. On pastoral farms, the largest source of farm methane emissions is enteric methane emissions.

The methods for estimating methane emissions are largely based on the methods used for the NZI. Deviations from the NZI are mentioned in the text.

1.2. Workings of the technical manual

The aim of the technical manual is to provide a level of detail so that users of OVERSEER can clearly see the underlying principles and sources of data used to build the components of the model. This technical chapter is part of a series of technical manuals currently under development to explain the inner working of the OVERSEER engine.

In the equations in this manual, units are shown using ( ) and cross-references other equations and sections within this manual or to other chapters of the technical manual are shown using [ ]. Equations with multiple '=' options are cascading alternatives in the order they are considered. The condition is shown on the right hand side. The variable and parameter names used are generally shortened names of the property, and this naming convention is similar to the convention used in the OVERSEER engine model.

1.3. Abbreviations and subscripts used

Abbreviations

DM	Dry Matter
DMI	Dry Matter Intake
IPCC	Intergovernmental Panel on Climate Change
GWP	Global Warming Potentials
ME	Metabolic Energy
NZI	New Zealand greenhouse gas emissions national Inventory (Ministry of the Environment 2016)
RSU	Revised Stock Units

Subscripts:

antype	animal types within OVERSEER (dairy, dairy replacements, sheep, beef, deer, dairy goats, other)
block	user defined block

2. Enteric methane emissions

Enteric methane emissions are calculated by multiplying total DMI (DMI from pasture, supplements, and crops) by an enteric methane emission factor. DMI is estimated monthly from the animal's energy requirement and feed ME content. The NZI uses a similar procedure, but then converts the results to per head basis for reporting (Ministry of the Environment 2016, Table A3.1.4).

Non-dairy goats, horses, alpacas, and llamas are entered as numbers of animals for different classes, with each class assigned a RSU. An RSU is equivalent to 6000 MJ ME requirement per year (Woodford and Nicol 2004). Other stock can also be entered using a user-defined stock types and classes with a user-defined RSU. In contrast, the NZI uses implied emission factors to estimate annual enteric methane emissions from goats, horses, and swine.

The NZI noted that alternative methods for estimating methane emissions are available but were rejected due to difficulties in use for national inventories, lack of predictive power, or were based on animals fed indoors rather than pasture fed animals. Alternative calculations for a farm-specific model were also considered, but rejected. Farm-specific models were considered such as the Blaxter & Clapperton equation. However, the information required to estimate terms in these models also estimates DMI, which the NZI is based on.

An earlier version of the model used digestible DM intake (DDMI) and an enteric methane emission factor. Ryegrass/white clover or good quality pasture used a methane emission factor of 26.5 g methane/kg DDMI (Clark pers. comm.). C4 or Kikuyu dominant pasture used a methane emission factor of 34.5 g methane/kg DDMI (Ulyatt *et al*., 2002). A higher emission factor could also be used for browntop, unimproved pasture, and poor quality pasture. The effect of pasture types is now mediated through the effect of feed quality on DMI, as noted above.

The NZI estimates the proportion of gross energy intake lost as methane, which has not been implemented in this model.

2.1. Default enteric methane emissions factors

The default enteric methane emission factors used in the model are shown in Table 1. The emissions for dairy, sheep, beef and deer uses the NZI enteric methane emission factors (Ministry of the Environment 2016) as they have been determined by measurements made in NZ (Ministry of the Environment 2016). As in the NZI, the adult dairy cattle value is assumed to apply to all dairy and beef cattle, the deer emission factor is the average of adult dairy cattle and adult sheep, and a lower emission for young sheep is used. Methods used for other animal types are detailed in sections 2.4 and 2.5. The default enteric methane emission factors shown in Table 1 can be modified for each animal class by the user.

Table 1. Default enteric methane emission factors for each animal types.

Animal types	DMImethane (g methane/kg DMI)
Dairy	21.6
Dairy replacements	21.6
Sheep (> 1 year old)	20.9
Sheep (<= 1 year old)	16.8
Beef	21.6
Deer	21.25
Dairy goats	20.9
Other	also see section 2.5
Non-dairy goats	20.9
Camelids	20.9
Horses	1.8 [1]
User-defined	1.5 [1]

[1] units are kg methane/RSU

Although total DMI is estimated on a monthly basis, no evidence was found that the enteric methane emissions varied over time, or varied between sites.

It was assumed that feed quality or type of feed fed to the animals had no effect on methane emission factors. Thus, for example, different pasture types including lucerne, pasture based supplements, by-product supplements, concentrates, grains, or crops had the same emission factor (g methane/kg DMI). The current consensus, based on calorimeter measurements, is that the best prediction of enteric methane emissions is DMI (Kelliher pers. comm.). Feed quality (ME and DM content of the individual components of the diet, which the user can enter) affects the amount of DMI. Thus, for animals grazing pasture, as the quality of feed decreases, pasture ME content decreases, and DMI increases to achieve the same animal ME intake; hence methane emissions increase.

The scientific results on the effect of lotus or products containing tannin on enteric methane emissions were considered not consistent enough to include in the model. No adjustment is made for animals fed indoors or in animal shelters.

2.2. Dairy, beef, deer

Enteric methane emissions (kg methane/year) for dairy, dairy replacement, beef, and deer animals (kg methane) are estimated as:

Equation 1: $Entericmethane_{ntype} = \Sigma_{mon}(DMI_{antype} * DMImethane_{antype} / 1000)$

DMI is the total dry matter intake (kg DM/month).

DMImethane is the enteric emission factor (g methane/kg DMI) [Table 1].

1000 converts g methane to kg methane.

2.3. Sheep

The NZI has different enteric methane emission factors for young (< 1 year) and older sheep (Table 1). Thus, the model estimates DMI for all sheep and for young sheep (animals <= 1 year old, or <= 365 days as applied in the model) if animal numbers are added via the monthly stock reconciliation. If sheep animal numbers are entered as RSU, 20% of the total sheep ME requirements is assumed to come from young sheep.

Thus, enteric methane emissions for sheep (kg methane/year) are estimated as:

Equation 2: $$Entericmethane_{sheep} = \Sigma_{mon}(DMI_{sheep} - DMI_{young}) * DMImethane_{antype} / 1000 + \Sigma_{mon}(DMI_{young}) * DMImethane_{young} / 1000$$

DMI is the total dry matter intake (kg DM/month).
DMIyoung is the dry matter intake (kg DM/month) for sheep <= 1 year old.
DMImethane is the enteric emission factor (g methane/kg DMI) [Table 1].
$DMImethane_{young}$ (g methane/kg DMI) [Table 1, sheep <= 1 year old].
1000 converts g methane to kg methane.

2.4. Dairy goats

Dairy goat DMI is estimated using the animal metabolic requirements sub-model as for sheep, except using goat specific parameters. The increased productivity in dairy goats (Morris pers. comm., Prosser pers. comm.) supports use of this approach rather than a fixed per head value used by the NZI. The enteric methane emission factor is assumed to be the same as for adult sheep. Thus, enteric methane emissions for dairy goats (kg methane/year) are estimated as:

Equation 3: $$Entericmethane_{dairygoats} = \Sigma_{mon}(DMI_{dairygoats}) * DMImethane_{sheep} / 1000$$

DMI is the total dry matter intake (kg DM/month).
DMImethane is the enteric emission factor (g methane/kg DMI) [Table 1].
1000 converts g methane to kg methane.

2.5. Other animal types

Enteric methane emissions (kg methane/year) for other stock types are the sum of emissions from goats, horses, alpacas and llamas, and user-defined stock type.

Equation 4: $$Entericmethane_{other} = Entericmethane_{goats} + Entericmethane_{horse} + Entericmethane_{camelids} + Entericmethane_{userdefined}$$

Entericmethane is the enteric emissions (kg methane/year) for goasts [section 2.5.1], horse [section 2.5.2], camelids [section 2.5.3] or user defined animal [section 2.5.4].

2.5.1. Non-dairy goats

For non-dairy goats, annual ME requirements is estimated from the number of animals and RSU. This is distributed monthly and then divided by the feed ME content to obtain DMI. The enteric methane emission factor is assumed the same as adult sheep (Table 1) to be consistent with dairy goats.

This differs from the NZI, which uses a country-specific value of 9 kg methane/head/year. The implied emission factor for goats was based on sheep in 1990 but was not indexed over time as there were no data to support productivity increases that have been seen in sheep. This value is larger than the IPCC recommendation of 5 kg methane/head/year.

Enteric methane emissions for non-dairy goats (kg methane/year) are estimated as:

Equation 5: $Entericmethane_{goats} = \Sigma_{mon}(DMI_{goats}) * DMImethane_{non-dairygoats} / 1000$

DMI is the total dry matter intake (kg DM/year).

DMImethane is the enteric emission factor (g methane/kg DMI) [Table 1].

1000 converts g methane to kg methane.

2.5.2. Horses

Default methane emissions for horses are based on the NZI implied emission factor of 18 kg methane/head/year. Enteric methane emissions measurements have not been made in New Zealand, so NZI uses values recommended by the IPCC. If it is assumed that a head is equivalent to the intake of ten RSU, this gives an emission factor of 1.8 kg methane/RSU/year. This compares to about 10 kg methane/RSU/year for sheep, given an implied emission factor of 10 kg/head sheep/year (Ministry of the Environment 2016) and one head of sheep being equivalent to one RSU.

Enteric methane emissions for horses (kg methane/year) are estimated as:

Equation 6: $Entericmethane_{horse} = RSU_{horses} * DMImethane_{horses}$

RSU is the entered number fo RSU's for horses per year.

DMImethane is the enteric emission factor (kg methane/RSU) [Table 1].

2.5.3. Camelids

Camelids include alpacas and Llamas. Pinares-Patino *et al*. (2003) have suggested the enteric methane emissions factor of adult alpacas and sheep should be broadly similar (see their Figure 1). It seems reasonable to infer that adult sheep and llamas should have similar enteric methane emissions factors. The number of animals and RSU are used to estimate the animal's metabolic energy (ME) requirement, distributed monthly and then dividing by the feed ME content to get dry matter intake.

Enteric methane emissions (kg methane/year) for camelids are estimated as:

Equation 7: $Entericmethane_{camelids} = \Sigma_{mon}(DMI_{camelids}) * DMImethane_{camelids} / 1000$

DMI is dry matter intake (kg DM/year).

DMImethane is the enteric emission factor (g methane/kg DMI) [Table 1].

1000 converts g methane to kg methane

2.5.4. User-defined stock

For user-defined stock, the animal type is not known to the model. As ruminant stock should be entered elsewhere in the model, it is assumed that user-defined stock are all non-ruminants and hence the implied emissions factor for swine (1.5 kg methane/head/year) is used as a default emission factor, with 1 head equivalent to 1 RSU.

Enteric methane emissions for user-defined stock (kg methane/year) are estimated as:

Equation 8: $Entericmethane_{userdefined} = RSU_{userdefined} * DMImethane_{user-defined}$

RSU is the user-defined number of RSU's per year entered.

DMImethane is the enteric emission factor (kg methane/RSU) [Table 1].

3. Methane emissions from dung

The quantity of dung DM produced by each animal type is estimated monthly as the sum of DMI * (1-digestibility) of each dietary component. Thus, the quantity of dung DM accounts for the number of animals and diet quality. The dung is separated into that deposited on pasture and that transferred to the farm dairy shed, lanes, feed pads, loafing pads, and wintering pads. Dung separation follows the same pattern as separation for P, given that most excreta P is in the dung.

There is a range of effluent management systems available within the model, such as applying effluent directly from sumps, 2-pond system, holding ponds, separation systems, as well as storage or solids such as sludge’s, bunker material or separated solids. Literature reviews indicate that methane losses from these systems are not the same as those from dung deposited on pasture.

In the field, the number of 2-pond systems with direct discharge is decreasing. Most farmers are using a spray system, either directly from a sump (no storage) or with storage. There is increasing pressure to add storage ponds in some areas as part of a deferred irrigations system. In some cases, storage ponds are the 2 pond system except that the effluent is applied back onto the land.

The use of feed pads and wintering pads is increasing but still only affects a small number of dairy farms. They are seen as a potential mitigation option for reducing N leaching, and hence it is important the model should capture any changes in greenhouse gas emissions if these systems are used. These systems are increasingly storing effluent in bunkers or compost heaps, and there is increasing use of application of solids to lands.

Methane emissions from wetlands, peat soils, waterlogged soils, septic tank sludge, or septic tank or composting sewage systems on house blocks has been assumed to be zero.

3.1. Dung deposited on paddocks

The default methane emission factors for dung deposited on pasture are shown in Table 2 and follow the NZI methane emission factors for dung (Ministry of the Environment), except use the values shown in an original spread sheet for calculating the NZI that had an additional decimal place). The NZI provide no data for dairy replacements but the emission factor is assumed to be that of dairy cattle. The dung paddock methane emission factor for dairy goats and other animals was assumed to be the same as for sheep. The user can modify these.

Table 2. Default methane emission factors for dung deposited in paddocks.

Animal type	Dung methane emission factor (g methane/kg DM dung)
Dairy	0.98198
Dairy replacements	0.98198
Sheep	0.691
Beef	0.98198
Deer	0.915
Dairy goats	0.691
Other	0.69

The model assumes that the dung emission factors are constant. Although Saggar *et al*. (2003) reported data that indicated that methane emissions from dung produced by different diets varied, this is not included in this model at this stage. The emission factors are assumed to be the same for each month.

Thus, the emission of methane from dung deposited on paddocks is calculated as:

Equation 9: $dungmethane_{antype} = \Sigma_{mon}(dungDM_{antype}) * methaneDung_{antype} / 1000$

dungDM is the dung DM deposited on paddocks (kg dung/month).

methaneDung is the methane emission factor for dung (g methane/kg DM dung) [Table 2].

3.2. Dung in effluent

Methane emission from stored effluent is higher than that from dung applied to pasture, and is higher from applied slurries than from stored effluent (Saggar *et al*., 2003 and 2004, Luo *et al*., 2008). The NZI treats methane emission from effluent dung added to anaerobic ponds explicitly but emissions for other effluent dung is implied to be the same as that from dung deposited on pasture. The additional inputs for this model allow emissions from a wider range of effluent management systems to be modelled.

Thus, the emission factors for dung in effluent were based on estimating emissions for the following storage methods:

- Anaerobic pond storage
- Storage of solids

And the following application methods

- Direct application
- Application of slurry
- Application of solids
- Exported

As effluent was transferred within the effluent management system, dung was allocated to one of these primary methods. The distribution of dung within the effluent management system was assumed to be the same as for P as most excreta P is in dung.

The losses from each method were related to emissions from dung deposited on pasture. Apart from this difference, emissions from dung effluent from difference animal sources were treated the same.

3.2.1. Anaerobic ponds

Methane emissions from a 2-pond system were based on the NZI methodology. Thus, methane emissions (kg methane/year) from anaerobic ponds are estimated as:

Equation 10: $methane2pond_{antype} = dung2pond_{antype} * (1 - Ash) * Bo * 0.67 * MCF$

$dung2pond_{antype}$ in the effluent dung added to 2 pond system (kg dung/year).
Ash is the ash content of manure (0.08).
Bo is the maximum methane-producing capacity of manure, 0.24 (m^3 CH_4 kg^{-1}).
0.67 is the conversion factor of m^3 CH_4 to kg CH_4 (kg/m^3).
MCF is the methane conversion factor for uncovered anaerobic lagoon, average annual temperature 15º C (0.74).

3.2.2. Solids stored

All solids from feed pads or winter pads (separated solids, bunker effluent, scrapped effluent), or separated solids from holding ponds have the option to indicate type of storage, with option of no storage, covered or uncovered storage, and if storage occurs, the length of storage (months). Solids can be applied to land or exported.

Saggar *et al*. (2004) quoted overseas data that indicated that emissions from dung in solid manure storage were 14 times higher than from dung on pasture (3.7/0.25, where 0.25 is average paddock in Table 8 in Saggar *et al*. 2004).

Saggar *et al*. (2003) also reported data that indicated that the effect of storage on methane emissions is dependent on time of storage and temperature. In a summary, Luo *et al*. (2008) indicated that the type of bunker and temperature had no effect on methane emissions. The temperature within bunkers is likely to be more uniform that that in material stored outside. Therefore, methane emissions from dung stored in bunkers is treated as uncovered storage. The effect of temperature has been ignored.

The literature (Saggar *et al*., 2003) indicates that losses may be lower from uncovered bunkers than from covered bunkers due to drying out and hence less anaerobic conditions. Decreasing the pH can decrease methane emissions in pig effluent (Berg *et al*., 2005) but as no reports of pH manipulation of effluent where found for New Zealand, this has been ignored.

Solids applied directly to pasture were assumed to have the same emission factor as dung deposited on paddocks.

Therefore, methane emissions (kg methane/year) from stored effluent or effluent from bunkers are estimated as:

Equation 11: $MethaneStored_{antype} = \sum(Dungstored_{antype} * f(Time) * Dungmethane_{antype})$

$Dungstored_{antype}$ is dung added to storage (kg dung/year).

Dungmethane is the emission factor for dung deposited on paddocks (kg methane/kg dung) [Table 2].

f(Time) is a factor for time.

and where

Equation 12: $f(Time) = \sum(2 * Time)$ covered, $f(Time) <= 14$

$= \sum(1 * Time)$ uncovered, $f(Time) <= 7$

Time is the entered time in storage (months).

3.2.3. Direct application

In the NZI, only effluent dung stored in anaerobic lagoons is separated out (5% of total effluent dung) and a different emission factor applied. As the other common effluent application method is spray, this implies that effluent dung applied as spray has the same emission factor as dung applied directly to paddocks.

Equation 13: $methanespray_{antype} = dungspray_{antype} * Dungmethane_{antype}$

$Dungspray_{antype}$ is the dung applied as spray directly from the sump (kg/ha dung).

Dungmethane is the emission factor for dung deposited on paddocks (kg methane/kg dung) [Table 2].

Note*: to be consistent with the use of importing/exporting effluent within greenhouse gas product reporting, this should be calculated on a block basis.*

3.2.4. Pond slurry

Saggar *et al*. (2004) quoted overseas data that indicated that emissions from applied slurry were 43 times higher than from dung deposited on pasture. In contrast, it was noted in the NZI (Ministry of Environment 2011, p 251) that oxidation ponds are typically de-sludged every 20 years and as it is largely stabilised, methane emissions are unlikely to be significant. Thus, the high emissions associated applying sludge would only apply for sludge with a limited age. As the frequency of de-sludging 2-pond and holding ponds is an input, a linear decrease in emissions rate over a 5-year period was adopted.

Thus, methane emissions (kg methane/year) from applying sludge was estimated as:

Equation 14: $MethaneSlurry_{antype} = DungSlurry_{antype} * Dungmethane_{antype} * 43 * f(freq)$

$Dung2pond_{antype}$ is the dung applied as slurry (kg dung/year).

Dungmethane is the emission factor for dung deposited on paddocks (kg methane/kg dung) [Table 2].

43 is the ratio methane emissions in fresh sludge to dung deposited on paddocks.

and where

Equation 15: $f(freq) = (6 - freq)/5$

freq = frequently effluent pond is emptied (entered value).

6 = year that sludge is stabilised.

***Note**: to be consistent with the use of importing/exporting effluent within greenhouse gas product reporting, this should be calculated on a block basis.*

3.2.5. Solids applied

The emission factor for solids was assumed to be the same as that for dung deposited on pasture.

Therefore, methane emissions (kg methane/year) from solids applied to a block are estimated as:

Equation 16: $MethaneSolids_{antype} = \sum(DungSolid_{antype} * Dungmethane_{antype}$

$Dungsolid_{antype}$ is the dung in solid fraction added to block (kg dung/year).

Dungmethane is the emission factor for dung deposited on paddocks (kg methane/kg dung) [Table 2].

***Note**: to be consistent with the use of importing/exporting effluent within greenhouse gas product reporting, this should be calculated on a block basis.*

3.2.6. Exported effluent

Any emissions after exporting (application of exported material on another farm) are ignored. However, if the effluent is stored prior to export, then the storage losses are included.

3.2.7. Other effluents

The emission factor for other effluents was assumed to be the same as that for dung deposited on pasture.

Therefore, methane emissions (kg methane/year) from solids applied to a block are estimated as:

Equation 17: $MethanePaddock_{antype} = \sum(DungPaddock_{antype} * Dungmethane_{antype}$

$DungPaddock_{antype}$ is the dung applied to block (kg dung/ha/year)

Dungmethane is the emission factor for dung deposited on paddocks (kg methane/kg dung) [Table 2].

***Note**: to be consistent with the use of importing/exporting effluent within greenhouse gas product reporting, this should be calculated on a block basis.*

3.3. Dung deposited on structures

3.3.1. Farm dairy

Methane emissions from dung deposited in the farm dairy is estimated by treating dung as follows:

- sump as ‘direct application’.
- 2-pond as ‘aerobic ponds’. Emissions from applying pond sludge are estimated if pond slurry is added to a block, or exported effluent otherwise.
- holding pond – see section 3.3.2.
- export as ‘exported effluent’.

It is assumed that there is no methane emissions from carbon added as unutilised supplements (from the feed pad or in-shed feeding).

3.3.2. Holding ponds

Methane emissions from dung deposited in a holding pond is estimated by treating dung as follows:

- if effluent is stored in ponds short term (spray and spray + stir options) then treated as ‘direct application’, otherwise treated as ‘anaerobic pond’.
- separated solids as ‘solids stored’.
- separated solids applied to block as ‘solids applied’, otherwise as ‘exported effluent’.
- pond sludge as ‘pond slurry’ if added to a block, or ‘exported effluent’ otherwise. The time of de-sludging is a user input.

3.3.3. Lanes

In the NZI, only effluent dung stored in anaerobic lagoons is separated out (5% of total effluent dung) and a different emission factor applied. As the other common effluent application method is spray, this implies that effluent dung added to lanes has the same emission factor as dung ‘other effluents’.

3.3.4. Standoff or loafing pads

The model assumes that standoff pads are scraped. Methane emissions from dung deposited on standoff pads is estimated by treating:

- dung captured by lining as ‘farm dairy effluent’ (see 3.3.1). It is assumed that this is removed prior to methane emissions occurring.
- dung not captured by lining as ‘other effluents’
- if the pad was scraped regularly:
    - dung not captured by lining (that removed by scraping or that left and incorporated into the standoff pad surface) as ‘other effluents’. It is assumed that methane emissions from dung deposited on a loafing pad is the same as that deposited on lanes.
    - dung not captured by lining and stored as ‘solids stored’
    - dung removed and added to a block as ‘solids applied’, or ‘exported effluent’ otherwise.
- if the pad was not scraped regularly:

- dung not captured by lining as ‘solid stored’ with a 12 month time period. It is assumed that methane emissions from dung deposited on a loafing pad and left long term is similar to that from storing effluent.
- there is no additional loss if scraped dung is stored.
- dung removed and added to a block as ‘solids applied’, or ‘exported effluent’ otherwise.

3.3.5. Wintering pads/animal shelters

Methane emissions from dung deposited on uncovered wintering pads is estimated by treating:

- dung deposited on pad surface, less any removed by lining as ‘solids stored’.
- dung in separated solids and scraped material from concrete feeding apron as ’solids stored’.
- dung from effluent from lining the wintering pad, or separated or flushed liquid from concrete apron is either added to farm dairy or options as for farm dairy are provided.
    - although pond slurry can be added to blocks, as interval cannot be entered it is assumed that this is > 6 years
- dung left on uncovered pads (dung incorporated into surface of pad) as ‘other effluent’. It was assumed that dung left would be similar to that from dung deposited on lanes.
    - If the pad is unlined, it is assumed that there is no dung effluent loss by leaching.

Methane emissions from dung deposited on covered wintering pads/animal shelters is estimated by treating:

- dung deposited in lined bunker as ‘solids stored’ with an average time of half time between cleaning out of bunker.
- separated solids or scraped effluent from unlined bunker as ‘solids stored’ based on solid storage time.
- dung in collected liquid effluent is either added to farm dairy system or options as for farm dairy are provided.
- although pond slurry can be added to blocks, as interval cannot be entered it is assumed that this is > 6 years.

It is assumed that there is no methane emissions from C added to effluent as unutilised supplements. In high supplement feeding regimes with poor supplement, the amount of unutilised supplement C can exceed that from excreta.

3.4. Imported effluents

Methane emission from the application of imported pig slurry is estimated using data from Saggar *et al*. (2004) as 1.071 g methane per kg dung C. The dung C content is estimated by assuming that dung C and nitrogen loadings are similar for slurry, dung C is 10 times N loading for solids, and 5 times for pond slurry material. Losses from storage facilities and the piggery shed remain with the piggery. Note that pig slurry can be added as a farm-link and allocated to blocks, or as a block fertiliser input.

To ensure emissions are additive across farms, dung in imported dairy effluent is assumed to have emissions similar to 'other effluent'. Note that exported effluent have no emissions so in effect, this shifts the emissions associated with applying farm dairy effluent from the farm producing the effluent to the farm receiving the effluent. Dung in dairy effluent can be imported directly from another file and allocated to blocks, or as a block nutrient input under fertilisers. A factor of 8.15 is used to convert N in effluent to dung DM.

Thus, methane emissions (kg methane/ha/year) from imported effluents are estimated as:

Equation 18: $MethaneImport_{block}$ = ImportedPigUntreatedN * 1 * 1.071 + ImportedPigSolidN * 10 * 1.071 + ImportedPigSlurryN * 5 * 1.071 + ImportFertPigUntreatedN * 1 * 1.071 + ImportFertPigSolidN * 10 * 1.071 + ImportFertPigSlurryN * 15 * 1.071 + ImportedDairyDung * $Dungmethane_{dairy}$ + ImportFertDairySolidN * 8.15 * $Dungmethane_{dairy}$ + ImportedFertDairyLiquidN * 8.15 * $Dungmethane_{dairy}$

1.071 is the methane emission for pig sluury (g methane per kg dung C).

Dungmethane is the emission factor for dung deposited on paddocks (kg methane/kg dung) [Table 2].

Note: Imported pig and dairy effluents is currently not used in the model

4. Crop residues

The estimation of methane emissions from burning of crop residues follows the NZI methodology. Although the model allows residues from any crop to be burnt, in practice, most residues burning occur for the main grain crops of wheat, oats, and barley

Residual yield (kg DM/ha) is calculated from yield (kg/ha DM) and harvest index. Harvest index is a crop specific parameter whereas yield is entered by the user.

Residue C (kg C/ha) is then estimated from the C fraction of the residue (Ministry of Environment 2011, Table 4.F). For crops other than barley, wheat, or oats, the average C fraction for these crops was used. Thus:

Equation 19: Residue C = Residue yield * Fresid

Residual yield is the residaul yield of the crop (kg DM/ha).

Fresid is the C fraction of residue and is:

0.4567	barley
0.4853	wheat
0.4567	oats
0.4662	otherwise

The methane emission (kg methane/ha/crop) due to burning crop residues is then estimated as:

Equation 20: CropResiduemethane$_{block}$ = Residue C * 0.9 * 0.005 * 1.333

Residuce C is the carbon content of residue material (kg C/ha) [Equation 19].

0.9 is the fraction oxidised [Ministry of Environment 2011, Table 4.F].

0.005 is the emission ratio for methane [Ministry of Environment 2011, p142].

1.333 is the ratio of molecular weight of C to methane (CH_4)

Burning of crop residues is not considered a net source of CO_2 because the CO_2 released into the atmosphere is reabsorbed during the next growing season (Ministry of Environment 2011, p141).

5. Savannah burning

Methane emissions from burning of savannah (tussock) is included in the NZI (Ministry of Environment 2011, p139). As burning of savannah it is not currently an input for the model, methane emissions from burning savannah are not included.

6. Wetlands and riparian strips

Wilcock and Sorell (2008) noted that

> *"Wetland ecosystems are a major source of CH_4 emissions as a result of the decomposition of organic matter via methanogenesis in anaerobic sediments."*

Anaerobic sediments can also occur in riparian strips, and in stream system itself.

The effect of wetlands (natural and artificial) on reducing N loss is included in the model. Thus methane emissions from wetlands could be included if sufficient information was found after a scientific review. Similarly, the effect of riparian strips on reducing P runoff is included, and thus methane emissions from anaerobic sediments could be included if sufficient information was found after a scientific review. The stream system is outside the scope of this model. If wetlands within riparian strips are included, a clear definition of the boundary between riparian strips and stream system is required.

Currently, methane emissions from anaerobic sediments are currently not included in the model.

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