OVERSEER®

OVERSEER® Technical Manual

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

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Effluent management

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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 development of specific nutrient sub-models described in this chapter include:

Nitrogen	M A Shepherd, S F Ledgard, C A M de Klein and D M Wheeler
Phosphorus	R McDowell, A K Metherell and R M Monaghan
Potassium	A K Metherell and P L Carey
Sulphur	B S Thorrold and D M Wheeler
Ca, Mg, Na	P L Carey and A K Metherell
Acidity	C A M de Klein, R M Monaghan and A G Sinclair

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Effluent management

1. Introduction

1.1. Effluent management

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 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 nutrient contents of the feed sources, nutrient intake is calculated.

Nutrient intake is partitioned between animal products (based on entered production data) and excreta. Excreta is then partitioned between urine and dung which is then deposited onto blocks or distributed to farm structures such as farm dairy's, lanes and races, and pads. A schematic diagram is shown in Figure 1. The distribution of nutrients to structures is on a time basis, as described in the Intakes chapter. A mechanism to use measured data was considered but has not been implemented because both nutrient concentration and flow rate of liquid effluent from the farm dairy are highly variable. Hence a large number of measurements are required. Note that farm generated liquid and solid effluents which are well characterised can be entered as an organic fertiliser input (Fertiliser chapter), provided interpretation of outputs takes account of the export/import set-ups required.

The distribution and fate of nutrients and dung dry matter (DM) deposited on farm structures is determined by construction of the farm structure (for example, types of surfaces), how the animals use the structure (for example, length of time on a structure), and how effluent (excreta deposited and unutilised feed) is managed. The nutrients in the effluent management systems may be returned to blocks as effluent applications, where they are incorporated into block processes and the block nutrient budget, or may leave the farm directly (exported, leached or as atmospheric gases) and hence are incorporated into the farm nutrient budget. At the same time, atmospheric N emissions (volatilisation, denitrification and nitrous oxide emissions), and methane emissions from dung DM that enters the effluent management system are also estimated, and incorporated into the greenhouse gas emission reports.

Nutrients in excreta deposited on farm structures and in the effluent management systems are:

- estimated at the farm scale, hence nutrient totals are used.
- estimated for each animal enterprise so that different effluent management systems can be used for different animal enterprises (for example, winter pads/animal shelters for beef and deer enterprises can have different effluent management systems), and so that the greenhouse gas foot print can be estimated.
- estimated monthly for N and P. The nitrogen model is on a monthly time scale (Crop N sub-models chapter), and the susceptibility of effluent P to runoff losses is dependent on the time of application.

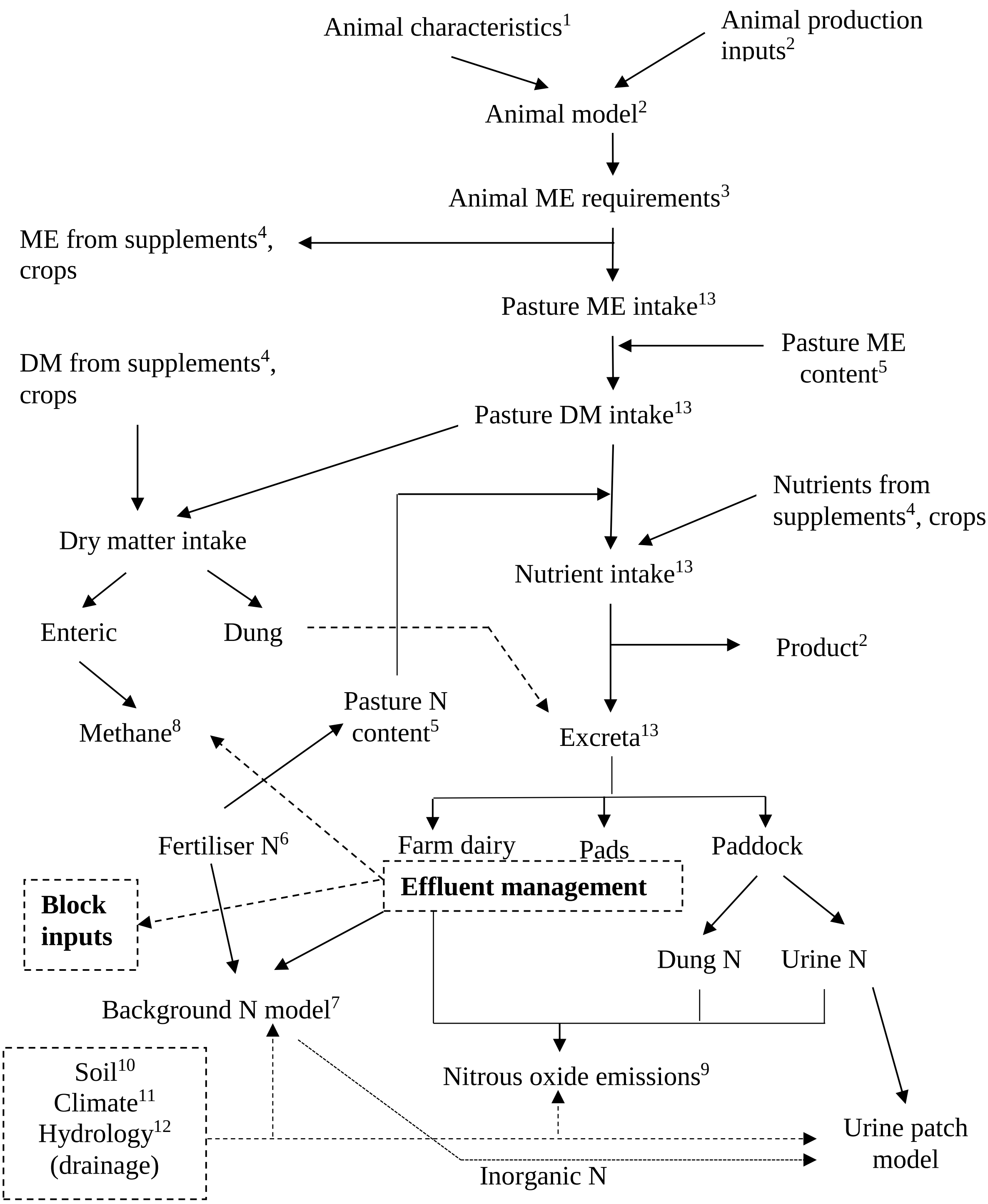

Figure 1. Relationships between sub-models and ME, DM and nutrient intakes (shown in bold), with a focus on N. Relevant Technical Manual chapters are indicated by superscripts.[1] Animal characteristics, [2] Animal model, [3] Metabolic energy requirements of animals, [4] Supplements, [5] Characteristics of pasture, [6] Fertilisers, [7] Crop N sub-models, [8] Methane emissions, [9] Nitrous oxide emissions, [10] Properties of soils, [11] Climate, [12] Hydrology, [13] Intakes.

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.

When describing equations in this manual, units are shown using ( ) and cross-references to other equations and sections within this chapter 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, chemical symbols, and subscripts

Abbreviations

DM dry matter

Chemical symbols:

N, P, K, S, Ca, Mg, Na, and Cl refer to the nutrients nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, sodium and chlorine respectively.

Subscripts

mon month.

nut the nutrients nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg) and sodium (Na), and either chloride (Cl) or the calculated value for acidity.

block a given block as defined in the Introduction chapter.

antype animal enterprise.

2. Effluent management systems

2.1. Objective

The objective of the modelled effluent management system is to identify the:

- Amount of nutrients in liquid effluent from the farm dairy and/or the wintering pad animal shelter effluent management systems that are applied to blocks.
- Amount of nutrients in solid effluents from different sources that are applied to blocks.
- Amount of nutrients in effluent exported from the farm.

- Atmospheric gas emissions (volatilisation, denitrification and nitrous oxide emissions) from excreta effluent N within the effluent management system.
- Amount of dung DM from different sources so that methane emissions can be estimated.

The amount of nutrients in effluent and their sources are shown in section 2.4.1 and 2.4.2, the distribution of nutrients within the effluent management system is described in section 3, and outputs for nutrients in described in section 6.

Similarly, the amount of dung DM in effluent and their sources are shown in section 2.4.3, the distribution of nutrients within the effluent management system is described in section 5, and outputs for nutrients in described in section 6.

2.2. Definition of structures

The definitions of farm structures are based on Dexcel (2005), Luo *et al*. (2008) and Luo and Longhurst (2008).

2.2.1. Farm dairy

The farm dairy is the place where milking occurs.

In-shed feeding is the feeding of supplement during milking. If in-shed feeding is selected, supplements (brought in or farm grown) or farm-grown fodder crops must be allocated to in-shed feeding.

In-shed feeding assumes that there is no additional effluent added to the effluent management system because the animals are fed while milking.

Farm dairy applies to both dairy cows and dairy goats. As both animals are unlikely to be on a farm at the same time, a single farm dairy effluent management system is used.

2.2.2. Feed pad

A feed pad is normally a hard surface area (usually concrete) sited adjacent to the farm dairy where stock can be held for some time (1-2 hours), either prior to or after milking, and provided with supplementary feed. Feed pads are usually included in a farm system to improve supplementary feed use compared to paddock feeding.

If a feed pad is selected, some supplements (brought in or farm grown) or farm-grown fodder crops must be allocated to the feed pad.

Currently this only applies to dairy cows.

2.2.3. Standoff or loafing pad

A standoff pad is a specially built area where stock can be withheld from grazing during wet periods to minimise damage to pasture. These pads are typically constructed of free-draining materials such as sawdust, bark, wood chips, lime, or a soft metal (rock) mix. Since cows may be withheld for extended periods (20 hours/day) an area of about 8-10 m^2 per cow is recommended (Dexcel 2005).

There is no provision for stock feeding while the animals are on the standoff/loafing pad.

Currently this only applies to dairy cows.

2.2.4. Wintering pads/animal shelters

A wintering pad or animal shelter is a specially built area where animals are withheld from pasture for extended periods and supplementary feeds are brought to them. The herd may spend several months on the pad so a similar sized area as for stand-off pads is required for cows to lie down, as well as additional space for feeding. In some cases, rather than supplements being brought to the animals, or in addition to supplements, animals are allowed to graze pastures for a limited time (e.g. 3-6 hours) each day. In some structures, the feeding and bedding areas are separate, with the feeding area being a concrete apron similar to a feed pad.

A wintering barn or animal shelter is similar to the wintering pad, except that it is covered. The animals are usually withheld from pasture for extended periods and supplementary feeds are brought to them in the wintering barn.

Animals on wintering pads/animal shelter can be recorded as grazing pasture on a monthly basis while on the pad, or only being fed on the wintering pad/animal shelter. If the option to only feed animals on the wintering pads/animal shelter is selected, or if in any given month no grazing on pasture is selected, then supplements (brought in or farm grown) or farm-grown fodder crops must be allocated to the wintering pad/animal shelter.

A wintering pad/animal shelter can be described for animal enterprises other than Sheep or ‘Other’.

2.2.5. Lanes and races

Lanes and races are structures used by animals to move about the farm. While animals are on them, excreta is deposited as described in the Intakes chapter.

2.3. Describing the effluent management system model

The description of the effluent management system model is based on Luo and Longhurst (2008). When setting up the effluent system, a generic approach was taken. Features of structures and management practices that effect a change in nutrient flows are used to describe the system. This was partly due to information on separation ratios, and loss and emission rates only being known for some options. The follow generalised constructs have been used in the effluent management system:

<u>Farm dairy effluent management</u>

Effluent managed through the farm dairy or wintering pad effluent management system have management options, ‘Spray from sump', '2 pond + discharge', 'Holding pond', and 'All exported'. The holding pond option includes sub-options of 'Spray regularly', 'Stir & spray regularly', 'Spray infrequently', and 'Liquid exported'. The definitions of the management options are shown in Table 1. The behaviour of farm dairy or wintering pad effluent management systems are the same, although the interface presentation and inputs differ.

Table 1. Definitions of options for farm dairy effluent management systems.

Option	Description	
Spray from sump	All effluent is applied to land directly from a sump at the time it is generated (following each milking). There is no separation of solids. There is a volatilisation loss of N associated with the process of spraying.	
2 pond + discharge	Effluent is added to 2 stage oxidation ponds. The effluent is separated into atmospheric loss (N), sludge, and nutrients lost to direct to freshwater.	
Holding pond	Effluent is added to a holding pond, with separation into sludge and liquid depending on the options selected. For N, atmospheric losses vary with each treatment. The treatment options available are:	
	Spray regularly	Some settling of effluent to sludge, the rest applied to land.
	Stir and spray regularly	Little sludge formed due to stirring process.
	Spray infrequently	Effluent is held in a holding pond long enough for solids to settle out forming a sludge layers, typically about 2 weeks.

Liquid effluent that is not exported is assumed to be applied from the farm dairy or wintering pad effluent management system. It can be applied to pastoral, cut and carry, fodder crop, cropping and fruit crop blocks. The type of effluent (liquid effluent from the farm dairy or wintering pad/animal shelter) is specified at the block level. In addition, on blocks that receive liquid effluent:

- The depth of application can be selected, with options 'Low application method', 'Irrigator - fast (< 12 mm)', 'Irrigator - medium (12-24 mm)', and 'Irrigator - slow (> 24 mm)'. This is used to estimate runoff nutrient losses.
- An option to select whether or not ‘Applications are actively managed’. This implies that during application, the application equipment is monitored to ensure that there is no losses, and that application depths and rates are managed such that there is no ponding or overland flow losses. Note that the model assumes best management practices are followed, and that active manage implies more stringent monitoring than BMP is in place.
- For pastoral blocks, the ‘Percentage of block area receiving effluent’ can be entered. By default, 100% is assumed. This splits the block into areas that receive effluent and those that don’t. It assumes that all other inputs and management are the same. This caters for blocks where a small portion of the paddock may not receive effluent, such as its corners, or a steep face.
- Months effluent is applied must be entered for fodder and cropping blocks, and can be entered if the Holding pond option 'Spray infrequently' is selected. This can be used to describe deferred irrigation options (see section 3.2.4.1).

Solid separation

Solids are separated into a liquid and solid component, with the ratio varying for each nutrient.

Solids management method

Solid effluent can be stored (see Storage of solids before application). The solids can be applied to specified block(s) or exported directly. Solid effluents can be applied to pastoral, cut and carry, and to fodder, cropping and fruit crop blocks. When applied to blocks, the type of solid and the month of application is specified as a block input for each type of solid applied.

Storage of solids before application

Solids can be stored either under cover or in uncovered stacks, or not stored. Storage conditions affect the proportion of N lost as atmospheric gases, and the amount of nutrients lost from the stored stack due to leaching. If stored, the months of storage are entered. This affects the proportion of N lost as atmospheric gases.

Concrete feeding surfaces

These are feed pads, or concrete feeding aprons within a wintering pad/animal shelter. The concrete surface has:

- The 'Manure removal method' for feed pads or 'Concrete apron cleaning method' for wintering pads/animal shelters have options of 'Scraped (no water)' or 'Flushed with water'.
- With a removal method of 'Flushed with water', there is the option 'Solids are separated'. Typically, a solid separation system is used after flushing. With a removal method of 'Scraped (no water)' there is the option 'Solids are separated' or 'Scraped material added to farm dairy effluent system' which are mutually exclusive. Typically liquid effluent is separated out when removed from the pad or when scraping.

Uncovered surfaces

The uncovered surface of stand-off pads and uncovered wintering pads are treated in a similar manner. The management of these surfaces includes:

- Pad surface, with options, 'Carbon rich (sawdust, bark, woodchips)' and 'Inert (lime, rockmix)'.
- An option to select 'Lined, concrete floor or subsurface drained and effluent captured'
- An option to select 'Surface scraped regularly'

Bunkers

Bunkers only occur in covered wintering barns and animal shelters.
The options for the 'Bunker lining material' are 'No lining material', 'Carbon rich (sawdust, bark, woodchips)' and 'Soil'. These affect the degree of separation of nutrients into liquid and solid fractions, and the atmospheric gas emissions. If the option 'No lining material' is selected, the options are the same as those for concrete feeding surfaces. If the bunker is lined with carbon rich material or soil, the time (months) between first adding animals and cleaning out the bunker must be entered and also whether or not liquids are drained away is selected. The latter is similar to 'Lined, concrete floor or subsurface drained and effluent captured' specified for a lined standoff/loafing pad.

2.4. Model inputs

2.4.1. Nutrients

The amount of excreta deposited on farm structures is defined in the Intake chapter. The variables, definitions and where they are used in this chapter is shown in Table 2.

Table 2. Input variables that represent the amount of excreta deposited on farm structures, the variable definitions and the section in which they are used.

Input	Definition	In section
$nuttoeffluen_{antype, nut}$	Excreta deposited on farm dairy.	3.1
$nutfromfeedpad_{antype, nut}$	Excreta deposited on feed pad.	3.3
$nutfromstandoff_{antype, nut}$	Excreta deposited on standoff/loafing pads.	3.4
$nutfromwinpad_{antype, nut}$	Excreta deposited on wintering pad/animal shelters.	3.5
$nuttolane_{antype, nut}$	Excreta deposited on lanes and races.	3.6

2.4.2. Unutilised feed

Feed that is fed in the milking shed or on pads but not utilised is assumed to join the effluent management system. The nutrients in unutilised feed are added after atmospheric losses associated with excreta deposition are estimated. For wintering pad/animal shelters, the amount of nutrients in unutilised feed (kg nutrient/year) is estimated as:

Equation 1: $$UnutilisedWP_{antype, nut} = SupNutUnUtilWP_{antype, nut} + CropNutUnUtilWP_{antype, nut} + SupFarmLeftNutUnUtilWP_{antype, nut}$$

SupNutUnUtilWP is the amount of nutrient in unutilised supplements (kg nutrient/year) fed on the wintering pad/animal shelters [Supplements chapter].

CropNutUnUtilWP is the amount of nutrient in unutilised crops (kg nutrient/year) fed on the wintering pad/animal shelters [unpublished].

SupFarmLeftNutUnUtilWP is the amount of nutrient in unutilised feed left over by dairy goats (kg nutrient/year) fed on the wintering pad/animal shelters [Supplements chapter].

Similar estimates are made for unutilised supplements left on the feed pad (UnutilisedFP) and in-shed feeding (UnutilisedMilk), except there is no left-over feed.

2.4.3. Dung dry matter

The amount of dry matter in excreta dung deposited on farm structures is defined in the Intake chapter, as are variables, definitions and the chapter in which they are used (Table 3).

Table 3. Input variables that represent the amount of dry matter (DM) in excreta dung deposited on farm structures, definitions and the section in which they are used.

Input	Definition	In section
$dungtoeffluent_{antype}$	DM in excreta dung deposited in farm dairy.	5.1
$dungfromfeedpad_{antype}$	DM in excreta dung deposited on feed pad.	5.2
$dungfromstandoff_{antype}$	DM in excreta dung deposited on standoff/loafing pad.	5.3
$dungfromwinpad_{antype}$	DM in excreta dung deposited on wintering pad/animal shelters.	5.4
$dungtolane_{antype}$	DM in excreta dung deposited on lanes and races.	5.5

3. Distribution of nutrients

This section describes the fate of nutrients in excreta. Calculations are undertaken for each animal enterprise and nutrient.

When describing atmospheric N losses, reference is given to the variable that defines the nutrient rate (kg N/year) that the calculations for estimating atmospheric N losses are based on, and the case reference. The case reference refers to the method used to estimate atmospheric N losses (section 4.1). It is also used in other sections of the technical manual to refer to a particular source. Thus, for shed deposition (section 3.1) the input rate is nuttoeffluent, and the case reference is LShed.

Similarly, when describing nutrients that are lost from the effluent, a reference is given to the nutrient rate that the calculations are based on, and the case reference.

3.1. Shed deposition

The deposition of nutrients in the farm dairy during milking are estimated based on time (Intakes chapter).

Atmospheric N losses when excreta is deposited on the shed’s concrete area (nuttoeffluent, Intakes chapter) are estimated as described in section 4.1 (LShed case).

The remaining nutrients (nutfromshed) enter the farm dairy effluent management system (section 3.2.1).

3.2. Farm dairy effluent management

Farm dairy effluent management model describes the movement and fate of nutrients in from the combination of excreta deposited in the dairy shed and on the feed pad, liquids from standoff/loafing pad (liquid only), and in effluent from wintering pads/animal shelters are directed to the farm dairy effluent system. There is only one farm dairy effluent management option to cover both dairy cows and dairy goats as it was considered unlikely that both dairy and dairy goat enterprises would be present on the same farm.

3.2.1. Farm dairy effluent

Total nutrients in effluent from the dairy shed and other structures (feed pad, standoff/loafing pads and wintering pads/animal shelters) that are managed by the farm dairy effluent system are accumulated as:

Equation 2: $nutinput_{nut} = nutfromshed_{antype, nut} + feedpadtoeffluent_{antype, nut} + WinPadtoeffluent_{antype, nut} + standofftoeffluent_{antype, nut}$

nutfromshed is the nutrient in excreta deposited on the shed's concrete area (kg nutrient/year) [section 3.1].

feedpadtoeffluent is the nutrient in excreta deposited on the feed pad that is directed to the farm dairy effluent system (kg nutrient/year) [section 3.3].

WinPadtoeffluent is the nutrient from effluent from the wintering pad/animal shelter that is directed to the farm dairy effluent system [section 3.5.2].

standofftoeffluent is the nutrient in liquid component of effluent from excreta deposited on the standoff/loafing pad (kg nutrient/year) [section 3.4].

In addition, nutrients in unutilised feed that was fed in the milking shed or on the feed pad that have not already been accounted for is accumulated as:

Equation 3: $UnutilisedFeed_{nut} = UnutilisedMilk_{antype, nut} + UnutilisedFP_{antype, nut}$

UnutilisedMilk is the nutrients in unutilised feed that was fed in the milking shed (kg nutrient/year) [Supplements chapter].

UnutilisedFP is the nutrients in unutilised feed that was fed on the feed pad (kg nutrient/year) [Supplements chapter].

Nutrients in unutilised feed from the wintering pad/animal shelters is included in wintering pad/animal shelter management (section 3.5).

Depending on the selected management option the model determines how the nutrients in farm dairy effluent management system (nutinput, Equation 2) and utilised feed (UnutilisedFeed, Equation 3) are managed and distributed. The management options are spray from sump (section3.2.2), 2-pond plus discharge direct to stream (section 3.2.3), holding pond (section 3.2.4) and exported (section 3.2.4.1).

3.2.2. Spray from sump

Atmospheric N losses when excreta (nutinput, Equation 2) is sprayed onto blocks are estimated as described in section 4.1 (LSpray case).

Atmospheric N losses are subtracted from nutinput before unutilised feed is added total distributed to blocks as liquid effluent application (section 6.1).

3.2.3. 2-pond plus discharge

Atmospheric N losses when excreta (nutinput, Equation 2) is added to a 2-pond treatment system are estimated as described in section 4.1 (Lpond case).

It is assumed that some nutrients settle as sludge in the bottom of the pond. It is also assumed that nutrients in unutilised feed also settle as sludge at a rate similar to that of solids from effluent. Hence, unutilised feed (Equation 3) is added to the effluent and then separated into solid (sludge) and liquid components assuming a long settling time (section 3.7.2).

The discharge from a 2-pond system is estimated as:

Equation 4: ponddischarge = (liquid - sludge)

and by definition, the discharge is directly to stream (section 6.5).

Atmospheric N losses from pond sludge are estimated as described in section 4.1 (Lsludge case). The remaining sludge is selected to be either exported as a solid (section 6.4) or applied on blocks (section 6.2, HPpondsludge case).

Leaching losses through the pond lining are ignored because it is assumed that ponds are well constructed and lined such that losses through the pond lining are minimal.

3.2.4. Holding pond

If solid separation is selected to occur before the effluent (nutinput, Equation 2) enters the pond, then:

- The effluent is separated into solid and liquid components (section 3.7.1).
- Nutrients in unutilised feed (Equation 3) is added to the solid component.
- Separated solids are assumed to be stored in a stack. Therefore, storage losses from the solids are estimated (section 3.8) based on the entered storage method and time in storage.
- Depending on the option selected, nutrients in solids is either exported as a solid (section 6.4) or is accumulated for distribution to blocks (SolidsHP, section 6.2).

If solids are not separated, then unutilised feed is added to the liquid component of the effluent.

Atmospheric N losses when the liquid component is added to the holding pond are estimated as described in section 4.1 (LHoldingPond case). The approach used assumes that atmospheric N losses from the liquid component when solid separation occurs are the same as that from non-separated effluent plus unutilised feed, and that atmospheric N losses occur close to the time of addition.

The liquid component is then separated into liquid and sludge components, with the separation ratio based on the selected liquid effluent management option (section 3.7.2). As above, the approach used assumes that atmospheric N losses from the liquid component when solid separation occurs are the same as that from non-separated effluent plus unutilised feed.

Sludge is selected to be either exported as a solid (section 6.4) or applied on blocks (section 6.2, HPondsludge).

The liquid component is selected to be either exported as a liquid (section 6.4) or applied on blocks (section 6.2).

Leaching losses through the pond lining are ignored because it is assumed that ponds are well constructed and lined such that losses through the pond lining are minimal.

3.2.4.1. *Deferred applications and storage*

Deferred effluent applications is where effluent is not applied if conditions are not conducive to minimising environment impacts. The technical definition is that the depth of application of effluent must be less than the available soil water deficit at time of application, otherwise effluent remains stored. The holding pond liquid effluent management option 'Stir and spray infrequently' implies that effluent storage is available through the provision of a suitable sized pond and effluent applications are deferred when practicable. Thus:

- If the months effluent applied is not specified, then the approach used assumes that effluent is applied in the months lactation and hence milking is occurring, but that within each month, the effluent is applied to minimise overloading of the soil. .
- If months effluent applied are selected, then the approach used assumes that effluent is applied within the month selected.

The months effluent is applied can vary between blocks. The model assumes that nutrient storage facilities do not result in additional losses, and that there is sufficient storage and pumping and distribution capacity to achieve the above objectives.

3.2.5. Exported

All nutrients in excreta that could have entered the farm dairy effluent system (nutinput, section 3.2.1) and unutilised feed (Equation 3) are exported as a liquid (section 6.4). Any atmospheric N losses are assumed to occur on the receiving farm.

3.3. Feed pad

When animals are on the feed pad, excreta nutrients deposited on the feed pad are assumed to be directed to the farm dairy effluent management system. However effluent can be separated in liquid and solid components before it joins the farm dairy effluent management system.

Atmospheric N losses when excreta is deposited on the feed pad (nutfromfeedpad, Intakes chapter) are estimated as described in section 4.1 (LFeedPad case).

If the manure removal method option 'Scraping (not water)' is selected then:

- if the option 'Solid separation' is selected, the effluent is separated into a solid and liquid components (section 3.7.1), and nutrients in unutilised feed fed on the feed pad is added to the solid component; else

- if the option ‘Scraped material added to farm dairy effluent system’ is selected then all nutrients in the effluent and unutilised feed is added to the liquid component; otherwise
- all nutrients in the effluent and unutilised feeds fed on the feed pad is added to solid component.

Alternatively, if the manure removal method option ‘Flushing with water’ is selected then:

- if solid separation is selected then the effluent is separated into solid and liquid components (section 3.7.1), and unutilised feed fed on the feed pad is added to the solid component; otherwise
- all effluent and unutilised feeds fed on the feed pad are added to liquid component.

If there are nutrients in the solid component, then:

- Storage losses from the separated solids are estimated (section 3.7.1) based on entered storage method and time in storage.
- Nutrients in the solid component are selected to be either exported as a solid (section 6.4) or are accumulated for distribution to blocks (section 6.2, SolidsFP).

Nutrients in the liquid component are transferred to farm dairy effluent management system (section 3.2.1, feedpadtoeffluent).

3.4. Standoff/loafing pads

Atmospheric N losses when excreta is deposited on the standoff/loafing pad (nutfromstandoff, Intakes chapter) is estimated as described in section 4.1 (Lstandoff case).

The surface of the standoff pad is assumed to be scraped at regular intervals if the option ‘Surface scraped regularly’ is selected, or once or twice a season otherwise. Any scraped effluent and bedding material is assumed to be stored in a stack.

If the option ‘Surface scraped regularly’ is not selected, then it is assumed that deposited excreta accumulates on the pad surface and that losses are equivalent to losses from an uncovered stack with 12 months storage (section 3.8).

The remaining deposited nutrients are separated into ‘Liquid’ or ‘Solid’ components if the selected pad surface is ‘Inert’, or into ‘Liquid’, ‘Solid’ or ‘Left’ components if the pad surface is ‘Carbon rich’ (see section 3.7.3 for definitions).

If the option ‘Lined, concrete floor or subsurface drained and effluent captured’ is selected, it is assumed that the liquid component enters the farm dairy effluent system (section 3.2.1, standofftoeffluent).

Alternatively, if this option is not selected, then nutrients in the liquid component are assumed to be lost as leaching (section 6.5, LStandoffLoss). This can result in high loss in the ‘Loss to water’ term of the farm nutrient budget, and ‘Other sources’ term in the N and P reports.

Nutrients in the component that are 'Left' are assumed to accumulate on the farm and hence nutrients N, P and S are added to immobilisation. Other nutrients are added to inorganic components (section 6.5, LStandoffLoss).

Storage losses from the solids stored in a stack are estimated based on entered storage method and time in storage (section 3.8). The remaining nutrients in the solid component are selected to either exported as a solid (section 6.4) or are accumulated for distribution to blocks (section 6.2, SolidsST).

3.5. Wintering pads/animal shelters

The concrete feeding apron of a wintering pad/animal shelters is assumed to be similar to feed pads, and uncovered bedding material is assumed to be similar to standoff/loafing pads. Covered systems with bunkers are considered separately.

Nutrients in excreta deposited on the wintering pad/animal shelter is divided between the concrete feeding apron and the bedding area based on time. Thus:

Equation 5: BeddingRate = nutfromwinpad * (1 - (TimeConcrete / 24))

Equation 6: ConcreteRate = nutfromwinpad * TimeConcrete / 24

nutfromwinpad is the amount of nutrient deposited as excreta on the uncovered wintering pad/animal shelter (kg nutrient/year) [Intakes chapter].

TimeConcrete is the entered time spend on the concrete feeding apron (hours).

If the option 'Concrete feeding apron is present' is not selected, then any unutilised feed fed on the wintering pad/animal shelter is added to the bedding rate:

Equation 7: BeddingRate = BeddingRate + $\text{UnutilisedWP}_{\text{antype, nut}}$

3.5.1. Covered bunkers

Covered animal shelters are assumed to have a bunker. Atmospheric N losses when excreta is deposited in the bunker (BeddingRate, Equation 7) are estimated as described in section 4.1 ($\text{Lbunker}_{\text{Unlined}}$ or $\text{Lbunker}_{\text{Lined}}$ case, depending on whether selected 'Bunker lining material' is 'No lining material' or not respectively).

If the bunker lining material option 'No lining material' is selected (i.e. it is concrete bunker with no soil or carbon rich material) then if the bunker cleaning method is 'Scraping, no water' then

- if 'Solids are separated' is selected, the effluent is separated into 'Solid' and 'Liquid' components (section 3.7.1), and unutilised feed fed on the bedding area (i.e. when there is no concrete apron) is added to the 'Solid' component; else
- if the option 'Scraped material added to farm dairy effluent system' is selected then all effluent and unutilised feed is added to the 'Liquid' component; otherwise
- all effluent and unutilised feed fed on the feed pad is added to the 'Solid' component.

Otherwise if the bunker cleaning method option 'Flushing with water' is selected then:

- if ‘Solids are separated’ is selected then the effluent is separated into ‘Solid’ and ‘Liquid’ components (section 3.7.1), and unutilised feed fed on the feed pad is added to the ‘Solid’ component; otherwise
- all effluent and unutilised feed fed on the feed pad are added to the ‘Liquid’ component.

Alternatively, if the selected option for bunker lining material is not ‘No lining material’ (i.e. it is lined with soil or carbon rich material) then if the option ‘Liquids drained away (added to liquid effluent)’ is selected, the effluent is separated into ‘Solid’ and ‘Liquid’ components (section 3.7.1).

Nutrients in the ‘Solid’ and ‘Liquid’ components are distributed based on wintering pad/animal shelter solid and liquid effluent management options (section 3.5.1 and 3.5.2 respectively).

3.5.2. Uncovered bedding

Atmospheric N losses when excreta is deposited on the uncovered bedding material (BeddingRate, Equation 7) are estimated as described in section 4.1 ($LWinpad_{Bedding}$ case). This is the estimated loss at time of deposition.

If the option ‘Surface scraped regularly’ is not selected, then it is assumed that deposited excreta sits on the pad surface and that losses are equivalent to losses from an uncovered stack with 12 months storage (section 3.8). Atmospheric N losses from the scraped material (BeddingRate) are estimated as described in section 4.1 ($LStack_{Scraped}$ case).

The remaining deposited nutrients are apportioned between ‘Liquid’ and ‘Solid’ components if the selected pad surface is ‘Inert’, or into ‘Liquid’, ‘Solid’ and ‘Left’ components if the pad surface is ‘Carbon rich’ (section 3.7.3).

If the option ‘Lined, concrete floor or subsurface drained and effluent captured’ is selected, the liquid component enters the wintering pad/animal shelter liquid effluent system (section 3.5.1). If this option is not selected, then nutrients in the liquid component are assumed to be lost as leachate (section 6.5, Lwinpadbed). This can result in a large loss in the ‘Nutrient removed to water’ term of the farm nutrient budget, and the ‘Other sources’ term in N and P reports.

Nutrients in the ‘Left’ component are assumed to accumulate on the farm. Hence nutrients N, P and S are added to immobilisation and other nutrients are added to inorganic components (section 6.5, Lwinpadbed).

Nutrients in the ‘Solid’ component are added to the wintering pad/animal shelter liquid effluent system (section 3.5.1).

Nutrients in the ‘Solid’ and ‘Liquid’ components are distributed based on wintering pad/animal shelter solid and liquid effluent management options (section 3.5.1 and 3.5.2 respectively).

3.5.3. Concrete apron

The methods for distributing nutrients deposited on the concrete feeding apron are similar to those used for feed pads. Thus atmospheric N losses when excreta is deposited on the concrete surface (ConcreteRate, Equation 6) are estimated as described in section 4.1 ($Lwinpad_{concrete}$ case).

If the manure removal method option is 'Scraping (not water)' is selected then:

- if solid separation is selected, the effluent is separated into 'Solid' and 'Liquid' components (section 3.7.1), and unutilised feed fed on the concrete apron is added to the 'Solid' component; else
- if the option 'Scraped material added to farm dairy effluent system' is selected then all effluent and unutilised feed is added to the 'Liquid' component; otherwise
- all effluent and unutilised feeds fed on the feed pad is added to 'Solid' component.

Alternatively, if the manure removal method option 'Flushing with water' is selected then:

- if solid separation is selected then the effluent is separated into 'Solid' and 'Liquid' components (section 3.7.1), and unutilised feed fed on the feed pad is added to the 'Solid' component; otherwise
- all effluent and unutilised feeds fed on the feed pad are added to 'Liquid' component.

If there are nutrients in the 'Solid' component, then storage losses from the separated solids are estimated (section 3.8) based on the entered storage method and time in storage.

Nutrients in the 'Solid' and 'Liquid' components are distributed based on wintering pad/animal shelter solid and liquid effluent management options (section 3.5.1 and 3.5.2 respectively).

3.5.1. Solid effluent management

If there are nutrients in the solid component from covered bunkers (section 3.5.1) or uncovered bedding (section 3.5.2), or from the concrete feeding apron (section 3.5.3), then:

- Storage losses from the solids are estimated (section 3.8) based on the entered storage method and time in storage.
- The nutrients in the 'Solid' component is selected to either exported as a solid (section 6.4) or is accumulated for distribution to blocks (section 6.2, SolidsWP).

3.5.2. Liquid effluent management

Liquids from covered bunkers (section 3.5.1), uncovered bedding (section 3.5.2), or from the concrete feeding apron (section 3.5.3) can be added to the farm dairy effluent system (WinPadtoeffluent) or the wintering/animal shelter can have its own effluent management system.

The wintering pad effluent management systems parallel the farm dairy effluent systems. It allows effluent from the farm dairy and wintering pads to be applied to different blocks. The options and methods used to estimate the fate of nutrients in liquid effluent from the wintering pad are the same as the farm dairy. Thus:

- Any atmospheric N losses are covered by the Linpad case.
- 2-pond plus discharge uses the same method used for farm dairy effluent (3.2.3), except that nutrients in pond sludge applied on blocks (section 6.2) is accumulated as WPpondsludge.
- Spray from sump uses the same method used for farm dairy effluent (3.2.2), except that nutrients applied on blocks (section 6.1) are accumulated as WPeffluent.
- Holding pond options uses the same method as used for farm dairy effluent (3.2.4), except that nutrients applied on blocks (section 6.1) is accumulated as WPeffluent, and nutrients in pond sludge applied on blocks (section 6.2) is accumulated as WPpondsludge.
- Export uses the same method as used for farm dairy effluent (3.2.5).

3.6. Lanes and races

Nutrient losses from lanes and races are estimated and added to the loss to water item in the farm nutrient budget. There are currently no mitigation options to reduce these estimated losses. However, any changes that result in changes in intake, and hence the amount of nutrient transferred to lanes and races, is reflected in the loss to water.

Management factors such as beaming of lanes and races, the number of stock crossings or bridges, or losses through runoff directly out of the yard or farm entrances have not been included in the model.

Atmospheric N losses when excreta is deposited on the lanes and races (nuttolane, Intakes chapter) is estimated as described in section 4.1 (LLane case).

The proportion of N that is leached varies with rainfall (section 3.6.1), with a base level of 15%. The remaining N is added to the immobilisation pool.

For potassium (K), the proportion of K deposited on lanes and races that is leached is based on the leaching loss factor calculated for a pastoral block's non-urine part, assuming a high soil K level of 12 and a leaching loss factor equivalent to the maximum leaching potential. Thus:

Equation 8: $propleach = (0.0075 + 0.00005 * 12) * 6$

6 is the maximum leaching potential.

The remaining K is added to the inorganic pool.

For phosphorus and sulphur, it is assumed that 30% of the P deposited on lanes and races is lost as leaching. The remaining P and S are added to the immobilisation pool.

For Ca, Mg, and Na, it is assumed that the proportion of deposited nutrient that is leached varies with rainfall (section 3.6.1), with a maximum of 20% being leached. The remaining Ca, Mg and Na is added to the inorganic pool.

For acidity, it is assumed that the material is an organic material with NH_4, NO_3 and organic N ratios similar to that of effluent. Hence the change in acidity associated with leaching is estimated as:

Equation 9: $Leach_{H+} = (0.14 * 0.178 * nuttolane_{antype, N} + 0.07 * 0.815 * nuttolane_{antype, N}) / nuttolane_{antype, N} * lossoff_{antype, LLane, leach, N}$

The remaining acidity is assigned to the inorganic pool.

Nutrients added to the immobilisation or inorganic pool may not necessarily remain on the lanes and races. They may also represent nutrients that run off the edge of lanes and races into paddocks and are not leached or lost to waterways.

3.6.1. Rainfall adjustment

For lanes and races, the proportion of nutrients that are leached is adjusted for rainfall. This factor is based on an earlier model whereby it was considered that the maximum rate of leaching was 1.6 times that at 1150 mm/year rainfall.

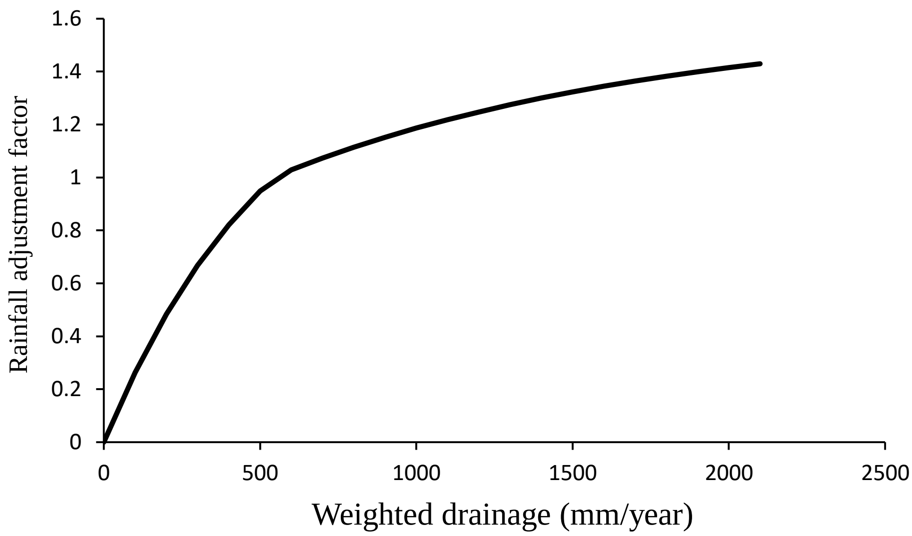

Figure 2. Relationship between the weighted drainage and the rainfall adjustment for estimating leaching losses.

When drainage is greater than or equal to 550mm, the rainfall adjustment factor (LLeach) is estimated as:

Equation 10: Lleach = (1.6 - 1.6 * Exp(-0.000805 * (Wdrainage + 680)))
Wdrainage is the area weighted drainage (mm/year).
680 is the mean national potential evapotranspiration (mm/year).

Otherwise if the weighted drainage is less than 500, it is estimated as:

Equation 11: Lleach = 1.6 - 1.6 * Exp(-0.0018 * Wdrainage)

Drainage is estimated as the difference between the area weighted average rainfall for pastoral and cropping blocks on the farm, and the national average potential evapotranspiration of 680 mm/year (McDowell et al., 2005). For hard surfaces, drainage through the profile is probably lower. Hence the weighted drainage (Wdrainage, mm/year) is estimated as:

Equation 12: drainage = (Wrain - 680) * 0.8

Wrain is the area weighted average rainfall for pastoral and cropping blocks on the farm (mm/year).

680 is the national average potential evapotranspiration (mm/year).

3.7. Separation

3.7.1. Solid separation

If solid separation is used, then the effluent is separated into a liquid and solid components:

Equation 13: solid = rate * $\text{ratioseparationsolid}_{nut}$

Equation 14: liquid = rate * (1 - $\text{ratioseparationsolid}_{nut}$)

rate is the amount of effluent (kg nutrient/year).

ratioseparationsolid is the separation ratio (Table 4).

This approach assumes that the separation ratio is the same for the different types of separation systems, such as mechanical separation, seepage walls, or settling ditches.

Table 4. Proportion of nutrients separated into the solid component when solid separation systems are used.

	N	P	K	S	Ca	Mg	Na	H
Ratio	0.30	0.95	0.10	0.50	0.95	0.85	0.35	0.63

3.7.2. Sludge separation

If effluent is added to a pond, some nutrients settle out in the pond sludge.

Equation 15: pondsludge = rate * $\text{ratiopondsludge}_{nut}$

Equation 16: liquid = rate – pondsludge

rate is the amount of effluent (kg nutrient/year).

ratiopondsludge is the separation ratio (Table 5).

The separation ratio is dependent on how long the effluent is allowed to settle in the pond. The short settling time is defined as effluent in the pond for less than 2 weeks, or greater than 2 weeks when stirring occurs. The long settling time values are used when effluent is in the pond for 2 weeks or more without stirring. Based on these definitions, the long settling time values are used for 2-pond systems, and ‘Spray infrequently’ option for holding ponds, and the short settling time is used for the ‘Spray regularly’ option for holding ponds. For the option, ‘Stir and spray regularly’, it is assumed that stirring results in little sludge settling, and hence 10% of the short settling time is applied.

Table 5. Proportion of nutrients added to a pond that settle as sludge (Luo and Longhurst, 2008).

Settling time	N	P	K	S	Ca	Mg	Na	H
Short	0.10	0.30	0.033	0.165	0.31	0.28	0.12	0.23
Long	0.30	0.70[1]	0.10	0.50	0.95	0.85	0.35	0.56

[1] Greater than the value reported by Luo and Longhurst (2008).

3.7.3. Bedding materials

Separation on a standard pad is dependent on whether the surface has an inert or carbon rich material on the surface. Inert material includes lime and rock mix. Carbon rich includes sawdust, bark and woodchips.

For inert material, the separation into solid and liquid component is estimated as:

Equation 17: $Solids = rate * STSolidInert_{nut} / 100$
Equation 18: $Liquid = rate - solids$

rate is the amount of effluent (kg nutrient/year).
STSolidInert is the separation ratio for inert bedding material (Table 6).

For carbon rich material, the separation into solid and liquid component is estimated as:

Equation 19: $Solids = rate * STSolidCrich_{nut} / 100$
Equation 20: $Liquid = rate * STLiquidCrich_{nut} / 100$
Equation 21: $Left = rate - solids - liquid$

rate is the amount of effluent (kg nutrient/year).
STSolidCrich is the separation ratio for solids from carbon rich bedding material (Table 6).
STLiquidCrich is the separation ratio for liquids from carbon rich bedding material (Table 6).

Table 6. Separation ratio (%) for carbon rich bedding (Luo and Longhurst, 2008).

Type of material	N	P	K	S	Ca	Mg	Na	H
STSolidInert	30	80	10	50	95	85	35	62
STSolidCrich	30	80	10	50	95	85	35	62
STLiquidCrich	18	0.2	40	15	0	0	45	14

3.8. Storage losses

If the selected method of storage is ‘Uncovered stacks’ then leaching losses are estimated as:

Equation 22: $Leached_{nut} = solid_{nut} * StorageLeach_{nut} / 100 * timestorage / 12$

solid is the rate that solid effluent is stored in the stack (kg nutrient).

StorageLeach is the proportion of nutrient in the solid that is leached each year [Table 7].

timestorage is the entered time in storage (months).

Atmospheric N losses from stored solids are estimated as described in section 4.1 ($LStack_{Storage}$ case).

Nutrients lost to the atmosphere or leached are deducted from the solid input and added to nutrient losses (section 6.6).

Table 7. Leaching losses (% per year) from stored effluent (Luo and Longhurst, 2008).

	N	P	K	S	Ca	Mg	Na	H
StorageLeach	5	0	10	5	0	0	10	13

4. Atmospheric N losses

Atmospheric N losses are estimated and identified separately for each type of loss (volatilisation, denitrification) to align with nutrient budget outputs, and for each type of loss (volatilisation, denitrification, nitrous oxide) and each animal enterprise to align with greenhouse gas output and footprint reports.

Atmospheric N losses from effluent are accounted for at the farm level. Consideration was given to accounting for atmospheric N losses when spraying at the block level, i.e. ascribing losses to a given block. For simplicity, this was not adopted.

4.1. Generic

Atmospheric N losses, volatilisation, denitrification and nitrous oxide emissions, are estimated for different effluent sources (and cases referred to in section 3) for a given rate (kg N, section 3) using the methods referred to in Table 8. Unless indicated, the effluent source rate is reduced by the amount of volatilisation, denitrification and nitrous oxide emissions before being used in subsequent calculations in section 3. Thus:

Equation 23: rate = rate - volatloss - denitloss - NitOxide

rate is the effluent rate from section 3 (kg N).

volatloss, denitloss and NitOxide (kg N) using the method referred to in Table 8.

The estimated rates of volatilisation, denitrification and nitrous oxide emissions are then used to develop nutrient budget and greenhouse gas reports (section 6.7).

Table 8. Source of atmospheric N losses, and methods use to estimate them.

Source	Description	Method
LShed	Losses from farm dairy from excreta deposited on the yard.	4.2.1
LSpray	Losses during the spraying process.	4.2.1
LPond	Losses while in the 2-pond system.	4.2.1
LHoldingpond	Losses when effluent is added to a holding pond.	4.2.1
LSludge	Losses from sludge when sludge is removed from the pond.	4.2.1
LFeedpad	Losses from feed pad.	4.2.2
LStandoff	Losses on deposition on a standoff pad	4.2.1
LBunker	Losses from effluent in bunker of covered wintering pad ($LBunker_{lined}$ or $LBunker_{unlined}$)	4.2.1 and 4.2.3
LWinPad	Losses from excreta deposited on bedding from an uncovered wintering pad/animal shelter ($Lwinpad_{Bedding}$)	4.2.1
	Losses from excreta deposited on a concrete apron $Lwinpad_{Concrete}$	4.2.2
LStack	Losses from stored solids ($LStack_{Storage}$)	4.2.4
	Losses from scraped solids from an uncovered wintering pad/animal shelter ($LStack_{Scraped}$)	4.2.1
LRace	Losses from lanes and races	4.2.1

4.2. Methods

4.2.1. Rate constants

For each source, the amount of volatilisation, denitrification and nitrous oxide emissions is estimated from the amount of N in the effluent (rate), with rate estimated as outlined in section 3, multiplied by an emission rate. For the effluent sources listed in Table 9, the emission rates are assumed to be constant over time and hence the timing of deposition is not required. Thus volatilisation, denitrification and nitrous oxide emissions (kg N/year) are estimated as:

Equation 24: volatloss= rate * rvolat

Equation 25: denitloss = rate * rdenit

Equation 26: NitOxide = rate * rnitoxide

rate is the amount of N for a given effluent source (kg N/year) from which emissions occur (section 3).

For the sources listed in Table 9, the volatilisation, denitrification and nitrous oxide emission rates (rvolatloss, rdenitloss and rnitoxide) are assumed to be constant over time. The following assumptions have been made when estimating atmospheric N losses.

- The pad surface has no effect on emission rates when excreta is deposited (Luo and Longhurst, 2008).
- Emissions from lanes and races is assumed to be the same as emissions from uncovered bedding.

- Spray losses are assumed to only occur freshly sprayed effluent is applied. When effluent is sprayed from holding ponds, the spray losses are assumed to be zero, although losses from holding ponds can occur.

Table 9. Volatilisation, denitrification and nitrous oxide emission rates.

Case code	Volatilisation	Denitrification	Nitrous oxide	Source[2]
LShed	0.06	0	0	1
LSpray	0.02	0	0	1
LPond	0.30	0.20	0.01	2
LHolding pond	0.15	0.05	0.001	2
LSludge	0.35	0	0	1
LStandoff	0.02	0.0001	0.0001	2
$LBunker_{Lined}$	- [1]	0.01	0.10	1
$LBunker_{Unlined}$	- [1]	0.001	0.02	1
$LWinpad_{Bedding}$	0.02	0.0002	0.0001	1
$LStack_{Scraped}$	0.30	0.10	0.01	1
LLane	0.02	0.0002	0.0001	

[1] See section 4.2.3.
[2] Sources: 1 = unknown; 2 = Luo and Longhurst (2008).

4.2.2. Concrete surfaces

Nitrous oxide emissions for feed pads were estimated as described by Luo and Longhurst (2008). The losses were based on the number of cows and hours cows were on the concrete surface, such that:

Equation 27: volatloss = 2 / 1000 * CowHours

Equation 28: denitloss = 65 / 1E6 * CowHours

Equation 29: NitOxide = 65 / 1E6 * CowHours

CowHours is the number of cow-hours on the feed pad or concrete apron of the wintering pad.

If cows are on the concrete surface all the time, then this equates to a volatilisation loss of about 17.5 kg N per cow per year, and a denitrification and nitrous oxide loss of about 0.57 kg N/cow/year.

4.2.2.1. *Cow-hours*

Cow hours is the number of cows multiplied by the number of hours on the structure. For feed pads, the number of cow-hours is estimated as:

Equation 30: $CowHours = \sum_{mon}(NumberMilkers_{mon} * FeedPadmonthProp_{dairy, mon} / 100 * FeedPadmonthTime_{dairy, mon} * daysinmonth_{mon})$

NumberMilkers is the number of milking cows each month [Animals chapter].

FeedPadmonthProp is the entered percentage of animals fed each month on the feed pad.

FeedPadmonthTime is the entered time spent on the pad each day (hours).

daysinmonth is the number of days in a given month.

Animals other than the dairy enterprise can use wintering pads/animal shelters. However, emission factors are only available for dairy systems. Therefore, the number of cow hours is calculated first based on cow equivalents. Thus:

Equation 31: $CowHours_{antype} = \sum_{mon}(CowEquivalents * WinPadmonthProp_{ansys, mon} / 100 * TimeApron * daysinmonth_{mon})$

CowEquivalents is the number of cow-equivalents.

WinPadmonthProp is the entered percentage of animals fed each month on the winering pad/animal shelter.

TimeApron is the entered time spent on a concrete apron each day

For dairy enterprise, cow equivalents is the number of milkers (Animal chapter). For other enterprises, the stock numbers on farm is converted to cow equivalents based on the actual and standard number of revised stock units (RSU) per animal. Thus, for dairy goats:

Equation 32: $CowEquivalents = NumberMilkersGoats * RSUperanimal_{dairygoats} / RSUperanimal_{dairy}$

NumberMilkersGoats is the number of milking goats [Animals chapter].

RSUperanimal is a standard number of RSU per animal [Animals chapter].

For other enterprises, cow equivalents is estimated as:

Equation 33: $CowEquivalents = RSU_{antype} / RSUperanimal_{dairy}$

RSU is the entered RSU or calculated RSU [Animals chapter].

RSUperanimal is a standard number of RSU per animal [Animals chapter].

4.2.3. Animal shelter bunkers

Initial volatilisation losses when excreta is deposited vary with bunker lining material, being 7, 8, and 9% for the options ‘No lining material’, ‘Carbon rich (sawdust, bark and woodchips’, and ‘Soil’ respectively (Luo and Longhurst, 2008).

Additional volatilisation losses while excreta remains in the bunker is estimated as:

Equation 34: $addvolatloss = BeddingRate * AnnVolat / 100 * TimeBunker / 12 / 2$

BeddingRate is the amount of N in excreta in the bunker.

AnnVolat is the annual volatilisation rate, which is 60% for unlined bunkers, and 30% for other bunkers’ lining materials.

TimeBunker is the entered time between first adding animals and cleaning out of bunker (months).

2 gives the average storage time in the bunker.

The initial and additional volatilisation losses are added together to give total volatilisation losses.

4.2.4. Stored material

The annual volatilisation loss from stacks is estimated as 30% per year of the N added to the stack (Luo and Longhurst, 2008). This loss predominately occurs within a short time of going into storage (Luo, AgResearch, pers. comm.). Thus:

- 50% of the annual volatilisation loss occurs within the first month of storage.
- An additional 30% of the annual volatilisation loss occurs if time in storage is greater than 1 month
- An additional 15% of the annual volatilisation loss occurs if time in storage is greater than 2 months
- Additional volatilisation loss occurs for each month in storage, up to 12 months of storage, estimated as:

Equation 35: 0.05 * (timestorage - 3) / 9

The annual denitrification loss from stacks in the first year is estimated as 10% per year of the N added to the stack (Luo and Longhurst, 2008) for the first year. This loss occurs throughout the storage period (Luo, AgResearch, pers. comm.). Thus:

- 10% of the annual denitrification loss for the first year occurs within the first 3 months of storage, with a third of this occurring for each month of storage.
- An additional loss of 10% per month of the annual denitrification loss for the first year occurs up to 12 months of storage.
- An additional annual denitrification loss of 5% per year, spread evenly over months for storage from 13 to 24 months.
- An additional annual denitrification loss of 1% per year, spread evenly over months for storage greater than 25 to 36 months.

The annual nitrous oxide emission rates from stacks in the first year is estimated as 1% per year of the N added to the stack (Luo and Longhurst, 2008) for the first year. This loss occurs throughout the storage period (Luo, AgResearch, pers. comm.). Thus:

- 10% of the annual nitrous oxide loss for the first year occurs within the first 3 months of storage, with a third of this occurring for each month of storage.
- An additional loss of 10% per month of the annual nitrous oxide loss for the first year occurs up to 12 months of storage.
- An additional annual loss of 0.5% per year, spread evenly over months for storage from 13 to 24 months.
- An additional annual loss of 0.1% per year, spread evenly over months for storage greater than 25 to 36 months.

5. Distribution of dung DM

Dung DM is used to estimate methane emissions (Calculation of methane emissions chapter). Dung DM is tracked for each animal enterprise because the emission factors for methane from dung vary with animal enterprise.

Most of the P in excreta is in dung. Therefore, it is assumed that the distribution of dung throughout the effluent system is similar to that for P. Dung in any exported effluent is ignored because it is assumed that any methane emissions occur on the receiving farm.

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

5.1. Farm dairy

Total dung DM that enters the farm dairy effluent system on the feed pad is estimated as:

Equation 36: $\text{dungIn} = \text{dungtoeffluent}_{\text{antype}} + \text{dungfeedpadtoeffluent}_{\text{antype}} + \text{dungWinPadtoeffluent}_{\text{antype}} + \text{dungstandofftoeffluent}_{\text{antype}}$

The dung DM is separated into the '*S*olid', 'Liquid', and 'Left' components based on P (section 3.2).

If the 'Spray from sump' option is selected, all dung DM is added to dung deposited on paddocks (section 6.8).

If the option '2-pond plus discharge is selected, all dung DM is added to the anaerobic pond variable (section 6.8). Dung DM in slurry applied to blocks is added to the dung slurry variable (section 6.8). Hence if slurry is applied on blocks, there are two sources of methane emissions from the dung, firstly from the anaerobic pond and then on application of slurry.

If the option 'Holding pond' is selected:

- If solid separation is selected, storage-time for dung DM in the solid component is estimated (section 6.8) based on the entered storage method and time in storage.
- Dung DM that is not in the pond solids' sludge (i.e. in the ponds) is added to the holding pond short duration variable if 'Spray' or 'Spray plus stir' options are selected. Otherwise it is added to the anaerobic pond variable (section 6.8).
- Dung DM in the 'Solid' component applied to blocks is added to the dung deposited on paddocks variable (section 6.8).
- Dung DM in slurry applied to blocks is added to the dung slurry variable (section 6.8).

5.2. Feed pad

Dung DM deposited on the feed pad (Dungfromfeedpad, Intakes chapter) is separated into the 'Solid' and 'Liquid' components based on P (section 3.3), and then distributed as follows:

- Storage-time for stored dung DM is estimated (section 6.8) based on the entered storage method and time in storage.

- Dung DM in the ‘Liquid’ component is transferred to the farm dairy effluent management system (section 5.1, dungfeedpadtoeffluent).
- Dung DM in the ‘Solids’ component applied to blocks is added to the dung deposited on paddocks (section 6.8).

5.3. Standoff/loafing pads

Dung DM deposited on the standoff/loafing pad (Dungfromstandoff, Intakes chapter) is separated into ‘Solid’, ‘Liquid’, and ‘Left’ components based on P (section 3.4), and then distributed as follows:

- If the standoff/loafing pad is lined, dung DM in the ‘Liquid’ component is transferred to farm dairy effluent management system (section 5.1, dungstandofftoeffluent).
- Dung DM in the ‘Liquid’ component that is not transferred to the farm dairy effluent management system, and dung DM in the ‘Left’ component is added to dung DM deposited on paddocks (section 6.8). It is assumed that methane emissions from dung deposited on a pad surface is the same as dung deposited on a paddock.
- If the option ‘Surface scraped regularly’ is selected, then storage-time for dung DM in the ‘Solid’ component is estimated (section 6.8) based on the entered storage method and time in storage. Otherwise storage-time is estimated for the total ‘Solids’, ‘Left’ and ‘Liquid’ components.
- Dung DM in solids applied to blocks is added to dung DM deposited on paddocks (section 6.8).

5.4. Wintering pads/animal shelters

For both covered and uncovered systems, dung DM deposited on wintering pads/animal shelters (Dungfromwinpad, Intakes chapter) is separated into total ‘Solid’, ‘Liquid’, and ‘Left’ components for both the bedding area and concrete apron based on P (section 3.5.1 or 3.5.2, and 3.5.3 for the concrete feeding apron), and then distributed as follows:

- Storage-time for store dung DM is estimated (section 6.8) based on the entered storage method and time in storage.
- Dung DM in the ‘Liquid’ component is transferred to the farm dairy effluent management system (section 5.1, dungfeedpadtoeffluent) or to the wintering pad/animal shelter effluent management system. Dung DM in wintering pad/animal shelter effluent management system is distributed as described for the equivalent options for the farm dairy system.
- Dung DM in solids applied to blocks, or in the ‘Left’ component is added to the dung deposited on paddocks (section 6.8).

5.5. Lanes and races

Methane emissions from dung deposited on lanes and races is assumed to be the same as dung deposited on paddocks, and hence dung DM deposited on lanes and races (dungtolane, Intake chapter) is added to the dung deposited on paddocks (section 6.8).

6. Outputs

The following information about effluent applied to blocks is required for the block calculations. The names of relevant variables referred to in other sub-models are given in brackets.

- The total amount of nutrient in liquid effluent from farm dairy and wintering pad systems (LiquidEff).
- The monthly amount of N and P added as effluent from the farm dairy, or wintering pad (EffluentNmon, EffluentWPNmon, EffluentNmon, EffluentWPNmon).
- The total amount of nutrient in solid effluent added (from all sources) (SolidEff).
- The monthly amount of N and P applied as solid effluent from all sources (EffluentSolidNmon, EffluentSolidPmon).
- The amount of inorganic N in effluent applied from all sources.
- The concentration of N in both liquid and solid fractions.

It is assumed that effluent is distributed evenly (i.e. the application depth and therefore nutrient loading rate per ha is constant) each month that effluent is applied.

Whether the block receives liquid effluent from the farm dairy or wintering pad management system

The month effluent is applied from holding ponds can be selected if applications are applied infrequently. Months effluent is applied must be selected when applied to crops or fruit crop blocks.

When adding effluent nutrients to blocks, the animal enterprise from which the effluent is derived is not required. The source of effluent is tracked so that different application times can be entered.

6.1. Liquid effluent applied on block

6.1.1. Total amount to apply

When calculating the total amount to apply the enterprise effluent is derived from need not be accounted for. Therefore, liquid effluent from farm dairy's that is applied to blocks is accumulated, thus:

Equation 37: $EffPdk_{nut} = \sum liquid_{nut}$

liquid is the amount of nutrients in farm dairy effluent applied to a block from a given animal enterprise (kg nutrient/year).

Similarly, effluent from the wintering pad/animal shelter that is applied to blocks is accumulated in the variable WPeffluent.

6.1.2. Block nutrient loading rates

For each block, for each month that effluent is applied, the rate of application (kg nutrient/ha/month) is estimated as:

Equation 38: $Monapplied_{nut} = EffPdk_{nut} * ratio / area_{block}$

EffPdk is the total amount of liquid effluent from the farm dairy to be applied to blocks (kg/year) [Equation 37].

area is the block area (ha).

where ratio is:

Equation 39: $ratio = (area_{block} * AreaEffluent / 100) / AreaEffhaMonthFDE$

area is the block area (ha).

AreaEffluent is the entered or default proportion of the block receiving effluent (%).

AreaEffhaMonthFDE is the area-month (ha) for farm dairy effluent [section 6.1.4].

A similar calculation is undertaken for wintering pad/animal shelter effluent for those blocks on which effluent is applied using WPeffluent (section 6.1.1) and AreaEffhaMonthWP (section 6.1.4), to give MonappliedWP.

The total amount of nutrient applied as effluent on a block (kg nutrient/ha/year) is then summed across monthly applications of farm dairy and wintering pad effluent as:

Equation 40: $EffluentLiq_{nut} = \Sigma_{mon}(Monapplied_{nut} + MonappliedWP_{nut})$

Note that for acidity, a negative value is interpreted as effluent being an input. Typically effluent shows an alkalisation (negative acidity) effect in the nutrient budget.

6.1.3. Monthly nutrient loading rates

The nitrogen models require the amount of N in effluent added in both the inorganic and organic N forms. The P loss model requires the amount of effluent P added each month. Thus:

Equation 41: $EffInorganicN_{mon} = Monapplied_{N} * 0.19$

Equation 42: $EffluentNmon_{mon} = Monapplied_{N} * 0.81$

Equation 43: $EffluentPmon_{mon} = Monapplied_{P}$

This approach probably underestimates the amount of inorganic N when solids have been separated, for example, when using solid separation, or liquids collected from lined standoff pads. The ratio (0.19, 0.81) may also differ if the effluent contains a high proportion of unutilised feed. These possible effects have been ignored.

Similar calculations are undertaken for wintering pads/animal shelters before the monthly inorganic fraction of the farm dairy is added to that of the wintering pads/animals shelters EffInorganicN (Equation 41), that is the inorganic N from farm dairy or wintering pads is not differentiated in the nitrogen sub-models. Monthly amounts of organic N and P are estimated separated for wintering pads/animal shelters (EffluentWPNmon, EffluentWPPmon). This would allow for the possibility of different release rates from the two sources.

6.1.4. Area-month

The area-month is estimated by adding the area within each block to which effluent is applied for each month that it is applied. If timing of application is not specified, it is assumed that effluent is applied in months that lactation is occurring. Thus:

Equation 44: $AreaEffhaMonthFDE = \sum area_{block} * AreaEffluent / 100$

area is the block area (ha).

AreaEffluent is the entered or default proportion of the block receiving effluent (%).

A similar calculation is undertaken for wintering pads/animal shelters to give AreaEffhaMonthWP, except that the default month of application is the month that effluent is generated (i.e. months that animals are on the wintering pad).

This approach means that that the amount of a given nutrient applied each month is constant. Hence, differential rates between blocks only occur if the number of months effluent is applied differs between the blocks. This also means that the amount applied each month is not necessarily directly proportional to the amount of excreta or unutilised feed in the effluent management system in a given month.

6.2. Solids to block

6.2.1. Total amount to apply

Nutrients in solid effluents from given sources as shown in Table 10 can be applied to different blocks. This allows solids from different sources to be applied at different times to different blocks.

Table 10. Source of solid effluent that can be applied to blocks.

Variable	Description	Source
HPpondsludge	Pond solids/sludge	3.2.3, 3.2.4
SolidsHP	Holding pond separated solids	3.2.4
WPpondsludge	Pond solids/sludge - wintering pad	3.5.1
SolidsFP	Solids from feed pad	3.3
SolidsST	Solids from loafing pad	3.4
SolidsWP	Solids from wintering pad/animal shelter	3.5.1

6.2.2. Block nutrient loading rate

For each block, the month and type of solid effluent applied is selected. For each block, the amount of nutrient applied as solid is estimated as:

Equation 45: $SolidEff_{nut} = HPpondsludge_{nut} / Areapondsludge * FDEPondFrequency$
$+ SolidsHP_{nut} / AreaHPSepSolids$
$+ WPpondsludge_{nut} / AreaWPpondsludge$

+ $SolidsFP_{nut}$ / AreaSolidsFP

+ $SolidsWP_{nut}$ / AreaSolidsWP

+ $SolidsST_{nut}$ / AreaLoafing

HPpondsludge, SolidsHP, WPpondsludge, SolidsFP, SolidsWP, SolidsST are solids (kg nutrient/year) from different sources [Table 10].

Areapondsludge, AreaHPSepSolids, AreaWPpondsludge, AreaSolidsFP, AreaSolidsWP, and AreaLoafing is the total area to which solids are applied for a given source of solid (ha) [section 6.2.3].

FDEPondFrequency is the entered frequency that the pond sludge is applied (number of years).

As the month solids are applied are specified, then the month that N or P applied as solid effluent (EffluentSolidNmon, EffluentSolidPmon) can be determined. The model currently doesn't differentiate between solids from different sources when estimate N releases rates (Crop N model chapter), and hence a total across all solids is used.

The amount of inorganic N in solid effluents is assume to be zero.

Note that for acidity, a negative value is interpreted as effluent being an input. Typically effluent shows an alkalisation (negative acidity) effect in the nutrient budget.

6.2.3. Area-month

The area-month is estimated by adding the block area for blocks effluent is applied on for each month that it is applied. The total area solids are applied on is the sum of corrected block area for each month solid is applied. Hence on a farm with a given type of solid applied in one month on block 1 and on two months on block 2, then the total area solids are applied in block 2 is twice that in block 1. This approach assumes that the same rate of a given solid effluent is applied each month. Hence based on the previous example, the annual nutrient loading rate in block 2 is twice that in block 1.

6.3. Release rates

The release rates determine the rate of release of organic N from applied effluent in the crop N sub-model (Crop N sub-models chapter). The release rates are estimated as:

Equation 46: ko_liq = a_Stover * NconcLiq

Equation 47: ko_solid = a_Stover * NconcSolid

a_Stover is a constant [Crop N submodels chapter].

NconcLiq and NconcSolid is the N content (kg/kg) of the organic fraction in the liquid and solid effluents respectively.

It is assumed that the N concentration in the organic fraction is the same for all sources, including both solids and liquid. A concentration of 0.021 is used.

This was based on organic N derived mainly from dung. This may under or overestimate the release rate if the effluent contains a high proportion of unutilised feed with a different N content compared to the organic fraction to that of dung.

6.4. Exported effluent

The animal enterprise or source of the effluent is no longer required because liquid and solid effluent that is exported is accumulated. Thus:

Equation 48: $\text{EffluentSolidLiquid}_{nut} = \sum \text{liquid}_{nut}$
Equation 49: $\text{EffluentSolidExport}_{nut} = \sum \text{solid}_{nut}$

6.5. Stream discharges

The discharge from a 2-pond system is assumed to be direct to stream. Thus:

Equation 50: $\text{pondtostream}_{nut} = \sum \text{ponddischarge}$

6.6. Nutrient loss

Nutrient losses due to leaching, the accumulation in organic material (immobilisation) or inorganic pool is tracked for each animal enterprise and source. These are used to generate farm nutrient budgets and estimate indirect nitrous oxide emissions. They are referred to in other sections of the technical manual as:

$$\text{lossoff}_{antype,\ source,\ losstype,\ nut}$$

where source is lanes and races (code LLane), standoff pads (Lstandoff), storage (Lstorage) or wintering pad beds (Lwinpadbed), and losstype is leaching, immobilisation or inorganic.

6.7. Atmospheric N losses

This Technical Mannual describes the total volatilisation, denitrification and nitrous oxide emissions from farm structures and effluent management systems serving each animal type, effluent source and emission type used to estimate greenhouse gas footprints. These are referred to as:

Equation 51: $\text{NlossAt}_{antype,\ Lsource,\ AtVolat} = \Sigma \text{volatloss}$
Equation 52: $\text{NlossAt}_{antype,\ Lsource,\ AtDenit} = \Sigma \text{denitloss}$
Equation 53: $\text{NlossAt}_{antype,\ Lsource,\ AtN2O} = \Sigma \text{NitOxide}$

Lsource is the source and associated method of calculation [Table 8].

volatloss, denitloss, NitOxide are estimated N losses for each source and animal enterpirse as described in section 4.

6.8. Dung DM

The estimation of methane emissions from dung is described in the Calculation of methane emissions chapter. As methane is included in the greenhouse gas footprints, methane emissions are estimated for each animal enterprise for those sources listed in Table 11.

Table 11. Source of dung dry matter used to estimate methane emissions.

Variable	Description
ghgdungPaddock	Dung deposited on blocks, and dung deposited on pad surfaces where the emission factors are the same a dung deposited on blocks.
ghgdungslurry	Dung in slurry when slurry applied to blocks.
ghgdungHPshort	Dung added to holding ponds where the resident time is less than 2 weeks.
ghgdunganaerobic	Dung added to 2-pond system, or to holding ponds where the resident time is more than 2 weeks.
ghgdungStoretime	Rate by time used to estimate methane emissions from stored dung. The method is described in the Calculation of methane emissions chapter.

7. References

Dexcel, 2005. Minimising muck, maximising profit. Stand-off and Feed pads – design and management guidelines. Dexcel, Hamilton, New Zealand.

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