OVERSEER® Technical Manual

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

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Calculation of nitrous oxide 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 nitrous oxide component of the model described in this chapter include:

David Wheeler, AgResearch Ltd

Frank Kelliher, AgResearch Ltd

Jiafa Luo AgResearch Ltd

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Calculation of nitrous oxide emissions

1. Introduction

1.1. Background

This report documents the methods for calculating nitrous oxide (N_2O) emissions within the OVERSEER® Nutrient Budgets engine (OVERSEER). Nitrous oxide emissions are reported as part of the greenhouse gas emission reports.

This document should be read in conjunction with other reports. In particular, calculation of nitrous oxide emissions are dependent on estimation of animal ME requirements, dry matter intake, fertiliser N applications and effluent management system. The relationship between the main reports and estimation of nitrous oxide emissions, and nitrous oxide emissions and greenhouse gas reporting is shown schematically in Figure 1.

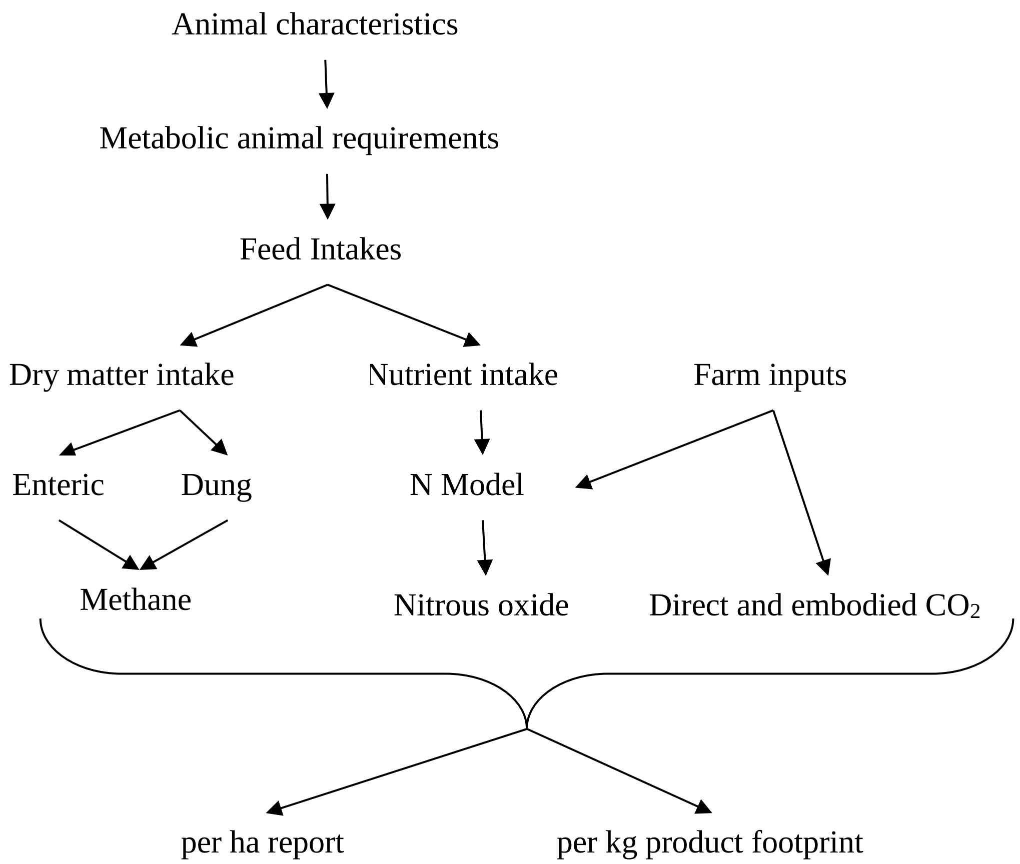

Figure 1. Relationship between main reports within the technical manual and estimation of methane emissions.

The sources of nitrous oxide emissions have been separated into emissions from excreta, N added to soil, and indirect emissions. Indirect emissions are those emissions that occur off-farm but are associated with the farm, i.e., from N leached or volatilised from the farm.

Nitrous oxide (N_2O) emissions are calculated using a <u>farm-specific</u> methodology but following New Zealand greenhouse gas emissions inventory (NZI) (Ministry of the Environment 2016) principles. Generically, nitrous oxide emissions for a range of sources are estimated as a pool size multiplied by an emission factor (EF):

Equation 1. $N2O_{source} = pool_{source} * EF_{source}$

Pool size is always the model calculated pool size using farm-specific data. The variation from the NZI method is indicated in the text.

The reason for differences between NZI and OVERSEER is that the NZI emission factors do not reflect differences between farms due to physical attributes (e.g., effect of climate, soil type, drainage on soil water status) or to the effect of differences in timing of urine deposition. On a farm, animal excreta are not necessarily deposited on the pasture each month because of the use of feed pads of grazing off. As the nitrogen model uses a monthly time step, the emission factor should also be on a monthly basis. Therefore, a farm-specific emission factor based on soil moisture status was developed to estimate the monthly emission factor for urine. Annual emission factors are converted to monthly values using the farm-specific emission factor for urine, such that the sum of emissions over 12 months adds up to the annual emission factor. Emission factors from farms structures and effluent management system are based on a review by Luo and Longhurst (2008).

For crops (fodder crop, tree crops, arable and vegetable crops), fertiliser direct and indirect nitrous oxide emissions are included using the same methodology as for pastoral blocks. Any nitrous oxide emissions from wetlands, riparian blocks, or tree blocks are not included.

Nitrous oxide emissions are split into four broad categories, direct from excreta deposited in paddocks, fertiliser, other farm sources, and indirect emissions. The model estimates nitrous oxide emissions in units of kg N_2O-N. As nitrous oxide emissions feed into the greenhouse gas model, the ability to be able to allocate emissions to different sources is required. Thus, nitrous oxide emissions are calculated for animal types, blocks or the whole farm as appropriate.

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

<u>Abbreviations</u>

DM	Dry matter
EF	emission factor
IPCC	Intergovernmental Panel on Climate Change
NZI	New Zealand greenhouse gas emissions national inventory (Ministry of the Environment 2016)
N_2O	nitrous oxide

<u>Subscripts:</u>

antype	animal types within OVERSEER (dairy, dairy replacements, sheep, beef, deer, dairy goats, other)
block	block set up by the user

2. Nitrous oxide emission factors

The nitrous oxide emission factors are selected in the order:

- farm specific value (default)
- user-defined annual emission factor
- annual NZI emission factor

For the last 2 options, the NZI values are used by default, although the user can specify emission factors.

2.1. Default annual NZI factors

The emission factors used within the NZI are shown in Table 1. N_2O emissions from excreta are currently calculated from an annual N excreta value, although this annual figure is determined by integrating monthly excreta data. Thus these values are, in effect, <u>annual</u> emission factors.

The NZI emission factor is a weighted average across drainage classes. Luo and Longhurst (2008) noted that:

> *"New Zealand currently uses a country-specific EF_{3PRP} value of 0.01, based on Carran et al. (1995), Muller et al., (1995) and de Klein et al. (2003). An assessment of the N_2O emissions measured from dairy cattle urine at 17 field measurement trials, as part of the series of seasonal trials conducted in three locations (Waikato, Canterbury and Otago) over a range of soil drainage classes (well-drained, imperfectly-drained and poorly drained), showed that the geometric mean of EF3 was 0.90% (Kelliher et al., 2005). When disaggregated by soil drainage class and weighted for land area representing each of these drainage classes, the geometric mean was 0.70%. It was concluded that the NzOnet trial data supported the use of the country-specific value of 1% (Kelliher et al., 2005).*

N_2O emissions from excreta are currently calculated from an annual N excreta value, although this annual figure is determined by integrating monthly excreta data. "

Recently, the NZI adopted separate emission factors for dung and urine such that the emission for dung from cattle, sheep and deer were lower than from urine. The large difference between cow and sheep urine as noted by de Klein *et al*. (2004) has not been included.

Table 1. NZI annual emission factors for nitrous oxide.

IPCC name	Description	Value (kg N_2O-N/kg N)[1]
Direct		
EF1	N input to soil	0.01 [2]
EF2	Organic soil mineralisation due to cultivation	8 [3]
$EF3_{Al}$	Waste in anaerobic ponds	0.001
$EF3_{SSD}$	Waste in the solid waste and dry lot animal waste management systems	0.02
$EF3_{P\&P\ Urine}$	Excreta urine and animal waste added to pasture	0.01
$EF3_{P\&P\ Dung}$	Excreta dung	0.0025
$EF3_{OTHER}$	Waste in other animal waste management systems	0.005
Indirect		
EF4	Volatilisation	0.01
EF5	Leaching	0.0075

[1] Source: Ministry of Environment (2016).
[2] Lower emission factor of 0.048 for $EF1_{UREA}$ in Ministry of Environment (2016) has not been implemented.
[3] units are kg N_2O-N/ha/year.

2.2. OVERSEER and user–defined annual emission factors

User defined annual emissions factors can be entered following the same groupings as NZI emission factors. The user defined categories, and the categories used with the program, are broader than the NZI categories as shown in Table 2. OVERSEER uses default NZI emission factor if a user-defined factor has not been supplied.

User-defined emissions factors should be used with caution.

Table 2. OVERSEER emission factor categories for nitrous oxide.

Description	OVERSEER name	NZI default
Direct		
N input to soil	EFN2O1	EF1
N input to soil as effluent or organic material	EFN2O1spray	$EF3_{P\&P}$
Waste in anaerobic ponds	EFN2Opond	$EF3_{Al}$
Waste in the solid waste and dry lot animal waste management systems	EFN2Osolid	$EF3_{SSD}$
Waste in other animal waste management systems	EFN2Oother	$EF3_{OTHER}$
Excreta urine	EFN2OUrine	$EF3_{P\&P}$
Excreta dung	EFN2ODung	$EF3_{P\&P\ Dung}$
InDirect		
Volatilisation from urine	EFN2OIndirectExcrVolat	EF4
Leaching from urine	EFN2OIndirectExcrLeach	EF5
Background volatilisation	EFN2OIndirectBkgdVolat	EF4
Background leaching	EFN2OIndirectBkgdleach	EF5

2.3. Farm specific monthly urine emission factor

A primary driver of nitrous oxide emissions is the soil's aeration status which can be approximated by water-filled pore space (WFPS) (Kelliher *et al*., 2005). WFPS is estimated daily via the hydrology sub-model as:

Equation 2. $WFPS_{day} = SM_{day}/SMmax$

SM_{day} is the daily soil water content to 600 mm depth (mm) [Hydrology chapter].

SMmax is the soil water content at saturation to 600 mm depth(mm) [Charateristics of soils chapter].

The relationship between denitrification, nitrous oxide emissions and WFPS for a given day was based on EcoMod (Johnson *et al*., 2008), with a schematic example is shown in Figure 2.

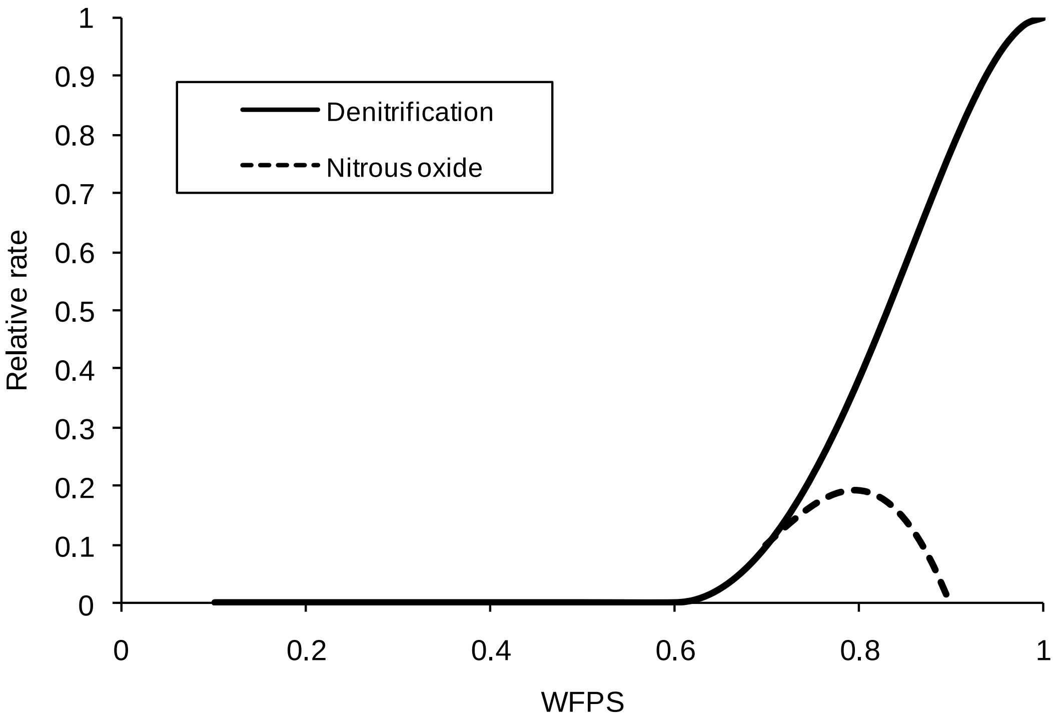

Figure 2. Relationship between water filled pore space (WFPS) and the relative rate of denitrification and nitrous oxide emissions.

To apply this sub-model requires an estimate of the WFPS at which denitrification starts (threshold WFPS). The threshold WFPS is generally greater for coarse-textured than fine-textured soils (Table 3). De Klein and van Logtestijn (1996) proposed that the critical WFPS for many soils is equivalent to field capacity or above. The critical threshold was modelled using a relationship between the threshold values (Table 3) and clay content based on soil texture, with a minimum of 0.83. Using this relationship, the nitrous oxide emissions rate for urine tended to underestimate typical emissions from urine and the timing was not always appropriate (J Luo, pers. comm.). A better estimate was obtained by reducing the critical threshold by 0.2 for volcanic soils, and 0.12 for other soils. This may in part be due to modelling the block scale where parts of the block have soil at different WFPS, whereas many of the thresholds may have been set using a soil at uniform WFPS. Thus threshold WFPS is estimated as:

Equation 3. ThresholdWFPS = (89.922-0.4297 * clay)/100 – soilfactor

clay is top soil clay content (%).

soilfactor	= 0.19	volcanic soils
	= 0.12	otherwise

Monthly urine emission factors are sensitive to the threshold water filled pore space. The drainage model drains water from the profile above field capacity, and soil water contents are typically only above field capacity for a few days. Therefore, nitrous oxide emissions are dependent on the difference between threshold water filled pore space and filled pore space at field capacity. In some soils, particularly heavy textures soils, monthly urine emission factors are very high using Equation 3 as the difference was large. As a temporary measure to reduce the incidence of exceedingly high emission factors, the threshold water filled pore space was limited to a minimum value of 90% of water filled pore space at field capacity.

Table 3. Threshold values of water-filled porosity above which in situ denitrification rates increase (from Barton *et al.*, 1999).

Soil texture	Water-filled porosity (%)	Reference[2]
Sand	>82	de Klein and van Logtestijn (1996)
Sandy loam	Linear	Sexstone *et al*. (1988)
Sandy loam	>74	Barton *et al*. (1999)
Fine sandy loam	>83	Ruz-Jerez *et al*. (1994)
Loam	>70	Bergstrom and Beauchamp (1993)
Loam	>83	de Klein and van Logtestijn (1996)
Loam	>62	Grundman and Rolsten (1987)
Loam	>57	Johnsson *et al*. (1991)
Loam	100% WHC [1]	Nommik and Larsson (1989)
Loam	>62	Ryden (1983)
Loam	>80	Ryden and Lund (1980)
Clay loam	>50	Nelson and Terry (1996)
Clay loam	>74	Estavillo *et al*. (1994)
Clay loam	>70	Jordan (1989)
Clay loam	>60	Sexstone *et al*. (1988)
Silty clay	>70	Jordan (1989)
Clay	100% WHC [1]	Nommik and Larsson (1989)
Peat	>71	de Klein and van Logtestijn (1996)

[1] WHC, water holding capacity.
[2] see Barton *et al*. (1999) for references.

When WFPS is greater than threshold WFPS, then the rate of denitrification from urine is estimated as:

Equation 4. $RateDenit_{day} = SIN(PI / 2 * fdenit^2) * MaxDenitRate * ftemp$

SIN and PI are mathematical functions

fdenit and ftemp are factors [Equation 5 and Equation 6 respectively].

MaxDenitRate = 30

where

Equation 5. $fdenit = (WFPS_{day} - ThresholdWFPS) / (1 - ThresholdWFPS)$

$WFPS_{day}$ is the daily water filled pore space.

ThresholdWFPS is the WFPS at which denitrification starts [Equation 3].

and

Equation 6. $ftemp = ((Temp_{mon} - Tmin) * (Topt-Tmin + (Topt - Temp_{mon}))) / ((Tref-Tmin) * (Topt-Tmin + q*(Topt-Tref)))$

$Temp_{mon}$ is the monthly average temperature (°C).
Tmin is 0 (°C).
Tref is 20 (°C).
Topt is 25 (°C).
q is 1.

The partitioning between nitrous oxide and N_2 assumes that initially all losses are nitrous oxide, and that as the soil wets up there is a linear shift towards N_2 losses until after WFPS is 0.9, after which all losses are N_2. It was assumed that nitrous oxide losses occurred when WFPS was 0.1 greater than threshold WFPS:

Equation 7. N2OonlyWFPS = ThresholdWFPS + 0.1
ThresholdWFPS is the WFPS at which denitrification starts [Equation 3].
MaxDenitWFPS = 0.9.

such that N2OonlyWFPS is less than MaxDenitWFPS. Thus nitrous oxide emissions from urine is estimated as:

Equation 8. $RateN2O_{day} = RateDenit_{day} * fN2O$

fN2O	= 0	if $WFPS_{day}$ > MaxDenitWFPS
	= 1	if $WFPS_{day}$ < N2OonlyWFPS
	= (MaxDenitWFPS - $WFPS_{day}$) / (MaxDenitWFPS – N2OonlyWFPS)	

MaxDenitWFPS = 0.9
$WFPS_{day}$ is the water filled pore space.

The calculations give a maximum denitrification rate of about 600 g/m^2 N in ideal conditions. Hence, the daily emission factor (kg N_2O-N/kg N) is estimated as:

Equation 9.	$EFN2O_{day}$	= 0	$WFPS_{day}$ <= ThresholdWFPS
		= $RateN2O_{day}$ / 600 * 100	otherwise
Equation 10.	$EFDenit_{day}$	= 0	$WFPS_{day}$ <= ThresholdWFPS
		= $RateDenit_{day}$ / 600 * 100	otherwise

Monthly nitrous oxide emission factors where then estimated as:

Equation 11. $EFN2OUrine_{mon} = \sum_{day\ in\ mon}(EFN2O) / DaysInMonth_{mon}$
Equation 12. $EFDenitUrine_{mon} = \sum_{day\ in\ mon}(EFDenit) / DaysInMonth_{mon}$

Example average monthly nitrous oxide emission rates using this approach are shown in Figure 3 to Figure 4. The calculated emission rates are higher when average WFPS and temperature (as set by region) are higher. On pumice soils, emissions are low due to the calculated threshold WFPS being higher than the WFPS at field capacity and fast drainage rates meaning that conditions for nitrous oxide emissions are not attained. As rainfall increases, the period that peak nitrous oxide emissions occur increases (Figure 5).

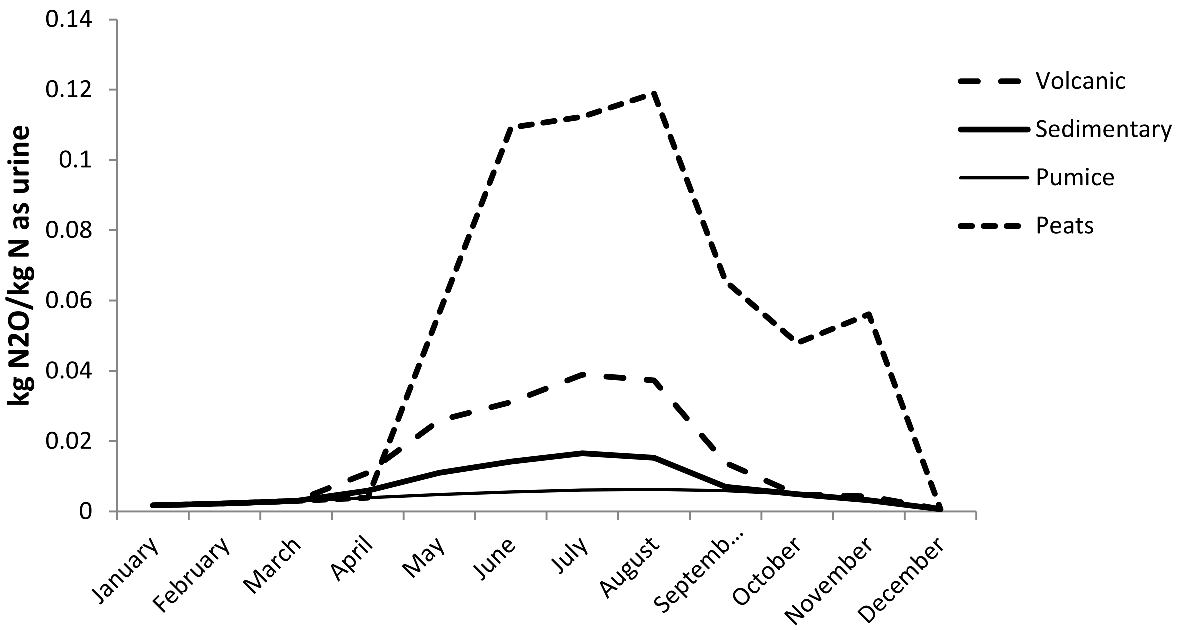

Figure 3. Monthly nitrous oxide emission rate for urine for four soil groups at 1200 mm rainfall in the Waikato Coromandel region.

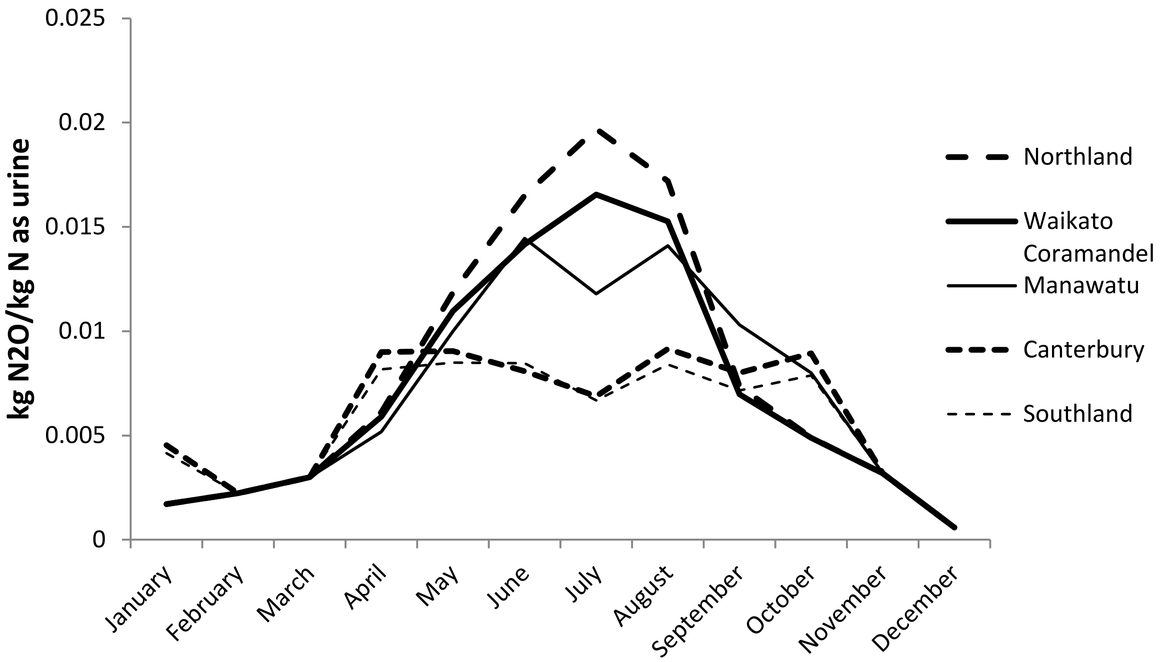

Figure 4. Monthly nitrous oxide emission rate for urine for a sedimentary soil at 1200 mm annual rainfall in five different regions.

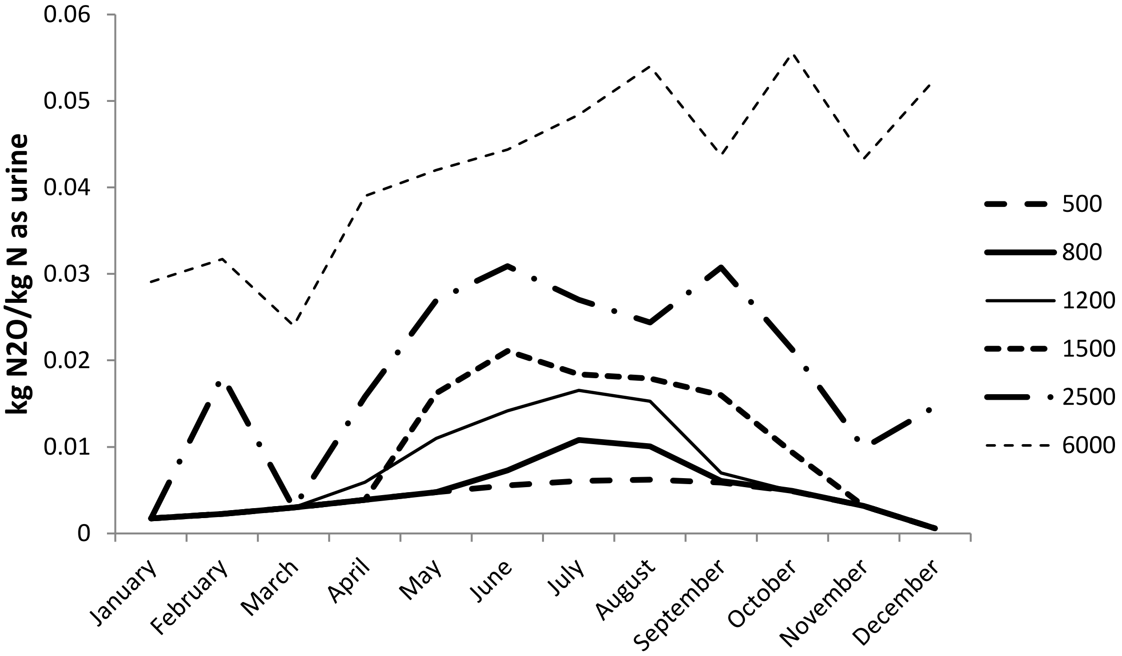

Figure 5. Monthly nitrous oxide emission rate for urine for a sedimentary soil in the Waikato-Coramandel region at six annual rainfalls.

Examples of the impact of changing soil type and rainfall on whole farm emissions for a typical Waikato dairy farm and a Southland farm with mole/tile drained paddocks are shown in Table 4. The soil type difference observed in Figure 3 can also be seen in whole farm emissions for the Waikato farm. Shallow stony brown soils have low AWC and in the conditions used are close to field capacity; hence nitrous oxide emissions are very high.

Table 4. Example of nitrous oxide emissions (expressed as CO_2 equivalents/ha) from different soils at 900mm and 1800mm rainfall.

Soil	900	1800
Waikato dairy farm		
Allophanic	1612	4152
Brown	1715	3994
Peat	4698	17238
Pumice	1157	1420
Southland brown soil with mole/tile drains		
Brown	2962	7777
Brown shallow stony soil	7573	15265
Pallic (pugging = occasional)	2833	6383
Pallic (pugging =winter or rain)	3010	8138

Johnson noted that when applying his model, *"soils with field capacity close to saturation may be susceptible to more denitrification than soils where there is quite a difference between saturation and field capacity."*

The corollary is that sites with low rainfall or soil moisture characteristics such that the threshold WFPS criterion was rarely attained such as for pumice soils or lighter textured soils have low nitrous oxide and denitrification emissions rates. As the NZNI uses the same emission factor irrespective of soil type, it is assumed that there must be some emissions on all soils. This was achieved by assuming a minimum emission rate that was based on 0.4 times the NZI emission factor, distributed monthly using a typical distribution function. The typical distribution was a polynomial based on the assumption that the maximum emission rate was about 0.09% in late winter and a minimum rate of 0.02% in summer. It was assumed that there was no difference in patterns with climate, soil group, or source. The average weighted value is 0.96, which is close enough to 1. The proportion of emission each month is shown in Figure 6 and is estimated as:

Equation 13. $pMinEmiss_{mon} = denit_{mon} / totalMon$

$denit_{mon} = -0.0049658 * mon^3 + 0.059658 * mon^2 - 0.020409 * mon + 0.37657.$

$totalmon = \Sigma(denit_{mon}) / 12.$

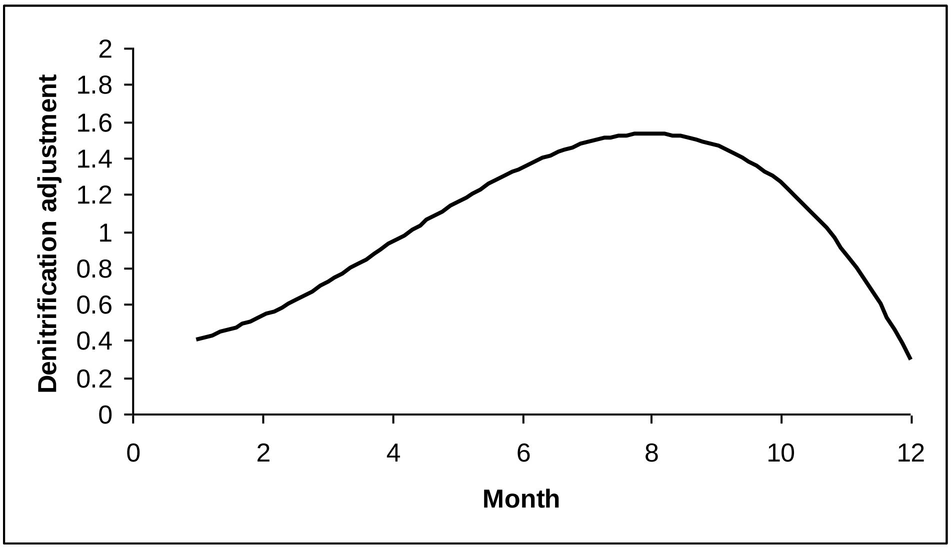

Figure 6. Estimated denitrification rate relative to annual average (adjustment =1) for each month.

The farm-specific monthly emission factor for urine for a given block was estimated as:

Equation 14. $MonEFN2OUrine_{mon} = EFN2OUrine_{mon}$ $MonEFDenit_{mon} >= minrate_{mon}$

Equation 15. $MonEFDenitUrine_{mon} = EFDenitUrine_{mon}$ $MonEFDenit_{mon} >= minrate_{mon}$

$minrate_{mon} = 0.01 * 0.4 * pMinEmiss_{mon}$

2.4. Monthly distribution of annual emission factors

OVERSEER requires user-defined annual emission factor or NZI emission factor to be distributed monthly to capture the effects of management timing. This was based on farm-specific urine emission factor (see section 2.3.). Thus:

Equation 16. $propEFN2O_{mon} = MonEFN2OUrine_{mon} / (\sum_{mon} MonEFN2OUrine_{mon} / 12)$
$MonEFN2OUrine_{mon}$ is the farm-specifc urine emission [see section 2.3].

Thus for a given annual emission factor, the monthly emission factor for a given block is:

Equation 17. $MonEFN2O_{mon} = AnnualEF * propEFDenit_{mon}$
AnnualEF is the default of user entered annual emission factor

2.5. N added to soil emission factor

If it is assumed that the same processes affect nitrous oxide emissions from urine or N added to soil, then the farm-specific emission factor for N added to soil can be estimated on a block basis as:

Equation 18. $MonEF1_{mon} = MonEFN2OUrine_{mon} * factor$
factor = EFN2O1 / modelaverage
modelaverage = 0.01

It is assumed that the average monthly urine emission factor ($MonEFN2OUrine_{mon}$) for the whole country is similar to the NZI value for $EF3_{P\&P}$ of 0.01. Thus if EFN2O1 is 0.01 (the default), factor is 1. To simplify inputs so that farm specific emission factor for N added to soil is the same as emission factor for urine, it is assumed that factor is 1.

If the annual user-defined emission factor is entered, or the default NZI factors are used (farm-specific option not used and no user-defined emission factor entered), the monthly emission factor for N added to soil is estimated as:

Equation 19. $MonEF1_{mon} = EFN2O1 * propEFN2O_{mon}$
EFN2O1 is the annual entered or default emission factor.
$propEFN2O_{mon}$ [see section 2.4].

The annual average value is estimated on a block basis as:

Equation 20. $AverageEF1 = \sum MonEFN2OUrine_{mon} / 12$

3. Excreta deposited in paddocks

OVERSEER estimates the amount of urine and dung deposited on a block each month for each animal type. Similar to the NZI, excreta N for each animal type is estimated as N intake less that removed in product. Excreta N for each animal type is then separated to dung and urine based on dietary N content. Excreta deposited on structures such as feed pads is removed, and the remaining dung and urine for each animal type is then distributed to blocks. The distribution to blocks is done so that block-specific sub- models for leaching, atmospheric losses, DCD and emission factors can be applied.

If farm-specific emission factors are used (the default), the monthly emission factor for urine (see section 2.3) is used. Otherwise, the monthly emission is user-defined or NZI annual emission factor (see section 2.2) distributed monthly (see section 2.4). Note that emission factor applies to total excreta deposited on pasture - volatilisation is not removed first.

Direct nitrous oxide emissions (kg N_2O-N/ha/month) from excreta urine for each month, block and each animal type is based on the NZI method (Ministry of Environment 2016) and is estimated as:

Equation 21. $urineemission = urineN * MonEFN2OUrine_{block,\ mon}$

urineN is the urine N added to pasture (kg N/ha/mon) for each animal type.

MonEFN2OUrine is the emission factor for urine (kg N_2O-N /kg N as urine).

and excreta dung (kg N_2O-N/ha/month) as:

Equation 22. $dungemission = dungN * EFN2ODung_{block,\ mon}$

dungN is the dung N added to pasture (kg N/ha/mon) for each animal type.

EFN2ODung is the emission factor for dung (kg N_2O-N/kg N as dung).

If DCD is applied, the reduction in nitrous oxide emissions for excreta due to DCD is estimated for each block for each month. The amount of N saved (kg N_2O-N/ha/month) is estimated as:

Equation 23. $urinesaved = urineemission * RDCDN2O_{block,\ mon} /100$

Total direct excreta nitrous oxide emissions for each animal type (kg N_2O-N/year) is estimated as:

Equation 24. $N2OExcreta_{antype} = \sum_{block}(Netemission_{antype,\ block} * area_{block})$

$$Netemission_{antype,\ block} = \sum_{mon}((urineemission_{ntype,\ block,\ mon} - urinesaved_{ntype,\ block,.\ mon}) + dungemission_{ntype,\ bloc,\ mon})$$

4. N added to soil

Nitrous oxide emission from N added to soil is calculated for each block.

4.1. Synthetic N fertiliser

Direct fertiliser nitrous oxide emissions (kg N_2O-N/ha/month) are estimated for each month on each block using a method based on the NZI method (Ministry of Environment 2016). Emissions from N added in organic materials (composts, imported effluents) are dealt with separately. NZI removes volatilisation and denitrification from fertiliser before applying the emission factor (Ministry of Environment 2016). Volatilisation is calculated for each N type, but to simplify calculations, it is assumed that all volatilisation is removed from the ammonium component of the material. The modelled rate of denitrification is based on the background N sub-model, which includes N inputs from all sources. Hence, it is difficult to ascribe denitrification to a specific product and so is ignored.

The monthly-apportioned emission factor for N added to soil see 2.5) is used. The emission factor was considered higher for nitrate fertilisers, with size of the increase based on scientific opinion (J Luo, pers. comm.). It is assumed the emission factor is the same for incorporated fertiliser.

Thus direct fertiliser N_2O emissions (kg N_2O-N/ha/month) are estimated as:

Equation 25. $FertEmissions_{mon} = (FertN - Fertvolat) * MonEF1_{mon} + FertN0_3 * MonEF1_{mon} * 1.5 + FertMix * MonEF1_{mon} * 1.2$

FertN is the other fertiliser N added as urea and NH_4 form (kg N/ha/month).
Fertvolat is the total volatilisation from all N fertiliser.
$FertN0_3$ is the fertiliser N added as nitrate (kg N/ha/month).
FertMix is the fertiliser N added as nitrate/NH_4 mix (kg N/ha/month).
$MonEF1_{mon}$ is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

If DCD is applied, the reduction in nitrous oxide emissions for fertiliser due to DCD is estimated for each block for each month. The amount of N saved (kg N as N_2O/ha/month) is then estimated as:

Equation 26. $NFertSaved_{mon} = FertEmissions_{mon} * RDCDN2O_{mon} / 100$

RDCDN2O is the reduction in nitrous oxide emission for fertiliser due to DCD

Total direct fertiliser nitrous oxide emissions for each block (kg N_2O-N/ha/year) are estimated as:

Equation 27. $NFertN2O_{block} = \sum_{mon}(FertEmissions_{mon} - NFertSaved_{mon})$

4.2. Crop residues

If crop residues are retained, the NZI estimates the amount of N retained in residues as twice the product yield (seed yield of pulses and soybeans or annual crop production) using a Tier 1 approach. Thus, the NZI assumes that half the total biomass is harvested as grain. OVERSEER includes crops with a wide range of harvest index, and using the NZI methodology would not be appropriate for farm-specific emissions.

Roots are not explicitly included in this calculation of residues in the NZI although it would make sense to include them. The root N fraction is probably well within the error you would expect in the total biomass or residue calculation. As total residue and root N is estimated, and as the residue to root ratio varies between crops, both have been include in the estimation of residual calculations.

Thus, residual yield (kg DM/ha) and root N is calculated from yield and crop parameters if farm-specific emission are used or estimated based on

The NZI estimates residue N that is burnt from product yield, residue to crop ratio and dry matter fraction of residue and N:C ratio for barley, wheat, and oats (Ministry of Environment 2016). Residue N from product yield, harvest index, and typical N concentrations in residues for any residue that the user selects as burnt. This approach is similar to that used in the NZI, but covers a wider range of crops, and includes crops where the yield may be distributed in more than one way. Thus, calculated residue N is used.

N from residues can be released over several months and hence applying a monthly value has limited value. Therefore, annual average value is used.

The crop N sub-model covers multiple years. Nitrous oxide emissions are only included for events that occur in the current year.

4.2.1. Roots

When roots are added to the soil (cultivation, end of crop), including those from cultivation of pasture, nitrous oxide emissions (kg N_2O-N/ha/ year) are estimated as:

Equation 28. $\text{RootN2O}_{block} = \text{Root N} * \text{AverageEF1}$

Residue N is the calculated residue N (kg N/ha/year).

AverageEF1 is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

4.2.2. Retained residues

If residues are retained, nitrous oxide emissions (kg N_2O-N/ha/year) are estimated as:

Equation 29. $\text{ResidueN2O}_{block} = \text{Residue N} * \text{AverageEF1}$

Residue N is the calculated residue N (kg N/ha/year).

AverageEF1 is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

4.2.3. Burnt residues

It is assumed that the nitrous oxide emissions from burnt residues is independent of soil conditions and hence is constant for the year. In contrast, it is assumed that residue N not oxidised is added to the soil and hence the monthly-apportioned emission factor for N added to soil (see 2.5) is used. Thus, nitrous oxide emissions from burning residues (kg N_2O-N/ha/year) are estimated as:

Equation 30. $$\text{ResidueN2O}_{block} = \text{Residual N} * \text{foxidised} * 0.007 + \text{Residual N} * (1 - \text{foxided}) * \text{MonEF1}_{mon}$$

Residue N is the calculated residue N (kg N/ha/year).

foxidised is the fraction oxidised, set at 0.9 [Ministry of Environment 2016].

0.007 is the emission ratio for N_2O [Ministry of Environment 2016].

MonEF1_{mon} is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

4.3. Savannah burning

Although methane emissions from burning of savannah (tussock) is included in the NZI (Ministry of Environment 2016), burning of savannah it is not an input in OVERSEER.

4.4. Farm effluent

The NZI calculation includes all manure that is spread on agricultural soils, irrespective of the animal waste management system it was initially stored in.

The same approach has been used, and is applied to both liquid and solid effluent applied. The monthly-apportioned emission factor for N added to soil (see 2.5) is used.

The estimate of effluent applied to a block already has N volatilised or denitrification removed in the effluent management sub-model. This is similar to the NZI, where the emission factor is applied to the rate of effluent applied net of volatilisation.

The inorganic portion of effluent applied is assumed to behave similar to that of synthetic N fertiliser, whereas the solid portion is expected to behave more like a residue material.

Thus for each block, total direct nitrous oxide emissions from added effluent (kg N_2O-N/ha/year) are estimated as:

Equation 31. $$EffluentEmissions_{block} = \sum(InorgN * MonEF1_{mon}) + \sum((EffluentN - InorgN) * averageEF1)$$

EffluentN is the effluent N applied (kg N/ha/mon).
InorgN is the rate of inorganic N in effluent (kg N/ha/mon).
$MonEF1_{mon}$ is the emission factor (kg N_2O-N/kg N added) [see section 2.5].
AverageEF1 is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

4.5. Imported effluent

Imported dairy effluent can be either piggery or imported dairy effluent from another farm, and either solids or liquids are applied. Applying imported effluent dairy effluent is assumed to have a similar rate of nitrous oxide emissions as applying farm effluent.

Total direct nitrous oxide emissions from added organic fertiliser for each block (kg N_2O-N/ha/year) are estimated as:

Equation 32. $$ImportEffEmission_{block} = \sum(InorgN * MonEF1_{mon}) + \sum((ImportEfftN - InorgN) * averageEF1)$$

ImportEfftN is the imported effluent N applied (kg N/ha/mon).
InorgN is the rate of inorganic N in imported effluent (kg N/ha/mon).
$MonEF1_{mon}$ is the emission factor (kg N_2O-N/kg N added) [see section 2.5].
AverageEF1 is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

4.6. Pasture and supplement residues

Pasture residues are from unutilised pasture (10-15% of that grown). The NZI assumes no N_2O emissions although Kelliher (pers. comm.) indicated that in work he is doing the rate was closer to 0.013 kg NO_2-N/kg N that the 0.01 kg NO_2-N/kg N used in the NZI for N added to soil. In addition, there is a steady turnover in roots that add residues to the soil. Neither has been included.

Unutilised portion of supplements feed in the field also have no N_2O emissions in the NZI and has not be been included.

4.7. Organic fertiliser

Within NZI, N applied to land, including that from fertiliser, effluent and crop residues have an emission factor EF1. Organic fertiliser includes dairy factory effluent, imported dairy effluent or piggery effluent, and composts and other organic material. Applying organic fertiliser is assumed to have a similar rate of nitrous oxide emissions as applying farm effluent.

Total direct nitrous oxide emissions from added organic fertiliser for each block (kg N_2O-N/ha/year) are estimated as:

Equation 33. $OrgFertEmission_{block} = \sum(InorgN * MonEF1_{mon}) + \sum((orgFertN - InorgN) * averageEF1)$

orgFertN is the organic fertiliser N applied (kg N/ha/mon).
InorgN is the rate of inorganic N in organic fertiliser (kg N/ha/mon).
$MonEF1_{mon}$ is the emission factor (kg N_2O-N/kg N added) [see section 2.5].
AverageEF1 is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

4.8. N fixation

Crops that include biological N fixation include peas, lentils, beans, lupins, white clover seed crops, and pasture. NZI accounts for N_2O from biological N fixation for peas and lentils. It is assumed that N_2O emissions from biological N fixation by beans and lupins should be estimated using the same method as for peas and lentils.

N_2O emissions from N fixation by clover in pasture occur when the excreta is produced (Luo pers. com.). DeKlein reported data that indicated that emissions occurred but these were lower under clover than when fertiliser was used. There may be a small loss associated with inefficient cycling of fixed N within a pasture system but it seems to have been ignored.

On cut and carry and high supplement removal blocks, most supplements exported are used for animal feed (and hence included in excreta of receiving farm) or animal bedding (factored into emissions from feed pads) and thus the N fixation component can be ignored.

The difficult crop is a white clover seed crop, where some of the crop is grazed. Given that most of the herbage is probably consumed by grazing animals, N_2O emissions from N fixation for this white clover seed crop is also ignored.

As there is a time lag between when N is fixed and the release of N to the soil, and the release of N can occur over a period of time, the average emission factor is used. Thus, for the crops peas, lentils, beans, and lupins, N_2O emissions due to N fixation (kg N_2O-N/ha/year) are estimated as:

Equation 34. $NfixN2O_{block} := Nfix_{block} * AverageEF1$

Nfix is the calculated rate of N fixation (kg N/ha/year).
AverageEF1 is the emission factor (kg N_2O-N/kg N added) [see section 2.5].

5. Effluent management and farm structures

As N is deposited on farm structures and moves through the effluent management system, gaseous N emissions, including nitrous oxide, result in reducing N available for the next process. Hence nitrous oxide emissions are calculated as part of the effluent management system. The main sources are feed pads, wintering pads/animal shelters, ponds, and stored material. Details of the methods used are given in the effluent management document (in preparation).

Nitrous oxide emissions from effluent management and farm structures are estimated for each animal type and source, that is:

Equation 35. $N2OEffStrut_{antyepe} = N2Oeffluent_{antyepe,\ source} + N2Ostructure_{antype,\ source}$

6. Wetlands and riparian strips

Wilcock and Sorell (2008) in a study of greenhouse gas emissions on 3 streams in the Waikato, reported that all 3 streams were a net source of nitrous oxide emissions. In their abstract they said

> *"Although small on a catchment scale compared to emissions from intensively grazed pastures, they were significant relative to low-intensity pastures and other agricultural land uses. Because hydraulic variables (viz. depth, velocity and slope) strongly influence turbulent diffusion, complete denitrification can best proceed to N_2 as the dominant end-product (rather than N_2O) in riparian wetlands, rather than in open stream channels where N_2O fluxes are sometimes very large."*

In contrast, United States Environmental Protection Agency (2010) reported that

> *"The available research indicates that wetlands are a negligible source of N_2O. There is some evidence that they may be a small sink (i.e., removing N_2O from the atmosphere) but no global estimates have been made"*

Nitrous oxide emissions from wetlands are not estimated in OVERSEER. However if wetlands are entered, N removed primarily by denitrification is shown.

Nitrous oxide emissions from streams are not estimated as they are not included within the farm boundary. Note that indirect nitrous oxide emissions would include nitrous oxide emissions from streams for N sourced from the farm.

7. Cultivation of organic soils

The emission factor due to cultivation of histosols of 8 kg N_2O-N/ha/year as reported in the NZI (Ministry of Environment 2016) is the IPCC default value.

The NZI defines histosol as organic soils as an as well as a soil containing an horizon with more than 17 per cent organic matter content (includes slightly peaty, peaty and peat soils of 17 – 30, 30 – 50 and > 50 per cent organic matter content), and that 0.1 m of this horizon occurs within 0.3 m of the surface. These extra soils are included because expert opinion is that cultivation of these soils would result in similar nitrous oxide emissions to the cultivation of organic soils.

The user can enter carbon level directly, or can identify soil order or soil group, and select top soil texture. Given that 17% organic matter is equivalent to about 9.88% C, the soils that meet this definition are those with an entered carbon greater or equal to 9.88%, organic soil order or peat soil group. In addition, as the top soil texture is for the top 10 cm, then top soil textures that have a default carbon > 9.88% are also included. These are the Loamy peat, Peat, Peaty loam, Peaty sandy loam, Peaty silt loam and Silty peat top soil textures, but not the Peaty sand (average carbon of 9.1).

The cultivation leading to this source of nitrous oxide emissions only occurs on crop and fodder crop blocks, and when pasture is cultivated in the year of assessment. It is assumed that there is no additional emissions if more one than one crop is grown with a year, and no emissions for a crop-to-crop rotation between years. In addition, it was assumed that cultivation method (conventional, minimum till, roundup + direct drill) has no effect on the emission factor, that time of cultivation has no effect, and that other emissions such as direct emissions from fertiliser still apply.

Thus, emissions due to cultivation of organic soils (kg N_2O-N/ha/year) are estimated as:

Equation 36. $\text{N2OCroporganic}_{\text{block}} = 8$

8. Indirect emissions

Indirect emissions are those emissions that occur off-farm but are from N leached or N volatilised from the farm.

OVERSEER estimates N leaching and volatilisation from urine, and from N fertiliser and other sources (background) separately. Background N leaching loss is estimated monthly from soil N content, which is dependent on all inputs except urine, and site-specific parameters. Thus, background N leaching is dependent on fertiliser inputs as well as input sources such as dung, organic material, rainfall, irrigation, and N fixation.

Background N volatilisation is from fertiliser and is dependent on the source of the material and conditions at the time of application.

DCD has no direct effect on indirect N_2O emissions but can reduce these emissions due to reduced N leaching. Other N leaching mitigation options would have the same effect.

As these emissions occur outside the farm boundary and the relationship between time of loss from the farm and the rate of emissions off-farm is unknown, then annual emission factors are used. Thus, indirect emissions are estimated on a block basis (kg N_2O-N/ha/year) as:

Equation 37.
$$\begin{aligned}\text{N2OInDirect}_{\text{block}} = {} & \text{urinevolat}_{\text{block}} * \text{EFN2OIndirectExcrVolat} \\ & + \text{urineleach}_{\text{block}} * \text{EFN2OIndirectExcrLeach} \\ & + \text{fertvolat}_{\text{block}} * \text{EFN2OIndirectBkgdVolat} \\ & + \text{othervolat}_{\text{block}} * \text{EFN2OIndirectBkgdVolat}\end{aligned}$$

+ $otherleach_{block}$ * EFN2OIndirectBkgdLeach

urinevolat is the total volatilisation from urine (kg N/ha/year).

urineleach is the total leaching from urine (kg N/ha/year).

fertvolat is the total fertiliser N volatilisation (kg N/ha/year).

othervolat is the total volatilisation from background N sub-model (kg N/ha/year).

otherleach is the total leaching from background N sub-model (kg N/ha/year).

EFN2O variables are emission factors [see section 2.2].

In addition, indirect nitrous oxide emissions from direct losses to the streams such as through drains, discharge from a 2-pond system and direct deposition in streams and leaching or volatilisation from farm structures are estimated at a farm level (kg N_2O-N/year) as:

Equation 38. $N2OInDirect_{farm}$= directtostream * EFN2OIndirectBkgdLeach

Directtostream is the N discharged direct to stream from drains or 2-pond system.

EFN2OIndirectBkgdLeach is the emission factors [see section 2.2].

Equation 39. $N2OInDirect_{antype}$= IndirectVolat * EFN2OIndirectBkgdVolat + IndirecLleach * EFN2OIndirectBkgdleach

IndirectVolat = $\sum_{antype} NVolat_{antype, source}$

IndirecLleach = $\sum_{antype} Nleach_{antype, source}$

NVolat is the volatilistation losses from pads, races, storage sytems, etc. (kg N/ha/year) [lossoff, Effluent management chapter].

Nleach is the leaching loss from pads, races, storage sytems, etc. (kg N/ha/year) [[lossoff, Effluent management chapter].

EFN2O variables are emission factors [see section 2.2].

9. NOx emissions

NOx emissions from burning crop residues are currently ignored. The indirect effects on global warming of a number of gases, including NOx, cannot currently be quantified and consequently, these gases do not have global warming potentials (Ministry of Environment 2016) and are not included in emissions totals.

10. References

Barton L, McLay C D A, Schipper L A, and Smith C T 1999 Annual denitrification rates in agricultural and forest soils: a review Australian Journal Soil Research 37: 1073-93.

de Klein C A M, Li Z, and Sherlock R R 2004. Determination of the N2O emission factors from animal excreta or urea fertiliser, following a winter application in two regions of New Zealand. A final report of an NzOnet study from August 2003 to June 2004. Report prepared for the Ministry of Agriculture and Forestry, New Zealand.

de Klein C A and Van Logtestijn R S 1996 Denitrification in grassland soils in The Netherlands in relation to irrigation, N-application rate, soil water content and soil temperature. Soil Biology and Biochemistry 28: 231-237.

Johnson I R, Chapman D F, Snow V O, Eckard R J, Parsons A J, Lambert M G, and Cullen B R 2008. DairyMod and EcoMod: biophysical pasture simulation models for Australia and New Zealand. Australian Journal of Experimental Agriculture 48: 621–631.

Kelliher F M, Scotter D R, Li Z, and de Klein C A M 2005 Water filled pore space and the direct nitrous oxide emission factor for excreta deposited by grazing animals onto pastoral soils. Reported prepared for the Ministry of Agriculture and Forestry.

Luo J and Longhurst B 2008. Improved livestock management systems and nutrient losses from manure deposition and treatment - A support document for Overseer nutrient budget model. AgResearch Internal Publication.

Ministry of the Environment 2016. New Zealand's greenhouse gas inventory 1990 – 2014. Ministry of the Environment, Wellington, New Zealand.

United States Environmental Protection Agency 2010. Methane and Nitrous Oxide Emissions From Natural Sources. http://www.epa.gov/outreach/pdfs/Methane-and-Nitrous-Oxide-Emissions-From-Natural-Sources.pdf

Wilcock R J and Sorrell B K 2008. Emissions of Greenhouse Gases CH_4 and N_2O from Low-gradient Streams in Agriculturally Developed Catchments. Water Air Soil Pollution 188: 155–170.