Ministry for Primary Industries
Manatū Ahu Matua

Trends in dairy effluent management

Final Report

MPI Technical Paper No: 2018/70

Prepared for the Ministry for Primary Industries
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ISBN No: 978-1-98-857149-2 (online)
ISSN No: 2253-3923 (online)

June 2017

New Zealand Government

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Final report: Trends in dairy effluent management

Mike Rollo, Stewart Ledgard and Bob Longhurst

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RE450/2017/041

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1. Executive Summary

Traditional New Zealand dairy farm systems involve cows grazing pastures and most excreta is returned directly to the grazed paddock. However, a proportion of excreta is also transferred to the milking shed and surrounding yards. This project extends work reported in the early-2000s that estimated this annualized proportion at 6% for milking cows, assuming no other off-paddock structures were used. This value has been used in the New Zealand agricultural greenhouse gas inventory for all years from 1990 to 2015 and this was linked to only one, generic, manure management system. Manure management systems are used to collect, store and process animal excreta. However, in recent years there has been an increase in use of other off-paddock structures (e.g. feed pads) where manure has been collected and there has also been an increase in types of manure management systems used. This project aims to update earlier methodology to account for multiple off-paddock structures that collect animal excreta and the multiple manure management systems, by i) reviewing data on the use of these structures and systems, and ii) developing an accounting tool to estimate the fate of dairy cow excreta.

We have collated recent data that reflects the increased use of off-paddock structures on New Zealand dairy farms to better manage animal excreta. This data details usage of these structures and the relative proportion of each structure in use. There was little data available on the use of these structures to allow estimates back to 1990, as required for inventory calculations, so expert judgement was collated on trends of usage to allow estimates back to 1990. This summary of data indicated that there was insignificant (<1%) use of off-paddock infrastructures in 1990, whereas by 2017 it had increased to 30% of farms using feed-pads and 25% using stand-off pads.

This data was used, with the same methodology as applied previously based on relative time spent on the infrastructures, to recalculate the proportion of annual excreta transferred by milking cows to the milking shed, surrounding yards and infrastructures at 8.5% in 2015/16. Apportioning this amount across all dairy cattle results in 7.1% of nitrogen excreted entering the MMS. This value (7.1%) is suggested to replace the 5% currently in the Agricultural GHG inventory used for the Tier 1 calculations of emissions from nitrogen excreted by dairy animals for 2015/16.

The net effect of this increase in animal excreta to MMS was a small (0.4%) decrease in in total CO_2-equivalent emissions from dairy cattle excreta for an average NZ dairy farm, based on 2015/16 season information. This was associated with a small increase in the methane (CH_4) emission factor but a small decrease in nitrous oxide emission factor from farm dairy effluent (FDE) applied to pasture compared to that for direct deposition of excreta (dominated by urine) using the current NZ GHG Inventory factors.

A sensitivity analysis was carried out to examine the effect of the current approach of estimating the proportion of excreta-N entering the MMS based on proportion of lactation days in the year, compared to accounting for temporal variation in N excretion. The latter was calculated on a monthly basis for an average NZ dairy farm in 2015/16 using the OVERSEER® nutrient budget model version 6.2.3 (hereafter called OVERSEER). It indicated that the current approach underestimated the excreta N entering the MMS by approximately 12%. However, this is hard to quantify accurately and will vary greatly with farm practise.

Data was also summarised on the MMSs used on NZ dairy farms and showed large changes over time. In 1990, it was estimated that 90% of dairy farms in NZ used systems based on 2-ponds and discharge to water, with only 10% using land application. By 2017 this was markedly reversed to 88% of dairy farms using land application. Additionally, there has been a change in the type of MMS. Of the farms using land application, 92% have holding ponds while 8% use land application with direct pumping of FDE from a sump, while this was estimated at 50% for each system in 1990.

A tool (Excel spreadsheet model) has been developed as part of the project that incorporates this data, the revised methodology used to estimate the percentage of animal excreta entering manure management systems, the trends in usage as determined by expert judgement, and the increased options of manure management systems available. It enables calculation of the proportion of excreta deposited on the farm dairy, associated yards and related infrastructure that is captured into a manure management system (assuming all excreta deposition to all infrastructures is captured in the MMS). It then distributes the collected manure into different manure management systems according to data available on the types of systems used for the year of study. The tool will be populated with data from 1990 to 2016 that was collected or estimated for New Zealand dairy farms and can be updated in future years as new annual data is collected.

2. Background

Under traditional New Zealand (NZ) farm systems for lactating dairy cows, the greatest proportion of animal excreta is returned directly to the grazed paddock, but a proportion is also transferred to the milking shed and surrounding yards. In a review for Ministry for Primary Industries (MPI), Ledgard and Brier (2004) estimated that in the early-2000s, an annual average value of 6% was appropriate for the proportion of excreta entering the farm dairy effluent (FDE) system via the milking shed and yards from all lactating dairy cattle (i.e. excluding replacement animals). This value has since been used in the NZ greenhouse gas (GHG) Inventory. However, with general dairy intensification over time, including the use of feed-pad areas on farms for feeding brought-in supplementary feeds, there is likely to have been an increase in the proportion of animal excreta that enters the FDE system (including that from feed-pads). There has also been an increase in the use of stand-off pads and animal shelters or housing systems, even if just for a few months of the year, and this would result in a larger proportion of excreta directed to the FDE system.

Additionally, there has been a greater variety in the types of manure management systems (MMSs) used on dairy farms in NZ. Changes in the data collected for the annual Agricultural Production Survey (APS) have recently occurred, to account for this increase in types of MMS. The new APS questions seek information about 6 MMSs (section 3.1) compared with the one generic MMS that was assumed in use in the early-2000s.

This project aims to provide a summary of the use of off-paddock infrastructure on dairy farms over time. This information is then used to estimate the relative excreta deposition to pasture and to the identified infrastructure systems (dairy shed, feed-pad, stand-off pad and animal housing systems). The key drivers of excreta deposition in the different infrastructures are defined and relevant data collected. Anticipated significant gaps in data were realised, and expert opinion has been used to address these gaps. The project also reviews data on the types of MMSs and uses expert opinion to project their relative use back to 1990.

This report covers development of a tool to calculate the relative distribution of excreta to off-paddock infrastructures and to different manure management systems, identification of relevant data sets, and some results. A glossary (Appendix 8.1) lists common abbreviations and terms used throughout this report. Details of calculations and results are included in a range of appendices (Appendix 8.3 to 8.7).

3. Tool

A Tool has been developed as a Microsoft Excel® (Excel) workbook that will, given suitable data, allow users to input annual data for a given year about the use of offpaddock facilities on dairy farms e.g. estimated total nitrogen excreted (NEx), infrastructures used, and time spent (%days in year, hours per day) on the different structures. Data was not available to estimate the time spent on farm raceways. It has been necessary to include usage information based on expert judgement due to the limited data available. Users will be able to add new infrastructure types to the tool. The structure and usage of the tool are described briefly in Appendix 8.2.
The Tool includes the calculation methodology of Ledgard and Brier (2004) for the proportion of total annual excreta deposited on the farm dairy and associated yards and collected into an effluent system. Data from New Zealand dairy farms (covered in section 4, based on surveys and expert judgement) has been incorporated into the tool so that changes over time can be observed.

Outputs from the tool include an updated estimate of the time spent in the farm dairy i.e. the milking platform and surrounding area where animal excreta is collected. This updates the value calculated by Ledgard and Brier (2004). Annual estimates of the relative excreta deposition on the different off-paddock structures are calculated and from these, nitrogen input into a generic manure management system (MMS) is calculated. This assumes that the excreta deposited on these infrastructures is collected into a MMS, which may not always be the case, e.g. excreta on some stand-off pads may not be captured into a MMS, while excreta from some animal housing systems (with slatted floors or deep litter barns) may be collected in a separate system to that of the FDE. The ability to enter information about differing MMSs, their properties and usage has been included. The tool has been structured to allow subsequent linking of GHG emission factors (EFs) if required, but these are not included.

Where a data set has been included in the tool, the relevant worksheet is named in the discussion in section 4 (refer also to Appendix 8.2). The purpose of the tool is not to serve as a database for the infrastructure and MMS data, but to allow estimation of the proportion of NEx distributed to the farm dairy and subsequently between the different MMSs for a given year.

3.1 Agricultural Production Statistics (APS) of manure management systems

New questions have been included in the 2017 APS survey of StatsNZ to collect information on the use of different MMSs (Table 1) and the Tool allows incorporation of these results when they become available (Appendix 8.2).

Table 1. List of type of MMSs included in the new (2017) question in the APS to gather information on use of MMSs, as supplied by MPI.

APS line code (LC)	MMS	Additional text in APS question
5900	Multiple pond system	with anaerobic and aerobic ponds that discharge
5901	Multiple pond system	with anaerobic and aerobic ponds which occasionally discharge and use land application the rest of the time
5902	Single storage ponds/tanks	with sufficient storage to irrigate when suitable - no solid separation system
5903	Single storage ponds/tanks	which include a solid separation and storage system
5904	Sump storage	storage for at least 1-2 days prior to irrigation
5905	Other	please specify

4. Data sets

We sought data sets with information on off-paddock structures used, number of days the structures are used, the number of cows using the structure, and hours per day using the structure. A literature survey undertaken as part of this project did not identify any relevant data sets for follow up other than those listed below.

4.1 Botha and O'Connor (2015)

A report prepared by AgResearch for DairyNZ (Botha and O'Connor, 2015) motivated by interests in animal welfare, was identified as having relevant data for this project, i.e. use of a range of off-paddock infrastructures, by regions of NZ. Their report details results from 380 respondents of a survey of dairy farmers, about the size and usage patterns of a range of off-paddock systems for dairy farms. This data has been included in the tool (see worksheet (w/s) "NEX distribution - annual"; Appendix 2) and forms an important part of the re-estimation of the percentage of NEx entering the farm dairy and off-paddock infrastructures, that are subsequently transferred to the generic farm MMS.

An example of the information included in the report by Botha and O'Connor (2015) is given in Figure 1. It shows the distribution of different types of off-paddock systems by region across New Zealand. Information on the timing of use of the structures was also collected and an example of the data is given in Figure 2.

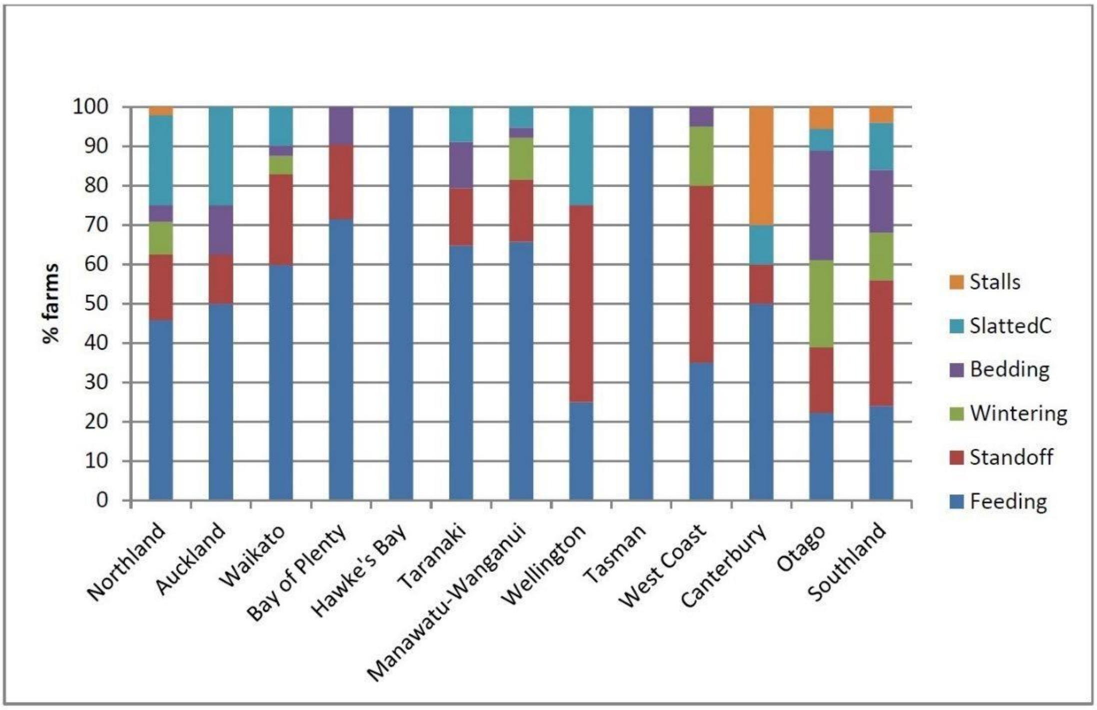

Fig. 1: Types of off-paddock infrastructure systems used across regions (Botha and O'Connor, 2015). Legend abbreviations: Stalls (Freestalls - housed, with stalls for cows), SlattedC (Loose-housed with slatted concrete), Bedding (Loose-housed with bedding material), Wintering (Wintering pad - feeding and lying), Stand-off (Stand-off pad - lying surface but no feeding) and Feeding (Feed pad - feeding but no lying).

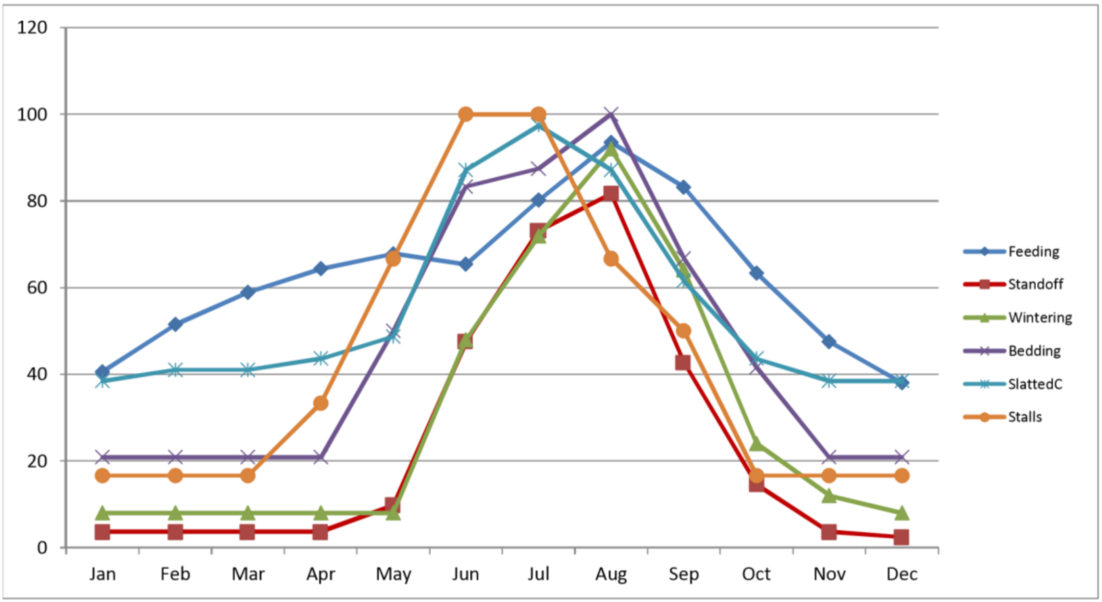

Fig. 2: Monthly usage (%) of off-paddock systems (from Botha and O'Connor, 2015).

4.2 DairyNZ data on usage of off-paddock infrastructures on NZ dairy farms

Dairy NZ supplied extracts from a set of 458 OVERSEER files with information about regional usage of off-paddock infrastructures on NZ dairy farms for the 2015-16 season. This information is summarised in Tables 2 (by region) and 3 (by region and structure type). While this data did provide additional information on regional variation, there were caveats about the quality and amount of information and it was not possible to differentiate the data on the timing of usage. Consequently, this data was not used specifically for deriving the final summary of trends in infrastructure use.

Table 2. Regional percentage of farms with structures present on farm.

Region	Percentage of farms with structures	Percentage of farms without structures
Northland	24%	76%
Bay of Plenty	61%	39%
Waikato	31%	69%
Taranaki	50%	50%
Lower North Island	39%	61%
West Coast-Tasman	23%	77%
Marlborough-Canterbury	34%	66%
Otago	23%	77%
Southland	15%	85%
Total	**32%**	**68%**

Table 3. Regional percentage of farms with different structure types present on farm[1].

Region	Feed pad	In-shed feeding system	Wintering pad	Winter standoff	Total[2]
Northland	65%	23%	31%	0%	119%
Bay of Plenty	67%	44%	22%	0%	133%
Waikato	47%	49%	12%	14%	122%
Taranaki	50%	50%	0%	21%	121%
Lower North Island	42%	48%	18%	12%	121%
West Coast-Tasman	20%	70%	20%	10%	120%
Marlborough-Canterbury	10%	95%	5%	20%	129%
Otago	30%	91%	26%	13%	161%
Southland	13%	80%	33%	23%	148%

[1] restricted to farms with at least one structure

[2] sum to more than 100% as some farms have more than one structure

4.3 Data set of infrastructures and manure management systems derived using expert opinion

There are many gaps in data over time, particularly for the earlier years of the period between 1990 and 2016. We have attempted to fill some of these gaps by using estimates from experts. Discussions with experts helped assess trends over time on the use of offpaddock infrastructures and manure management systems. Experts consulted include practising researchers, regional council contacts and industry contacts, all with many years of knowledge and experience related to the changes in use of off-paddock structures on NZ dairy farms. Information on dairy farm infrastructures from Luo et al. (2013) has been summarised as part of the expert judgements. However, it was of limited value because it had limited temporal coverage.

This dataset (Table 4) was collated from discussions with industry contacts whose knowledge also spanned many years. This information was included in the workbook, and was used to weight current values to enable calculations back to 1990.

Table 4 shows that there has been an increase in the use of the different off-paddock structures on NZ dairy farms over time. In 1990, there was no use of structures, other than the farm dairy and associated yards, whereas by 2015 there was significant use of feedpads and stand-off pads, with a much lesser use of animal shelters and housing.

Table 4. Summary of expert opinions on usage trends (%) of off-paddock structures and manure management systems on NZ dairy farms on average for 1990-2017. Data from actual farm surveys in 2008 by MAF (Kira *et al*., 2008) and in 2015 by AgResearch (Botha and O'Connor, 2015; data on structures only) are also included.

					MAF		AgR		
	1990	1995	2000	2005	2008	2010	2015	2017	Experts and References
Structures									
Feed pads	0	0	<1	7	19	27	29	30	Ian Williams, Pioneer
Stand-off pads	0	0	0	1	15	22	22	25	Chris Glassey, Dairy NZ
Animal shelters	0	0	0	0		1.5	3.3		
- slatted floor	*0*	*0*	*0*	*<1*	*1.0*	*1.3*	*1.8*		Zoe Pow, Herd Homes
- carbon bedding	*0*	*0*	*0*	*0*		*0.2*	*1.5*		
Free-stall barns	0	0	0	0		0.5	1		
Effluent management									
2-pond + discharge to water	90	90	50	20	15*	12*	12*	12*	Theresa Wilson, ex-DairyNZ
Land application	10	10	50	80	85*	88*	88*	88*	Bala Tikkisetty, WRC
- via sump	*5*	*5*	*20*	*20*	*20*	*15*	*10*	7	Theresa Wilson, ex-DairyNZ
- via pond	*5*	*5*	*30*	*60*	*65*	*73*	*78*	81	
Solid separation	0	0	0	<1	6	8	10	12	Nick Morison, PPP
- mechanical	*0*	*0*	*0*	*<1*	*1*	*1.5*	*2.5*	*2.5*	John Scandrett, Scandrett Rural
- Passive (weeping wall)	*0*	*0*	*0*	*<1*	*5*	*6.5*	*7.5*	*9.5*	Amanda Hodgson, Archway
Number of dairy herds in NZ	14685	14736	13892	11883		11735	11918		DairyNZ Dairy Statistics

* hybrids of both systems are used, estimated at 27% of farmers in the MAF 2008 studyResults and Discussion

The data collected has shown that there has been a large change over time in the use of off-paddock infrastructures on dairy farms in NZ. In 1990 their use was estimated to be insignificant (<1%), whereas by 2017 it had increased to 30% of farms using feed-pads and 25% using stand-off pads (Table 4). This data was used to recalculate the average time a cow spends in the farm dairy, originally estimated by Ledgard and Brier (2004) to be 6% for a 12-month period (i.e. including non-lactating period over winter). This value is used in the current NZ Agricultural GHG Inventory Model (AIM) to estimate the amount of NEx from mature dairy cows entering the MMS (i.e. excluding replacement animals). This calculation is based on the percentage of time an average cow spends in the farm dairy per day ("T_c" in Ledgard and Brier, 2004) which is averaged over the lactation period, and then over the whole year. An average lactation length of 270 days is used, consistent with that used for AIM. Ledgard and Brier (2004) adjusted this to reflect all dairy cattle (i.e. including replacements) to be 5%, which is used in AIM for the Tier 1 N_2O emission calculations for NEx.

Options are available in the Tool (Appendix 8.2) to make calculations using the input values used by Ledgard and Brier (2004) (where the farm dairy was the only off-paddock structure), or alternatively, to use the more recent data that re-estimates the distribution of NEx using a national average weighting by regional milk production information and usage of a range of off-paddock structures, and then from a generic MMS to a range of MMSs. This also uses a more recent estimate of lactation length of 276 days (c.f. 270). These estimates of relative excreta deposition onto these structures, and movement into MMSs are summarised in Table 5. Based on this data for 2015/16, the estimate of the proportion of excreta captured in the farm dairy and off-paddock infrastructures for lactating cows for a 12-month period is 8.5% (details in Appendix 8.3).

The net effect of this increase in animal excreta to MMS was a small (0.4%) decrease in in total CO_2-equivalent emissions from dairy cattle excreta for an average NZ dairy farm, based on 2015/16 season information. This was associated with a small increase in the methane (CH_4) emission factor but a small decrease in nitrous oxide emission factor from farm dairy effluent (FDE) applied to pasture compared to that for direct deposition of excreta (dominated by urine) using the current NZ GHG Inventory factors (see Appendices 8.3 to 8.7 for details).

Another factor that can influence the estimated values for the amount of N entering the FDE system on dairy farms is the temporal pattern of N excretion by animals associated with differences in feeding, milk production and stage of lactation through the year. This aspect was evaluated using data for the average NZ dairy farm for 2015/16 using data from the DairyNZ DairyBase using the OVERSEER model. It showed that when the monthly variation in N excretion was accounted for, as opposed to the Inventory method which currently assumes the same rate of N excretion for all months of the year, there was an increase in amount of N estimated to enter the FDE system (Appendix 8.5). Estimates were 9.4% of NEx entering the FDE system when accounting for temporal variation (Table A8.5.4; based on 86.5% of Nex in lactating months from Table A8.5.2) compared to 8.5% entering the FDE system when using a constant monthly NEx rate and the number of lactation days in the year (i.e. Table A8.5.3, based on 75% of Nex during lactation period). The latter is the current method used and this analysis indicates that it may be underestimating the FDE-N by approximately 12%. This was largely influenced by the much lower rate of N excretion during the three-month period when cows are nonlactating and when no FDE is being collected (Fig. A8.5.1). In practice, this temporal pattern will vary greatly with a range of factors including the dairy farm system, pattern of use of brought-in feeds and infrastructures, as well as the winter feeding system. This means that it would be difficult to establish a simple approach to accurately account for this temporal variation in NEx across dairy farms in NZ.

Table 5. Summary comparison of key inputs and estimates of the proportion of excreta captured in the farm dairy and off-paddock infrastructures, estimated using values from Ledgard and Brier (2004), and re-estimated using recent data that reflects use of offpaddock structures on dairy farms for the 2015/16 season (Botha and O'Connor, 2015).

Quantity	Ledgard and Brier (2004)	Estimates using recent data (2015)
Lactation length (days)	270[1]	276[2]
H_c/S_n[4]	11.5	12.6[6]
T_c[4]	5.8%	8.48%[6]
% use of off-paddock infrastructures	0%[5]	22.7%[6]
[7]% excreta to generic MMS (lactating only)	5.8%[8]	8.5%
[9]% excreta to generic MMS (all dairy)	4.8%[10]	7.1%

[1] Ledgard and Brier (2004) and AIM use 270 days.

[2] Current value is 276 days (Dairy Statistics, 2015-16, Table 4.3).

[3] H_c/S_n is the average cows/milking-cluster (Ledgard and Brier, 2004)

[4] T_c is the percentage time average cow spends in farm dairy per day on an annualised basis (Ledgard and Brier, 2004). Updated estimates used data from 2009-2015 extracted from DairyBase. [5] Ledgard and Brier (2004) calculations had no off-paddock structures other than the farm dairy.

[6] New estimates derived using data from Botha and O'Connor (2015) [7]
Ledgard and Brier (2004).

[8] Rounded to 6% in AIM

[9] After applying the methodology used by Ledgard and Brier (2004)

[10] Rounded to 5% in AIM.

The data derived from farm surveys and expert opinion on types of MMSs used has also shown large changes over time. In 1990, it was estimated that 90% of dairy farms in NZ used systems based on 2-ponds and discharge to water, with only 10% using land application (Table 5). By 2017 this had markedly reversed to 88% of dairy farms using land application. Additionally, there has been a change in the type of MMS. Of the farms using land application, 92% have holding ponds while 8% use land application with direct pumping of FDE from a sump. In 1990, these proportions were 50% for each system. By 2017, it was also estimated that 12% of dairy farms use solid separation of FDE after collection, with 79% using a weeping wall method and 21% using mechanical separation (Table 5). These different MMSs affect the fate of the carbon and N in the FDE, which determines the extent of GHG emissions from the FDE before and after land application (e.g. IPCC, 2006). Potentially, the NZ GHG Inventory could be updated to account for different emission factors according to the type of MMS, such as by using the default factors from IPCC (2006). For example, the ammonia loss factor from MMSs in IPCC (2006) varies from 7% for a daily-spread system (corresponding to FDE applied daily via a sump) to 35% from an anaerobic lagoon. Likewise the N_2O emission factor from IPCC (2006) for the MMSs in Table 5 varies from 0 kg N_2O/kg N for uncovered anaerobic lagoons to 0.005 kg N_2O/kg N for solid storage. When specific emission factors for the different MMSs in NZ are agreed on by MPI it would be possible to add these into the Tool for calculation of the GHG emissions from the MMSs.

5. Acknowledgements

This project was supported by funding from MPI, contract no. 405032.

DairyNZ for permission to use data from Botha and O'Connor (2015), for extracting and supplying data from DairyBase and supplying the infrastructure use data extracted from DairyNZ OVERSEER files.

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Stats NZ for permission to include new questions in the APS related to MMS [supplied by MPI].

Theresa Wilson (ex-DairyNZ) for feedback on the data in Table 4.

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7. Appendices

7.1 Glossary of terms and abbreviations

Table A7.1. Glossary of terms and abbreviations.

Term	Description
AIM	NZ Agricultural GHG Inventory Model (MPI)
APS	Agricultural Production Statistics (by Stats NZ)
CH_4	Methane, a GHG
Cluster	Cluster (of four cups) used for milking a dairy cow
CO2-e	CO_2 equivalent
DMI	Dry matter intake of animals i.e. amount eaten
EF	Emission factor
Excel	Microsoft Excel® spreadsheet application
Farm dairy	Milking platform and surrounding area where animal excreta is collected
FDE	Farm dairy effluent
FDM	Faecal dry matter, dung deposited onto pasture while grazing
GHG	Greenhouse gas
GPG	IPCC Good practice guidelines
GWP	Global warming potential
H_c/S_n	Average cows/milking-cluster (Ledgard and Brier, 2004)
IPCC	Intergovernmental Panel on Climate Change
Kt	Kilo tonne (1,000,000 kg)
LC	Line Code, used by Stats NZ to identify information from APS
MMS	Manure Management System
MPI	Ministry for Primary Industries
N	Nitrogen
NEx	Nitrogen content of excreta
NH_3	Ammonia
N_2O	Nitrous oxide, a GHG
NIR	National Inventory Report, published by MfE
Off-paddock structure	Any man-made structure used to hold animals (may be covered or uncovered) off pasture e.g. feed pad
PR&P	Pasture, range and paddock (PR&P or PRP)
T_c	% time average cow spends in farm dairy per day (Ledgard and Brier, 2004)
UNFCC	United Nations Framework Convention on Climate Change
VBA	Visual Basic for Applications
Workbook	Excel file
w/s	Worksheet (in an Excel workbook)

7.2 Tool structure and operation

The tool was developed as an Excel workbook, and the reader is assumed to be familiar with basic Excel terminology e.g. worksheets, cells and the use of worksheet formulae. The Tool is structured to store data related to off-paddock structures and manure management systems, and the relevant calculations (as worksheet formulas) necessary to estimate how excreted N is distributed to these structures and MMSs. The data are stored, and calculations implemented, using a series of worksheets and VBA code. The user can navigate the workbook using hyperlinks to access the main functionality from a home worksheet (Figure A8.2.1). Most worksheets have detailed explanations relevant to the source of data or calculations used on the worksheet. Table A8.2.1 lists the main worksheets in the workbook with a brief description of their functionality. References to data sets used are included in cell comments where appropriate. After following a hyperlink, the user can retrace their steps using built-in standard Excel navigation options e.g. Alt and left-arrow key. A separate usage guide for the tool is provided.

Trends in Dairy Farm Infrastructure

Navigation			
Calculations	Data sets	General information	Results in report appendices (by appendix number)
Detailed annual	Botha and O'Connor (2015)	Glossary	8.4 Detailed calculation of emissions from NEx (cf Figure A8.4.1)
Temporal calculations	DairyBase on shed size and cup numbers	References	8.5 Appendix 8.5 (compare results for differing %NEx values)
	Dairy NZ data on usage	APS survey questions	8.6 Updating mean cow to cluster ratio (Hc/Sn)
	Expert opinions - trends	IPCC flow chart N_2O from NEx	8.7 Mean time lactating cows spend in farm dairy
		Colour coding key	
		Time constants	

Fig. A7.2.1: Users are brought to this worksheet when the tool workbook is opened[1]. It acts as a table of contents, allowing the user to access the main sections of the tool using hyperlinks.

[1] Always choose to "Enable macros" when opening the tool workbook.

Table A7.2.1. Names and descriptions of key worksheets in the tool[1].

Worksheet name	Description of functionality on the worksheet
Home	Home worksheet with hyperlinks to allow quick navigation to more detailed worksheets with calculations and data sets
Detailed annual (calculations)	Hyperlinks to access detailed annual calculations
NEX distribution - annual	Data & calculations to distribute NEx to off-paddock structures and MMS
Time in farm dairy - annual	Calculations based on Ledgard and Brier (2004), and updates using recent data sets (Appendix 8.7)

[1] Selection of worksheets only.

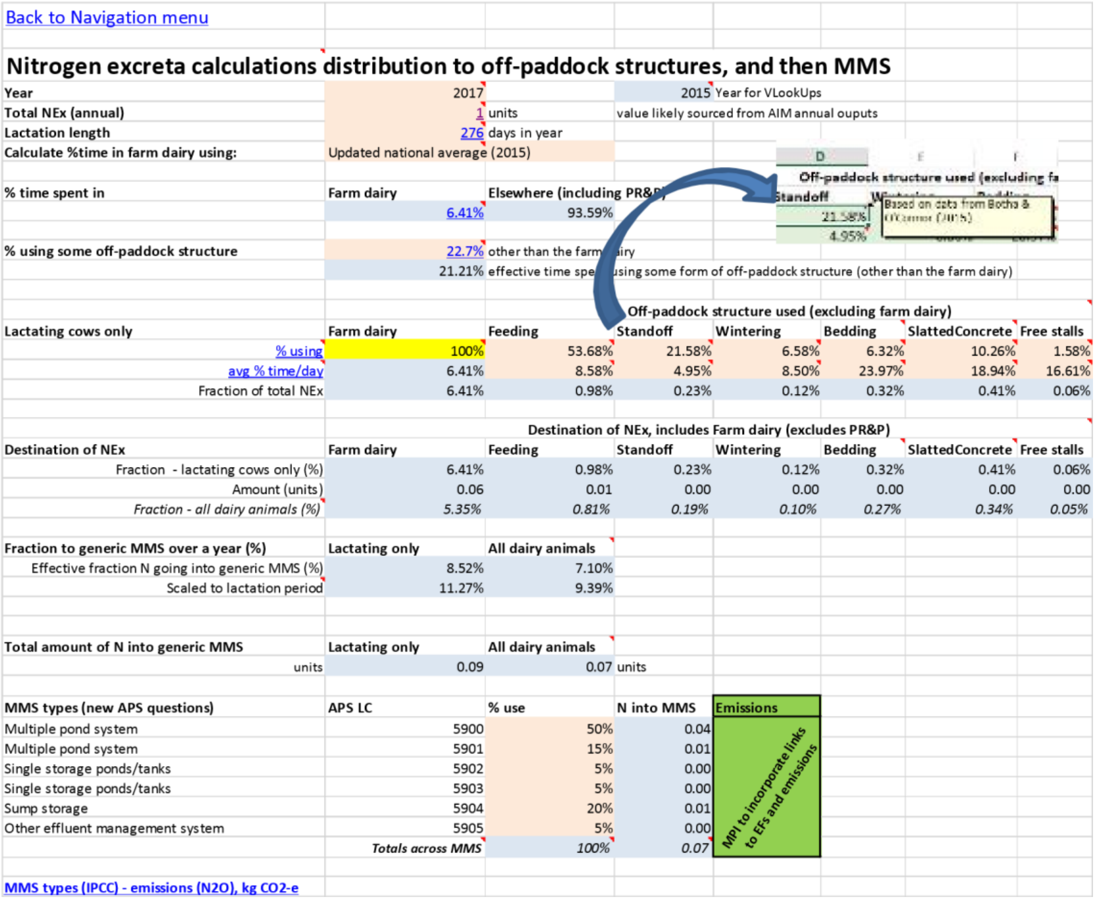
Cows per cluster (averages)	National avg. cows/milking cluster weighted by regional variation in milk production
Cows per cluster (data)	Regional raw data to calculate national average above
Colour coding key	Explains colour coding cells (data, calculations)
Time constants	Days/year, minutes in day as used in calculations
Appendix 8.5	Hyperlinks to worksheets allowing recalculation of the results in Tables A.8.5.3 and A.8.5.4, or comparison of two user specified %NEx values

The limited use of Visual Basic for Applications (VBA) code (the programming language for Excel), is outlined in Table A8.2.2.

Table A7.2.2: Description of functionality of VBA code used in the workbook.

Worksheet or VBA code module	VBA code description
ThisWorkbook	Force start on worksheet "Home" when workbook is opened
Cows per milking cluster (data)	Updates cows/ milking cluster raw data after changes e.g. extra data
Cf emissions for %NEx to MMS	Automatically calculate emissions for 2 user specified values of %NEx to MMS
Table A8.5.3	Setup and calculate results reported in Table A8.5.3
Table A8.5.4	Setup and calculate results reported in Table A8.5.4
modEmissions_CH4	Allows calculation of CH_4 emissions using user defined functions in worksheet formulas
modEmissions_N2O	Allows calculation of N_2O emissions using user defined functions in worksheet formulas

The Tool worksheet "NEX distribution - annual" (Figure A8.2.2) mimics the flow of NEx from milking dairy cows onto off-paddock structures specified, including the farm dairy, before entering a generic MMS. It is then apportioned into the MMSs specified by APS categories. The worksheet formula used on this worksheet are implemented in VBA code in the code modules modEmissions_CH_4 and modEmissions_N_2O.



Back to Navigation menu							
Nitrogen excreta calculations distribution to off-paddock structures, and then MMS							
Year	2017		2015	Year for VLookUps			
Total NEx (annual)	1	units	value likely sourced from AIM annual ouputs				
Lactation length	276	days in year					
Calculate %time in farm dairy using:	Updated national average (2015)						
% time spent in	**Farm dairy**	**Elsewhere (including PR&P)**					
	6.41%	93.59%					
% using some off-paddock structure	22.7%	other than the farm dairy					
	21.21%	effective time spent using some form of off-paddock structure (other than the farm dairy)					
			Off-paddock structure used (excluding farm dairy)				
Lactating cows only	**Farm dairy**	**Feeding**	**Standoff**	**Wintering**	**Bedding**	**SlattedConcrete**	**Free stalls**
% using	100%	53.68%	21.58%	6.58%	6.32%	10.26%	1.58%
avg % time/day	6.41%	8.58%	4.95%	8.50%	23.97%	18.94%	16.61%
Fraction of total NEx	6.41%	0.98%	0.23%	0.12%	0.32%	0.41%	0.06%
		Destination of NEx, includes Farm dairy (excludes PR&P)					
Destination of NEx	**Farm dairy**	**Feeding**	**Standoff**	**Wintering**	**Bedding**	**SlattedConcrete**	**Free stalls**
Fraction - lactating cows only (%)	6.41%	0.98%	0.23%	0.12%	0.32%	0.41%	0.06%
Amount (units)	0.06	0.01	0.00	0.00	0.00	0.00	0.00
Fraction - all dairy animals (%)	*5.35%*	*0.81%*	*0.19%*	*0.10%*	*0.27%*	*0.34%*	*0.05%*
Fraction to generic MMS over a year (%)	**Lactating only**	**All dairy animals**					
Effective fraction N going into generic MMS (%)	8.52%	7.10%					
Scaled to lactation period	11.27%	9.39%					
Total amount of N into generic MMS	**Lactating only**	**All dairy animals**					
units	0.09	0.07	units				
MMS types (new APS questions)	**APS LC**	**% use**	**N into MMS**	**Emissions**			
Multiple pond system	5900	50%	0.04	MPI to incorporate links to EFs and emissions			
Multiple pond system	5901	15%	0.01				
Single storage ponds/tanks	5902	5%	0.00				
Single storage ponds/tanks	5903	5%	0.00				
Sump storage	5904	20%	0.01				
Other effluent management system	5905	5%	0.00				
	Totals across MMS	*100%*	*0.07*				
MMS types (IPCC) - emissions (N2O), kg CO2-e							

Fig. A7.2.2: Layout of worksheet “NEX distribution - annual” in the Tool mimics the flow of NEx and MMSs. Cell comments are used to reference relevant data and calculation methodologies used in the tool e.g. for “Standoff” as indicated by arrow.

The tool has been structured (Figure A8.2.3) to include information from the APS on MMSs. Example values have been used to illustrate the calculations that will occur, namely weighting by % usage of each MMS, to estimate the amount of N excreta entering each MMS. This will potentially allow MPI to estimate emissions from each MMS used, when supplied with appropriate emission factors (EF). The tool has a facility to map existing MMS to the proposed new APS questions.

MMS types (new APS questions)	**APS LC**	**% use**	**N into MMS**	**Emissions**
Multiple pond system	5900	50%	35.52	MPI to incorporate links to EFs and emissions
Multiple pond system	5901	15%	10.66	
Single storage ponds/tanks	5902	5%	3.55	
Single storage ponds/tanks	5903	5%	3.55	
Sump storage	5904	20%	14.21	
Other effluent management system	5905	5%	3.55	
	Totals across MMS	*100%*	*71.04*	

Fig. A7.2.3: Specification of new MMS as per the new APS questions. NB: % use values are for illustration only, with Total NEx = 1000 units.

7.3 Re-estimating the fraction of NEx to MMS based on all dairy cows

Ledgard and Brier (2004) applied a known proportion of NEx entering a MMS (6%) from lactating dairy cows across all dairy classes, giving 5% for all dairy cattle (including replacements), which has been used for Tier 1 calculations in AIM. If we assume the replacement rates, and relative amounts of dry matter intakes and N retained are similar, we can estimate the proportion of NEx entering the MMS for all dairy classes as follows.

p = %entering MMS for lactating dairy cows (as a decimal value) - this is given e.g. 6%
p' = %entering MMS for all dairy cattle (decimal), estimated as 5% by Ledgard and Brier (2004)

$p' = p \times NEx_{lactating} / (\text{total NEx})$

$= p \times NEx_{lactating} / (NEx_{lactating} + NEx_{all\ other\ classes})$ where

$NEx_{lactating}$ is the NEx from lactating dairy cows (averaged over a whole year)

Using the results from Ledgard and Brier (p=6, p'=5), it follows that

$NEx_{all\ other\ classes} = 0.2 \times NEx_{lactating}$ where

$NEx_{all\ other\ classes}$ (i.e. replacement animals) is specified as a fraction (20%) of the NEx from lactating animals. This would be available from AIM. The value used for recalculation has been assumed to be the same (20%) as used in the original (Ledgard and Brier, 2004) calculations. This can be changed in the tool.

From this the expression for p' simplifies to

$p' = p \times (5/6)$

For the revised value of p (8.5%) based on use of off-paddock infrastructures, p' is approximately 7.1%. This is the value to use for Tier 1 inventory calculations involving NEx, based on the data of off-paddock infrastructure use that applies for 2015/16, and following the methodology detailed in Ledgard and Brier (2004).

7.4 Calculation of emissions from NEx

Calculation of emissions resulting from NEx involves tracking the fate of nitrogen from excreta as it is split between deposition on to pasture (pasture range and paddock, PR&P) and into the MMS. This involves splitting the NEx between urine and dung (for PR&P), and accounting for manure products from the MMS being spread onto pasture as an organic fertiliser in FDE. All processes involve direct CH_4 and N_2O emissions, indirect emissions via NH_3 volatilisation and nitrate leaching, with fractions and EFs specific to each process. Methane emissions from dung (PR&P) and MMS product applied to pasture as organic fertiliser must also be accounted for. The calculations are detailed by MPI (MPI, 2013). The N_2O EF for organic fertiliser (EF_1-fde) applied to pasture has been updated to 0.0025 (MfE, 2017, and van der Weerden *et al*., 2016).

The following diagram (Figure 3 from MPI, 2013) outlines the pathways for N_2O calculations after nitrogen has been excreted. The following need to be noted,

- for nitrogen deposited during grazing, volatilisation and leaching are calculated for both the dung and urine components, as well as direct emissions
- for “Stored” N (in MMS) $FRAC_{GASM}$ = 0.35 and $FRAC_{LEACH}$ = 0 (the MMS is sealed)
- waste from the MMS is applied to pasture as “organic fertiliser”, and in addition to direct emissions (EF_1-fde = 0.0025), is also subjected to volatilisation and leaching ($FRAC_{GASM}$ = 0.10 and $FRAC_{LEACH}$ = 0.07) EF_5 is 0.0075 (MfE 2017).

This flow tracing the fate of N excreted by dairy cows has been replicated in the tool to mimic this flow chart, using fractions and EFs from the current NIR (MfE 2017) and allows calculation of total CO_2-equivalent emissions (CH_4 and N_2O) from all dairy animals for a given amount of excreta or NEx. The calculation of N_2O emissions can be reduced to the following equation, giving the N_2O emissions for one unit of NEx as a function of the percentage of NEx from all dairy cattle entering the MMS. Note this does not include enteric methane emissions.

N_2O = -0.000168875[1] x p’ + 0.0103714286[1] (kg N_2O)

[1] assumes current NIR fraction and EF values (MfE, 2017)

where p’ is % (as decimal) of NEx entering the MMS for all dairy animals p’ = 5% Ledgard and Brier (2004), p’ = 7.1% based on current recalculations using recent (2015) information on offpaddock infrastructure use

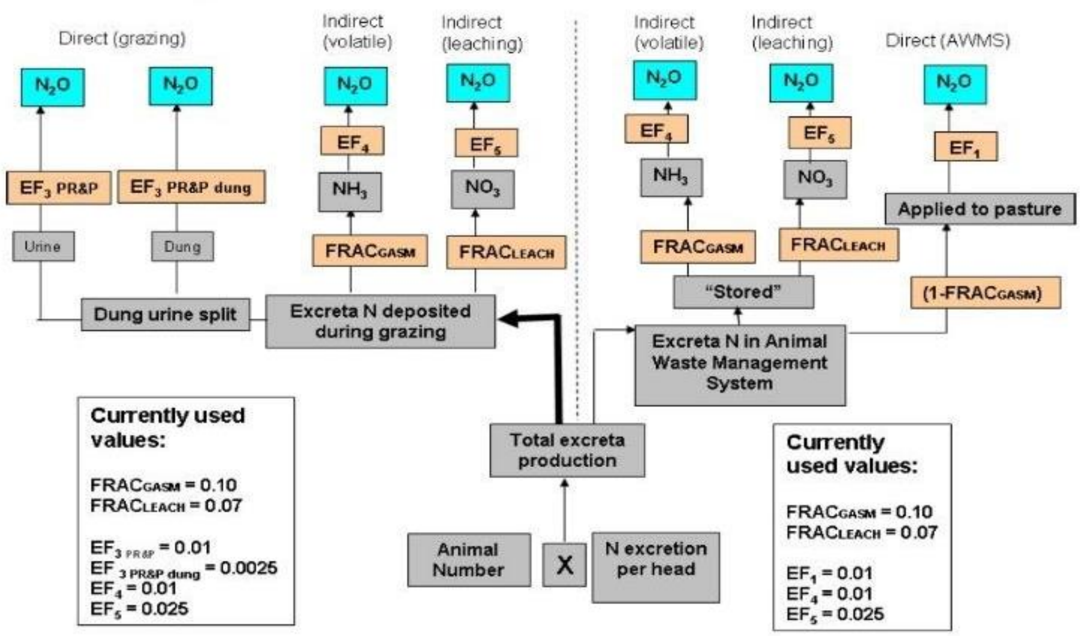


Fig. A7.4.1: Flow chart of N_2O emissions resulting from NEx pathways (MPI 2013). NB: CH_4 emissions also occur from dung deposited on pasture during grazing, and from farm dairy effluent applied to pasture (as organic fertiliser).

7.5 Results comparing alternative values of %excreta entering MMS (for all dairy cattle)

OVERSEER version 6.2.3 was used to setup an average NZ dairy farm for the 2015/16 season using the specifications in Table A8.5.1. The animal dry matter intake (DMI) and NEx results from OVERSEER (Table A8.5.2) were then used to estimate total CO_2equivalent emissions from excreta, accounting for the two possible pathways (grazing and via an MMS) and including CH_4 emissions when excreta is applied to pasture as dung or FDE. The monthly patterns are shown for NEx (Fig. A8.5.1), estimated using OVERSEER. Emission calculations were made using the original estimate (6% of excreta from dairy cows into MMS) from Ledgard and Brier (2004) when there was no use of off-paddock infrastructure, and the revised figure (8.5% excreta into MMS) which allows access to a range of off-paddock structures in addition to the farm dairy (Botha and O'Connor, 2015). These are summarised in Table A8.5.3 for data based on annual average information, i.e. assuming the same average monthly rate of DMI and N excretion throughout the year.

Table A7.5.1. Specifications for the NZ average dairy farm (2015/16 season) in OVERSEER based on data from the DairyNZ DairyBase database.

Farm area (ha)	163
Cows/ha	2.94
Replacement rate (%)	22
Milksolids production (kg/ha/yr)	1095
Milk production (L/ha/yr)	12300

Table A7.5.2. Estimates of animal dry matter intake (DMI) and N excreted (NEx[1]) from OVERSEER for dairy cows on an NZ average dairy farm (2015/16 season) based on farm data from the DairyNZ DairyBase. It was assumed that all replacements were grazed off farm.

	Jan	Feb			Mar	Apr Jun	May	Jul	Aug	Sep				Oct	Nov	Dec	T
DMI (kg)							79394 83880										21
NEx (kg)	6443	193616 5957	168634	104982	4823	2975 3003	2908	5340	6665	204028 6884	209091	225889	228061	6410	6909	7435	65

[1] Proportion of total NEx in lactation months = total NEx (excluding April-June)/total NEx = 86.5%

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DMI (kg)	216200	193616	168634	104982								
NEx (kg)	6443	5957	5957									

In practice, there is large monthly variation in DMI and NEx throughout the year associated with large variation in milk production and with approximately three months of the year in which cows are not lactating, and so not returning excreta to the MMS. To assess the possible effects of this monthly variation, the actual calculated monthly values for DMI and NEx for the average NZ dairy farm for the 2015/16 season from OVERSEER (described in Tables A8.5.1 and A8.5.2 and Fig. A8.5.1) were used, including setting the NEx to the FDE system (MMS) for April to June to zero. The emissions calculated using this monthly data showed a small decrease in total MMS emissions and similar small percentage changes between annual average percentage excreta returned to a MMS of 5.8% (rounds to 6%) and 8.5% (Table A8.5.3). These values were adjusted to the lactating period only (Table A8.5.4[3,4]). The tool calculates the values reported in tables A8.5.3 and A8.5.4 on worksheets "Table A8.5.3" and "Table A8.5.4".

Table A7.5.3. Assessing the effect of updating H_c/S_n and access to increased off-paddock infrastructure, with total NEx spread evenly during the year, as currently used in AIM. DMI and NEx were calculated using OVERSEER 6.2.3 (see Fig. A8.5.1) for an NZ average dairy farm (2015-16 season). Results are CH_4 and N_2O emissions, both presented as CO_2-e, from MMS, direct excreta deposition onto paddocks, manure applied to paddocks, and N_2O emissions from the MMS. Excludes replacement animals.

% of excreta entering MMS	CH_4 (kg)	N_2O (kg)	Total[1] (kg)
5.8%[2]	11,335	201,306	212,642
8.5%[3]	11,372	200,398	211,770
Percentage change (%)	+0.3%	-0.5%	-0.4%

[1]Total is CO_2-equivalents from all CH_4 and N_2O emissions associated with excreta and FDE (to pasture and from MMS), excluding enteric CH_4

[2]Ledgard and Brier (2004), access to farm dairy only. NB: 5.8% used for these calculations (Fig A8.7.1), this value was rounded to 6% in Ledgard and Brier (2004)

[3]Updated estimate %NEx to generic MMS accounting for use of all off-paddock infrastructures (Botha and O'Connor, 2015). See Fig A8.2.2.

Table A7.5.4. Assessing the effect of updating H_c/S_n and access to increased off-paddock infrastructure, using monthly patterns of NEx. DMI and NEx were calculated by OVERSEER 6.2.3 (see Fig. A8.5.1) for an NZ average dairy farm 2015-16 season). Results are CO_2-e CH_4 emissions from excreta and FDE applied to pasture, and N_2O emissions from the MMS. Excludes replacement animals.

% of excreta entering MMS[1]	CH_4 (kg)	N_2O (kg)	Total[2] (kg)
6.8%[3]	11,512	201,285	212,797
9.4%[4]	11,544	200,515	212,059
Percentage change (%)	+0.3%	-0.4%	-0.3%

[1]Excreta to FDE (via MMS) set to 0 for April to June, with values given applying to the lactating period only

[2]Total is CO_2-equivalents from all CH_4 and N_2O emissions associated with excreta and FDE (to pasture and from MMS), excluding enteric CH_4

[3]Ledgard and Brier (2004). Lactating cows only, adjusted for lactating months only i.e. 7.81% (T_c in Fig A8.7.1) * 0.865, where 0.865 is the fraction of total NEx in lactating months (Table A.8.5.2)

[4]Updated estimate, lactating cows only, using recent data accounting for use of offpaddock infrastructures (Botha and O'Connor, 2015). Adjusted for lactating months only i.e. 8.48% (T_c in Fig A8.7.2) * 0.865 + 2.11, where 0.865 is the fraction of total NEx in lactating months (Table A.8.5.2) and 2.11 is percentage of time spent in off-paddock structures excluding the farm dairy

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dairy	6,443	5,957	4,823	2,975	2,908	3,003	5,340	6,665	6,884	6,410	6,909	7,435	65,752
Total	6,443	5,957	4,823	2,975	2,908	3,003	5,340	6,665	6,884	6,410	6,909	7,435	65,752

Fig. A7.5.1: Monthly pattern of excreta-N (NEx) for an NZ average dairy farm for 2015/16 calculated using OVERSEER.

7.6 Updating mean cow to cluster ratio (Hc/Sn)

Ledgard and Brier (2004) estimated a mean cow to cluster ratio (H_c/S_n) of 11.5 to 1, resulting in a national average time of 112 minutes per day that a lactating cow spends in the farm dairy. A data set on cow population, type of dairy shed and average number of milking clusters per dairy shed for 2007/08 to 2014/15 was sourced from DairyBase and was used to update these values to 12.57 (H_c/S_n) and 122 minutes per day. These values, and the time spent on other off-paddock structures, were used to revise the annual estimate of excreta entering MMS from all dairy cattle to 11%. This data set and associated calculations are in the tool.

Re-estimation of the national average mean cow to cluster ratio (H_c/S_n), weighted by regional milk production (12.57), is shown in Fig. A8.6.1. These calculations are in the tool, and this value is used in the calculation of %NEx entering the MMS. Note that data from Marlborough-Canterbury and Otago-Southland were excluded from the calculations due to the high number of split milkings in these datasets. The data for these regions is included in the tool, but not shown in Fig. A8.6.1.

7.7 Mean time lactating cows spend in farm dairy

Based on the mean cow to cluster ratio (Hc/Sn), Ledgard and Brier (2004) estimated the national average time that a lactating cow spends in the farm dairy as 112 minutes per day. This calculation is available in the tool (Fig. A8.7.1). Using the updated data now available, this has been recalculated as 122 minutes per day (Fig. A8.7.2).

Region	Include region?	Effective ha	kg MS/ha	MilkProduction	MilkProduction (weighted)	Cows per cup (average)	Cows/milking-cluster (weighted)
Northland	Yes	155.23	831.15	129022.69	0.14	12.19	1.76
Waikato	Yes	140.92	1126.94	158807.86	0.18	13.20	2.35
Bay of Plenty	Yes	140.34	1111.73	156020.56	0.17	13.29	2.32
Taranaki	Yes	111.79	1109.22	124001.06	0.14	10.59	1.47
Lower North Island	Yes	147.69	1031.19	152291.58	0.17	13.10	2.24
West Coast - Tasman	Yes	189.88	905.62	171960.70	0.19	12.58	2.43
Marlborough-Canterbury	No	231.05	1487.52	0.00	0.00	17.49	0.00
Otago-Southland	No	206.37	1226.34	0.00	0.00	13.83	0.00
Nb: Data from Marlborough-Canterbury and Otago-Southland excluded due to high number of split milkings in these datasets							
			National total MilkProduction			***National average (weighted by regional milk production)***	
				892104.46			***12.57***

Fig. A7.6.1: The national average mean cow to milking-cluster ratio (H_c/S_n) for regions of New Zealand based on data from DairyNZ DairyBase for 2007/08 to 2014/15.

Percentage of time an average cow spends in farm dairy per day

Note: equation for Tc%, variables and explanations are all from Ledgard & Brier (2004).

See time constants

Quantity	Value	Comment
H_c/S_n	***11.50***	Nb: this is the average cows/milking-cluster value used in calculations by Ledgard and Brier(2004)
t_r	9	time (minutes) taken to milk each row, or for the rotary platform to do one complete rotation
M_d	2	number of milkings per day
Avg time in farm dairy		
- daily T_c (%)	7.81%	Percentage of time an average cow spends in farm dairy per day (during lactation period). Based on equation $Tc = ((((H_c/S_n) + 1) * t_r)/2) * M_d)/1440) *100$, §4, pg 5.
- whole year	5.78%	%, averaged over each day in whole year (365 days)
	112.50 avg mns/day in farm dairy	

Fig. A7.7.1: Ledgard and Brier (2004) original calculation of average time that a lactating dairy cow spends in the farm dairy. Lactation length = 270 days.

Percentage of time an average cow spends in farm dairy per day

Note: equation for Tc%, variables and explanations are all from Ledgard & Brier (2004).

See time constants		
Quantity	**Value**	**Comment**
H_c/S_n	***12.57***	Nb: this is the (national) average cows/milking-cluster (weighted by regional milk production), calculated on worksheet 'Cows per cluster (averages)'
t_r	9	time (minutes) taken to milk each row, or for the rotary platform to do one complete rotation
M_d	2	number of milkings per day
Avg time in farm dairy		
- daily T_c (%)	8.48%	Percentage of time an average cow spends in farm dairy per day (during lactation period). Based on equation $Tc = ((((H_c/S_n) + 1) * t_r)/2) * M_d)/1440) * 100$, §4, pg 5.
- whole year	6.41%	%, averaged over each day in whole year (365 days)
	122.15	***avg mns/day in farm dairy***

Fig. A7.7.2: Updated estimate of average time that a lactating dairy cow spends in the farm dairy based on data for the cow to milking cluster ratio from DairyNZ DairyBase data for 2007/08 to 2014/15. Lactation length = 276 days.