OVERSEER® Technical Manual

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

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Urine patch sub-model

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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 urine patch component of the model described in this chapter include:

Mark Shepherd, AgResearch Ltd

David Wheeler, AgResearch Ltd

Rogerio Cichota, AgResearch Ltd

Val Snow, AgResearch Ltd

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Urine patch sub-model

1. Introduction

1.1. Background

OVERSEER calculates nitrogen intake for an animal enterprise by first calculating the energy requirements for the enterprise using a standard metabolic model (Metabolic energy requirements of animals chapter). This is then converted to dry matter (DM) intake based on the feed sources fed to the animals and default values for their metabolisable energy (ME) contents. Based on these DM intakes and default values for N content of the feed sources, N intake is calculated. This is then partitioned between animal products (based on user-provided production data) and excreta.

Excreta is then partitioned between urine and dung which is then deposition onto blocks or included in the effluent management systems where excreta may be returned to blocks as effluent. Thus the amount of dung and urine deposited on a block by each animal enterprise each month is estimated.

OVERSEER splits N losses between background (inter-urine) and urine patch sub-models. Splitting N losses between a between background and urine patches is a common approach when modelling grazing systems (Hutchings *et al*., 2007; Snow *et al*., 2009).

Much of the N leaching in grazed pasture is driven by the urine patch (Monaghan *et al*., 2007; Selbie *et al*., 2015). Typically, modelling urine N losses from urine patches requires an estimate of the area of a paddock affected by urine patches each year. Although, there are published data on urine patch dynamics (Haynes & Williams, 1993; Moir *et al*., 2010; Selbie *et al*., 2015), the variation is large and is determined by a number of factors. Urinary N concentration and the N load per urine patch also varies: between animal species, between animals in the same herd, between days and between times in the day (Betteridge *et al*., 1986; Fillery, 2001; Kume *et al*., 2008; Hoogendorn *et al*., 2010; Selbie *et al*., 2015).

An alternative approach is to estimate the proportion of the N deposited (expressed as an average load of N per ha) that is leached, and this was the approach that was taken (section 2).

The relationship of the urine patch sub-model with other sub-models is shown in Figure 1.

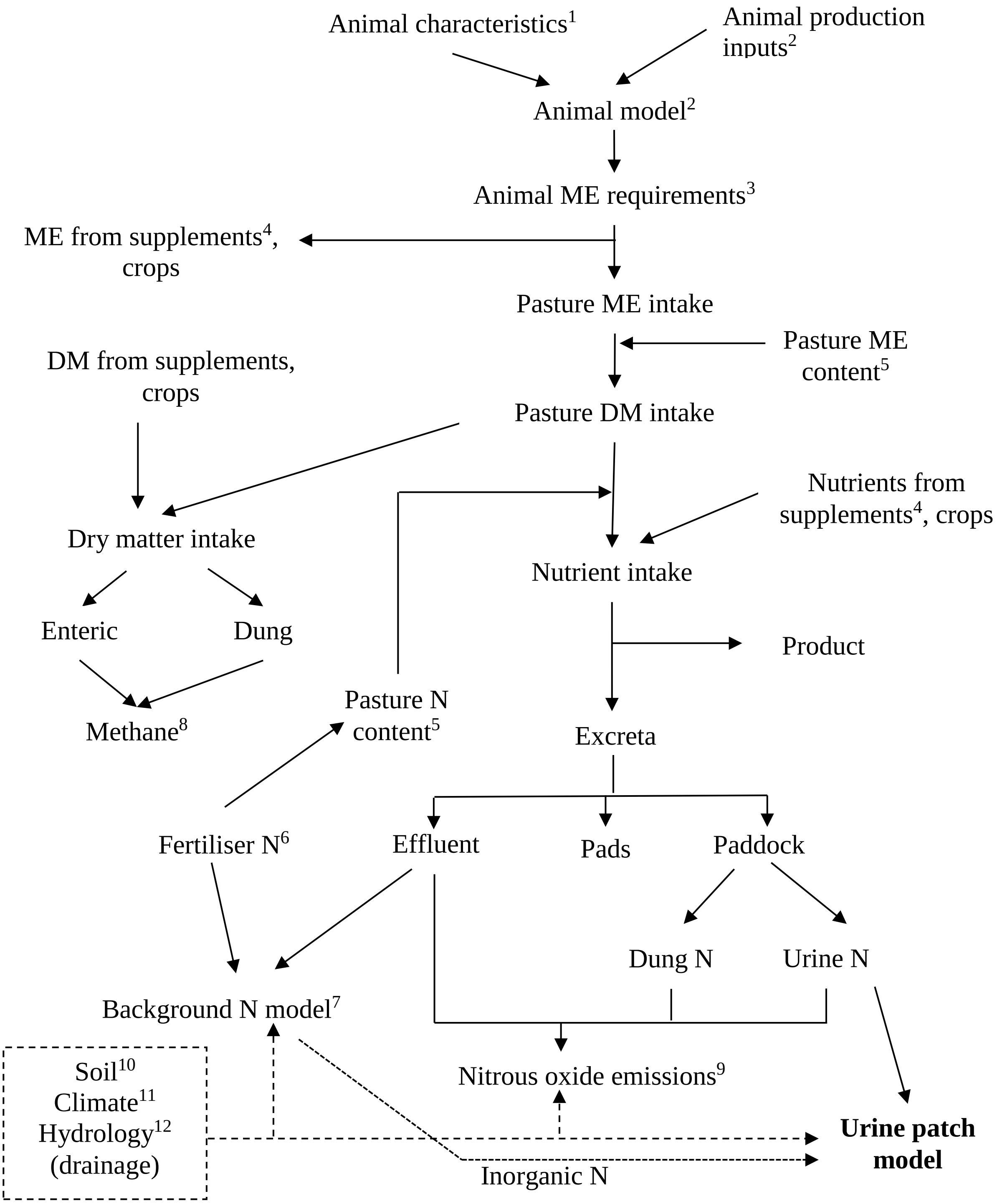

Figure 1. Relationships between sub-models and the urine patch model (shown in bold) for N, with relevant Technical Manual chapters indicated by superscripts (^{1} = Animal characteristics, ^{2} = Animal model, ^{3} = Metabolic energy requirements of animals, ^{4} = Supplements, ^{5} = Characteristics of pasture, ^{6} = Fertilisers, ^{7} = Crop N sub-models, ^{8} = Methane emissions, ^{9} = nitrous oxide emissions), ^{10} = Properties of soils, ^{11} Climate, ^{12} = Hydrology.

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 chemical symbols

Abbreviations

DM	Dry matter
PV	Pore volume
PAW	Profile available water

Chemical symbols

N, P, K, S, Ca, Mg, and Na refer to the nutrients nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, and sodium respectively. Acidity refers to the change in acidity.

2. Basis of the urine patch N sub-model

2.1. Background

OVERSEER estimates the load of excreta dung and urine N deposited on a block each month on a per ha basis. If the proportion of N deposited that is leached can be estimated, then the amount of N leached can be estimated, that is:

Equation 1: Nleach = Nload * propNleached

The proportion of urine N that is leached each month is required, as the amount of N deposited varies each month, and to allow mitigation options such as using wintering barns or grazing off to be captured.

Shepherd *et al*. (2011) measured the effect of different times of urine N application on N in drainage water in lysimeters. When the N in drainage water was plotted against cumulative drainage, it showed that there was little difference in the shape of the curves between application times, and that the appearance of N can happen in subsequent years. The shape of these curves were consistent with classical breakthrough curves that are observed when diffusion occurs. Snow *et al*. (2011), based on modelled results, and Shepherd *et al*. (2011) reported that the time of N deposition that resulted in greatest loss in drainage (critical timing) was late summer early autumn in the Waikato. Thus there is a lag between when urine is deposited and its appearance in drainage water below the root zone (usually mid to late winter).

A breakthrough curve defines the relationship between cumulative drainage (pore volumes) and the proportion of solute that passes a particular point in the leaching column. Breakthrough curves can be related to physical measurements in the field, and hence provide methods to validate them in future. Countering the movement of N down the profile is the removal of N from the patch due to processes such as volatilisation, denitrification and plant uptake. The combination of the two factors (movement and removal) gives the proportion of N that leaches each month, and hence critical months for urine N applications.

2.2. Standard urine patch

Urine patch volume, size, shape and loading are highly variable as noted in section 1.1. On a given farm, the extent of the variability is not known. The urine patch N sub-model is required to be farm-specific, cover all of New Zealand, and cover the wide range of management options within OVERSEER. A method to integrate the variability of urine patch characteristics, and to reflect the effect of time of urine N deposition on the proportion of N leached was also required. Hence the approach was to develop a standard urine patch N sub-model, whereby key processes are modelled using key drivers.

Most of the field trials where N leaching has been measured were predominately grazed by dairy animals (Watkins *et al*., 2014), and lysimeter trials mainly used urine N deposition rates that were within the range expected from lactating dairy cows. Therefore the standard urine patch was based on a typical dairy cow urine patch. The output was extrapolated to other animal enterprises (section 4.2).

2.3. Breakthrough curves

2.3.1. Methodology

APSIM, a detailed process-based model (Keating *et al*., 2003), was used to identify key factors that drive N leaching from the estimated monthly urine deposition. To do this, thousands of simulations were run for combinations of soils and climates across New Zealand (Cichota *et al*., 2012). Nitrogen was applied in different months at a rate of 750 kg N/ha using a profile depth of 75 cm, and simulations run for three years to capture the full amount of the N that was leached from the applied N. These factors could be summarised as those that affected the amount of drainage at a site (mainly soil-type, rainfall amount and distribution), and those that affected rate of N removal from the urine patch (time of N application, growing conditions). It was determined that the major soil property that affected leaching was the profile available water capacity. This approach therefore firstly allowed the identification of key factors that needed to capture to adequately describe the movement of N through the soil profile.

Based on the multiple APSIM simulations across a wide range of conditions, a transfer function (TF) or ‘breakthrough curve’ was identified, which defines the relationship between cumulative N leached (relative to the maximum amount of leachable urine N for that system) and cumulative soil water drainage expressed as pore volumes (PV) drained. Here, PV is based on the soil’s profile available water rather than its total water-holding capacity value.

However, implicit in the TF is that all pore volumes of drainage are equal. We know that this is not always the case because of bypass flow on some soils, and those that are mole/tile drained.

2.3.2. Breakthrough curve shape

2.3.2.1. *Curve shape*

Breakthrough curves are typically smooth sigmoid functions. Examination of the TFs generated by APSIM (Cichota *et al.*, 2012) and from experimental data suggested that, in most cases, these curves could be estimated using four straight lines (Figure 2). The curve can be defined by four points: the origin, the pore volume at which N starts to appear in drainage water (NPV_1); the pore volume at which all N from the urine patch is leached (NPV_3); and a mid-point (NPV_2, rNL_2) which describes the degree of curvilinearity. Relationships have been developed between annual precipitation and soil properties to describe the values of NPV_1 to NPV_3 (section 2.3.2.2).

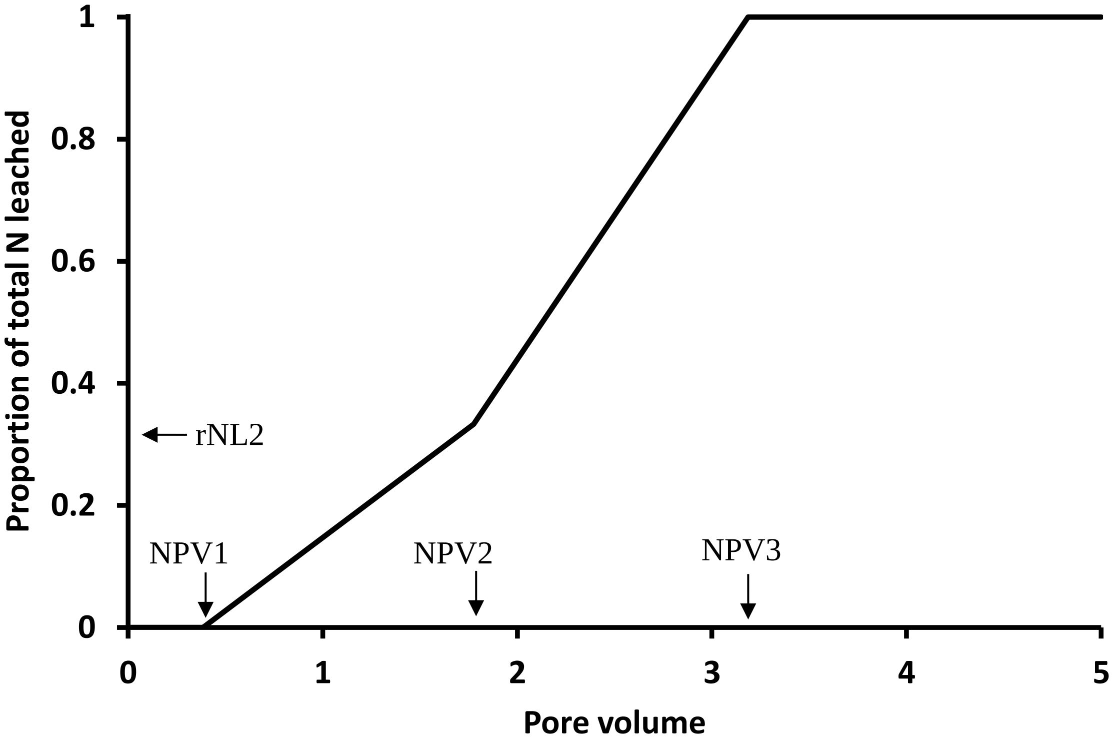

Figure 2. Shape of modelled breakthrough curve.

2.3.2.2. *Estimating curve parameters*

The parameters for estimating the breakthrough curve parameters are based on Cichota *et al.*, (2012). NPV_1 is estimated as:

Equation 2: $NPV_1 = Ao1 + \exp(a1rain + b1rain /rain)$
$+ 1 / (a1fracPaw + b1FracPAW * FractionPAW)$

Ao1, a1rain, b1rain, a1fracPaw and b1FracPAW are constants [Table 1].

rain is annual rainfall (mm/year) [Climate chapter].

FractionPAW is fraction of profile available water that has water present [Equation 2].

with a minimum value of 0.02. The fraction of PAW is estimated as:

Equation 3: FractionPAW = (SM600 – SMwilt600) / PAW600

SM600 is the soil water content to 600mm depth (mm) for the month urine is deposited [Hydrology chapter].

SMwilt600 is the soil water content to 600mm depth at wilting point (mm) [Hydrology chapter].

PAW600 is the profile available water to 600mm depth (mm) [Hydrology chapter].

Table 1. Constants for estimating NPV1, NPV2 and NPV3 (from Cichota *et al*., 2012)

Constant	Value
Estimating NPV1	
Ao1	0.0662649949
a1fracPaw	27.81002974
b1FracPAW	-25.26255652
a1rain	-0.772070139
b1rain	-1464.036794
Estimating NPV2	
Ao2	0.06177702
b2	0.5380788
Estimating NPV3	
Ao3	3.85111
b3rain	0.003552
b3PAW	-0.013112
b3temp	-0.107572

NPV_3, the pore volume when all solute is eluted, is estimated as:

Equation 4: NPV_3 = Ao3 + b3rain * rainsix + b3PAW * PAW750 + b3temp * tempsix

Ao3, b3rain, b3PAW and b3temp are constants [Table 1].

rainsix is the total rainfall (mm) for 6 months from the time urine is deposited.

tempsix is the average temperature (℃) for 6 months from the time urine is deposited.

PAW750 is the profile available water to 750 mm (mm).

with a minimum value of 1. The profile available water to 750 mm (PAW750) is estimated by scaling up the profile available water at 600 mm as the parameters where estimated using a soil depth of 75 cm (Cichota *et al*., 2012).

The middle point is defined by NPV_2 and rNL2. NPV_2 is estimated as:

Equation 5: $NPV_2 = Ao2 + b2 * NPV_3$

Ao2 and b2 are constants [Table 1].

NPV_3 the pore volume when all solute is eluted [Equation 4].

with a maximum value of 0.8 of NPV3, and a minimum value of NPV1 plus half the difference between NPV1 and NPV3. The proportion of N leached that occurs at NPV2, rNL2, is estimated as:

Equation 6: $rNL2 = \exp(aRNL + bRNL/ NPV_2)$

aRNL and bRNL are constants [Table 2].

NPV_2 is the pore volume near the midpoint [Equation 5].

with a maximum value of 1 and a minimum value of 0.5. The constants aRNL and bRNL depend on whether irrigation has been applied in a given month – the amount applied is not considered.

On shallow soils or soils with a low rooting depth, the curve is shifted to the left. If the maximum rooting depth is less than 60cm, then NPV_1, NPV_2 and NPV_3 are reduced by the maximum rooting depth (m) divided by 0.6. Impeded layers were considered to have no additional effect as profile available water and hence pore volume would be reduced.

Table 2. Constants used to estimate rNL2.

Month	**aRNL**		**bRNL**	
	No irrigation	**Irrigation**	**No irrigation**	**Irrigation**
January	0.033740	-0.23400	-1.42480	-0.77670
February	-0.283990	-0.73035	-1.11651	-0.54319
March	0.264638	-0.08988	-1.23959	-0.56532
April	0.124437	-0.12541	-1.28851	-0.56259
May	0.299038	-0.05237	-1.34237	-0.60980
June	-0.455680	-0.65071	-1.14309	-0.78950
July	-0.411600	-0.54218	-1.20279	-0.90025
August	0.152421	-0.09513	-1.42692	-0.74947
September	-0.114320	-0.43191	-1.40918	-0.82402
October	0.339188	-0.20257	-1.32793	-0.50982
November	0.241588	-0.35045	-1.25490	-0.53884
December	0.037365	-0.49951	-1.15839	-0.59416

The fitted parameters give a range of curve shapes between sites, and between months within sites. An example is shown for the 4 months for one site in Figure 3.

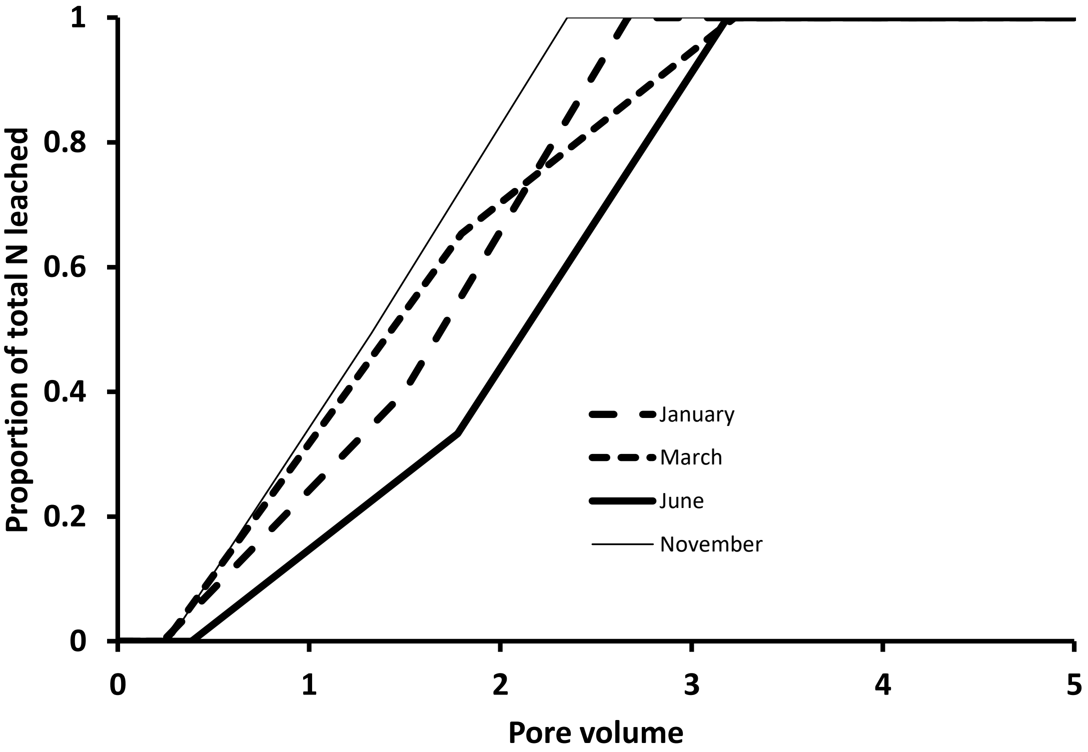

Figure 3. Example of breakthrough curves for different months.

2.4. Calibration

The focus of the calibration was to obtain a timing profile that was consistent with known field and lysimeter trial data, and to provide an estimate of total N leaching that was consistent with field trial data.

When calibrating OVERSEER outputs against field trial results, the following issues were identified:

- OVERSEER is a farm system model. Field trials are small scale (sub-block). For instance, in a block scale model, assume that the animals are grazing that block some time each month. In contrast, in field trials, animals graze the trial periodically. Therefore input data needed to be carefully entered into OVERSEER to represent the field trial set up.
- The N load deposited as urine on a block, N intake by animals, and/or stock numbers and production were not always reported. Given the relationship in Equation 1, this can be an important source of uncertainty in the calibration process.
- Field trials results occur for a given climate period, and hence the drainage during the trial duration is important. Therefore the modelled drainage was aligned with measured drainage, or drainage estimated using a more process orientated model.
- When entering climate data, the period of climate data and the effect on leaching needs to be aligned. For example, N in leachate is driven by the climate conditions prior to the drainage water appearing, not after. Hence, in some trials, year 1 data was

used with caution as the climate conditions prior to the first leachate collection were not reported.

- Field trials using ceramic cups measure both urine patch and background. It was assumed that N leaching from the urine patch was the dominant source of N and hence any variation or discrepancies were attributed to the urine patch N sub-model.
- Field trials using ceramic cups have considerable error associated with their estimates of N leaching – this has been estimated at 30-40%.

The first stage of the calibration process was to calibrate the effect of timing of urine deposition using the standard urine patch N sub-model against lysimeter trial data of Shepherd *et al*. (2011) by mimicking a lysimeter trial. The sub-model could reasonable predict the results from the timing of urine deposition.

OVERSEER N leaching outputs (urine patch plus background) were then calibrated against field trial data but keeping immobilisation, volatilisation, and denitrification at the initial values (as described in sections 3.3.3, 3.3.4, and 3.3.5). To get a reasonable calibration, a different pasture N uptake rate (section 3.4.3) was required (more than two times). Buckthought *et al*. (2016) have subsequently identified urine patch edge effects as an important contributor to this difference.

When calibrating against field trials, the initial standard urine patch N sub-model suggested that urine deposition in summer/early autumn was contributing to N leaching. This was considered too early, particularly given that timing was based on a single trial data set (Shepherd *et al*., 2011) and modelled outputs (Snow *et al*., 2011). Given the possible implications of an early timing on key farm operations in autumn (drying, tupping), the precautionary principle was applied so that standard urine patch N sub-model indicated that for the Waikato, urine deposition in autumn/early winter was the major contributor to N leaching from urine patches. To achieve this, uptake in late spring needed to be high enough so that N deposited in late spring/early summer was not contributing to leaching, and this was attributed to higher growth rates when pasture was in the reproductive phase. This led to uptake being increased by a reproductive factor (section 3.4.3.1.4). In addition, uptake needed to be higher in the South Island, although most South Island calibration trials were in Southland. This led to the inclusion of a South Island uptake factor (section 3.4.3.1.2).

An additional issue was that OVERSEER N leaching outputs was either over or under predicting leaching from 3 trials in Southland on pallic soils. These trials were all mole/tile drained, and the drainage and N leached was that measured from the drain outlets. The difference between trials appeared to be related to the efficiency of the drainage systems – leaching was lower in a trial where the drainage system was considered to be inefficient. In these conditions, it was considered that denitrification is probably higher, and hence denitrification was increased. The efficiency of the drainage system was determined by the relationship between natural profile drainage class, and propensity for pugging class (Characteristics of soils chapter). Unfortunately, when the ability to estimate soil water contents using site-specific soil profile water contents at wilting point and field capacity was added, this has resulted in high denitrification/low N leaching on some soils.

Last, the calibration curve was developed, and the output adjusted so that modelled and estimated values were consistent using a paddock factor (section 4.6). As the output from the standard urine patch N sub-model is calibrated against field trial data where variability in urine patch characteristics occur, then the standard urine patch N sub-model represents the integrated value of outputs that would result if all the variability in urine patch characteristics found in the field were modelled.

2.5. Implications

The implications of the process used include:

- OVERSEER predicts annual average outputs, including N leaching. Thus it is assumed that the relationship between using trial drainage and trial average outputs (average typically over 2-3 years) is the same as using long term average climate data (and hence drainage) and annual average outputs.
- It is possible that the ratio of the removal process may not be correct, for example the standard urine patch N sub-model is under-estimating uptake and over-estimating immobilisation.
- Given the precautionary approach used for calibrating the timing of urine deposition, the critical time for urine deposition may be earlier than the current model is predicting.
- The focus of the urine patch N sub-model is to estimate the proportion of N deposited in a given month that is leached. The sub-model does not report when N appears in drainage water. Although the sub-model estimates the proportion of N leached for a given drainage, the sub-model has not been calibrated against a time series of N concentrations in drainage water.
- The sub-model does not implicitly model the effect of timing of urine deposition on N leaching as observed in lysimeter and field trials – the effect of timing of urine deposition is an emergent property of the implemented model.

The outputs of the urine patch N sub-model are dependent on site characteristics. This results in the following observations:

- Soil properties influence the proportion of N leached. The pore volume is a function of profile available water, a soil property. For a given drainage, soils with low PAW have a higher pore volume for a given amount of drainage. If all N is leached at 3 pore volumes, then a soil with a PAW of 50mm requires 150 mm of drainage whereas a soil with a PAW of 100 mm requires 300 mm drainage. Hence the sub-model estimates that for a given drainage, the stony or sandy soils which have low PAW leach more N than medium textured soils that have higher PAW’s. The PAW also affects the critical time of N deposition. Soils with low PAW generally have a shorter period between deposition and appearance in drainage water. Hence for the same drainage, the peak in the critical risk period on low PAW soils shifts closer to winter, and the months with a significant risk increase.
- Temperature changes the proportion of N leached through its effect on biological processes, including immobilisation, volatilisation, denitrification, and uptake (as described in sections 3.3.3, 3.3.4, 3.3.5, and 3.4.3).
- Rainfall and irrigation affect drainage rates, that in turn affect the proportion of N leached. Hence over periods of no drainage there is no movement of N.

- The appearance of N from a urine patch in the drainage water may not occur in the year of deposition. This is consistent with Shepherd *et al*. (2011).
- The monthly N removal rates are driven by pasture or crop uptake, and when there is no uptake, there is potentially a high risk of N loss through leaching from the urine patch.

If uptake is high the proportion of N leached is lower, and vice versa. Hence uptake (N removal) is an important factor affecting N leaching. Examples of situations where the urine patch N sub-model can estimate higher susceptibility to leaching due to lower uptake include:

- Crops that are mature when grazed, as mature crops are no longer actively growing, and N uptake is low.
- Crops that are grazed followed by a fallow period, particularly if that grazing is in autumn/early winter.
- Environments where pasture uptake is low as it is too dry or too cold. An example is autumn grazing of lucerne, where lucerne is dormant over winter, and hence N uptake is low. Irrigation can increase N uptake over summer, and hence change the proportion of urine N deposition that is leached (note that total production and drainage also change).
- When there is high feed intake on feed pads, and animals are also grazed on pastures where uptake is low.

For the impact of low uptake on N leaching to be observed, drainage is also required.

The above provide generalisations. The actual proportion of urine N that is leached is due to the interaction between N uptake and pore volumes of drainage, and both of these are driven by site specific factors, such as soil properties, temperature, rainfall, and irrigation. In effect it is a race between N removal from the urine patch, and drainage pushing N through the bottom of the root zone.

3. Dairy cow standard urine patch N sub-model

3.1. Inputs

Inputs from the N urine patch sub-model are shown in Table 3. Unless indicated otherwise, monthly inputs are for the months January to December.

Additional inputs used for calibration or testing purposes are also shown in Table 4. The calibration values can substitute for the variables shown.

Table 3. Inputs to the urine patch N sub-model.

Input	Description
Region	Region.
Blocktype	Block type (pastoral, fodder crop, cropping, fruit crop).
MonUrineApplied	Month the urine is deposited.
NimmobPotential	N immobilisation potential.
rain	Annual rainfall (mm/year) [Climate chapter].
monrain	Monthly rainfall (mm/month) [Climate chapter].
montemp	Monthly average temperature (°C) [Climate chapter].
SMfield	Soil water content at field capacity (mm to 600 mm) [Hydrology chapter].
SMwilt	Soil water content at wilting point (mm to 600 mm) [Hydrology chapter].
SM	Soil water content (mm to 600 mm) for the month urine is deposited [Hydrology chapter].
MaxRootDepth	Maximum rooting depth (m) [Characteristics of soils, entered value].
ImpededLayerDepth	Depth to impeded layer (m) [Characteristics of soils, entered value].
HasIrrigation	Whether irrigation is applied in the month urine is deposited.
drainage	Drainage for each month (mm/month) [Hydrology chapter].
ftemp	Monthly temperature factor for mineralisation [Crop based N sub-models chapter].
fUrineUptake	Factor for adjusting monthly uptake rates. Calculated externally using method in section 3.4.3.1.4.
Transpir	Monthly estimated transpiration (mm/month) [Climate chapter].
PET	Monthly estimated potential evapotranspiration (mm/month) [Climate chapter].
UrineNadded	Amount of urine deposited on the block (kg N/ha/month).
fanimal	Animal enterprise factor. Calculated externally using method in section 4.2).
hardgrazed	Whether the farm is hard grazed prior to grazing off or placing animals on the wintering pad/animal shelter.
DCDLeach	DCD effectiveness on leaching for month N is deposited.
DCDN20	DCD effectiveness on nitrous oxide emissions for month N is deposited.
EFDenit	Emission factor for denitrification [Calculation of nitrous oxide emissions chapter].
AddedN	Amount of inorganic N added each month (kg N/ha/month).
UseUptakeMonth	Yes/No on whether monthly uptake data is used.
UptakeMonth *	Monthly uptake data (kg N/ha/month) starting from the month of urine deposition.
HasAnimalsOnBlock	Yes/No – whether animals are on the block.
PugOccurrence	Pugging occurrence class [Characteristics of soils, entered value].
ProfileDrainageClass	Profile drainage class [Characteristics of soil chapter, default of entered value].
DenitPug	Heavy soil adjustment for denitrification. Calculated externally using method in section 3.3.5.1).

Table 4. Inputs to the urine patch N sub-model for calibration/evaluation purposes.

Description	Variable	Section
Urine load (kg N/ha)	UrineLoad	3.3.2.1
Initial immobilisation rate	initialImmobilisation	3.3.2.1
Monthly immobilisation rate	immrate	3.4.4
Volatilisation rate	volloss	3.3.2.1
Denitrification rate	denitrate	3.3.5
Base uptake rate	uptake	3.4.3.1

3.2. Outputs

Outputs from the standard urine patch N sub-model are shown in Table 5. The outputs for volatilisation, denitrification and leaching are included directly in the nutrient budget. The NSave values are used to estimate the efficiency of DCD, and the other outputs are used for testing purposes.

Table 5. Outputs from the urine patch N sub-model.

Input	Description
NurineVolat	Volatilisation of N from urine (kg N/ha).
NurineDenit	Denitrification of N from urine (kg N/ha).
NurineLeach	Leaching from urine (kg N/ha).
NurineImmobInit	Initial immobilisation of urine N (kg N/ha).
NurineImmobMonth	Total monthly immobilisation of N from urine (kg N/ha).
NurineUptake	Total uptake by pasture or crops of N from urine (kg N/ha).
NSaveVolat	N saved from volatilisation due to DCD application (kg N/ha).
NSaveDenit	N saved from denitrification due to DCD application (kg N/ha).
NSaveLeach	N saved from leaching due to DCD application (kg N/ha).

3.3. Initial procedure

The standard urine patch N sub-model assumes that most of the immobilisation, volatilisation and denitrification occurs within a few days after deposition. The sub-model uses a standard N load (section 3.3.1), losses from immobilisation, volatilisation and denitrification are removed (sections 3.3.3, 3.3.4, and 3.3.5), and the remainder added to the urine patch N pools (section 3.3.2). The sub-model then operates on a monthly time step starting at the month of deposition and running until either all N in the N pools is used in a removal process (uptake, immobilisation), or the breakthrough curve (section 2.3.2) indicates that the remaining N has leached below the root zone (60 cm), or 24 months since deposition has occurred.

3.3.1. Standard urine patch N load

The N loading for the standard urine patch N sub-model is set to the same value as used by Cichota *et al*. (2012), that is 750 kg N/ha.

For calibration or lysimeter trials the N loading can be set.

3.3.2. Urine patch N pools

To model the time delay as ammonia and ammonium is nitrified, the urine load is split into 4 pools, ammonium pool (NH4pool), and 3 monthly nitrate pools ($NO3pool_i$) as ammonium is nitrified. The three nitrate pools are used for tracking purposes, and assumes that by the third month after deposition, all ammonium has been nitrified. Leaching is assumed to only occur from the nitrate pools.

3.3.2.1. *Initial ammonium pool*

Initially, losses due to volatilisation, denitrification and immobilisation are removed and the remaining N is allocated to the ammonium pool. Thus the initial ammonium pool is set as:

Equation 7: $NH4pool = UrineLoad * (1 - initialImmobilisation - volloss - denitrate)$

UrineLoad is the urine loading on a standard urine patch (kg N/ha) [section 3.3.1].

initialImmobilisation is the initial immobilisation rate [section 3.3.3].

volloss is the volatilisation rate [section 3.3.4].

denitrate is the denitrification rate [section 3.3.5].

3.3.3. Immobilisation

Two immobilisation rates are used, an initial rate and a monthly rate. The initial rate is based on the N immobilisation potential, being 0.20, 0.30 and 0.05 for standard, higher, and none settings respectively. For an N loading of 750 kg N, this equates to 150 kg N, 225 kg N and 37.5 kg N removed from the standard urine patch. The additional amount of N immobilised each month is described in section 3.4.4

3.3.4. Volatilisation

Volatilisation losses were initially based on a summary of volatilisation losses that indicated summer volatilisation losses from the urine patch were about 20%, and in the other seasons about 10%. The summer rate is higher than the New Zealand National Inventory rate of 10%. It was assumed that the difference between summer and other seasons was related to temperature, hence volatilisation is estimated as:

Equation 8: $volloss = 0.2 * (0.991 * (1 - \exp(-0.282 * (montemp_{mon} - 6.230))))$

montemp is the monthly air temperature (°C) for the month urine is deposited [input, section 3.1].

with a minimum value of 0.1 (Figure 4). Subsequent analysis indicated mean summer volatilisation rate was 15%, average loss of all seasons was 12.9% with a range of 1-38%, and 2 experiments on dry soils had very high losses (Selbie *et al.*, 2015). This indicates that the standard urine patch N sub-model may be over-estimating average volatilisation rates in summer, and that the effect of soil moisture may not be reflected in the rates.

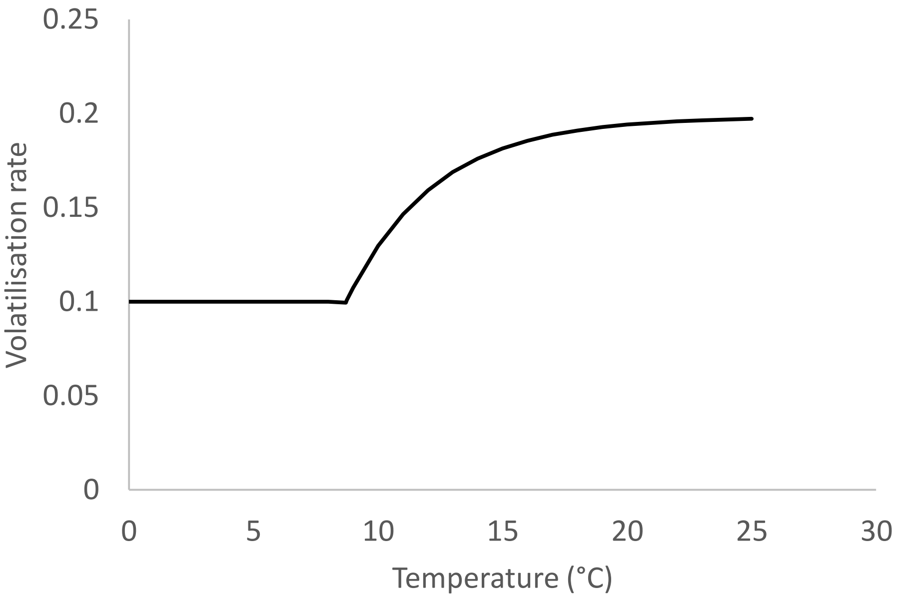

Figure 4. Effect of temperature on volatilisation rate of ammonia-N from the urine patch.

If DCD is applied, the reduction in volatilisation rate (DCDreduction) is estimated as:

Equation 9: DCDreduction = 0.2 * RDCDLeach /100

3.3.5. Denitrification

The denitrification rate is estimated from water filled pore space, as outlined in Calculation of nitrous oxide emissions chapter, and adjusted by a factor for heavy soils. This adjustment was made to take account of the lower than predicted N leaching rates on mole/tile drained pallic soils, and that the discrepancy appeared to be linked to the effectiveness of the drainage system. The amount of N that is denitrified from the standard urine patch is calculated as:

Equation 10: NurineDenit = urineN * denitrate
urineN is the urine N load in the standard patch (kg N/ha).
denitrate is the denitrification rate (kg/kg) [Equation 11].

The denitrification rate is estimated as:

Equation 11: denitrate = EFDenit * DenitPug
EFDenit is the denitrification rate (kg/kg) [Calculation of nitrous oxide emissions chapter].
DenitPug is a factor for heavy soils [section 3.3.5.1].

If the initial denitrification rate is greater than 0.7, immobilisation is increased by 1.5 times. If the estimated initial denitrification rate is between 0.35 and 0.5, immobilisation rate is adjusted as:

Equation 12: immrate = initimmrate * 1 + (1 - ((0.7 - denitrate)/ 0.35)) * 1.5
initimmrate is the immobilisation rate [section 3.3.3].

denitrate is the denitrification rate [Equation 11].

A maximum denitrification rate of 0.35 is then applied which gives a maximum of 262.5 kg N removed from the standard urine patch.

If DCD is applied, the reduction in denitrification rate (DCDreduction) is estimated as:

Equation 13: DCDreduction = 1.1 * RDCDN2O /100

RDCDN2O is the reduction in nitrous oide emissions for the month urine is deposited (%).

The amount of N saved is estimated as:

Equation 14: NsaveDenit = NurineDenit * DCDreduction

3.3.5.1. *Heavy soil adjustments*

As part of the calibration process, leaching was overestimated on mole/tile drained pallic soils, with the degree of overestimation depending on a qualitative assessment of the effectiveness of the drainage system (i.e. based on the amount of surface water and pugging damage observed). This suggested that one of the loss mechanisms was underestimated. Given that the other mechanism had some quantitative data, it was decided to focus on denitrification.

On heavy soils, it is likely that anaerobic conditions occur more frequently in microsites due to the finer soil texture. In pugged soils, anaerobic conditions are more likely to occur due to surface sealing, and due to slower permeability. There was no calibration data for heavy soils that were not pallic soils, but it was assumed that similar principles applied.

The reduction in N leaching was achieved by increasing denitrification rates on heavy soils (defined by subsoil clay level) when animals were present. The relationship between natural drainage class and pugging occurrence was used, based on the comparison discussed in the Characteristics of soils chapter.

The increase in denitrification rates was based on the subsoil clay content and Susceptibility to pugging or treading damage and the natural profile drainage class. The factor was applied in all months if ‘Susceptibility to pugging or treading damage’ was ‘Winter or rain’ and applied in May, June, July and August if ‘Susceptibility to pugging or treading damage’ was ‘Winter’. The increase is estimated as:

Equation 15: DenitPug = 0.25 * SubSoilClay * (1 + fclass)

SubsoilClay is the entered or default subsoil clay content (%) [Characertistics of soils chapter].

fclass is the estimated increase in denitrification [Table 6].

using a maximum value of 40% for the subsoil clay content.

Table 6. Increase in denitrification rates (fclass) as a function of the 'Susceptibility to pugging or treading damage' class (Pugging class) and Natural drainage class.

Pugging class	Well drained	Moderately well drained	Imperfectly drained	Poorly and very poorly drained
Rare [1]	0	0	0.2	0.4
Occasional	0	0	0.2	0.4
Winter	0.15	0.25	0.5	0.75
Winter or rain	0.25	0.5	0.75	1

[1] The increase for 'Rare' and 'Occasional' class for 'Susceptibility to pugging or treading damage' is not used in the standard urine patch N sub-model.

3.4. Monthly procedure

After estimating the initial reduction in urine N load due to immobilisation, volatilisation and denitrification, the standard urine patch N sub-model then operates on a monthly time step. The procedures used each month, starting from the month of urine deposition, are:

- Nitrification rates are estimated based on temperature (section 3.4.1.1).
- Nitrate pools are set up (section 3.4.1).
- Fertiliser (inorganic N) is added (section 3.4.1)
- Uptake is removed from each of the nitrate pools (section 3.4.3).
- Monthly immobilisation of N is removed from the three nitrate pools (section 3.4.3.3).
- Pore volume is estimated based on profile available water and drainage (section 3.4.5).
- The amount of N loss by leaching is estimated for each nitrate pool (section 3.4.6).

The cycle continues until either all N is used in a removal process (uptake, immobilisation), or the breakthrough curve indicates that the remaining N has leached below the root zone (60 cm).

3.4.1. Nitrate pools

For the month of urine deposition and the subsequent month, N in the ammonium pool is transferred to the first and second nitrate pools respectively as:

Equation 16: $\text{NO3pool}_i = \text{NH4pool} * (\text{nitriRate}_{mon} - \text{prevnitriRate}_{mon})$

nitriRate is the accumulative ammonium nitrification rate for the curent month (kg/kg) [section 3.4.1.1].

prevnitriRate is the accumulative ammonium nitritifation rate for the previous month.

In the third month after deposition, all remaining N in the ammonium pool is transferred to the third nitrate pool.

3.4.1.1. *Ammonium nitrification*

The amount of ammonium that is nitrified is based on measurements of soil ammonium levels taken from 0-75 cm soil cores from field trials that had DCD applied. The ammonium nitrification rate was based on the relationship between the rate of decline in soil ammonium levels and average air temperature at the beginning of the trial from seven trials in which soil data was available and used in development of the DCD sub-model (Shepherd *et al*., 2012).

The accumulative ammonium nitrification rate for a given time is estimated as:

Equation 17: $\text{nitriRate} = (1 - \text{dailynitriRate})^{\text{days}}$

dailynitrate is a daily nitrification rate [Equation 18].

days is number of days in the month urine N is deposited [Equation 19].

where the daily ammonium nitrification rate (kg/kg/day) is estimated as:

Equation 18: $\text{dailynitriRate} = 0.0071 * \text{montemp} - 0.0007$

montemp is the monthly air temperature (°C) for the month [input, section 3.1].

and the number of days for the month urine N is deposited is 15, and thereafter is estimated as:

Equation 19: $\text{days} = 15 + (\text{mon} - 1) * 30$

mon is the number of months since urine was deposited (1 is the month of deposition).

3.4.2. Additional inorganic N inputs

The standard urine patch N sub-model assumes that inorganic N inputs (fertiliser, inorganic N in effluent, N in irrigation water) are spread evenly over the block, including on urine patches, and that this added N contributes to the N pools and thus affects the amount of N leached. It is assumed that inorganic N from applications such as effluent have the same effect as applying inorganic fertiliser. Thus, any inorganic N applied is added to the urine patch N pools in the month they are applied.

Initially, the sub-model assumes that some of the inorganic N is not available to be leached or taken up due to immobilisation. The amount that is added to the urine patch N pools is estimated as:

Equation 20: $\text{AddInorgN} = \text{AddedN} * (1 - 0.05 * \text{ftemp})$

AddedN is the amount of inorganic N added to the block in a given month (kg N/ha/month).

0.05 is an immobilisation rate (kg/kg).

ftemp is the mineralisation tempertaure factor for mineralisation of organic matter for the month inorganic N is added [Crop based nitrogen sub-model].

The amount of inorganic N added in a given month (kg N/ha) is calculated within the background or crop models (Crop based N sub-models chapter) and is an input to the urine patch N sub-model (section 3.1). Thus added N is estimated as:

Equation 21: AddedN = N_Fert + N_organicFert + N_Irrig + N_rain + N_effluent + N_EffluentInorg - N_Volatil

N_Fert is inorganic N (soluble and inorganic portion or organic material) added in a given month (kg N/ha).

N_organicFert N released from the organic component within a given month (kg N/ha).

N_Irrig is N added in irrigation (kg N/ha).

N_rain is N added in rainfall (kg N/ha).

N_effluent N released from the organic component within a given month (kg N/ha).

N_EffluentInorg is inorganic N added in a given month (kg N/ha).

N_Volatil is N volatilised from fertiliser (kg N/ha).

The amount immobilised is the difference between added (AddedN) and AddinorgN. The amount of inorganic N added to the nitrate pools (Nmin, kg N/ha) is estimated as:

Equation 22: Nmin = AddInorgN * fertMinRate

where fertMinRate is the ammonium nitrification rate for the month of application, and then the amount nitrified is distributed to the three nitrate pools in proportion to pool size. The difference between fertiliser nitrate pool and added inorganic pool is added to the urine patch NH4 pool:

Equation 23: NH4pool = NH4pool + (AddInorgN - Nmin)

3.4.3. Uptake

For calibration purposes, or for the crop model (section 3.4.3.2), monthly uptake rates can be entered. Otherwise uptake is estimated each month (section 3.4.3.1).

3.4.3.1. *Pasture uptake*

Pasture uptake from the urine patch for a given month (kg N/ha/month) is estimated as:

Equation 24: uptake = baseuptake * fregion * $\text{fUrineUptake}_{\text{mon}}$ * fmoist

baseuptake is the base uptake rate (kg N/ha/month) [section 3.4.3.1.1].

fregion is a adjustment to uptake for South Island regions due to differences in pasture N concentrations [section 3.4.3.1.1]

fUrineUptake is a factor to adjust for monthly growth rates due to temperature and sunshine hours [3.4.3.1.4].

fmoist is a factor for soil moisture [3.4.3.1.3].

In the month of deposition, uptake is halved to take into account the delay in pasture growth response to the increased available nitrogen, and that a monthly model is used but urine can be deposition throughout the month.

3.4.3.1.1. Default base uptake

The base uptake for field trials that gave a reasonable calibration was 90 kg N/ha/month. This is equivalent to a maximum pasture growth rate in the presence of adequate moisture of 80 kg DM/ha/day, and a pasture N content of 3.7%.

For calibration purposes, a base rate could be entered.

3.4.3.1.2. Regional factor

Pasture N concentrations were consistently higher in the South Island than the North Island (Characteristics of pasture chapter). It is assumed that the same also occurs in the urine patch, and hence a region factor is estimated as:

Equation 25: $\text{fregion} = (1 + \text{regionNConc} / 3.8)$

regionNConc is the default N concentration for a given region (%) [Characteristics of pasture chapter].

3.8 is a reference pasture N concentration (%).

3.4.3.1.3. Moisture factor

The moisture factor is set as the ratio of transpiration over potential evapotranspiration, with a minimum value of 0.1. In the month of deposition, it is assumed that the urine patch supplies sufficient moisture to reduce the impact of a dry soil, hence the moisture factor is estimated as:

Equation 26: $\text{fmoist} = 1 – (1 - \text{Transpir}_{\text{mon}} / \text{ETP}_{\text{mon}})/ 2$

Transpir is the estimated transpiration (mm/month) [input, section 3.1].

ETP is the estimated potential evapotranspiration (mm/month) [input, section 3.1].

3.4.3.1.4. Factor for monthly uptake rates

The factor for adjusting uptake rate each month is based on the relative pasture growth. It is estimated in the individual block models, and monthly values included as an input into the urine patch N sub-model (section 3.1).

During the calibration process, the rate of removal of N from the urine patch was increased for cooler regions (Southern South Island) by using a South Island uptake factor, adjusted by temperature. This was additional to the higher pasture N contents already incorporated by the regional factor (section 3.4.3.1.2). This factor was applied to all South Island regions.

The factor for adjusting uptake rate is estimated as:

Equation 27: $\text{fUrineUptake} = \text{pasturegrowth}_{\text{mon}}/80 + (\text{AddUptakeCool}/100) * \text{fuptemp}_{\text{mon}}$

pasturegrowth is the estimated pasture growth rate (kg DM/ha/day) [Equation 29].

80 is the reference maximum pasture growth rate (kg DM/ha/day).

AddUptakeCool is an additional growth factor for cooler regions (kg DM/ha/day).

fuptemp is a temperature factor for uptake (Equation 28).

The calibration indicated that a value of 20 kg DM/ha/month for AddUptakeCool improved predictions. The effect was controlled by temperature (fuptemp) such that if the monthly average temperature was less than 10.7 °C it had a value of one, if greater than 12.7 °C it had a value of zero, otherwise it is estimated as:

Equation 28: fuptemp = -0.5 * monTemp + 6.35

montemp is the average monthly air temperature (°C) [Climate chapter].

Estimated pasture growth is used as a scalar, and hence it is assumed that the effect of temperature and sunshine hours on growth rates on a block and on the urine patch are relatively the same. Hence the estimated and reference maximum pasture growth is not necessarily the growth rate on the urine patch.

Daily growth rate (kg DM/day) for lucerne was the same as used for estimating growth of the clover component of pasture (Characteristics of pasture chapter).

The daily growth rate for non-lucerne pasture was estimated by either sunshine hours or temperature. During calibration, better results were obtained using a combination of the two methods, and increasing growth rates in spring, which was attributed to higher growth rates during the reproductive stage. Thus monthly pasture growth rate is estimated as:

Equation 29: pasturegrowth = Max(growthsun, growthtemp) * RepFactor

growthsun is the growth rate based on sunshine hours (kg DM/month) [Equation 30].

growthtemp is the growth rate based on temperature (kg DM/month) [Equation 31].

RepFactor is a reproductive factor [Equation 33].

The sunshine hours based growth was estimated from daily pasture growth from 3 sites (Whangarei, Palmerston North, Invercargill) as shown in Table 7 and mean monthly sunshine hours (Climate chapter). Thus, sunshine hours based growth (kg DM/ha/day) is estimated as:

Equation 30: growthsun = 0.6594 * monSunShine - 54.248

monSunShine is the monthly sunshine hours [Climate chapter].

except if monthly sunshine hours were less than 100, or mean monthly temperature was less than 5, in which case growth rate was estimated as twice the mean monthly temperature.

Table 7. Growth rates (kg DM/ha/day) for three sites (supplied by R Cichota, AgResearch, pers. comm.).

	Whangarei	Palmerston North	Invercargill
January	19.9	17.9	14.8
February	20.0	18.2	14.1
March	19.0	16.6	12.3
April	16.5	14.1	9.4
May	14.0	11.3	6.3
June	12.2	9.2	4.0
July	11.2	8.6	3.1
August	11.7	9.3	4.0
September	12.9	11	6.4
October	14.3	12.7	9.2
November	16.4	14.3	11.7
December	18.2	16.3	14.1

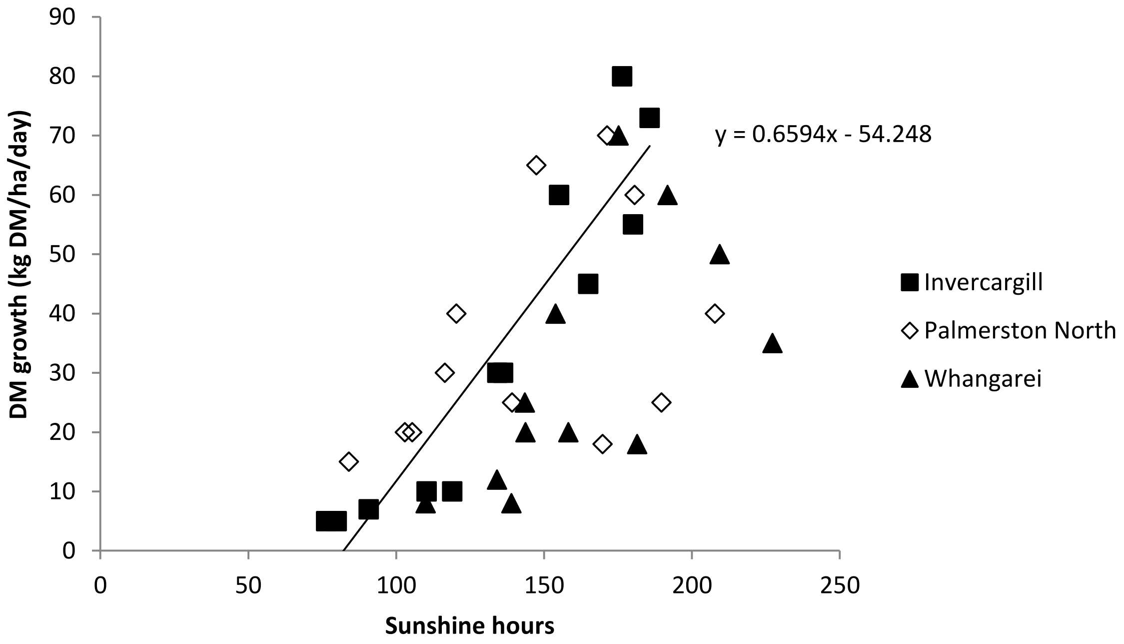

Figure 5. Relationship between sunshine hours and pasture growth rate for three sites. Values to right are mainly from summer period when soil moisture may be limiting.

The temperature based growth rate (kg DM/ha/day) is estimated as:

Equation 31: $\text{growthtemp} = 80 * \text{growtemp}$

where the temperature factor (growtemp) is estimated as:

Equation 32: $\text{growthtemp} = ((\text{montemp} - \text{Tmn})^{q}) * (\text{Tmx} - \text{montemp})) / ((20 - \text{Tmn})^{q}) * (\text{Tmx} - 20))$

montemp is the average monthly air temperature (°C) [Climate chapter].

Tmn and Tmn are constants for minimum and maximum temperature for pasture growth, with values of 2 °C and 32 °C.

q is a curvature constant with a value of 1.5.

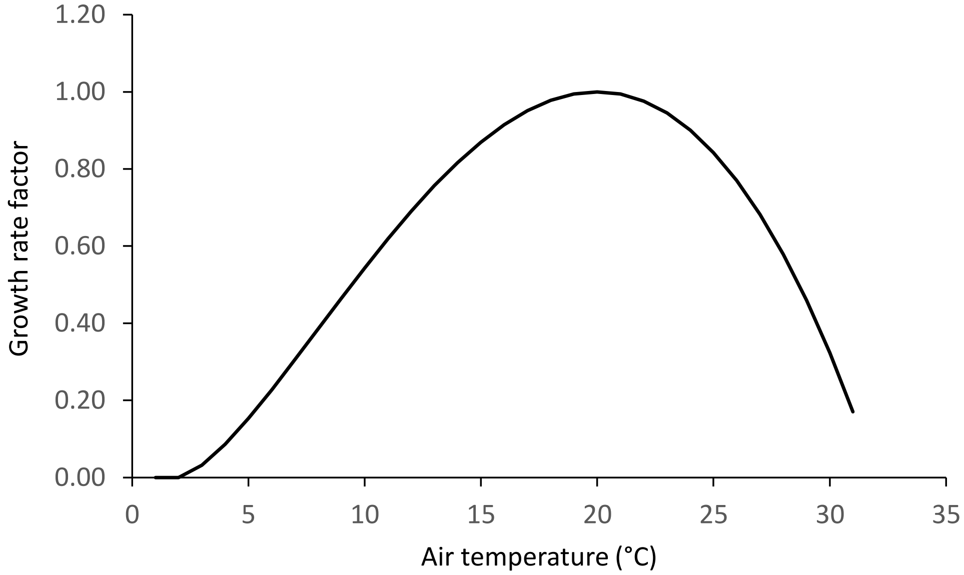

Figure 6. The effect of or air temperature on the temerature factor for pasture growth.

Reproductive growth is 1 for kikuyu based pasture, that is, pasture growth rates didn't increase when the pasture was in a reproductive phase. For other pasture types, it was assumed that the timing and strength of the reproductive growth was driven by temperature. Day length is a known initiator of reproductive growth but the calibration process indicated that the strength of the reproductive response to get sufficient uptake increased in the South Island. Hence if the month was between July and February inclusive, and mean monthly temperature was less than 18 °C, then the increase in growth during the reproductive phase is estimated as:

Equation 33: $\text{RepFactor} = -0.0367 * \text{montemp}^2 + 0.794 * \text{montemp} - 2.787$

montemp is the monthly air temperature (°C) [Climate chapter].

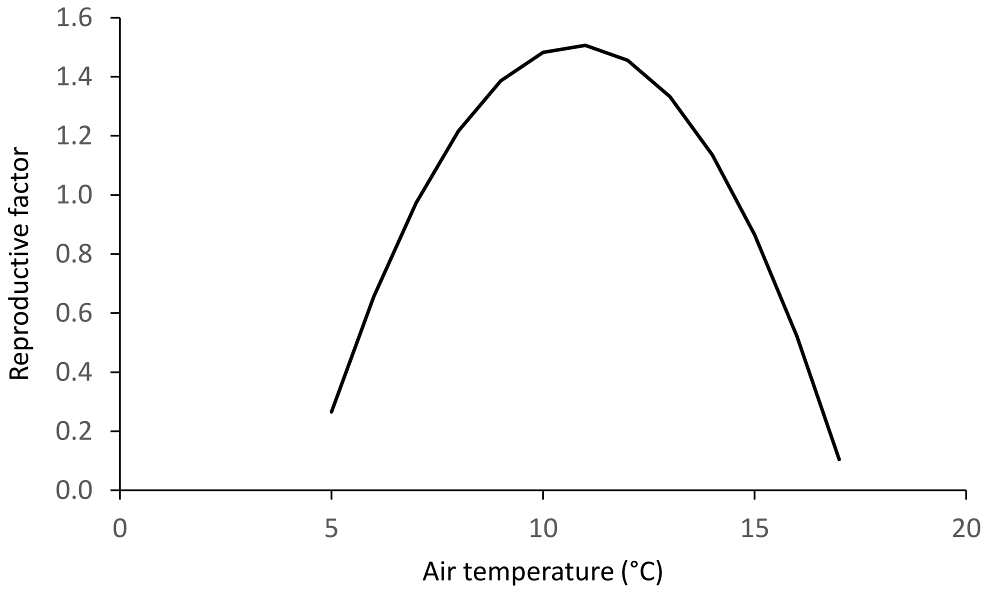

Figure 7. The effectof or air temperature on the reproductive growth factor.

3.4.3.2. *Monthly uptake on crop blocks*

For crop blocks, monthly uptake starting from the month of deposition is estimated. During the reporting year, if a non-pasture crop is growing then uptake was estimated as double the crop uptake, assuming that uptake was higher in the urine patch. This means that during fallow, or if a crop has reached maturity, uptake is zero.

If the crop contains a pasture phase, uptake is estimated as for pasture (section 3.4.3.1).

For a pasture or cut and carry block, it is assumed that management is the same each year. Hence uptake can be predicted beyond the last month of urine deposition by cycling through the monthly uptakes. In crops, the future rotation beyond the end of the input grid is not known. If the crop at the end of the rotation is permanent grazed pasture, it is assumed that that this is present for the next 12 months and uptake is also estimated as for pasture (section 3.4.3.1). This applies to fodder crop blocks as permanent grazed pasture is the final crop by definition. Otherwise a default uptake rate of 50 kg N/ha/month is used. This may over or under estimate N leaching from urine patch deposited on crops, particularly urine patches deposited in the last half of the crop rotation for the reporting year.

3.4.3.3. *Monthly uptake on fruit crop blocks*

For fruit crop blocks, it is assumed that urine deposition only occurs on the pasture section of the block, and hence uptake is estimated as for pasture (section 3.4.3.1). No account is taken of the possible effect of crop cover and shading on pasture growth rates, or on uptake by the fruit crop root system within the pasture area, when estimating uptake for the urine patch N sub-model.

3.4.3.4. *Removing N uptake*

If the estimated uptake is greater than the sum of the nitrate pools, then the difference is assumed to be uptake from the ammonia pool, that is N is preferentially removed from the nitrate pools. Nitrate uptake is removed from each nitrate pool in proportion to the size of each pool.

3.4.4. Monthly immobilisation

For each nitrate pool, monthly immobilisation and then the proportion of N that is leached is estimated. The amount of N immobilised (kg N/ha/month) is estimated as:

Equation 34: $\text{NImmob} = \text{NO3pool}_i * \text{immrate} * \text{ftemp}$

immrate is the monthly immobilisation rate (kg/kg).

ftemp is the temperature factor for organic matter decomposition [Crop N sub-models chapter].

and is removed from the nitrate pools. The monthly immobilisation rate is based on the potential N immobilisation status, and is 0.025, 0.07 and 0 for Standard, Higher and None settings for potential N immobilisation status respectively. The amount removed varies with the site, but it corresponds to approximately 15-20 kg N for Standard immobilisation potential status, and 45-55 kg N for High potential N immobilisation status.

3.4.5. Estimate pore volumes

If pore volume (PV) is estimated as:

Equation 35: $\text{porevol} = \text{cumdrainage} * \text{PAW600}$

cumdrainage is the cumulative drainage (mm at 600 mm depth).

PAW600 is the profile available water content at 600 mm.

The cumulative drainage is the sum of drainage from the month urine is deposited for the month of analysis, given that only half the drainage is added for the month urine is deposited.

3.4.6. Estimating N leached

If the estimated proportion of N leached (section 3.4.6.1) is 1 or greater, then all the nitrate pool is added to the leaching pool, otherwise the amount of N leached (kg N/ha) is estimated as:

Equation 36: $\text{StdNleach}_i = \text{NO3pool}_i * (\text{propleach} - \text{prevpropleach})$

NO3pool is one of three urine patch nitrate pools (kg N/ha).

propleach is the proportion of N leached for the current month [section 3.4.6.1].

prevpropleach is the proportion of N leached for the previous month.

and the nitrate pool size is reduced by the amount of N leached.

3.4.6.1. *Proportion of N leached*

The proportion that is leached is determined from the breakthrough curve. If the pore volume is greater than nPV2, then the proportion that is leached (propleach) is estimated as:

Equation 37: propleach= rNL2 + (porevol - nPV2) / (nPV3 - nPV2) * (1 - rNL2)

rNL2, nPV2, and NPV3 are constants that define the breakthrough curve [section 2.3.2].

porevolume is the calculated pore volume [section 3.4.5].

otherwise if the pore volume is greater than nPV1

Equation 38: propleach = (porevol - nPV1) / (nPV2 - nPV1) * rNL2

nPV1, rNL2, and nPV2 are constants that define the breakthrough curve [section 2.3.2].

porevolume is the calculated pore volume [section 3.4.5].

otherwise the proportion that is leached is zero.

4. Block urine N leaching

The amount of urine N leaching from a block for a given animal enterprise and given month is estimated as:

Equation 39: NurineLeach = BaseNleach * fAnimal * fHardgrazed * fNimmobStatus * fDCD * Paddockfactor

BaseNleach is the total amount of N leached from a block for a given animal enterprise and given month (kg N/ha/month) [section 4.1].

fAnimal is a factor to adjust leaching for different animal enterprises [section 4.2].

fHardgrazed is a factor to account for hard grazing prior to grazing off [section 4.3].

fNimmobStatus is a factor to account for user-defined Immobolisation potential [section 4.4].

fDCD is a factor that accounts for the effect of DCD on N leaching [section 4.5].

Paddockfactor is a calibration factor (section 4.6).

4.1. Base N leached

The base amount of N leached (kg N/ha/year)is estimated as:

Equation 40: BaseNleach = UrineNadded * Nleach / UrineLoad

UrineNadded is the urine load added to a given block for a given animal enterprise in a given month (kg N/ha/month).

Nleach is the amount of N leached from the standard urine patch (kg N/ha) [section 3.4.6].

UrineLoad in the initial urine N load in the standard urine patch [section 3.3.1].

4.2. Animal enterprise factor

Hoogendoorn *et al*. (2011) reported that N leaching losses from sheep and deer were about 60% of that from beef cows for the same intake. The relative leaching risk based on urine patch size indicated that leaching from sheep was about 55% that of dairy cows (M Shepherd, AgResearch, pers. comm.). Based on urinary patterns and urine patch characteristics (male cattle typically move when urinating and hence the patch size is narrower), it was also considered that male cattle had a lower risk of leaching than female cattle. Hence the estimated proportion of N leached was adjusted using a factor of 0.55 for sheep and deer enterprises, and for beef enterprises is estimated as:

Equation 41: $fAnimal = (0.675 * propmale/100) + (0.8 * (1 - propmale/100))$

propmale animal is the proportion of intake by male cattle (%) [Animal model chapter].

4.3. Hard graze factor

If the farm is hard grazed prior to grazing off or placing animals on wintering pads/animal shelters, then it is assumed that the probability of overlap of urine patches increases, and hence N leaching will increase. The hard grazing factor for the animal enterprise that deposited the urine patch is estimated as:

Equation 42: $fhardgrazed = 1 + 0.06 * blockSU / 100$

blockSU is the percentage of the total block intake eaten by the given animal enterprise from a given block [Animal model chapter].

4.4. Immobilisation potential factor

The amount of leaching and denitrification is adjusted for the N immobilisation potential by decreasing these by 15% if the potential is high (multiply by 0.85), and increasing them by 20% if the potential is none (multiply by 1.2).

4.5. Effect of DCD

The effect of DCD in reducing leaching is estimated as:

Equation 43: $fDCD = 1 - RDCDLeach/100$

RDCDleach is the percentage reduction in leaching due to DCD applications for the month urine is deposited.

The amount of N saved from leaching (kg N/ha) due to DCD applications is estimated as:

Equation 44: $NSaveLeach = NurineLeach / fDCD * RDCDLeach$

4.6. Paddock factor

The paddock factor was included as part of the calibration process to adjust estimated N leaching to that measured in paddocks. In effect it is the slope of the calibration curve.

A value of 1 is used.

5. Other nutrients

The only other additional nutrients considered are S, K and Ca. The loss of P from urine patches is included in the P loss sub-model. For other nutrients (Mg, Na), OVERSEER assumes that there are no additional losses from urine patches.

5.1. Sulphur

The amount of sulphur leaching from a urine patch is estimated as part of the minimum sulphur leaching sub-model (Block nutrient budgets chapter).

5.2. Potassium

Leaching of K from the urine patch is treated essentially the same as background leaching except that it is reduced for non-dairy female animals. K leaching from urine patches (kg K/ha/year) is estimated

Equation 45: KurineLeach = urineK * Klossrate * urineKloss

urineK is the amount of urine K deposited on a block (kg K/ha/year).

Klossrate is the soil based loss rate (kg/kg) [Block nutrient budgets chapter].

urineKloss, the urine K loss facto that accounts for differences in animal enterprises [Table 8].

No account is taken of the timing of urine K, for example if animals are grazed or wintered off the blocks.

Table 8. The urine K loss factor for animal enterprises.

Animal Enterprise	Urine K loss factor
Dairy	1
Dairy replacements, female beef animals	0.85
Others	0.75

5.3. Calcium

OVERSEER assumes that Ca leaching from urine patches is driven by leaching of N from urine patches, and uses this component only from the Ca leaching sub-model [Block nutrient budgets chapter]. Thus:

Equation 46: CaurineLeach = NurineLeach * 0.786

NurineLeach is the amount of N leaching from a urine patch (kg N/ha/year) [section 4].

0.786 is a regression constant for Ca leaching [Block nutrient budgets chapter].

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