Bio-economic system-dynamics modelling to investigate strategic management options in New Zealand sheep farming enterprises.

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Abstract

The average and range of production and profit levels achieved in New Zealand sheep farming enterprises indicate potential for improvement across many farms. Ewe wastage, use of terminal sires, and breed transition to produce higher value wool are issues currently pertinent to the profitability of farms on New Zealand North Island Hill Country with dual-purpose breeding ewe flocks. A bio-economic system-dynamics sheep farm model was identified as appropriate to model these profitability scenarios where changes in ewe flock structure were integral. The objectives of the current research were: to develop the model; validate output through examining ewe flock wastage (premature ewe losses) rates; and use the model to investigate use of terminal (meat breed) sires to increase income from lamb sales, and a gradual flock breed transition from purebred Romney to ¾ Merino ¼ Romney to increase income from wool sales. Component modules were flock dynamics (including sheep sales), sheep feed demand, feed supply from pasture, feed balance, wool production, and economics. Model output aligned with previously published industry data and was therefore considered a realistic representation of New Zealand North Island Hill Country sheep farming systems. Flock wastage rates ranging from 5% to 21% were studied, sheep enterprise cash operating surplus (COS) reduced by $1,069 per 1% increase in ewe wastage rate due to reductions in numbers of lambs for sale. The scope for terminal sire use in self-replacing flocks was limited by requirements for purebred ewe lambs. The maximum proportion of the breeding flock able to be bred with terminal sires ranged from 18% to 65% and was greater with higher lambing rate and lower replacement rate. Maximising terminal sire use increased COS by up to $101/ha compared with no use of terminal sires, due to higher survival and growth rates in crossbred lambs sold earlier for higher prices. Flock breed transition through crossbreeding a Romney flock with Merino sires demonstrated reductions in COS during the breed transition period and greater COS post-breed change. Net present value analysis showed whole farm COS with breed transition to be up to 26% greater than maintaining the purebred Romney flock. Breed transition scenarios with higher Merino-Romney crossbred ewe lamb selection intensity achieved lower average wool fibre diameter, with a longer breed transition period (i.e. ten years of transition) and greater economic benefit. Overall, the model was effective in investigating the selected scenarios and the results can be used to inform decision making of New Zealand farmers.

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List of abbreviations

Term	Definition
µm	Micron
½M½R	½ Merino ½ Romney
¾M¼R	¾ Merino ¼ Romney
b	Lamb birthweight
BCS	Body Condition Score
C	Culling
c	Culling rate
COS	Annual Cash Operating Surplus (employed as a profit indicator)
D	Deaths
d	Death rate
DFS	Desired flock size
DM	Dry matter
EBITR	Earnings Before Interest, Tax, and Rent
EUR	Euro
F	Foetal loss rate
f	Adjustment parameter for fibre diameter
FD	Fibre diameter
$Feed_{Sheep}$	Proportion of total farm feed consumed by sheep
G	Average ewe daily wool growth
Ha	Hectare
i	Age class
kg	Kilogram
kt	kilotonnes
L	Lamb liveweight at weaning
LB	Lambs born
LM	Lambs weaned
LR	Lambing rate
LW	Liveweight
ME	Metabolisable energy
ME_L	Metabolisable energy required for lactation
ME_m	Metabolisable energy required for maintenance
ME_P	Metabolisable energy required for pregnancy
ME_w	Metabolisable energy required for wool growth
N	Adjustment parameter for lamb birth rank
N/ktex	Newtons per kilotex
NPV	Net present value
NZD	New Zealand dollars
P	Proportion of flock bred with non-maternal breed sires
Q	pasture quality
R	Replacement ewe requirements
r	Discount rate
RR	Relative reproductive rate
S	Scanning rate

$Sort_w$	Selection of Merino-Romney crossbred ewe lambs at weaning
$Sort_{10}$	Selection of Merino-Romney crossbred ewe lambs after wool testing (around ten months of age)
SU	Stock Unit
t	tonnes
T	Time point
USD	United States dollars
W	Ewe average annual wool production
w	Wool production adjustment parameter
WP	Wool production
WR	Wastage rate
Y	Ewe flock
α	Lamb age at weaning

Chapter One

Introduction

1.1 Introduction

New Zealand exported $NZD 3.8 billion and $543 million of sheep meat and wool, respectively, from 27.3 million sheep (17 million breeding ewes) managed on 23,403 sheep and beef farms in 2018 (Beef + Lamb New Zealand Economic Service, 2019a). The majority, i.e. approximately 52%, of breeding ewes in New Zealand are Romney, a dual-purpose breed producing sheep meat and coarse wool (with a fibre diameter > 30 µm; Cranston *et al.*, 2017). Changes in the value of lambs for slaughter and the relatively low value of coarse wool have led to the majority of New Zealand sheep and beef farm income being generated through sales of live animals for meat, rather than wool compared to twenty years ago, shifting the production focus for many farmers (Beef + Lamb New Zealand Economic Service, 2019a, 2019b). Lambing rates (lambs weaned per ewe presented for breeding) in 2018 ranged from 80% to 180% averaging 132% across New Zealand flocks, while profit (e.g. EBITR; Earnings Before Interest, Tax, and Rent) ranged from $0/ha to $1,500/ha across New Zealand sheep and beef farms with a median of $450/ha (Beef + Lamb New Zealand, 2020), indicating the potential for increased production and profitability on many farms.

Bio-economic modelling is a relatively cost effective and timely method of evaluating farm systems which can be used to identify strategies to potentially improve New Zealand sheep farming enterprise production and profit (McCall *et al.*, 1994; Meinke *et al.*, 2001; Woodward *et al.*, 2008). Farm systems models can be broadly categorised as either optimisation or simulation models. Optimisation approaches attempt to predict the best solutions and alternatives for resource management and allocation. While simulation approaches attempt to model the behaviour of the system while describing and explaining farm responses (Flichman and Jacquet, 2003). There are numerous existing bio-economic models of various sheep farming systems in different countries, including New Zealand. New Zealand sheep farm bio-economic models currently in use are both steady state optimisation models: Farmax, a sheep and beef farm model that simulates feed supply and demand to test for feasibility while optimising parameters (Marshall *et al.*, 1991); and AgInform, a sheep and beef farm resource allocation model which maximises profit (Rendel *et al.*, 2013). Systems dynamics is a type of simulation modelling technique effective for modelling systems with numerous interconnected components and feedback processes (Walters *et al.*, 2016) such as those existing in a breeding flock, and for modelling systems in both steady and transition states (isee Systems, 2017). System dynamics has recently been used to test *ex ante* dynamic impacts of feedbacks from different scenarios and technical interventions in animal production systems focused around breeding stock (Hamza and Rich, 2015; Shane *et al.*, 2017; Lie *et al.*, 2018) including New Zealand pastoral farm systems (García, 2000).

Sheep farming enterprise operating profit can be improved through either increasing income and/or reducing expenses (Shadbolt and Martin, 2005). The annual cost of replacing capital breeding stock lost due to death and culling has been identified in international studies as a significant expense for animal production systems due to greater costs for rearing replacement stock and associated production losses (McGregor, 1979; Bailey and Currin, 1999; Tozer and Heinrichs, 2001; McHugh, 2012). Ewe wastage (losses of breeding ewes due to death and premature culling) has received recent attention in New Zealand and has been estimated to range from less than 5% to more than 20% of ewes in a flock (Griffiths, 2016; Griffiths *et al.*, 2017), but it is not known how ewe wastage affects production and profit at a farm system level. Ewe wastage in New Zealand could be investigated using a bio-economic system-dynamics model of a sheep flock where changes in flock replacement requirements, flock age structure, production, feed requirements, and profit can be quantified. This knowledge of the cost of ewe wastage would allow farmers to make informed decisions around mitigation efforts.

New Zealand sheep farmers have made significant gains in lambing rates with the national average increasing from 101% in 1990 to 132% by 2018 (Davidson, 2012; Beef + Lamb New Zealand Economic Service, 2019a), and lamb carcass weights increased from 13.0 kg to 18.6 kg during the same period (Mackay *et al.*, 2012; Beef + Lamb New Zealand Economic Service, 2019a). The price farmers receive for lamb varies within, as well as between, years, but is generally highest in Spring (September to November) and lowest in Autumn (March to May) (Beef + Lamb New Zealand Economic Service, 2019c). Strategies to increase the proportion of lambs sold earlier after weaning (typically November/December) would likely increase prices received for lamb per kg and sheep enterprise income. One potential strategy to sell a greater proportion of lambs earlier is the use of terminal (meat breed) sires, as post-weaning growth rates of crossbred lambs from terminal sires have been observed to be up to 30% greater than their purebred (or straightbred) counterparts (Clarke and Meyer, 1982; McEwan *et al.*, 1995). Use of terminal sires in New Zealand appears to be relatively low compared with international sheep production systems (Banks and Ross, 2003; Rodriguez-Ledesma *et al.*, 2011; Beef + Lamb Economic Service, 2019a). One possible limiting factor for terminal sire use is the requirement for purebred ewe lambs for annual replacement of ewes leaving the flock due to death and culling. A bio-economic system-dynamics model of a sheep farming enterprise could investigate how the maximum proportion of terminal sires varies with changes in flock dynamics and any associated gains in production, feed balance, and profit. The results of this modelling of terminal sire use can be used to inform New Zealand farmers' decision making around breeding policies and ram selection.

Since the 1980s, the real values of mid-micron wool (i.e. with a fibre diameter of 24 to 30 µm) and fine wool (with a fibre diameter of < 24 µm) have risen while the real value of coarse wool (> 30 µm) has fallen. Many farmers producing coarse wool now consider shearing an animal welfare necessity rather than source of income and the average proportion of gross income derived from wool sales has reduced from 12% in 2010 to 6% in 2018 for New Zealand North Island Hill Country farms (Beef + Lamb New Zealand Economic Service, 2019b; Bootsma and Searle, 2019). In theory, production of mid-micron wool with relatively high value which is appropriate for multi-year contracts (Wallace, 2018; The New Zealand Merino Company, n.d.), while still achieving suitable lamb production, could be achieved with a flock of ¾ Merino ¼ Romney (¾M¼R) crossbred sheep (fibre diameter of < 26 µm; Dobbie *et al.*, 1985; Meikle *et al.*, 1988; Wuliji *et al.*, 1995; Andrews *et al.*, 1995, 1998; Everett-Hincks *et al.*, 1998; Muir and Thomson, 2013). However, there is uncertainty about how production and profit would change during the breed transition and how long it would take to replace a purebred Romney flock with an equivalent ¾M¼R flock, which are producer concerns (BakerAg, 2019). A bio-economic system-dynamics model can simulate a ewe flock both in steady state such as the Romney and ¾M¼R flocks at stable size at the beginning and end of the breed transition, and simulate the transition period with annual changes in numbers of sheep of differing breeds and age classes. The model could quantify annual changes in production, feed demand, and profit for such breed transition strategies and identify appropriate Merino-Romney crossbred ewe lamb selection intensity to achieve sufficiently high value wool in a reasonable time frame. Information provided by bio-economic system-dynamics modelling would inform the decision making of coarse wool producing farmers interested in applying a breed change strategy to farming a Merino-Romney crossbred flock producing mid-micron wool.

Several strategies involving changes to ewe flock dynamics, i.e. changes in ewe flock age structure and use of sires of differing breeds, have not been previously explored at a farm systems level and have the potential to increase New Zealand sheep farming enterprise operating profit. This research used system dynamics modelling techniques to firstly create a sheep flock dynamics model with associated production of wool and sheep for sale, energy balance, and sheep enterprise operating profit. The developed model was then used to explore the effects of changes in flock dynamics during several profitability scenarios, for which the model was used in both steady and transition states.

The specific objectives of this thesis were to:

1. Use STELLA (isee Systems, 2019) to develop a bio-economic system-dynamics model of a New Zealand sheep farming enterprise focused around ewe flock dynamics.
2. Test the steady state, annual model by investigating the impacts of varying rates of ewe wastage.
3. Use the model in a steady-state, annual form to investigate scenarios where income from lamb sales increased through use of terminal sires.
4. Use the model in a multi-year transition form to investigate a scenario where wool fibre diameter decreased and income increased through a gradual flock breed change.

The research required the development of a bio-economic system-dynamics model of a New Zealand sheep farming enterprise from conception through utilisation for various profitability scenarios. STELLA (isee Systems, 2019) was identified as an appropriate system dynamics modelling software and it has previously been used to model livestock production systems (Hamza and Rich, 2015; Shane *et al.*, 2017; Lie *et* *al*., 2018) including New Zealand pastoral farm systems (García, 2000). Industry survey average values were used as a basis to inform the representative modelled sheep enterprises (Beef + Lamb New Zealand Economic Service, 2019b). The same base bio-economic system-dynamics model developed for a sheep enterprise was extended and used throughout the thesis and methodology describing model workings repeated where necessary.

Each of Chapters Three, Four, and Five used the model to investigate various profitability scenarios at a different stage of model development in chronological order as defined in the research objectives. This research modelled New Zealand North Island Hill Country (Class Four; Beef + Lamb New Zealand, 2018) sheep and beef farms, focusing only on the sheep operations and enterprise of the farm. Hill Country sheep enterprises in the Manawatu (Chapter Three), Gisborne (Chapter Four), and Hawke's Bay (Chapter Five) were modelled as these areas have large sheep populations where sheep farming operations are typically focused around flocks of Romney breeding ewes (Beef + Lamb New Zealand Economic Service, 2019b).

1.2 Model development

The flock dynamics module developed included seven ewe age classes, each with an age specific relative reproductive rate, and feedback loops such as calculation of replacement ewe lamb requirements for a flock in steady state of a stable size and the resultant effect on ewe numbers in each age class (Appendix One). Component modules of monthly feed supply, monthly sheep energy demand, monthly energy balance, lamb and coarse wool production, and cash operating surplus were developed alongside the flock dynamics component module, with model equations shown Appendix Three (with a glossary of equation terms in Appendix Two). The model was used at this stage to simulate a Romney flock with varying ewe wastage rates and validate the output through comparison with industry data (Chapter Three). After quantifying the effects of ewe wastage, the model was extended to estimate energy balance fortnightly and to include the use of terminal sires with an age differentiated breed strategy to produce crossbred lambs with different production to their purebred counterparts (Chapter Four). The effects of varying ewe loss rates were once again modelled, as replacement and lambing rates were altered to investigate their influence on the scope for terminal sire use in a self-replacing flock. The model was further extended to simulate a flock breed transition to produce higher value wool (Chapter Five). A similar crossbreeding feature to that used in Chapter Four was used to simulate production of crossbred lambs from Romney ewes and Merino rams. The model was further extended to simulate two more ewe flocks, where ½ Merino ½ Romney lambs entered a flock of the same breed. Second cross ¾M¼R lambs were produced through further crossbreeding with Merino rams, some of which then enter the ¾M¼R flock. The model was also extended for Chapter Five to incorporate effects of lamb selection intensity on Merino-Romney crossbred flocks' average wool fibre diameter and to include pricing for mid-micron wool, along with the feed requirements of Merino-Romney crossbred sheep, and total sheep and beef operating profit.

The bio-economic system-dynamics model output generated in the thesis can inform the decision making of farmers and their consultants when considering ewe wastage, breeding policies, or considering crossbreeding to produce higher value wool. While, model input data can be adjusted to model scenarios for specific sheep farming enterprises, it was not envisaged that the model will be used as a tactical decision support tool for within-production year decision making. Rather, it can be utilised to inform strategic, farm system level decision making and possibly adapted in the future for scenarios outside the scope of this research.

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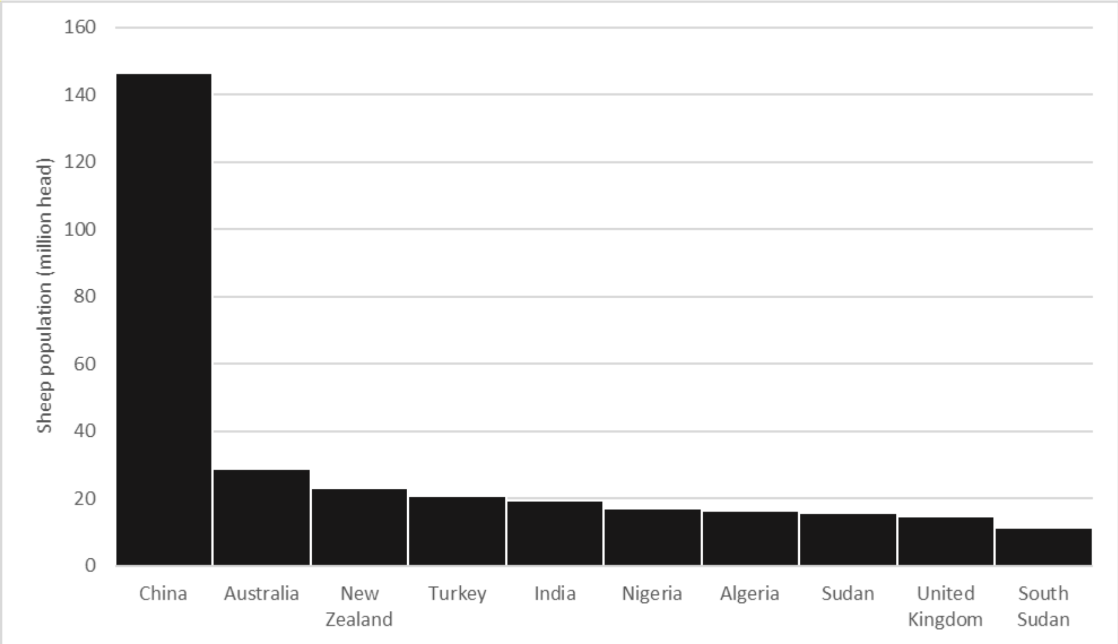
Chapter Two

Literature review

2.1 The world situation

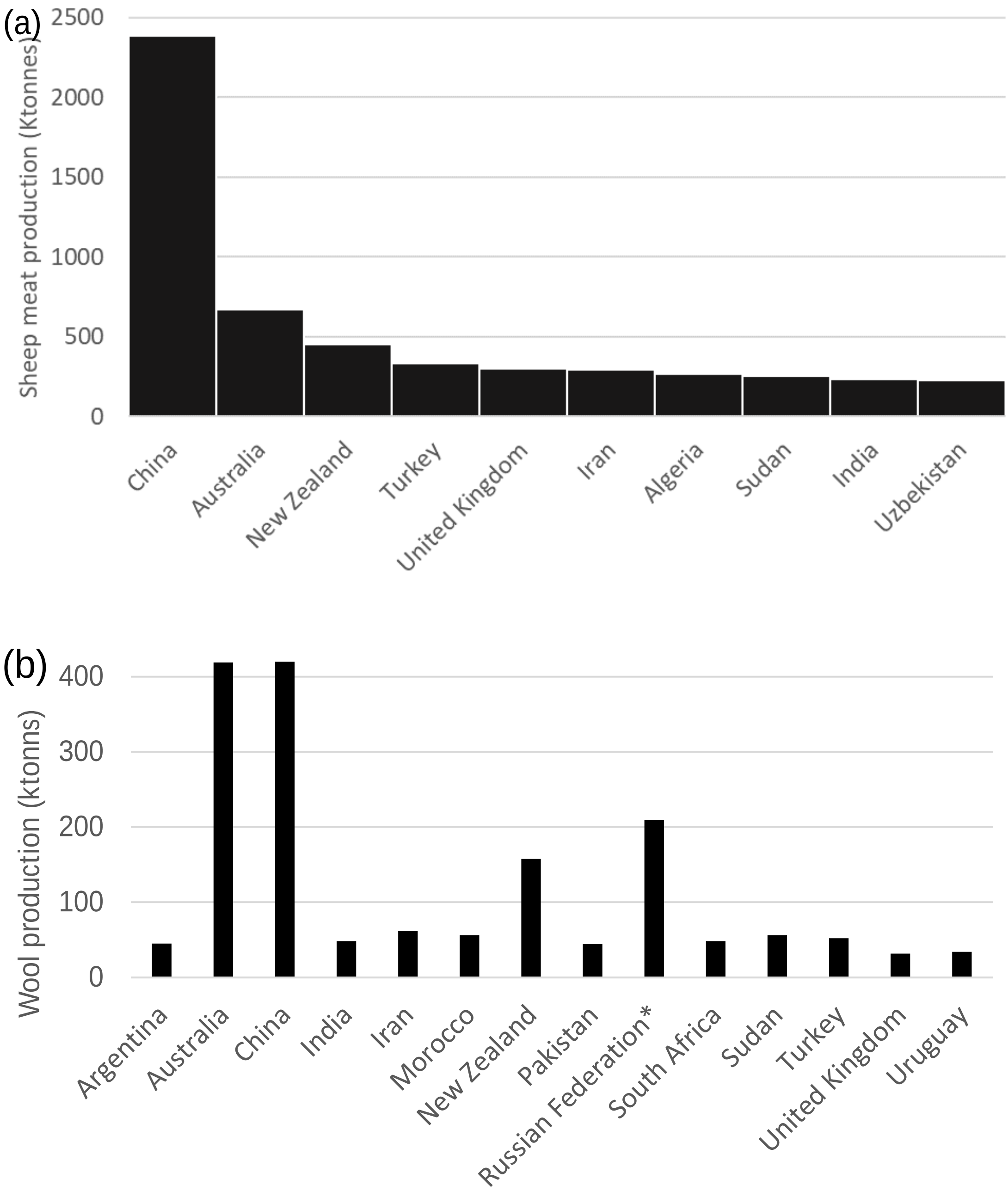
The world population of farmed sheep in 2014 was approximately 567 million with New Zealand having approximately 4% of the total world population (Figure 2.1) (FAO, 2019). However, it is acknowledged that these numbers are 'best' estimates of global sheep numbers and are subject to some inaccuracies in numbers reported as well as translation issues due to the word for sheep and goats being similar or the same in some languages.

Figure 2.1: Countries with the largest sheep populations (FAO, 2019).



The global production of sheep products in 2017 was estimated to be 15.2 million tonnes (t) of meat, 1.15 million t of wool, and 10.41 million t of milk (FAO, 2019; FAOSTAT, 2017; ABARES, 2017). In that year China, Australia, and New Zealand were the world's largest producers of sheep meat and wool (Figure 2.2a, b), while Turkey, China, and Greece were the largest producers of sheep milk (ABARES, 2017; FAO, 2019). The proportions of wool production classed as coarse, medium, and fine are shown in Figure 2.3 (ABARES, 2017). Australia and New Zealand were the largest exporters of wool, exporting 429 and 105 kilotonnes (kt), respectively in 2017. The largest exporters of sheep meat were Australia (390 kt) and New Zealand (373 kt) (ABARES, 2017; Beef + Lamb New Zealand Ecocnomic Service, 2019a), with New Zealand exporting the more lamb meat (303 kt) than Australia (280 kt) (ABARES, 2017).

Figure 2.2: World's largest producers of (a) sheep meat in 2017 and (b) greasy wool in 2014 (ABARES, 2017).



*Russian Federation includes the Commonwealth of Independent States members.

2.1.1 Changes in the world sheep population and production

Between 1994 and 2014 the world sheep population increased, with a proportionally greater increase in meat production (Table 2.1; OECD, 2016; FAOSTAT, 2017). However, wool production declined 22% during this period, driven by lower prices as textile processors increasingly use synthetic and cotton fibres (Gro-Intelligence, 2017).

Figure 2.3: Proportion of world clean wool trade of each type (ABARES, 2017).

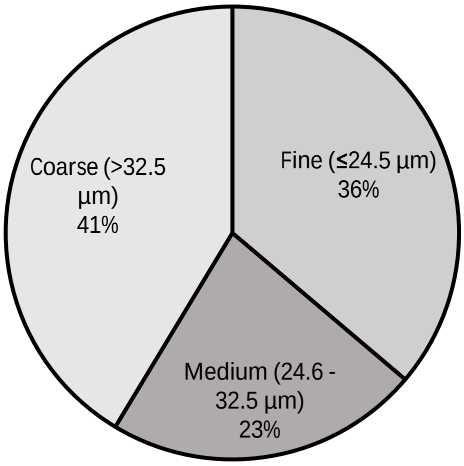


Table 2.1: Change in sheep meat and wool production and sheep population of the world and major producers from 1994 to 2014 (%) (FAOSTAT, 2017).

	Sheep meat	Wool*	Sheep population
China	+ 260	+ 85	+ 79
Australia	+ 11	- 56	- 45
New Zealand	- 6.7	- 42	- 39
World	+ 24	- 22	+ 8.3

*1994 to 2013.

2.2 The New Zealand Situation

2.2.1 Population

During 1980 to 2018, New Zealand sheep numbers declined from 68 to 27 million (Beef + Lamb New Zealand Economic Service, 2019a). Between 1990 and 2012, the area of sheep and beef farmland decreased by 28% due to conversion to dairying, viticulture, horticulture, forestry, urban use, reverted back to scrub and bush, or closed to conservation (Mackay *et al*., 2012). In 2017 there were 24,403 sheep and beef farms in New Zealand occupying 8,765 million ha and accounting for 63% of farmed land (Beef + Lamb New Zealand Economic Service, 2019a).

2.2.2 Breeds

The major sheep breeds used on New Zealand farms can be categorised as dual-purpose, terminal, or fine wool (Table 2.2). The majority of breeding flocks in New Zealand are made up of dual-purpose breeds for the production of meat and coarse wool (with a fibre diameter > 30 µm), of which the dominant breed is the Romney which accounts for 52% of the national breeding flock (Cranston *et al*., 2017; Beef + Lamb New Zealand Economic Service, 2019a). Terminal breed rams, such as Poll Dorset, Suffolk, and Texel, are used to produce crossbred lambs for slaughter with characteristics favouring meat production (Morris and Kenyon, 2014; Cranston *et al*., 2017). A small proportion, approximately 6%, of the national breeding flock are Merino, farmed in the high country of New Zealand producing fine wool (Beef + Lamb New Zealand Economic Service, 2019b).

Table 2.2: Principal Breeds of sheep in New Zealand adapted from Cranston et al. (2017).

Type	Examples	Wool fibre diameter (µm)	Lambing %
Dual-purpose	Romney, Perendale, Coopworth	31 to 40	90 to 150
Terminal	Poll Dorset, Suffolk, Texel	27 to 35	120 to 170
Fine wool	Merino, Corriedale	18 to 24	75 to 110

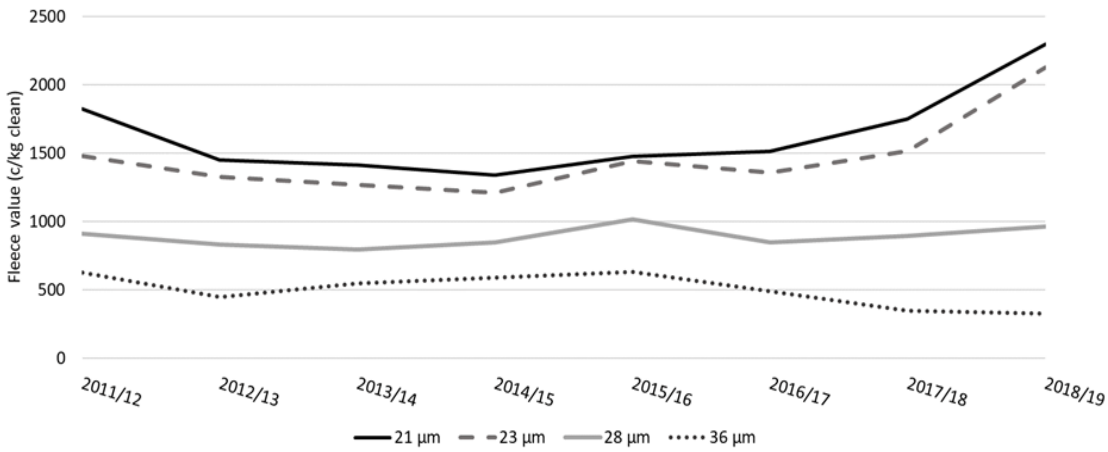
2.2.3 Wool and meat production

Changes in relative profitability of wool and meat production have led to a decline in wool production since 1980, from 380 kt of greasy wool to 139 kt in 2018 (Beef + Lamb New Zealand Economic Service, 2019a). Around 8% of wool produced in New Zealand is classed as fine wool used in clothing, while approximately 77% of wool has a fibre diameter of more than 30 µm and is predominantly used in carpet and outer garment manufacturing, which is lower in value (Figure 2.4; ANZ, 2013). Total sheep meat production in 2018 was 478 kt comprised of meat from 20.1 million lambs (78% of total sheep meat) and 4.1 million ewes (Beef + Lamb New Zealand Economic Service, 2019a). The majority of sheep farming enterprise income is derived from sale of meat and live animals (Beef + Lamb New Zealand Economic Service, 2019b). New Zealand's sheep milk industry is small and relatively new resulting in little industry data (Cranston *et al*., 2017). It is therefore not covered in this review.

2.2.4 Recent changes in productivity

There has been little change in stocking rates (animals per hectare) on sheep and beef farms since 1990 and total sheep meat production has been maintained, despite declining land area and sheep numbers, due to gains in per animal production (Mackay et al., 2012; Morris and Kenyon, 2014). These changes have occurred through advancements in breeding as well as changes in management practices such as pregnancy scanning, body condition assessment, preferential feeding of pregnant ewes bearing multiple lambs, and whole flock/herd health plans (Mackay et al., 2012; Morris and Kenyon, 2014). In 1990 the average lambing rate (lambs weaned per ewe presented for breeding) was 101% and by 2018 it had risen to 132%, ranging from an average of 101% for farms producing fine wool to 142% on farms with a greater proportion of finishing stock (Table 2.3; Davidson, 2012; Beef + Lamb New Zealand Economic Service, 2019a, 2019b). Between 1990 and 2017 the average carcass weight of lamb produced annually per ewe increased from 13 to 18.6 kg (Mackay et al., 2012; Beef + Lamb New Zealand Economic Service, 2019a).

Figure 2.4: Real New Zealand wool auction price from 2011 to 2019 (The New Zealand Merino Company, 2019).*



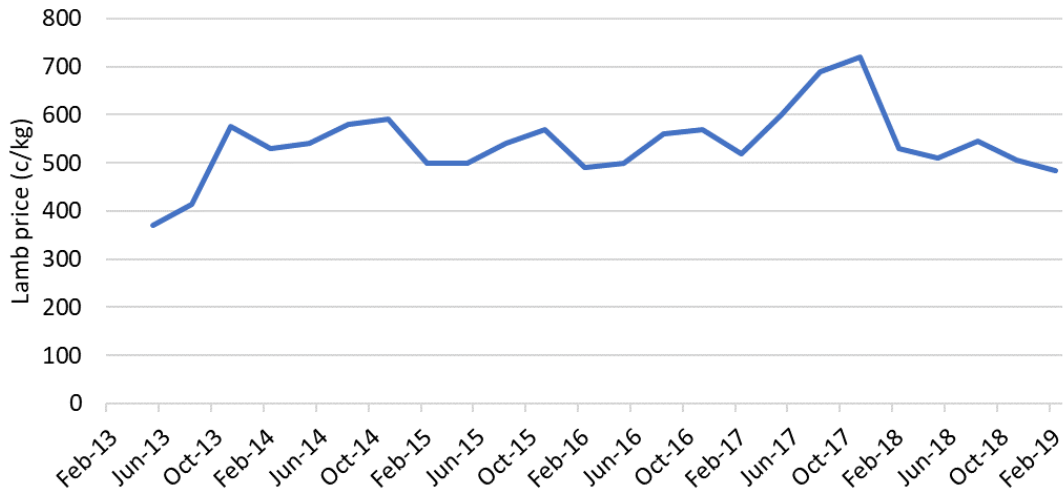
* Adjusted for inflation using the Reserve Bank of New Zealand's (2020) inflation calculator.

2.2.5 Exports

The relatively low-input and low-cost pastoral farming system in New Zealand, coupled with a low human population compared with stock numbers, allows it to be competitive in the global export market (Morris and Kenyon, 2014). In 2018, the majority of product from New Zealand sheep and beef farms was exported; 99 and 76% of sheep meat and wool, respectively (Beef + Lamb New Zealand Economic Service, 2019a). As shown in Figure 2.5, the price at which lamb is sold varies greatly within, as well as between years (Beef + Lamb New Zealand Economic Service, 2019a).

Export revenue in 2018 from sheep meat totalled $3.35 billion and wool exports earned $543 million (Beef + Lamb New Zealand Economic Service, 2019a).

Figure 2.5: Nominal price of New Zealand lamb per kg carcass from 2013 to 2019 (Beef + Lamb New Zealand Economic Service, 2019a).



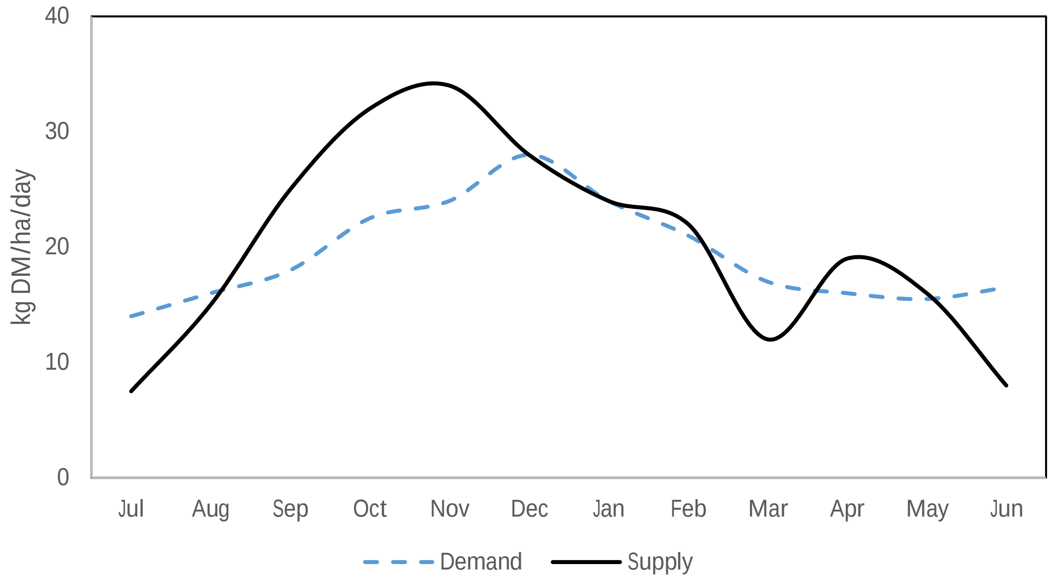
2.2.6 Sheep production systems in New Zealand

In New Zealand sheep systems, pasture accounts for more than 95% of the animals' diet and farms are extensive without housing or intensive supplementary feeding (Morris and Dymond, 2013; Morris and Kenyon, 2014). Sheep and beef cattle are usually farmed together in New Zealand to best match the pattern of pasture growth and to utilise the differing grazing behaviour of the two species to manage pasture quality, growth, and utilisation (Beef + Lamb New Zealand, 2012a). The ratio of sheep:beef stock units is generally greater in the South Island than in the North Island. For example, 36% of total farm stock units were sheep for the average Northern North Island Hill Country farm and 73% of total farm stock units were accounted for by sheep for the average Southern South Island Hill Country farms in 2017/18 (Beef + Lamb New Zealand Economic Service, 2019b). Where a stock unit is the equivalent of one adult 55 kg breeding ewe rearing one lamb and consuming 550 kg DM annually (Trafford and Trafford, 2011).

2.2.6.1 Feed

Although the seasonal pattern of pasture production and animal feed demand are similar (Figure 2.6), they are not perfectly matched, and farmers therefore make decisions to best match supply and demand. Farmers must manage farm feed supply as well as feed demand through managing breeding date, production targets, stocking rate, stock classes on-farm, and use of supplements (Beef + Lamb New Zealand, 2012a). Farmers grow forage crops and use supplements to fill feed gaps (Valentine and Kemp, 2007).

Figure 2.6: Pasture supply and feed demand for a 1,000 ha central North Island sheep and beef farm. Source: Webby and Bywater (2007)



2.2.6.2 New Zealand sheep and beef farm classes

Sheep and beef farming systems in New Zealand are divided into eight farm classes as shown in Table 2.3 and described below (Beef + Lamb New Zealand, 2018).

> "*Class one* South Island High Country: Extensive run country at high altitude carrying fine wool sheep, with wool as the main source of revenue. Located mainly in Marlborough, Canterbury and Otago.
>
> *Class two* South Island Hill Country: Mainly mid-micron wool sheep mostly carrying between two and seven stock units per hectare. Three quarters of the stock units wintered are sheep and one quarter beef cattle.
>
> *Class three* North Island Hard Hill Country: Steep hill country or low fertility soils with most farms carrying six to 10 stock units per hectare. While some stock are finished a significant proportion are sold in store condition.

Class four North Island Hill Country: Easier hill country or higher fertility soils than Class 3. Mostly carrying between seven and 13 stock units per hectare. A high proportion of sale stock sold is in forward store or prime condition.

Class five North Island Intensive Finishing: Easy contour farmland with the potential for high production. Mostly carrying between eight and 15 stock units per hectare. A high proportion of stock is sent to slaughter and replacements are often bought in.

Class six South Island Finishing-breeding: A more extensive type of finishing farm, also encompassing some irrigation units and frequently with some cash cropping. Carrying capacity ranges from six to 11 stock units per hectare on dryland farms and over 12 stock units per hectare on irrigated units. Mainly in Canterbury and Otago. This is the dominant farm class in the South Island.

Class seven South Island Intensive Finishing: High producing grassland farms carrying about 10 to 14 stock units per hectare, with some cash crop. Located mainly in Southland, South and West Otago.

Class eight South Island Mixed Cropping and Finishing: Located mainly on the Canterbury Plains. A high proportion of their revenue is derived from grain and small seed production as well as stock finishing."

2.2.6.3 North Island Hill Country farms

This thesis focuses on North Island Hill Country sheep and beef farms (Class Four; Beef + Lamb New Zealand Economic Service, 2019b). Therefore, only this class of farm is discussed in detail. Sheep enterprises on this farm class have a dual-purpose breeding ewe flock producing coarse wool and sheep for sale, including lambs and cull ewes. This is in addition to beef cattle and potentially deer. These two enterprises will not be discussed in any depth in this thesis as the research focused on the sheep enterprise. There are 3,055 North Island Hill Country farms, constituting the majority of 5,020 sheep and beef farms in the North Island and predominantly farming Romney ewes (Beef + Lamb New Zealand Economic Service, 2019a). Research on changes to the flock on North Island Hill Country farms would therefore have relevance for a large proportion of New Zealand sheep farms with a breeding flock of dual-purpose ewes.

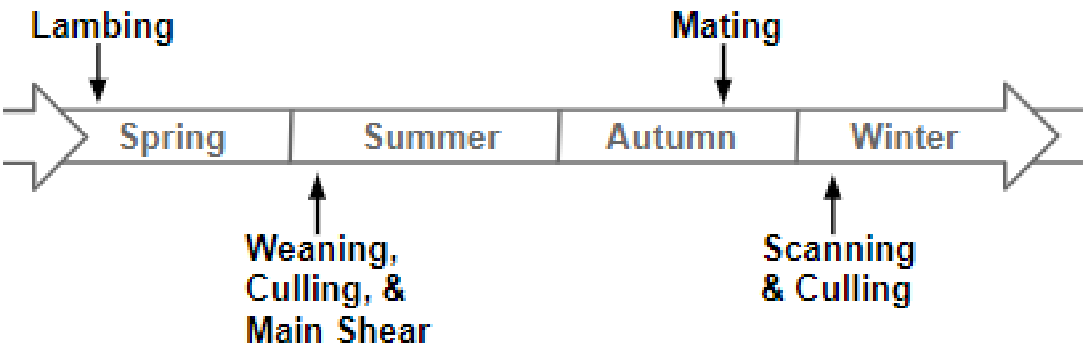
Table 2.3: New Zealand sheep and beef farm classes in 2017/18 (Beef + Lamb New Zealand Economic Service, 2019b).

Farm class	Effective area (ha)	Stock units* per ha	Lambing rate (%)	Sources of gross income (%)			
				Sheep	Beef	Wool	Other
1 SI High Country	8,162	1.4	109	42	18	28	12
2 SI Hill Country	1,572	4.1	125	59	24	11	7
3 NI Hard Hill Country	819	8.1	126	57	33	6	4
4 NI Hill Country	420	9.0	133	46	39	4	10
5 NI Intensive Finishing	283	10.3	134	36	45	3	16
6 SI Finishing-Breeding	493	7.7	139	56	21	5	18
7 SI Intensive Finishing	239	10.9	142	72	9	6	13
8 SI Mixed Finishing	396	5.6	132	7	5	1	88

SI = South Island. NI= North Island. *Where a stock unit was the equivalent of one adult breeding ewe rearing one lamb.

The calendar of events varies across sheep farming systems and environments. Sheep farming in New Zealand varies with land contour and climate which influences pasture production and hence the farm system and productive intensity. Seasonal breeding and the five-month gestation length of sheep determine the overall sequence of activities on a sheep farm (Figure 2.7; Dalton and Orr, 2004). Average size, stocking rate, flock lambing rate, and proportion of gross income from different enterprises are shown in Table 2.3 (Beef + Lamb New Zealand Economic Service, 2019a). There remains a range of lambing rates occurring on North Island Hill Country farms, e.g. for East Coast North Island Hill Country sheep farming enterprises in the 2017/18 production year the range of lambing rates were between 80% and 180%, although 90% of these farms had lambing rates between 105% and 145% (Beef + Lamb New Zealand, 2019). North Island Hill Country farms have breeding flocks mostly ranging from 125 to 2,893 ewes bred annually and the proportion of stock units accounted for by sheep mostly ranges from 20% to 60% of total stock units, where flocks are smaller and the proportion of sheep stock units lower in the Northland region. Of lambs not required for flock replacement, the proportion sold direct to slaughter averages 70%, ranging from 50.5% to 81.0%, with remaining lambs sold to another farm to finish for slaughter (Beef + Lamb New Zealand Economic Service, 2019b). North Island Hill Country farms may breed some of their hoggets (i.e. some ewes have their maiden lambing at 12-14 months of age rather than two years old, where a hogget is a weaned sheep between four and 16 months of age) which usually account for less than 10% of annual lamb production (Beef + Lamb New Zealand, 2012b; Beef + Lamb New Zealand Economic Service, 2019b). At a national level, in 2018, 47% of ewe hoggets were presented for breeding and of those bred, hoggets achieved a lambing rate of 65% (Statistics New Zealand, 2018). The following sections briefly outline the basic seasonal management of North Island Hill Country farms.

Figure 2.7: Basic calendar of major activities for a New Zealand breeding ewe flock.



2.2.6.4 Basic North Island Hill Country sheep calendar: Spring

Lambing occurs in spring to match seasonal pasture growth with the increasing nutritional demand of lactating ewes with the aim of ensuring high lamb survival and growth rates (Figure 2.8; Beef + Lamb New Zealand, 2012a). The level of observation and intervention with lambing ewes varies as although intervention for lambing difficulties and orphaned lambs is usually beneficial, human interaction can potentially increase ewe stress (Cranston *et al*., 2017). The late-pregnancy and lambing management is similar for hogget lambing but occurs one or two months later than the mixed-age ewe flock. Growth of lambs in early lactation is heavily dependent on ewe milk production, driven by ewe breed, body condition at lambing, nutrition, and lamb birth rank (i.e. single or multiple) (Kenyon and Webby, 2007).

Replacement ewe lambs born from ewes that were well fed in late-pregnancy and lactation have a better lifetime performance (Asmad *et al*., 2014). Ewes with multiple lambs have greater milk production and feed requirements (Alexander and Davies, 1959), they are therefore usually managed separately to those with a single lamb as they will lose condition in late-pregnancy if not well fed (Geenty and Sykes, 1986). Seasonal feed requirements of ewes and lambs are shown in Table 2.4 and energy requirements during lactation are shown in Table 2.5. Ewe milk production peaks three to five weeks post lambing and lambs begin grazing on pasture at three to four weeks of age (Barnicoat *et al*., 1949; Kenyon and Webby, 2007). Ewes typically lose weight during lactation as they mobilise their body reserves to meet energy requirements for milk production, with each kg of liveweight loss providing 35 MJ ME to the ewe (Kenyon and Webby, 2007). This loss should be kept to less than one body condition score (BCS) so as not to impair future performance (Kenyon *et al*., 2014). BCS is a measure of a sheep body fat, an indication of energy reserves, scored on a scale from one to five where five is very fat (Kenyon *et al*., 2014). Lambs' tails are removed at three to eight weeks of age to reduce the risk of dags and flystrike. Lambs are vaccinated around the same time against clostridial diseases and scabby mouth, and males may be left entire, or castrated, or turned into cryptorchids (Charleston, 1986; Besier *et al*., 2010).

Figure 2.8: Ewe lambing dates for North Island regions (Beef + Lamb New Zealand, 2019)

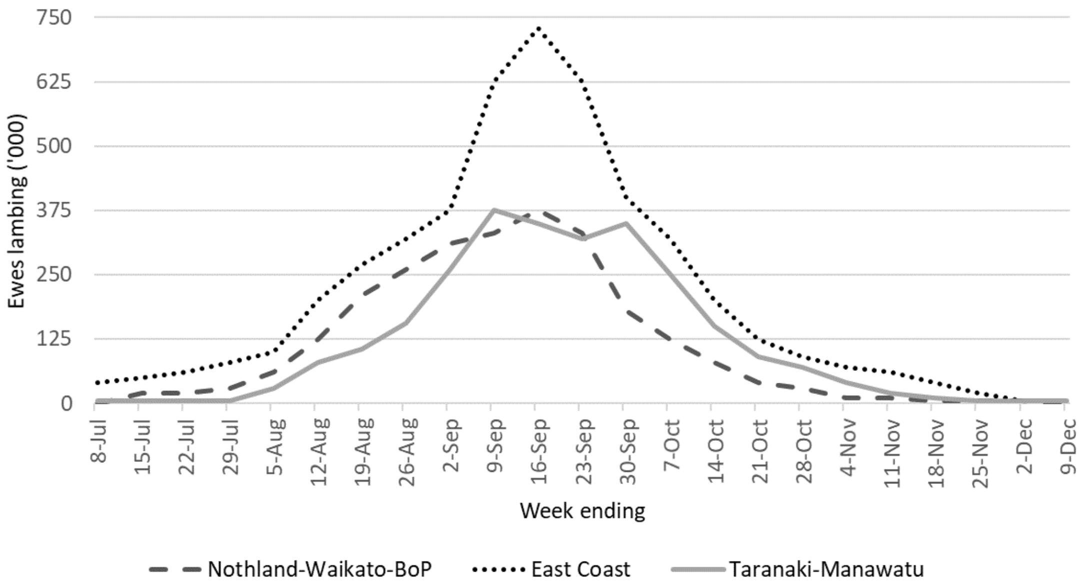


Table 2.4: Feed intake for target sheep production levels during the year (Kenyon and Webby, 2007; Beef + Lamb New Zealand, 2014). Where pasture cover was the level of feed available in the form of pasture.

	Target production level	Target pasture cover (kg DM/ha)
Ewes		
Ewes and lambs	180 - 200 g/day (lambs)	1,200 – 1,400
Summer	Maintenance	900 – 1,000
Mating	120 - 150 g/day	1,200 – 1,400
Mid-pregnancy	Maintenance	900 – 1,000
6 weeks pre-lamb	60 - 80 g/day	1,200
Lambs		
Spring	160 - 200 g/day	1,200 – 1,400
Summer	130 - 150 g/day	1,400
Autumn	80 - 100 g/day	1,200
Winter-spring	100 - 120 g/day	1,100
Hoggets summer	60 - 80 g/day	1,400

Table 2.5: The metabolisable energy requirements of ewes and their lambs during lactation (in addition to ewe maintenance requirement; Kenyon and Webby, 2007).

Lamb weaning weight (kg)	Weeks after lambing				Total for lactation
	+2	+6	+10	+12	
	MJ ME/ewe plus lamb(s)/day*				MJ ME
20	8.5	10.5	12.5	13.0	855
25	10.5	13.0	16.0	17.0	1075
30	12.0	16.0	20.0	21.0	1335
35	14.5	19.5	24.5	26.0	1625

* These would be doubled for ewes bearing twin lambs, i.e. total lactation requirements for a ewe bearing two lambs weaned at 25 kg would be 1,075 X 2 = 2,150 MJ ME. Requirements from pasture consumed by lambs prior to weaning are included.

2.2.6.5 Basic North Island Hill Country sheep calendar: Summer

Weaning occurs when lambs are approximately ten to twelve weeks old with a typical average weaning weight of 28 kg (Thompson *et al*., 2016). Lambs from hoggets are weaned younger and lighter than those from mature ewes to minimise the negative impact on hogget growth, i.e. at ten weeks of age at 23 kg liveweight (Mulvaney *et al*., 2009). Heavier ewe lambs are generally chosen as replacements for the breeding flock. Lambs not required as replacements and with a liveweight above a threshold of around 35 kg are generally sold direct to slaughter as prime lambs. The remaining lighter lambs are either grown to be sold prime or are sold to another farm as store lambs to be grown for slaughter there (Kenyon and Webby, 2007).

Numbers of lambs kept on farm for finishing depends on feed availability. These lambs require preferential feeding of high-quality forage to achieve high growth rates. Achieving lamb post-weaning growth rates of > 100 g/day is a challenge for most New Zealand sheep farmers (Brown, 1990). Lamb growth rates of > 200 g/day are achievable with high quality forage (i.e. high content of green material), including traditional ryegrass/clover pastures and/or alternative pastures with a high content of herbs and legumes (Kemp *et al*., 2010; Bywater *et al*., 2011; Somasiri *et al*., 2015). Higher growth rates occur when lambs eat the highest quality components of the pasture and leave the remainder for a lower priority stock class (Kenyon and Webby, 2007) and pasture cover (the level of feed available in the form of pasture) targets for lamb growth post-weaning are 1,400 kg DM/ha (Table 2.4; Kenyon and Webby, 2007). Systems that finish lambs sooner after weaning are more efficient, with lower lamb feed requirements for maintenance overall, less opportunity for health problems to develop, typically higher prices per kg of lamb carcass sold (Figure 2.5), and greater feed available post-finishing for other stock classes i.e. liveweight gain in ewes and replacement ewe lambs (Kemp *et al*., 2010; Beef + Lamb New Zealand, 2014). Adult ewes are often culled at weaning according to issues with physical condition (i.e. teeth, feet, body condition), reproductive performance (i.e. rearing), or age (i.e. over 6 years old; Bell, 2010). Sheep are typically shorn in summer, with lambs shorn after the main flock (Bell, 2010).

2.2.6.6 Basic North Island Hill Country sheep calendar: Autumn

Prior to breeding, farmers may increase ewe nutrition to increase their liveweight and improve reproductive performance, also called 'flushing' (Coop, 1966; Killeen, 1967; Ducker and Boyd, 1977). This includes re-gain of weight lost during the previous lactation and ewes in poor condition at weaning (i.e. BCS less than two) can be preferentially fed, i.e. on pastures with covers greater than 1200 kg DM/ha (Table 2.4), until the following breeding season when they should have a BCS of three to four (Kenyon *et al*., 2014). Liveweight gain in sheep requires approximately 55 MJ ME per kg (Kenyon and Webby, 2007). However, on commercial New Zealand farms there is often insufficient feed to meet all stock requirements and those of finishing stock are often prioritised over those of capital breeding stock, potentially to the detriment of reproductive performance (Kenyon and Webby, 2007).

Rams also gain weight prior to the breeding period and are checked for disease by a veterinarian to optimise quality and quantity of semen production (Cranston *et al*., 2017). Breeding would occur at the start of April for a lambing start date of 1 September and a ewe:ram ratio of 100:1 would be typical (Allison, 1975). In New Zealand the sheep breeding period is generally restricted to two to three oestrus cycles in total (i.e. two to three 17-day periods), with 70% of ewes becoming pregnant typically in the first 17 days of breeding (Allison, 1975; Knight *et al*., 1980). Gestational energy requirements are low during early pregnancy (approximately 50 days) and ewe feed requirements are similar to maintenance (Rattray *et al*., 1974), i.e. ewes can maintain a BCS of three or greater with pasture covers of 900 – 1,000 kg DM/ha acceptable (Kenyon and Webby, 2007; Kenyon *et al*., 2014). Maintenance requirements of ruminants are dependent on their liveweight, activity, quality of feed, sex, and age (CSIRO, 2007) and for adult sheep generally range between 7.5 to 11.0 MJ ME/day (Kenyon and Webby, 2007). Post-breeding, rams are either culled or put on a maintenance level diet until pre-breeding the following year (Cranston *et al*., 2017). On farms where hoggets are bred at around eight or nine months of age, this would occur after breeding of the mature flock (i.e. in approximately May and June) and those to be bred need to achieve a minimum liveweight of 35 - 40 kg by breeding (Kenyon *et al*., 2004).

2.2.6.7 Basic North Island Hill Country sheep calendar: Winter

In early winter the growth of pregnant and non-pregnant hoggets is a priority as low growth rates during their first year results in poor production in later life (Kenyon and webby, 2007). A hogget liveweight of 50 kg is targeted at lambing, to be gained over winter through feeding on pastures with covers of 1,400 kg DM/ha (Kenyon *et al*., 2004; Kenyon and Webby, 2007). Trans-abdominal ultrasound scanning of mated ewes occurs in early winter (when ewes are between 45 and 90 days pregnant), with non-pregnant ewes usually culled to save feed in preparation for winter and ewes carrying multiple foetuses identified (Kenyon and Webby, 2007). Ewes should maintain a BCS of three in winter which can be aided by growth of winter crops such as brassicas to meet feed requirements (Kenyon *et al*., 2014). Ewe feed requirements increase in mid-pregnancy with further increases in late-pregnancy when the majority of foetal growth occurs and ewe mammary tissue and colostrum are developed, increasing feed intakes (Table 2.6; Kenyon and Webby, 2007). Ewes carrying multiple foetuses are managed separately from those carrying one foetus as feed requirements increase earlier and to a higher level (Kenyon and Webby, 2007). Table 2.6 shows how energy requirements increase in late-pregnancy; these values can be doubled for a ewe carrying multiple foetuses, and multiple-born lambs are more affected by ewe nutrition during pregnancy than single-born lambs (Kenyon *et al*., 2009). Sufficient feeding of ewes during late-pregnancy is important to decrease the risk of perinatal ewe and lamb losses as ewes fed well in late-pregnancy have greater milk production (Hall *et al*., 1992; Bizelis *et al.*, 2000), giving birth to heavier lambs (Morris and Kenyon, 2004) with greater fat reserves (Rattray *et al*., 1986) that can better survive times of reduced feed (McDonald, 1962; Everett-Hincks *et al*., 2005; Kenyon et al., 2014). Two to three weeks prior to the start of lambing, ewes are shifted to their lambing paddock, typically on flat or gently sloping land with shelter (Tarbotton and Webby, 1999). Pastures covers of 1,200 – 1,400 kg DM/ha would be aimed for, to supply ewes and their lambs with a high quality and quantity of feed post-lambing, supporting high lamb survival and growth rates, however these would not always be achieved on commercial farms (Table 2.4; Kenyon and Webby, 2007). On some farms ewes may be fully shorn mid-winter, or only have the wool around the udder and breech removed to give lambs better access to teats (Cranston *et al*., 2017).

Table 2.6: The metabolisable energy requirements of ewes for pregnancy (in addition to ewe maintenance requirement) (Kenyon and Webby, 2007).

Lamb birth weight (kg)	Weeks before lambing				Total for pregnancy
	-6	-4	-2	0	
		MJ ME/ewe/day*			MJ ME
3	1.5	2.0	3.0	4.5	155
4	2.0	3.0	4.0	6.0	200
5	2.5	3.5	5.0	7.0	255
6	3.0	4.5	6.0	8.5	300

* These would be doubled for ewes bearing twin lambs, i.e. total gestation requirements for a ewe bearing two lambs born at 4 kg would be 200 X 2 = 400 MJ ME.

2.3 Profitability drivers for New Zealand North Island Hill Country sheep farming enterprises

Estimates of changes in sheep enterprise profitability can be indicated from changes in Cash Operating Surplus (COS). COS does not make assumptions about farm financial structure, consisting of gross income minus farm operating expenses, and excluding rates, interest, rent, and depreciation (Shadbolt and Martin, 2005). Sheep enterprise COS can therefore be increased through either increasing income and/or reducing expenses. The current research focuses on the sheep enterprise. Class Four North Island Hill Country farms have other enterprises on-farm such as beef production (Table 2.3), which is accounted for using the stock unit ratio of sheep:cattle to estimate the feed supply and working expenses for sheep (Beef + Lamb New Zealand Economic Service, 2019b).

2.3.1 Expenses

The largest operating expenses for a New Zealand sheep enterprise are fertiliser, labour, and repairs and maintenance (Beef + Lamb New Zealand Economic Service, 2019b). Opportunities to reduce these without significant reductions in production are limited. Fertiliser inputs in pastoral farming systems are necessary to achieve and maintain desired levels of pasture production. Inputs can be reduced in low-income years for short-term savings, however long-term reductions would have negative consequences on soil fertility, pasture growth, and production (Kemp *et al*., 2004). The consequences of reducing spending on repairs and maintenance would be similar, in that long-term reductions will reduce production or increase expenses at a later date, i.e. not maintaining machinery and having to replace it sooner. There is also a limit to possible reductions in labour expenses as stock management activities, i.e. drenching, weighing, tailing, and scanning sheep, are labour intensive and extensive Hill Country farms already have relatively low labour inputs. i.e. less than two full time labour units for 500 ha (Beef + Lamb New Zealand Economic Service, 2019b).

Another significant expense for farming systems with capital breeding stock is the annual cost of replacing stock lost due to death and culling and associated production losses. The cost of rearing replacement animals has been explored in international studies (Bailey and Currin, 1999; McGregor, 1979; Tozer and Heinrichs, 2001; McHugh, 2012). For New Zealand North Island Hill Country farms annual ewe replacement rates are typically between 20 and 35% (Griffiths, 2016; Cranston *et al*., 2017) and are made up of both ewes culled for age and those lost due to death and premature culling. The premature losses, also called ewe wastage, involve the loss of ewes before they reach the end of their potential productive lifespan and range from 2.8% to more than 20% of the ewe flock annually (Anderson and Heuer, 2016; Griffiths *et al*., 2017). Reducing ewe wastage would likely reduce the resulting production losses and replacement requirements (Griffiths *et al*., 2017). For New Zealand's national ewe breeding flock, a 5% increase in WR would require an estimated additional 960,000 replacements to maintain total flock size (Beef+ Lamb New Zealand Economic Service, 2019a). There is a lack of analysis examining the impact of ewe wastage on New Zealand sheep farms; quantification of changes in production, COS, and feed balance using bio-economic modelling will identify if ewe wastage is a significant issue reducing profitability and warranting further investigation.

2.3.2 Increasing sheep income

The average ratio of income from sheep and wool sales is 11.2:1 (Table 2.3) with sheep and wool sales accounting for 56% and 5%, respectively, of total farm income (Beef + Lamb New Zealand Economic Service, 2019b). As lamb sales make up the majority of sheep income for this farm type (Beef + Lamb New Zealand Economic Service, 2019b), gains in income can be made through increasing the rate of lambs weaned (and thus sold), carcass weight per lamb, or price per kg of carcass weight or store lamb sold. As discussed in Section 2.2.4, in recent years farmers have focused on increasing lambing rate and lamb carcass weight through changes in management, breeding, and nutrition. The range of lambing rates and proportion of lambs sold prime outlined in Section 2.2.6.3 indicate potential for many farms to increase sheep income through increasing lambing rate and/or carcass weight. Improvements in these factors that significantly increase income at a greater rate than the associated expenses would be expected to increase sheep enterprise profitability.

As exporters, New Zealand farmers rely on global market conditions which are affected by changes in overseas policies and exchange rates, resulting in price uncertainty (Ministry of Agriculture and Forestry, 2009; ANZ, 2014). The seasonal nature of pastoral farming in New Zealand inhibits the consistent supply of stock for processing and farm gate prices are influenced by any oversupply of stock from October to April which also determines upper limits to supply (Beef + Lamb New Zealand, 2017). Prices per kg of lamb carcass peak in spring and are lowest in late-summer (Beef + Lamb New Zealand Economic Service, 2019c). Though farmers do not have influence over lamb price trends, timing of lamb sales and weight sold will affect the income they receive.

There are numerous potential ways that farmers increase their income from sheep sales through changes in production and prices. One method of increasing production is increasing lamb growth rates and survival which can be achieved through improved ewe nutrition (Morris and Kenyon, 2004). In addition, choice of sire breed can affect lamb production through selection for traits within breeds or crossbreeding. Terminal sires, such as the Poll Dorset and Suffolk (Table 2.2) can be bred with a ewe flock to produce crossbred lambs with traits favouring lamb production compared with purebred lambs from maternal breed sires, e.g. post-weaning growth rates in crossbred lambs from terminal sires have been observed to be up to 30% faster than those of their purebred Romney counterparts (Carter and Kirton, 1975; Clarke and Meyer, 1982; McEwan *et al*., 1995). Using terminal sires to produce lambs that reach target slaughter weights sooner after weaning may achieve higher prices in most seasons (Figure 2.5) and this strategy could increase sheep income. The relationship between lamb growth rates and profit in New Zealand were found to be positive in previous work (Thompson *et al*., 2016). There has not been published research in New Zealand on the influence of flock dynamics (i.e. age structure, loss rates, reproductive performance) on the scope for using terminal sires in self-replacing flocks to increase lamb income. A bio-economic system-dynamics model of a sheep enterprise would be of use in investigating factors influencing the proportion of the ewe flock that can be bred with terminal sires, with associated changes in production, COS, and energy balance.

2.3.3 Increasing wool income

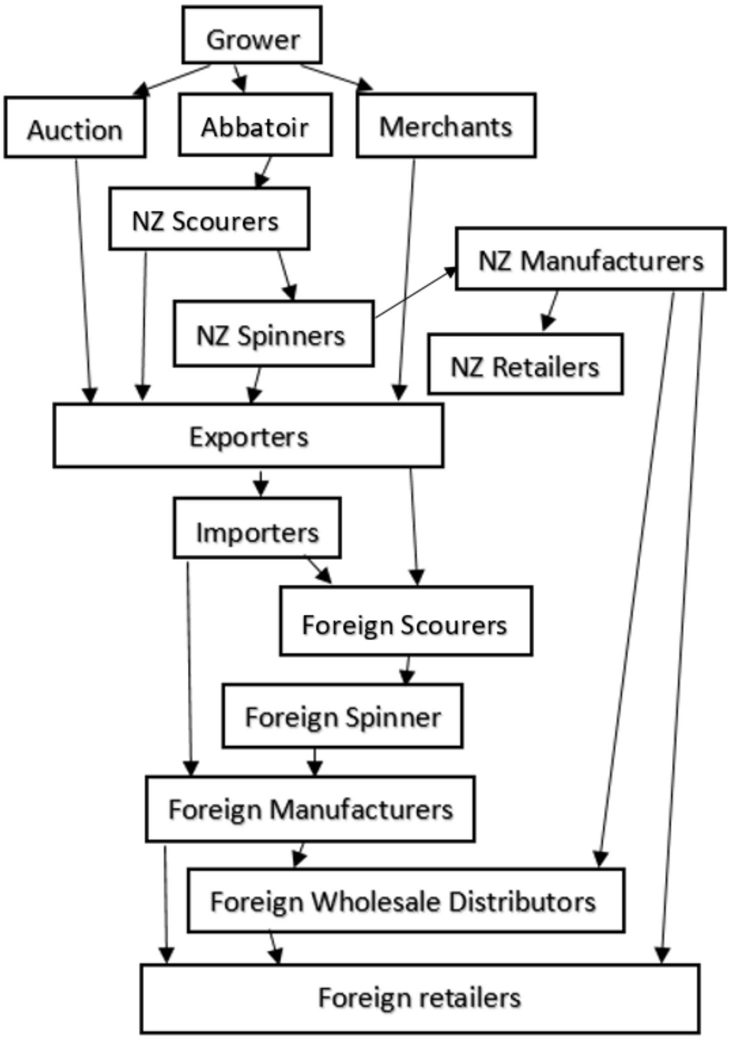
The real value of mid-micron wool, i.e. with a fibre diameter of 24 µm to 30 µm, and fine wool, with a fibre diameter of < 24 µm, has risen during the same period that the real value of coarse wool has fallen (Figure 2.4; Beef + Lamb New Zealand Economic Service, 2019a). New Zealand nominal prices for coarse wool have varied between 250 and 600c per kg clean since 1980 (Beef + Lamb New Zealand Economic Service, 2019a) and recent increases in shearing costs have resulted in many farmers considering shearing a welfare necessity rather than source of income, with flocks shorn only once per year (Bootsma and Searle, 2019).

2.3.3.1 New Zealand Wool Supply Chain

The supply chain for coarse wool has been described as "weak and fragmented to the point of being dysfunctional" (Faulkner, 2012) and involves many entities (steps) relative to other products, e.g. wool carpet may have between three and twelve transactions from the farm to its end use, (Figure 2.9; Faulkner, 2012; ANZ, 2013). Despite recent efforts to consolidate the New Zealand wool exporting sector, in 2013 there were around thirty-five exporters, with six controlling approximately 80% of exports. All but one exporter outsourced their scouring, washing of wool in hot water and detergent to remove the non-wool contaminants (ANZ, 2013). The majority (more than 70%) of New Zealand wool is processed overseas due to the low cost, often being exported again to the countries in which they are consumed (ANZ, 2013; Bray and Gonzalez-Macuer, 2010).

Fine wool and makes up approximately 8% of annual New Zealand wool exports (Beef + Lamb New Zealand Economic Service, 2019a). As shown in Figure 2.4 and Figure 2.10, the price at which New Zealand fine wool is sold is greater than coarse wool, reflecting the value of the end use products. Thus producers of fine wool earn approximately one third of gross income from wool sales unlike farmers with dual-purpose breeds producing coarse wool for whom 1-11% of gross income is from wool (Table 2.3; Beef + Lamb New Zealand Economic Service, 2019b). Communication across supply chains lowers uncertainty and inventory levels for involved entities. The aim of cooperation in supply chains is to predict and be driven by demand, delivering a product that consumers value (Chandra and Kumar, 2000). Since the mid-1990s New Zealand fine wool producers have increasingly sold their wool through multi-year contracts, with close relationships between producer and manufacturer to increase wool prices and price stability for producers and, for the manufacturer, assurance of supply of traceable fibre grown to desired specifications (Pawson, 2018). In contrast, the majority of coarse wool is sold via auction or to private buyers (Beef + Lamb New

Figure 2.9: New Zealand coarse wool supply chain. Source: ANZ (2013).

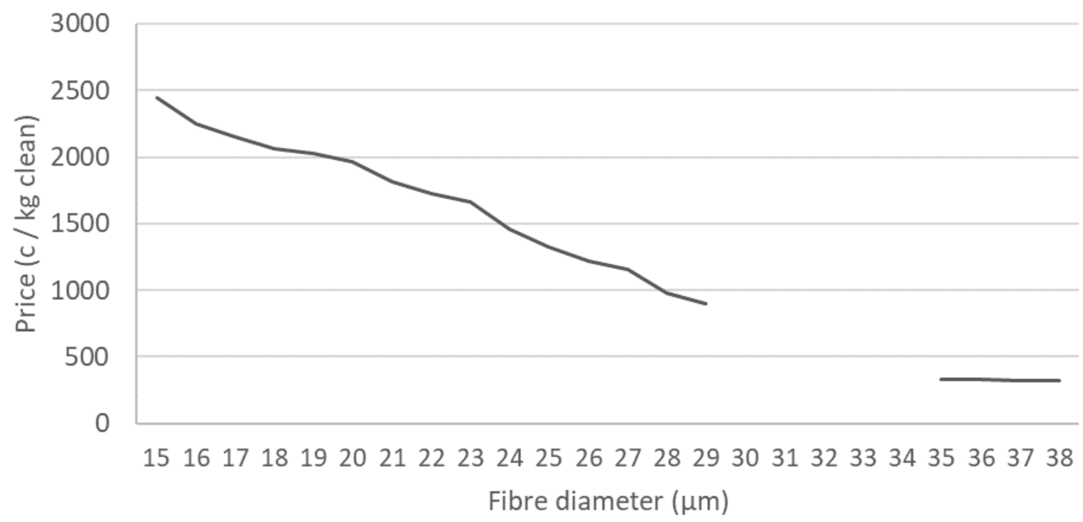


Zealand Economic Service, 2019a). New Zealand producers of fine wool can get secure, longer term contracts (e.g. up to five years) to supply wool for an agreed price through organisations such as The New Zealand Merino Company (The New Zealand Merino Company, n.d.). Fine wool can otherwise be sold at auction in Melbourne, Australia and Dunedin, New Zealand (Pawson, 2018; Carrfields Primary Wool, 2019). Mid-micron wool is typically used for woven outerwear, knitwear, and socks (Cottle, 2010). The market demand for mid-micron wool from crossbred Merino sheep has increased prices to supply manufacturers of garments such as woollen socks (Pawson, 2018). Multi-year supply contracts have recently become available for mid-micron wool, i.e. up to 26 µm with prices ranging from \$10 to \$15 per kg clean, applicable for wool from sheep with some Merino genotypes (Wallace, 2018).

2.3.3.2 Increasing Wool Income through Crossbreeding

A small number of North Island sheep farmers have shifted to a crossbred or purebred Merino flock in order to sell wool through multi-year contracts for higher and more stable prices (Stowell, 2012; Muir and Thomson, 2013; Hutching, 2019). Merino and Merino-crossbred sheep generally produce less wool than coarse wool breeds with the same shearing costs per ewe, i.e. Merino sheep produce an approximately 4.3 kg fleece and Romney sheep produce an approximately 5 kg fleece (Beef + Lamb New Zealand Economic Service, 2019b). However, Figure 2.10 shows the per kg price for mid-micron wool is significantly higher than coarse wool, potentially resulting in annual wool income per ewe of > $50 and $15 for mid-micron and coarse wool producing sheep, respectively (Carrfields Primary Wool, 2019). The mean fibre diameter values for New Zealand Merino-Romney crossbred sheep indicate that production of mid-micron wool appropriate for multi-year contracts (fibre diameter of less than 26 µm; Wallace, 2018) could be achieved with a flock of ¾ Merino ¼ Romney sheep (Dobbie *et al*., 1985; Meikle *et al*., 1988; Andrews *et al*., 1995, 1998; Wuliji *et al*., 1995; Everett-Hincks *et al*., 1998; Muir and Thomson, 2013).

Figure 2.10: Auctioned wool price for varying fibre diameters in October 2019 (Carrfields Primary Wool, 2019). Prices for wool with fibre diameters of 30 to 34 µm not available for that month.



Crossbreeding to produce a Merino-Romney crossbred flock has potential to increase wool income, however, there are concerns from a farmer perspective about impacts on health costs and productive performance (i.e. footrot, lambing rate, lamb growth, carcass dressing percentage) associated with Merino genotypes (BakerAg, 2019). Table 2.7 presents data from a series of New Zealand studies examining how fleece yield, greasy fleece weight, lamb weaning weight, adult ewe liveweight, 12 month liveweight, lambing rate, lamb survival, carcass dressing, post-weaning growth rate, and birth weight vary in Merino-Romney crossbred sheep with varying proportions of Merino genotypes.

Table 2.7: Range of published values for the effect of varying proportions of Merino genotypes in New Zealand Merino-Romney crossbred sheep on wool fibre diameter, greasy fleece weight, liveweight, lambing rate, lamb survival, carcass dressing, post-weaning growth rate, and birth weight.

Trait	% Merino	Published values Range	Median	% change from Romney	Reference
Average wool fibre diameter (µm)	0	36 – 39	38		Dobbie *et al*., 1985; Meikle *et al*., 1988; Wuliji *et al*., 1995; Andrews *et al*., 1995, 1998; Everett-Hincks *et al*., 1998; Muir and Thomson, 2013
	25	31 -35	33	-13	
	50	23 – 29	26	-32	
	75	21 – 25	23	-39	
	100	18 - 23	21	-45	
Greasy fleece weight less than one year old (kg)	0	2.86 – 3.6	3.23		Dobbie *et al*., 1985; Everett-Hincks *et al*., 1998; Wuliji *et al*., 1995; Scobie *et al*., 2005; Muir and Thomson, 2013
	25	2.7	2.7	-16	
	50	1.47 – 4.3	4.3	33	
	75	2.79	2.79	-14	
	100	1.88 – 4.1	2.99	-7	
Yield (%)	0	74.8 - 76.8	75.8		Wuliji *et al*., 1995; Everett-Hincks *et al*., 1998; Scobie *et al*., 2005; Muir and Thomson, 2013
	25	67.4 – 76.44	71.92	-5	
	50	74.5 – 84.0	79.25	5	
	75	74	74	-2	
	100	73.9 - 75.6	74.75	-1	
Weaning weight (kg)	0	19.2 - 26.1	22.65		Meyer and Kirton, 1984; Dobbie *et al*., 1985; Hinch, 1989; Everett-Hincks *et al*., 1998; Montgomery *et al*., 1989; Wuliji *et al*., 1995; Scobie *et al*., 2005; Muir and Thomson, 2013
	25	17.6 - 25.0	21.3	-6	
	50	17.4 - 23.0	20.2	-11	
	75	25.4	25.4	12	
	100	17.8 - 20.5	19.15	-15	
Adult greasy fleece weight (kg)	0	3.6 – 3.96	3.78		Dobbie *et al*., 1985; Meikle *et al*., 1988
	25				
	50	3.92 - 4.1	4.01	6	
	75	3.1	3.1	-18	
	100	3.8 – 4.26	4.03	7	

Adult ewe liveweight (kg)	0	50.0 - 54.7	52.35		Dobbie *et al*., 1985; Quirke *et al*., 1987; Meikle *et al*., 1988; Smith *et al*., 1989
	25				
	50	51.2 - 61.2	56.2	7	
	75	44.6	44.6	-15	
	100	40.8 - 49.7	45.25	-14	
12 month liveweight (kg)	0	41.7 – 45.1	43.4		Dobbie *et al*., 1985; Wuliji *et al*., 1995; Everett-Hincks *et al*., 1998
	25	40.1	40.1	-8	
	50	40.4 – 48.5	44.45	2	
	75	33.8	33.8	-22	
	100	42.5	42.5	-2	
Lambing rate (%)	0	100	100		Dobbie *et al*., 1985; Quirke *et al*., 1987; Scobie *et al*., 2005
	25				
	50	108 - 120	114	14	
	75				
	100	99 - 107	103	3	
Lamb survival to weaning (%)	0	79.0 - 95.5	87.25		Dobbie *et al*., 1985; Everett-Hincks *et al*., 1998
	25	91.5	91.5	5	
	50	87.5	87.5	0	
	75				
	100	86.5	86.5	-1	
Carcass dressing (%)	0	41.0 – 46.0	43.5		Meyer and Kirton, 1984; Kirton *et al*., 1995; Muir and Thomson, 2013
	25				
	50	41.7 – 46.0	43.85	1	
	75				
	100				
Post-weaning growth rate (g/day)	0	65.5 – 180	122.75		Hinch, 1989; Everett-Hincks *et al*., 1998; Scobie *et al*., 2005
	25	63.3	63.3	-48	
	50	60 - 165	112.5	-8	
	75				
	100	45	45	-63	
Birth weight (kg)	0				Hinch, 1989; Montgomery *et al*., 1989; Muir and Thomson, 2013
	25	4.0 – 6.7	5.35		
	50	3.5 – 5.2	4.35		
	75				
	100				

The range of values for each proportion of Merino genotypes and trait somewhat reflects their origins from numerous regions and farms with different production levels and genotypes. This range of production values observed for a given Merino proportion and knowledge gaps, e.g. where there aren't published comparisons for a given proportion, contributes to the uncertainty which is likely a deterrent for farmers interested in making such a breed change. There are also uncertainties around the time taken to transition to a breeding flock with mid-micron wool and flock production during the transition period (BakerAg, 2019; Rae, 1967). It appears there are no published New Zealand studies on changes in productivity and profitability for a multi-year flock breed transition from coarse to mid-micron wool producing sheep. A bio-economic system dynamics model could be used with currently available production and price data to quantify these changes for the sheep enterprise over the breed transition.

2.4 Systems Modelling

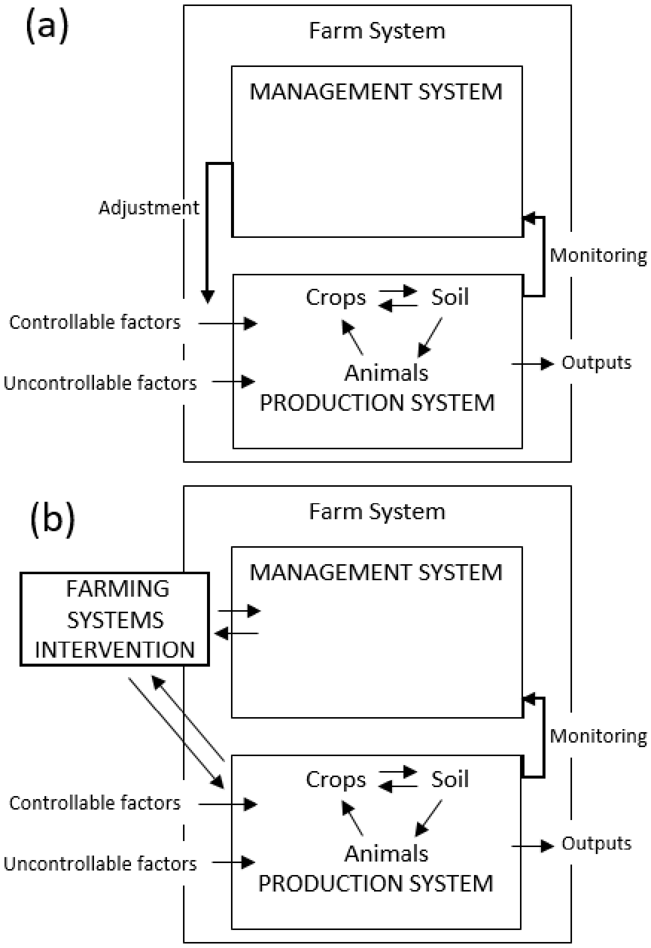
A system is a set of components interacting with a common purpose and responding as a whole to stimuli (Spedding, 1988). Systems thinking is "the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure" (Richmond, 1994). Systems approaches take a broad view while attempting to take all possible aspects into consideration and treats the world as a set of structured wholes while concentrating on different parts (Andrews, 2000). A livestock production system consists of various physical parts including land, crops, feed, animals, and labour alongside a human management component to produce animal or plant goods for consumption. The farm production system is monitored and controlled to achieve desired outcomes, including being a profitable business, however various factors affecting outcomes in farm systems are outside of managerial control such as prices and weather (Keating and McCown, 2001; Sterk *et al*., 2006).

2.4.1 Benefits of farm systems modelling

Farm systems research, at its core, aims to identify the problem/s that farmers are facing and produce results/strategies that are readily adoptable on farm for an overall improvement in farm performance (Figure 2.11; Anderson, 1985; Norman and Collinson, 1985; Jones *et al*., 1997). A systems approach enables the understanding of how external stimuli affect the farm and the behaviour of the whole farm system while requiring the definition of system boundaries and components (Rabbinge *et al*., 1994; Jones *et al*., 1997). Further, systems approaches in agricultural research have been identified as allowing influences of different components to be understood, therefore avoiding exaggerations in potential improvements in the whole farm performance when gains in component studies are extrapolated directly (McCall *et al*., 1994).

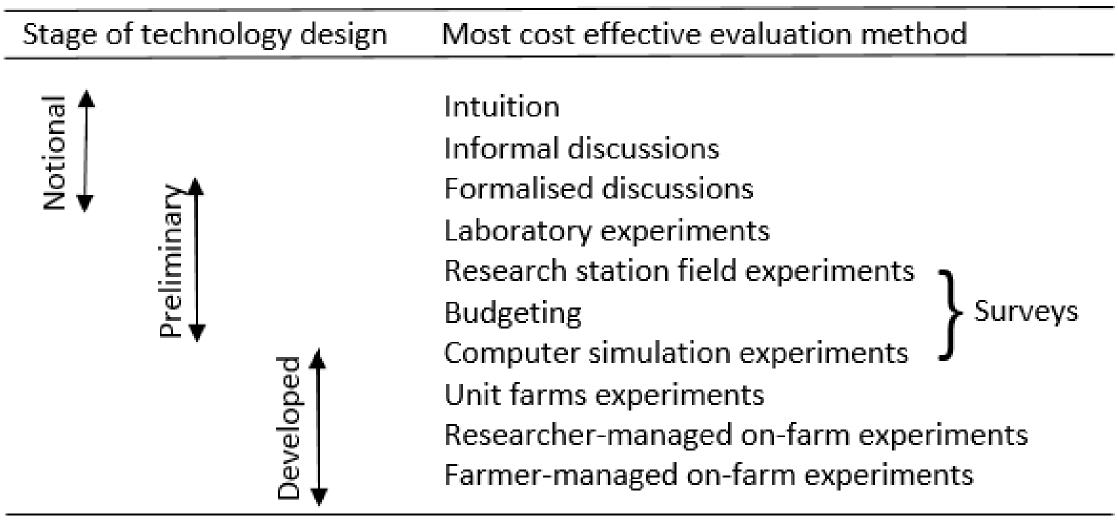
Experimental analysis of farming systems and alternative management requires a large amount of resources, notably time and money, and variability between years is difficult to capture (Meinke *et al*., 2001). While modelling is a relatively cost effective method of evaluating farm systems which can be carried out in a far shorter time period (Figure 2.12; Meinke *et al*., 2001; Woodward *et al*., 2008). The sensitivity of the system to numerous inputs can be understood and targets can be identified for improving farm performance

Figure 2.11: (a) The farm as a purposeful, managed system and (b) farm systems intervention. Source: Keating and McCown (2001).



(McCall *et al*., 1994). Models can be used to compare alternative farm structures and new technologies as well as exploring the long-term impact of technologies and policies. Spedding (1988) defined a model as "a simplified abstraction of the real world" which can be used to explore the core relationships between interrelated components and the effects of internal and external changes on the system as a whole. Hence, the model output should always be explored in relative rather than absolute terms (Thornley, 2001; Romera *et al*., 2004; Sterk *et al*., 2006). Where observations of a farm system are quantitative, hypotheses can be expressed numerically and mathematics used as a language to express the ideas (France and Thornley, 1984). Uses of modelling include: scientific research, advisory work, teaching, political decisions, and on-farm management (Korver and van Arendonk, 1988). Regardless of the scale, complexity, or type of model, the model will have limited usefulness if objectives were not clearly defined from the beginning of its development (France and Thornley, 1984).

Figure 2.12: Cost-effectiveness of farm systems research approaches. Source: Woodward et al. (2008).



2.4.2 Types of models

The farm can be considered a “dynamic, open, stochastic, and purposeful system” (McCown and Parton, 2006). A bio-economic farm model “links formulations describing farmers’ resource management decisions to formulations that describe current and alternative production possibilities in terms of required inputs to achieve certain outputs and associated externalities” (Janssen and van Ittersum, 2007). In most cases a certain type of model is well suited to one analytic approach and not another (Bellman and Dreyfus, 1962). Grazing systems are complex due to the interactions between pasture growth and production, animal grazing behaviour, animal nutritional demand and performance, flock/herd dynamics, and climate (Cacho *et al*., 1999). There are numerous benefits to making a model more complex including flexibility, improved capability to mimic the behaviour of the ‘true’ system, and more detailed, and possibly more accurate, outputs. However, challenges of model complexity include greater data needs, difficulty in construction/solution, delays in completion, affordability of model maintenance, and model opaqueness (McCown and Parton, 2006; Robertson *et al*., 2012). Determining the necessary complexity of a model requires the modeller to understand the detail while knowing when to simplify

(Janssen and van Ittersum, 2007). One approach to modelling a farm is to develop it around a representative farm which can be used to investigate the effects of major management changes. The majority of models where a representative farm has been used have obtained parameters from farm surveys (Robertson *et al*., 2012). Another approach is to construct a skeleton model which includes the basic farm structure and components and is functional once combined with an individual farm's data. This would provide more site specific output, potentially more meaningful to farmers (McCown and Parton, 2006).

2.4.2.1 Empirical and mechanistic

An empirical model is based on relationships found in data and any predictions are based on extrapolations of observed past behaviour and expectations of future behaviour (Austin *et al*., 1998). The main aim of these models is to describe the responses of the system for a single level of the organisational hierarchy. Therefore, their ability to investigate the effects of new constraints or specific alternative options is limited (Janssen and van Ittersum, 2007).

Mechanistic models operate on numerous levels where the lowest level is empirical, and predictions and observations are made at higher levels (France and Thornley, 1984). An example is plant growth where photosynthesis, respiration, water uptake, etc. would be the empirical components. Levels within a mechanistic model are connected with associated hypotheses and assumptions. A mechanistic model is always incomplete as there are always lower levels (i.e. underlying mechanisms down to the cell level) where empirical components could be modelled (Thornley, 2001). Mechanistic models are built on existing theory/knowledge and can be used for extrapolation and long-term predictions as they have the ability to simulate the behaviour of the system within and outside the range of observed data (Austin *et al*., 1998; Antle and Capalbo, 2001). They can become unmanageable once many levels are constructed and if transparency and the ability for modification is lost (Thornley, 2001). The assumptions in a mechanistic model can constrain its ability to model a set of data with as good a fit as an empirical model. However, empirical models only describe past behaviour, and use this to predict future behaviour, whereas system behaviour may be better understood with a mechanistic model (France and Thornley, 1984).

2.4.2.2 Deterministic and stochastic

Deterministic models make definite predictions for quantities without an accompanying probability distribution. This type of model may not be appropriate for the replication of processes that respond to uncertain variables and quantities that occur on a farm such as rainfall (France and Thornley, 1984; Thornley, 2001). However deterministic models can be run under constructed climate scenarios to take variation in weather into account (Woodward *et al*., 2008) and variables such as births and deaths can appear deterministic when very large numbers are modelled (France and Thornley, 1984).

Stochastic models include probability distributions, therefore including stochasticity in the model is important when modelling how a system responds to risk and uncertainty. Stochastic models can be difficult to manage, develop, and test as the size of a sequential decision problem can rapidly increase i.e. more data/calculations considered/made (France and Thornley, 1984; Thornley, 2001; Janssen and van Ittersum, 2007). Where stochastic parameters are dynamic, a multi-stage decision process may be used which, with numerous scenarios modelled, can become computationally difficult (Kazemi Zanjani *et al.,* 2013). An option would be building a deterministic model first and testing its ability to replicate the system behaviour before attempting a stochastic model, as many highly variable quantities can still be predicted deterministically (Thornley, 2001).

2.4.2.3 Dynamic and static

Static models do not include a time variable so do not take the effects of time into account; examples of outputs are crop yield at harvest or revenue at the end of a financial year (Janssen and van Ittersum, 2007). A static model can be a good approximation of the system behaviour where the system is near equilibrium or where the timeframe is short such that the surrounding environment could be considered constant (France and Thornley, 1984).

In dynamic models, quantities in the model vary with time which, for a livestock production system, would account for changes in feed demand and supply for within-year dynamics and changes in activities such as crop production or flock/herd structures for between-year dynamics (Janssen and van Ittersum, 2007). Outcomes in a given time period in a dynamic model will be affected by past decisions and have consequences for following periods i.e. the production in a given year is influenced by carryover effects of conditions and management decisions from previous years (Cacho *et al*., 1999; Romera *et al*., 2004). The nature of the time step, i.e. interval between and frequency of calculations, depends on the focus of the model i.e. strategic vs. tactical (Robertson *et al*., 2012). For example, a strategic focus to determine overall approach to problem solving and long-term goals may be run over numerous years or a decade, whereas a focus on tactics would have smaller timesteps towards the overall objective. Dynamic models are often represented by a set of differential, for continuous data such as plant growth, or difference, for discrete data such as days or weeks, equations (France and Thornley, 1984; Thornley, 2001).

2.5 Types of bio-economic systems models

In a survey of bio-economic models, Brown (2000) identified two main types. One type is concerned primarily with biological process models to which an economic analysis component is added. The other is economic optimisation, which includes various bio-physical components as activities among the various choices for optimisation. In this way, bio-economic farm systems models could be broadly categorised as either optimisation or simulation models. Optimisation approaches attempt to predict the best solutions and alternatives for resources management and allocation. Simulation approaches attempt to model the behaviour of the system while describing and explaining farm responses (Flichman and Jacquet, 2003). The objective of models is generally expressed either as the main reported result for simulation models or as the objective function in optimisation models (Robertson *et al*., 2012).

2.5.1 Simulation

Simulation models range from simple whole-farm budgets to complex dynamic bio-physical models consisting of various sub-models, i.e. for different animals and plants on the farm, feeding into a financial model (Pannell, 1996). The results of simulation models can be calibrated to what is found in reality and are therefore suitable to predict changes in technologies and policy in the short and medium term (Janssen and van Ittersum, 2007). Simulation models can represent biophysical processes in detail and account for seasonal variability. They do not aim to make recommendations of the optimal management or resource allocation for the system, but can be used to identify the most promising of available options (Woodward *et al*., 2008). These models are highly suitable for the goal of facilitating farmer learning about farm system changes (McCall *et al*., 1994; Andrews, 2000; Woodward *et al*., 2008).

2.5.2 Optimisation

The relevance and realism of the predictions/results of optimisation models can be questioned. For example, farmers often do not aim to manage the farm to its optimum in production or profit/revenue for various reasons including risk aversion, skills, and lifestyle goals (Janssen and van Ittersum, 2007). Optimisation models can be constructed with linear and non-linear equations. Where only linear equations are used, the objective function is treated as a linear combination of related activities and constraints. The predictive power of these models is limited where farm system behaviour (constraints and functions) is non-linear, and non-linear programming would be more appropriate (Janssen and van Ittersum, 2007). In non-linear programming, the maximum objective function is determined by the intersection of the non-linear function parameters which can provide more accurate model output compared with adapting farm systems behaviour into linear form (Benli and Kodal, 2003). Dynamic optimisation models can consist of both linear and non-linear equations; where resources are managed optimally over time (Kennedy, 1986). Dynamic recursive models run over numerous time periods where the starting values for each period are the end values of the previous one (Wallace and Moss, 2002). The problems of management decisions for resource allocation on-farm are that they are sequential and usually irreversible; the versatility and scope of dynamic optimisation make it a suitable tool to aid the solving of these problems (Kennedy, 1986). Bellman's principal of optimality, a necessary condition for optimisation in dynamic programming, is that "an optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the final decision", thus the overall solution is optimal (Bellman and Dreyfus, 1962).

2.5.3 Combined

Another approach is the combining of static optimisation and dynamic simulation with the aim of overcoming the limitations of each type (Robertson *et al*., 2012). The incorporation of some linear and/or non-linear programming into a simulation model can enable the user to know when an optimum is reached (Fu, 2002; Rani and Moreira, 2010). While simulation models enable the user to test numerous scenarios and identify the best one, an optimisation algorithm will search the decision space to find an optimum (Paul and Chanev, 1998).

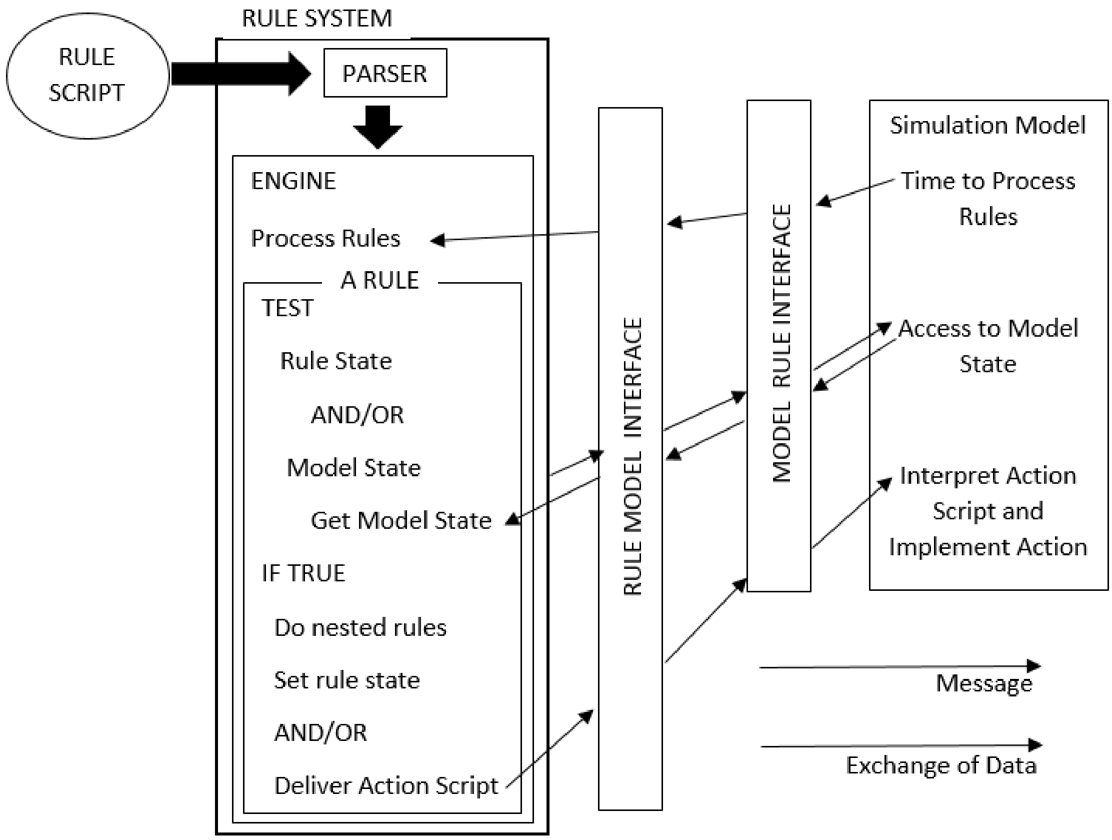
2.6 Uses and benefits of bio-economic models

Key drivers of the uptake of mathematical model use are the advances in modelling software, the need to integrate different parts of complex systems, and the availability of quantitative biological data (Thornley, 2001). A major difference in bio-economic models used for research and those used for farm management is the required level of accuracy. A model that is a flawed representation of behaviour can still be useful for researchers in understanding the system; whereas a farm management model should be based on data and knowledge (France and Thornley, 1984). The objective of model development will determine not only its type and equations, but also its scale. This is determined by the scale of the system it is investigating; for example, at the farm scale to investigate management decisions and at larger scale (catchment or region) to investigate the effects of policy (Pannell, 1996; Sckokai and Moro, 2006).

2.6.1 Farm management

Bio-economic models are potentially useful tools for aiding with difficult parts of farm management such as allocating resources in the face of environmental uncertainty. A model will usually not be valid for all situations and farm systems (Thornley, 2001). In some cases, the greatest benefit to farmers has been the learning that was facilitated by model use rather than specific model outcomes (McCown, 2002a; Webby, 2002). A management component of a farm systems model needs to respond realistically to changes in animal, pasture, and crop state as a farmer would manage a farm (Figure 2.13). One approach is using a series of decision rules such as: IF soil moisture reaches a threshold THEN sow crop (Shaffer and Brodahl, 1998). With this approach a single rule would represent an operation activity, groups of rules represent tactical decisions, and the farm strategy is the whole set of rules (Pietersma *et al*., 1998; Romera *et al*., 2004). This approach aids the shift of model outputs into recommendations for farmers, and researchers can understanding how farmers may react to changes in the environment and farm state (Woodward *et al*., 2008).

Figure 2.13: Example of IF-THEN rules in simulation model. Source: Shaffer and Brodahl (1998).



2.6.2 Research

A key use of bio-economic models in agricultural research is the identification of limiting factors in farm performance which warrant investigation into methods to overcome the constraints (McCall *et al*., 1994). Models enable the design and analysis of on-farm and component experiments so that new hypotheses may be tested with mechanisms behind results explored and predictions made, reducing the occurrence of *ad hoc* experimentation (Thornley, 2001; Sterk *et al*., 2006; Janssen and van Ittersum, 2007). Outputs and results of farm systems models should always assume uncertainty regardless of whether it is built into the model because of the unpredictable environment, e.g. weather and prices (Woodward *et al*., 2008). Bio-economic models are useful in the assessment of the value of a technology to farmers once research activities have identified it to be a solution to an agricultural problem (France and Thornley, 1984). Therefore, bio-economic models enable cost-effective exploration of numerous alternatives to test on the ground with component experimentation or case study farms.

2.6.3 Breeding

Bio-economic models are used to estimate economic values for traits in breeding objectives for livestock selection programmes. Models can describe the production system to investigate the economic value of genetic changes in traits and their robustness to variation in management, nutrition, climate, and market prices (Amer *et al*., 1999; Jones *et al*., 2004). The economic value of the traits within the system context can guide the selection emphasis of the breeding programme (Hazel, 1943; Krupová *et al*., 2014).

2.6.4 Policy

Bio-economic models can also be used to evaluate the effects of regulatory policy on agriculture, for example to assess the trade-off between economic and environmental objectives. These models are useful in evaluating the attractiveness of technologies and identifying incentives for their adoption (Ruben *et al*., 1998). They can be used to evaluate policy that has direct impacts on agricultural activities i.e. regulations, quotas, taxes, and subsidies (Falconer and Hodge, 2000; Janssen and van Ittersum, 2007). Use of a bio-economic model of farm systems can enable discussion about the impact of policies on farm profitability and operations at the time the policies and strategies are being developed, as well as the feasibility and efficacy of the changes that the policy aims to make (Wedderburn *et al*., 2011). These models may be conducted at a larger scale than a farm system model e.g. at a regional scale to analyse the effects of local government policy on land use, farm income, and the environment (Landcare Research, 2018).

2.7 Existing bio-economic sheep farm models

There are numerous existing bio-economic models of various sheep farm systems in different countries. Relevant examples of these are covered in Table 2.8, covering optimisation and simulation models for international and New Zealand sheep farming systems.

Table 2.8: Published bio-economic models of pastoral/grazing sheep farms.

International optimisation models	
Linear programming static model MIDAS for profit maximisation on a mixed cropping farm in western Australia.	Pannell, 1996
Deterministic, dynamic optimisation model of a Northern Scandinavian sheep farm to find combination of animal categories for profit maximisation.	Skonhoft, 2008
Dynamic optimisation model of Canadian sheep production systems to maximise marginal profit.	Fisher, 2001
International simulation models	
Model of UK sheep farm focusing on economic values for lamb growth.	Jones *et al*., 2004
Simulation model Ecoweight of a Slovakian multi-purpose sheep farm investigating profitability.	Krupová *et al*., 2014
Model simulating profitability of breeding traits for Czech sheep production system.	Wolfová *et al*., 2009
Dynamic simulation model of UK sheep farm to compare genetic gain.	Conington, 1999
Grazplan is a set of dynamic simulation models as decision support tools for temperate southern Australia looking at profitability and environmental sustainability.	Donnelly *et al*., 2002
Dynamic, stochastic simulation model of Irish sheep farm for profitability comparisons.	Bohan *et al*., 2016
New Zealand optimisation models	
GSL (Grazing Systems Limited) is a resource allocation linear programming model investigating marginal profitability for New Zealand sheep farms.	Grazing Systems Ltd., 2015
AgInform is a resource allocation/farm design dynamic optimisation model for profit maximisation of New Zealand sheep farms.	Rendel *et al*., 2013
Farmax pro models New Zealand sheep farm management. Models system to determine feasibility of feed demand and supply.	Marshall *et al*., 1991

New Zealand simulation models	
Dynamic model of New Zealand pastoral farm system made of mechanistic sub-models to investigate profitability and the interaction between stocking rate and soil fertility.	Wickham *et al*., 1997
Model for economic breeding values for New Zealand sheep farms.	Amer *et al*., 1999
Dynamic simulation model of New Zealand sheep farms to perform sensitivity analysis looking at the interaction of productivity and profitability.	Morel and Kenyon, 2006
Monte Carlo simulation model of a Canterbury sheep farm for analysis of risk, productivity and profitability.	Cacho *et al*., 1995
A simulation model of an extensive sheep and beef farm system to evaluate the impact of policy	Beck and Dent, 1987

2.7.1 International bio-economic sheep farm models

MIDAS (Model of an Integrated Dryland Agricultural System) is a model of a Western Australian mixed cropping farm. The model components include sheep, crop, and pasture activities as well as financial information. Linear programming is used to model profit maximisation and the model is used in research, extension, and education. MIDAS is used to evaluate management decisions and models sheep farming. However, sheep farming is modelled within the context of a mixed cropping farm and cattle are not included (Pannell, 1996). Grazplan is a model of Australian pastoral farming which includes a family of decision support tools and is mostly used in research to evaluate the effects of changes to farm system and management on profitability and environmental sustainability (Moore, 2001; Donnelly *et al*., 2002).

The Teagasc Lamb Production Model simulates an Irish, pastoral sheep farm with stochastic variables including lamb price and grass growth (Bohan *et al*., 2016). It has a monthly time step and aims to explore the profitability of changes to the farm system, such as differing lambing dates.

A Canadian sheep farming model developed by Fisher (2001) uses linear programming to maximise marginal revenue per lamb sold. A deterministic, dynamic bio-economic optimisation model of a sheep farming system in northern Scandinavia aimed to find the combination of stock classes to optimise profit (Skonhoft, 2008).

Models can be used to evaluate the economic values of animal traits (genetic gains) for breeding purposes, i.e. the effect of increase in carcass weight on farm profitability. Such models include both biological components (animal growth, flock dynamics, and feed supply) and an economic component (input costs and product prices). These have been developed for sheep farming systems in the United Kingdom (Conington, 1999; Conington *et al*., 2004; Jones *et al*., 2004), Slovakia (Krupová *et al*., 2014), and Czech and Slovak Federative Republic (Wolfová *et al*., 2009, 2011).

2.7.2 New Zealand bio-economic sheep farm models

The GSL (Grazing Systems Limited) model is a bio-economic whole farm model of a New Zealand pastoral farm – including sheep and beef farms as well as dairy. Linear programming is used to allocate farm resources where the marginal changes in productivity are reported to determine the tipping point for gains in profitability (Grazing Systems Ltd., 2015). The GSL model was used commercially to solve problems for individual New Zealand farmers but as of December 2019 information regarding the model and associated activities was not readily available.

New Zealand bio-economic modelling has been used to investigate economic values of traits in sheep for breeding, such as ewe reproductive performance (Amer *et al*., 1999). These do not have a focus on farm management and therefore are not suitable for investigating farm management and farm systems questions.

AgInform models resource allocation under variable production and market conditions to aid in New Zealand sheep and beef farm system design. In this bio-economic model the farm is treated as a group of land management units, each of which has an associated management strategy and production enterprise, using linear programming to maximise profit (Rendel *et al*., 2013). The steady-state model is used by scientists at the New Zealand Crown Research Institute, AgResearch, to investigate the profitability of different sheep farm systems and land uses (Thompson *et al*., 2016; Wall *et al*., 2018). The number of necessary calculations made during a model run for scenarios over multiple years and land units is large.

A simulation model of a North Island Hill Country extensive sheep and beef farm was developed to assess the impact of support and stabilisation policies that were removed in the 1980s (Beck and Dent, 1987). The model included the financial structure of the farm business, e.g. borrowing and credit, in order to explore the effect of farm subsidies at a farm level and estimate farm performance after their removal.

A model of feed supply and feed demand was used by Morel and Kenyon (2006) to explore the effect of changes in production on farm profitability. This model was used for research purposes and did not have a systems or management focus. Similarly, Wickham *et al*. (1997) used a model with an emphasis on soil and pasture as well as an animal model, to analyse the interactions between stocking and fertiliser rates for research purposes. Information on this model or its use has since not been published.

The Lincfarm bio-economic whole farm simulation model can be run deterministically or stochastically to analyse the impact of risk on a New Zealand sheep farm. The model includes a management component alongside pasture and flock production to investigate changes in productivity and profitability as well as the risk of a mis-match in farm feed demand and supply (Cacho *et al*., 1995; Finlayson *et al*., 1995; Cacho *et al*., 1999; Gicheha *et al*., 2014). This model has been used to investigate farm management problems for research purposes by scientists and students at Lincoln University.

Farmax is a bio-economic whole farm model of a New Zealand sheep and beef system, where the energy requirements of livestock and farm feed supply are calculated and compared to assess scenario feasibility while optimising specific parameters. Reports for individual scenarios and comparisons between alternatives are generated to investigate the profitability of management decisions (Marshall *et al*., 1991; White *et al*., 2010). Farmax is a steady-state model that can be run over numerous years and is used commercially across New Zealand, marketed as a decision support tool for farmers and farm consultants to judge which is the best action, from modelled scenarios, to take on-farm. Developers suggest that users are trained in Farmax to get the best possible use of the software/model (Farmax Ltd, n.d). As it is sold as a commercial product, the model has a user interface which does not allow the user to see how the model works and what equations are being used. The alterations that the user can make to the default equations and parameters is therefore limited.

2.8 Criticism of modelling

The use of whole farm models as decision support tools has not often been adopted by farmers hence there has been criticism of systems researchers as preoccupied with model building over application (Doyle, 1990; Keating and McCown, 2001; Prost *et al*., 2012). Farm systems modelling has also received criticism for the common abandonment of models after specific research questions have been answered with poor model adaptability and user friendliness (Reinmuth and Dabbert, 2017). Developers of whole farm models have aimed to provide a plan for farmers to follow but the volume of detailed, farm specific data required has often prevented the model from being used this way (Cox, 1996; Pannell, 1996). The cost of farmers' time to accurately model their farm and get relevant output may outweigh the benefits of doing so (Pannell, 1996). In New Zealand, the readily available for commercial use model, Farmax, is used by some farmers. However, it is recommended that users are trained in model use to get valuable output thus farm consultants more commonly use the model (Farmax Ltd, n.d). Farmer involvement in the development and use of whole farm models was usually in informing the exercise through surveys (Jones *et al*., 1997). Their involvement was important where the aim was for the farmers to adopt new technology or management practices (Meinke *et al*., 2001; McCown, 2002b; Woodward *et al*., 2008; Gouttenoire *et al*., 2011).

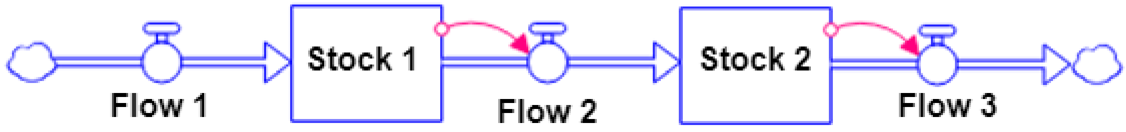
Keating and McCown (2001) suggest that the focus of farm systems modellers should be their relevance to real-world on-farm decision making and management and McCown (2002a) argued that agricultural systems researchers must innovate to succeed in bringing management science and practice closer together. Decision support tools, including whole farm models, are software readily accessible to a farmer to assist their decision making process and have been suggested as a way to achieve this (McCown, 2002b). Simulation models which demonstrate interactions within the farm system have been valuable as learning tools for farmers more so than decision-support tools (Webby, 2002). Bio-economic model outputs have been useful for aiding farmers to evaluate options through better understanding the costs and benefits involved in changes (Cox, 1996).

2.9 System dynamics modelling

System dynamics is a method of dynamic simulation modelling, effective for modelling systems with numerous interconnected components and feedback processes over time (Walters *et al*., 2016) such as those existing in a breeding ewe flock. Recent research has revealed the utility of system dynamics modelling in agricultural and livestock systems to test *ex ante* dynamic impacts of feedback from different scenarios and technical interventions (Hamza and Rich, 2015; Shane *et al*., 2017; Lie *et al*., 2018), including New Zealand farm systems (García, 2000).

System dynamics modelling is based around 'stocks' and 'flows', where the content of a stock is influenced by its starting value and the rate at which the content flows into and out of the stock each time step (Figure 2.14; Richmond, 1993). This type of modelling is useful to simulate the various groups of sheep in a breeding flock and their movements. For example, the number of mature ewes in each age class and their aging in an annual time step, where the effects of age on production can be used to estimate numbers of lambs weaned and weight of wool shorn. This stock and flow modelling style can demonstrate where limits occur, e.g. where the inward flow is insufficient to maintain the volume of a stock. For example, this could be useful where the numbers of ewe lambs weaned that are suitable as replacement animals do not meet the requirements to maintain flock size. System dynamics is particularly well suited to model systems with circular causality, i.e. feedback loops (isee systems, 2017). Feedback loops within a ewe flock would include calculations of replacement lamb requirements, dependent on ewes of each age leaving the flock due to death and culling, where the number of replacements influences the number of ewes in each age class of the flock. Another feedback loop is mature ewes producing lambs and a portion of those lambs entering the mature flock at a later time point. These characteristics of system dynamics modelling indicate that it may be an appropriate method of investigating profitability scenarios for a New Zealand sheep farming system. The ability to model, over one or multiple years, the effects of ewe flock age structure or the proportion of lambs weaned from terminal sires or impact of breed types on wool income would be useful to explore and determine changes in production and profit from these changes.

Figure 2.14: Example of stocks and flows in system dynamics modelling.



2.10 Conclusion

This literature review demonstrates that New Zealand North Island Hill Country sheep farming enterprises derive their operating profit primarily from sale of coarse wool, prime lambs and cull ewes with relatively low-cost production sold direct to slaughter, and store lambs. Changes in the production of wool and meat in dual-purpose breed sheep production systems in New Zealand have been explained alongside changes in the prices sheep farmers receive. Several potential strategies have been identified to increase operating profit through increased lamb production or increased wool income or reducing expenses which have not been previously quantified at a farm systems level.

A bio-economic system-dynamics model of a sheep farm is an appropriate mechanism to model profitability scenarios where the structure and changes in the breeding ewe flock are relevant and/or integral. Such a model could produce outputs to inform farmer decision making for strategic farm changes. System dynamics can be used to model a sheep flock with consistent numbers, such as when calculating required replacement ewe lambs based on numbers of ewes leaving the flock, or a flock with varying size such as breeding strategies when transitioning from one breed to a crossbred. Having identified several profitability scenarios for New Zealand sheep farming systems and the appropriate modelling technique to explore them, the specific objectives of this thesis were to:

1. Use STELLA (isee Systems, 2019) to develop a bio-economic system-dynamics model of a New Zealand sheep farming enterprise focused around ewe flock dynamics.
2. Test the steady state, annual model by investigating the impacts of varying rates of ewe wastage.
3. Use the model in a steady-state, annual form to investigate scenarios where income from lamb sales increased through use of terminal sires.

4. Use the model in a multi-year transition form to investigate a scenario where wool fibre diameter decreased and income increased through a gradual flock breed change.

2.11 References

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Chapter Three

The effect of ewe wastage in New Zealand sheep and beef farms on flock productivity and farm profitability.

3.1 Introduction

Between 1994 and 2014 the world total sheep population increased by 8.3%, with a proportionally greater increase of 24% in sheep meat production and a reduction in wool production of 22% (OECD, 2016; FAOSTAT, 2017). The majority of New Zealand wool is classed as coarse wool (referred to as strong wool in New Zealand) with a diameter greater than 30 µm (Beef + Lamb New Zealand Economic Service, 2016a). Changes in the relative values of lambs for slaughter and coarse wool have led to the majority of New Zealand sheep farm income being acquired through sales of live animals for slaughter, rather than wool compared to twenty years ago, shifting the production focus for many New Zealand sheep and beef farmers (Beef + Lamb New Zealand Economic Service, 2016a; Beef + Lamb New Zealand, 2018). Since 1990, New Zealand's total sheep meat production has remained relatively stable, despite declining land area and sheep numbers, due to gains in per animal production levels (Mackay *et al*., 2012; Morris and Kenyon, 2014). In 1990 average lambing rate was 101 % lambs weaned per ewe presented for breeding compared to 129% in 2015, and average lamb carcass weight increased from 13.0 kg to 19.5 kg over the same period (Mackay *et al*., 2012; Beef + Lamb New Zealand Economic Service, 2016a).

Sheep flock productivity levels are influenced by numerous interdependent factors including, but not limited to; sheep breed genetic composition, management decisions, lambing rate, and nutrition (Morris and Kenyon, 2014). One factor limiting flock productivity on sheep farms is ewe wastage. Ewe wastage includes on-farm mortality and premature culling of ewes before the potential end of their productive life (Griffiths *et al*., 2017). Current estimates of wastage rates (WR) across New Zealand commercial flocks range from 2.8% of breeding ewes to approximately 20%, with large variation between farms and between production years. It is not known how much of the variation in wastage rate in New Zealand flocks is driven by culling and deaths, however, ewe flock mortality rates (including missing ewes) have been reported to range from 2.8% to 16% (Anderson and Heuer 2016; Griffiths *et al*., 2017) and ewe reproductive performance is typically the main driver of culling (Cranston *et al*., 2017). Suggesting that wastage is driven by episodic climatic and disease events as well as management factors. Breeding ewe flocks are typically self-replacing, hence greater

WR necessitate increased numbers of replacement ewe lambs (Beef + Lamb New Zealand Economic Service, 2016b). Survey data from New Zealand North Island Hill Country sheep farms indicates total ewe loss rates of 18-25%, including deaths and culling combined, with culling accounting for 78-82% of ewe losses (Beef + Lamb New Zealand Economic Service, 2018a), similar to Irish flocks with 70-87% of losses as culls (Dawson and Carson, 2002; Keady, 2016). However, New Zealand data are quintile values only for the estimated 3,640 North Island Hill Country farms and therefore do not report the full range of WR occurring (Beef + Lamb New Zealand, 2016a; Beef + Lamb New Zealand Economic Service, 2018a).

Rearing replacement stock has been identified internationally as a significant on-farm cost in production systems (Bailey and Currin, 1999; Tozer and Heinrichs, 2001; Dawson and Carson, 2002; McHugh, 2012). Greater requirements for replacement ewe lambs reduce the number of lambs available for sale and reduce selection differential within the flock, reducing genetic gain (Turner *et al*., 1968). Further, ewe reproductive performance peaks at approximately 4-6 years of age (Turner *et al*., 1968; Dickerson and Glimp, 1975; Maijala, 1977; Notter, 2000), therefore, greater WR results in a greater proportion of younger ewes, reducing ewe flock average age, resulting in a less productive flock. For New Zealand's national ewe breeding flock, a 5% increase in WR would require an estimated additional 960,000 replacements to maintain total flock size (Beef + Lamb New Zealand Economic Service, 2016a). There is a lack of analysis examining the impact of WR on sheep farms; quantification will identify if ewe wastage is a significant issue reducing profitability and warranting further investigation.

Bio-economic models can simulate bio-physical farm elements and interactions with the economic component of the farm system (Bohan *et al*., 2016), e.g. modelling changes to system profitability as a result of changes in flock structure. Systems dynamics modelling is effective for simulating systems with numerous interconnected components and feedback processes (Walters *et al*., 2016) such as those existing in a breeding flock. Previous research has not considered dynamic effects of ewe wastage on the whole farm system. The objective of this study was to develop a bio-economic system-dynamics model of a representative New Zealand North Island Hill Country sheep farm with limited feed availability to explore changes in productivity and profitability with different ewe WR under current economic conditions. This study explores the impacts on farm profitability with varying WR and consequences for feed demand, flock structure, and animal performance.

3.2 Materials and methods

3.2.1 Introduction

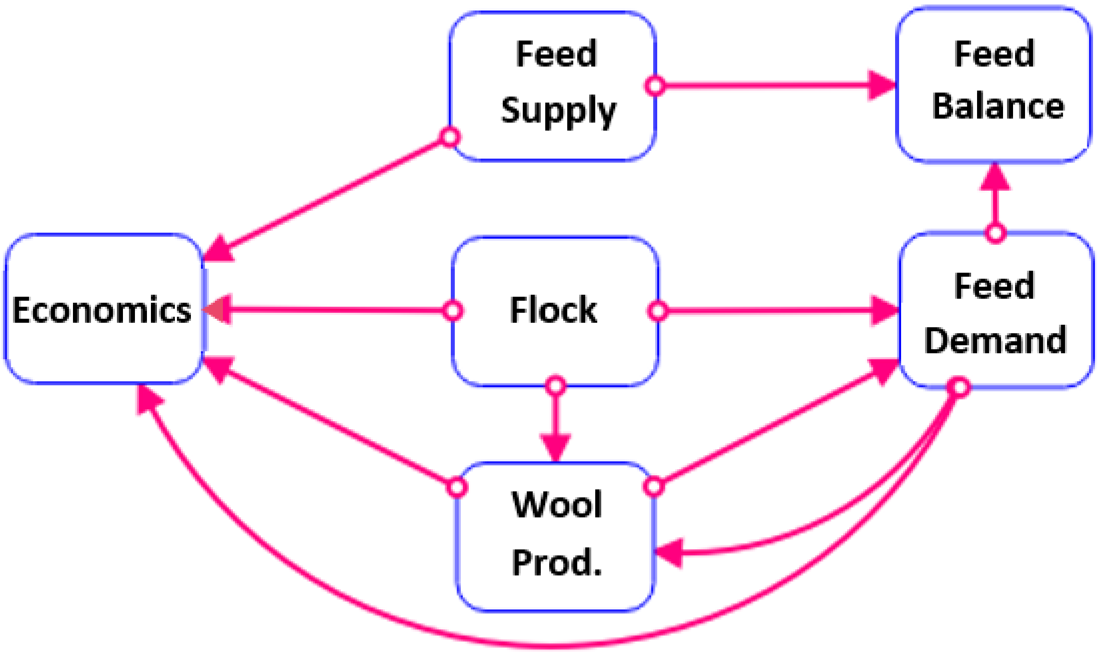
System dynamics modelling was used to capture flock dynamics and associated energy demand and production implications. Recent research has revealed the utility of this approach in agricultural and livestock systems to test *ex ante* dynamic impacts of feedbacks from different scenarios and technical interventions (Hamza and Rich, 2015; Shane *et al*., 2017; Lie *et al*., 2018) including New Zealand dairy farm systems (García, 2000).

The bio-economic system-dynamics model consisted of six modules each focusing on a separate sub-system of the sheep enterprise (Figure 3.1): ewe flock dynamics (Section 3.2.2); energy demand (Section 3.2.3); wool production (Section 3.2.4); feed supply (Section 3.2.5); energy balance (Section 3.2.5); and economics (Section 3.2.6). The flock dynamics module represented animals from birth to mature ewes, and included animals sold for meat production. The feed production, wool, energy demand, and economics modules were informed by the flock dynamics module. The model was constructed using STELLA version 1.7.1 (isee systems, 2017). The model was run for thirty consecutive years for each WR for numbers of ewes in each age class to stabilise, and a relevant selection of the model output from the final year is interpreted and discussed in this paper.

3.2.2 Flock

The model farm was based on an average New Zealand North Island Hill Country sheep and beef farm using mean 2015/16 production year data from the Beef + Lamb New Zealand Farm Survey Analysis (Beef + Lamb New Zealand Economic Service, 2018a). These farms are 423 hectare (ha) on average with a self-replacing flock of 1,879 ewes lambing annually in spring and extensively grazing pasture year-round. Only the sheep operations of the farm were considered in this model, producing lambs for slaughter and coarse wool with > 30 µm fibre diameter. Sheep operations in a North Island Hill Country sheep and beef farm constitute the majority of total farm stock units, the

Figure 3.1 High level diagram of modules in bio-economic system-dynamics model



remaining being beef cattle and/or deer (Beef + Lamb New Zealand Economic Service, 2018a). A stock unit has been defined as the equivalent feed consumption of a 55kg ewe weaning one 28 kg lamb, equal to 550 kg DM/year (DM = dry matter; Trafford and Trafford, 2011). Stock units for each scenario were calculated based on ewe prolificacy and liveweight for mature ewes (Parker, 1998), and included mature ewes, replacement stock, and rams. The ewe flock (Y) was divided into seven age (i) classes (Y_i), starting with Y_1 (maiden ewes, lambing at approximately one-year of age) Ewes in age classes $Y_{1\text{-}7}$ were presented for breeding to 19 rams (Equations 3.1 and 3.2; Figure 3.2). Y_0 and $Y_{0.5}$ represented lambs on-farm at lambing and post-weaning which may be sold or kept as replacements.

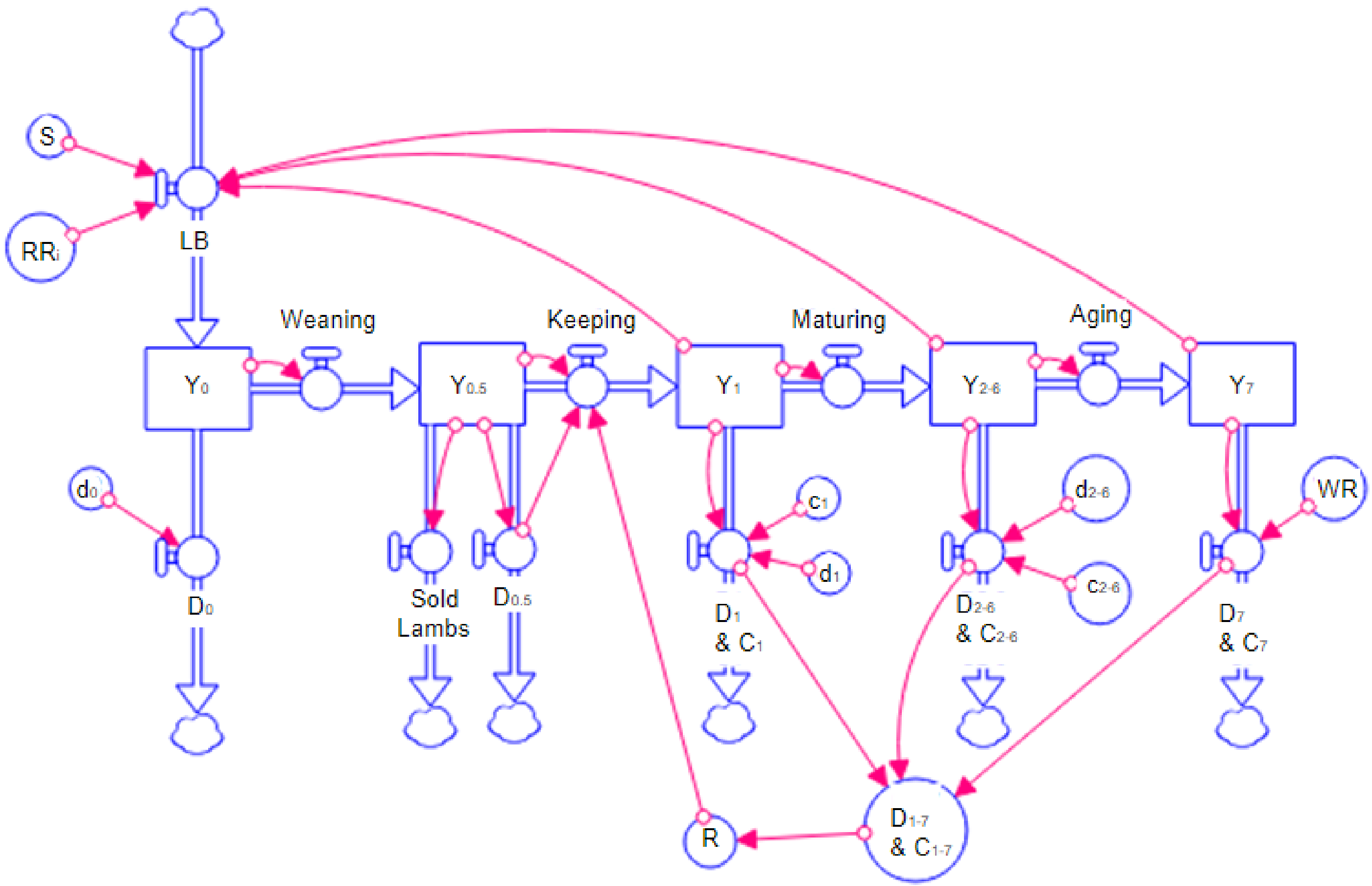
$$Y = \sum_{i=1}^{7} Y_i \qquad [3.1]$$

Where $$Y_i = Y_{i-1} - D_{i-1} - C_{i-1} \qquad [3.2]$$

And $$D_i = Y_i \times d_i \qquad [3.3]$$

And $$C_i = Y_i \times c_i \qquad [3.4]$$

Figure 3.2: Simplified diagram of the flock dynamics module. Where each age class (Y_i) is depicted with movements between age classes, culls (C_i) and deaths (D_i) due to culling (c_i) and death (d_i) rates, ewe replacement requirements (R), and lambs born (LB) as a function of Y_i and flock scanning rate (S), relative reproductive performance (RR_i), and wastage rate (WR).



All ewes from the previous age class (Y_{i-1}), except deaths (D_i) and culls (C_i), moved into the next age class at lambing, i.e. ewes entering Y_1 were 12 months of age (Equation 3.2). D_i and C_i were the product of Y_i and the age class specific mortality (d_i) and cull (c_i) rates (Equations 3.3 and 3.4).

A pre-weaning death rate (death rate, d_0) of 15% was assumed (Dalton *et al*., 1980; Amer *et al*., 1999; Beef + Lamb New Zealand, 2013), then a post-weaning death rate of 1% for $Y_{0.5}$. D_1 and C_1 used rates of 0.5% each, assuming that maiden ewes were not culled according to reproductive performance for their first mating and lambing. All live Y_7 ewes were culled at the end of their seventh year. In an average year on New Zealand sheep farms the majority of ewe deaths occur at lambing due to lambing difficulty or dystocia, metabolic diseases, or pneumonia (Quinlivan and Martin, 1971; Davis, 1974; Tarbotton and Webby, 1999). In this study all ewe deaths were assumed to occur at lambing and 20% of ewe culls for $Y_{2\text{-}6}$ occurred at pregnancy scanning, while the remainder occurred at weaning.

The reproductive rate of the ewe flock was the weighted average of the relative reproductive rate of ewes in each age class (RR_i). Lambs born (LB) was the product of ewes presented for breeding (Y_i), flock pregnancy scanning rate (S) assumed to average 1.5 foetuses per ewe bred for $Y_{2\text{-}7}$ (Beef + Lamb New Zealand Economic Service, 2016b), and average foetal loss rate (F) of 1% (Kelly, 1982; Equation 3.5). Differences in reproductive rate between age classes were accounted for by adjusting the pregnancy scanning rate for each age class with RR_i. Where RR_1 = 0.41, RR_2 = 0.85, RR_3 = 0.97, RR_4 = 1.04, RR_5 = 1.09, RR_6 = 1.06, and RR_7 = 0.99 (Hickey, 1960; Turner *et al*., 1968; Hight and Jury, 1970; Dickerson and Glimp, 1975; Thomson *et al*., 2004). The number of lambs born as singles and twins depended on whole flock reproductive performance (Amer *et al*., 1999).

$$LB = \sum_{i=1}^{7}(Y_i \times S \times RR_i) \times (1 - F) \qquad [3.5]$$

Replacement ewe requirements (R) were the sum of all deaths and culling of $Y_{1\ to\ 7}$ ewes to ensure stable flock size (Equation 3.6).

$$R = \sum_{i=1}^{7}(D_i + C_i) \qquad [3.6]$$

3.2.3 Feed demand

Monthly energy demand was based on the number of sheep in each stock class and their estimated energy demand in megajoules of metabolisable energy (MJ ME). Energy demand for all sheep was validated in a separate spreadsheet. Daily animal energy demand for maintenance (ME_m) was determined using Equation 3.7, with maintenance demand a further 10% greater for rams compared to ewes (White and Hodgson, 1999; CSIRO, 2007). A lambing date of 1st September was chosen to synchronise energy demand during early lactation with peak energy supply from pasture growth.

$$ME_m = \left[0.28 \times \frac{LW^{0.75} \times e^{-0.03 \times i}}{0.02 \times Q + 0.5}\right] \times 1.1 \qquad [3.7]$$

Where LW = liveweight (kg) and Q = pasture quality measured as MJ ME/kg DM, an average pasture quality value of 10 MJ ME/kg DM was assumed, considered a medium quality of pasture on New Zealand sheep and beef farms (Waghorn *et al.*, 2007).

A mature ewe liveweight value of 65 kg was used and liveweight for maiden ewes was assumed to be 45 kg when entering Y_1 (Thomson *et al*., 2004). Liveweight values used to calculate maintenance energy demand until entering Y_2 were averages for that class of animal, for example single born prime lambs were weaned at 30 kg and left the farm at 36 kg, hence demand for maintenance was based on an average liveweight of 33 kg.

Energy demand for reproduction (pregnancy and lactation) was modelled separately to demand for maintenance, weight change, and wool growth, and was based on numbers of lambs born and weaned per ewe. Energy demand for lactation (ME_L) was estimated based on values from Nicol and Brookes in Equation 3.8.

$$ME_L = 51.4 \times L + 134.7 \times \alpha - 1808 \qquad [3.8]$$

Where L = lamb liveweight at weaning (kg), and α = lamb age at weaning in weeks. Lambs were weaned at twelve weeks of age with liveweights of 30 and 28 kg for singles and multiple-born lambs, respectively (Morris and Kenyon, 2014).

Energy demand for pregnancy (ME_P) was based on the number of foetuses and lamb birthweight (Nicol and Brookes, 2007). Birth weights were 6 kg for a single-born lamb and 4.5 kg each for a multiple-born lamb, resulting in energy demand during gestation of 255 and 228 MJ ME per lamb, respectively (i.e. gestation of twins required 456 MJ ME).

Ewes were assumed to gain 0.1 kg per day for 6 weeks prior to mating and lose 0.15 kg per day for four weeks in early lactation. Energy demand for liveweight gain and loss were 55 MJ ME required for each kg of liveweight gain, and 35 MJ ME converted from each kg of liveweight loss (Nicol and Brookes, 2007). Lambs were sold either as prime (directly to slaughter) or store (to be grown for slaughter by another farmer). It was assumed that prime lambs were sold with a liveweight of 36 kg at 40 days and 72 days post-weaning for single- and multiple-born lambs, respectively. Store lambs were assumed to be sold five weeks post-weaning; and single-born store lambs weighed 33 kg and multiples weighed 31 kg.

Energy demand for ewes culled at pregnancy scanning was included up until scanning 78 days prior to lambing; while ewes culled at weaning had maintenance, wool growth, and live weight loss demand from lambing until weaning which occurred at twelve weeks into the model year.

3.2.4 Wool production

Average flock annual wool production (*W)* was 6 kg per ewe (Trafford and Trafford, 2011). Average flock daily wool growth (*G*) was 16.4 g/ewe/day. Total flock wool production (*WP*) was estimated using *G* and an adjustment parameter (w_i) for wool production for each age class ($w_{0.5}$ = -3.5, w_1 = -1.8, w_2 = -0.09, w_3 = 0.42, w_4 = 0.28, w_5 = 0.05, w_6 = -0.14, and w_7 = -0.5; Brown *et al*., 1966; McLaughlin, 1973; Rose, 1974). Wool production of ewes culled at weaning was excluded; all other animals were assumed to be on-farm for shearing, including lambs destined for sale, with sheep shorn once per year (Equation 3.9).

$$WP = \sum_{i=0.5}^{7} Y_i \times (W + w_i) \quad [3.9]$$

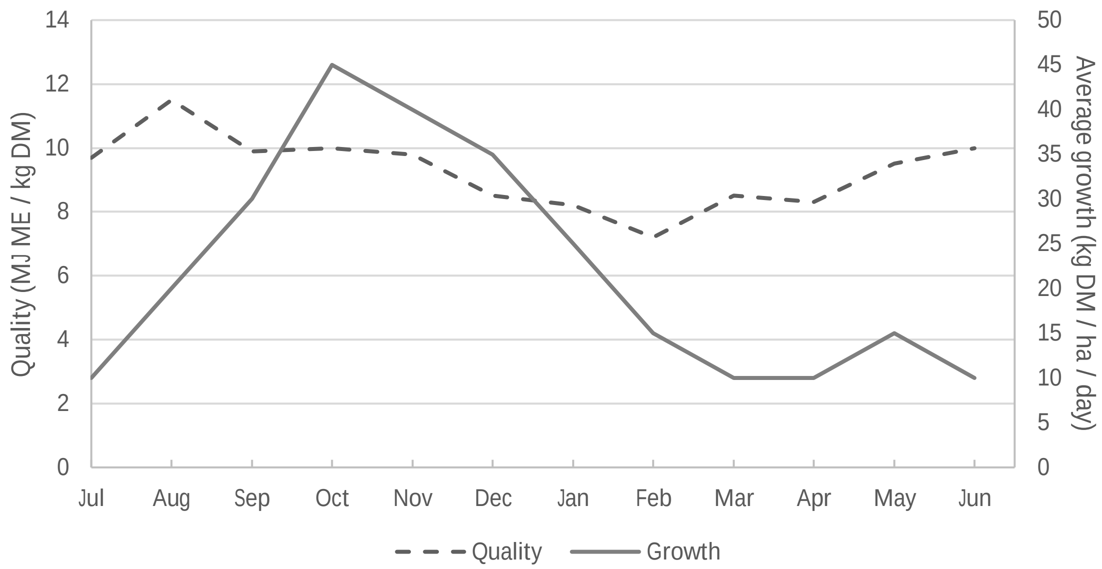
Energy demand for wool growth (ME_w) was estimated using the wool growth equation from CSIRO (2007; Equation 3.10).

$$ME_w = 0.13 \times (G - 6) \quad [3.10]$$

3.2.5 Feed supply

All feed was assumed to be from pasture only. Pasture growth (Trafford and Trafford, 2011) and quality (Bown *et al*., 2013) data for North Island Hill Country sheep and beef farms were used (Figure 3.3). Commercial farms of this type also farm beef cattle and/or deer (Beef + Lamb New Zealand, 2012), the farm modelled had 63.2% of SU as sheep, with this fraction of pasture available for sheep only (Beef + Lamb New Zealand Economic Service, 2018a). Pasture utilisation rates can vary from 40% to 80% on New Zealand farms (Hodgson, 1990). A feed adjustment parameter of 67% was used as a proxy for pasture utilisation, as no published utilisation values were available and with this adjustment energy supply from pasture matched sheep demand when WR = 5%. Total farm annual energy supply from pasture available for sheep was estimated to be 13.6 million MJ ME (Figure 3.3; Bown *et al*., 2013; Trafford and Trafford, 2011).

Figure 3.3: Monthly averages for pasture growth and quality on a North Island sheep and beef farm (Trafford and Trafford, 2011; Bown et al., 2013).



3.2.6 Economic data

All economic data was in New Zealand Dollars, NZD$ 1 = EUR€ 0.57 = USD$ 0.65 as of 30th October 2018 (XE.com). Farm income was based on mean average prices from the North Island Hill Country farm survey data for the Manawatu region in the 2015/16 production year, volume of wool sold, and numbers of lambs and ewes sold. Based on average data for this farm type, the proportion of lambs sold prime was 82.1%, with remaining lambs available for sale sold store (Beef + Lamb New Zealand Economic Service, 2018a). Production, prices, and expenses were used to calculate the sheep enterprise cash operating surplus (COS) on a per ha basis. COS was used as an indicator of sheep enterprise profit and included cash income of the farm minus cash operating expenses. Expenses were average values from industry survey data calculated on a per sheep stock unit basis (Beef + Lamb New Zealand Economic Service, 2018a; Table 3.1). Expenses were comprised of variable costs and the enterprise share of fixed costs (including costs of repairs and maintenance, vehicles, administration, ACC, and insurance) while excluding drawings, tax, interest, depreciation, and rent (Shadbolt and Martin, 2005). Dead ewes are disposed of on-farm in New Zealand, so they did not incur an additional cost.

Table 3.1: Commodity prices and enterprise expenses used to estimate farm profitability.

Commodity prices		Enterprise expenses	
Product	Value ($)	Expense	Value ($ per sheep stock unit)
Wool	4.03 / kg greasy wool	Operating expenses*	46.18
Prime lamb	88.23/ head	Animal health	5.00
Store lamb	73.91 / head	Shearing	5.64
Mutton	61.35 / head		

*Excluding those costs listed separately (Beef + Lamb New Zealand Economic Service, 2018a).

3.2.7 Wastage rates

Estimates of WR in New Zealand ranged from approximately 3% to 20% (Griffiths *et al*., 2017). A 2012-2014 study of 100,000 ewes on thirteen New Zealand commercial sheep farms over one or two years found ewe mortality rates ranged from 2.8% to 15.7% with a mean of 7.5% (Anderson and Heuer, 2016). Scottish Mule ewes had slightly greater death rates for ewes older than six years-of-age (Mekkaway *et al*., 2014). While, Keady (2016) found Irish ewes to have similar death rates across age classes, averaging 4.6% up to six years of age. Similarly, death rates of Australian Merino ewes in an average year have been found to be relatively consistent across age classes, increasing from an average of 2.2% to 5.5% once ewes were older than seven years-of-age. (Turner *et al*., 1959; Turner *et al*., 1968).

In the present analysis WR ranged from 5 to 21% (Table 3.2), and was split between cull and death rates for age classes $Y_{2\ to\ 6}$ at ratios such that culled ewes accounted for 81% of total ewe losses (a ratio of 19:81 for deaths:culling for $Y_{2\ to\ 6}$). The WR range matched estimates reported by Griffiths *et al*. (2017) and Anderson and Heuer (2016).

Culled Y_7 ewes were not included in WR in the present analysis as this was when they were assumed to have reached the end of their productive life and were all sold; WR only included their deaths.

Table 3.2: Wastage, culling, and death rates, as a percentage (%) of ewes 2 to 6 years of age ($Y_{2\ to\ 6}$), applied to simulate levels of ewe flock wastage (ranging from 5% to 21% of the ewe flock wasted).

Wastage	Culling $Y_{2\ to\ 6}$	Deaths $Y_{2\ to\ 6}$
5	2.60	0.35
7	5.40	3.40
9	7.90	3.50
11	9.90	3.60
13	12.80	3.80
15	15.30	4.00
17	18.00	4.50
19	20.50	4.50
21	23.00	5.00

In drought conditions, death rates for Australian Merino ewes were found to rise faster with increasing age, from an average of 3.7% for ewes aged 2 to 6 years of age to 11.1% and 18.6% for ewes aged seven and eight years, respectively (Turner *et al*., 1959). Published data suggest ewe death rates to be generally consistent between ewes aged two to six years. Therefore, in this study death rates were consistent over the $Y_{2\ to\ 6}$ age classes. The death rate for ewes in Y_7 matched WR so the overall proportion of $Y_{2\ to\ 7}$ ewes lost to death and premature culling, considered as wastage, was consistent (Table 3.2).

To further investigate the relationship between WR and profit, the model farm also had a range of WR applied (7-21%), but where cull and death rates each accounted for 50% of ewe losses (50:50) rather than the 19:81 ratio of deaths:cullling in the original analysis. A 50:50 ratio of total ewe flock losses for deaths and culling and could not be achieved with WR of 5%. With very low wastage of ewes in $Y_{2\ to\ 6}$, more ewes were retained in the flock and the number of culled Y_7 ewes increased.

3.3 Results and discussion

The results of increasing WR from 5% to 21%, on ewe flock composition and productivity, farm profitability, and sheep energy demand are discussed separately in the following subsections, along with implications for sheep production systems.

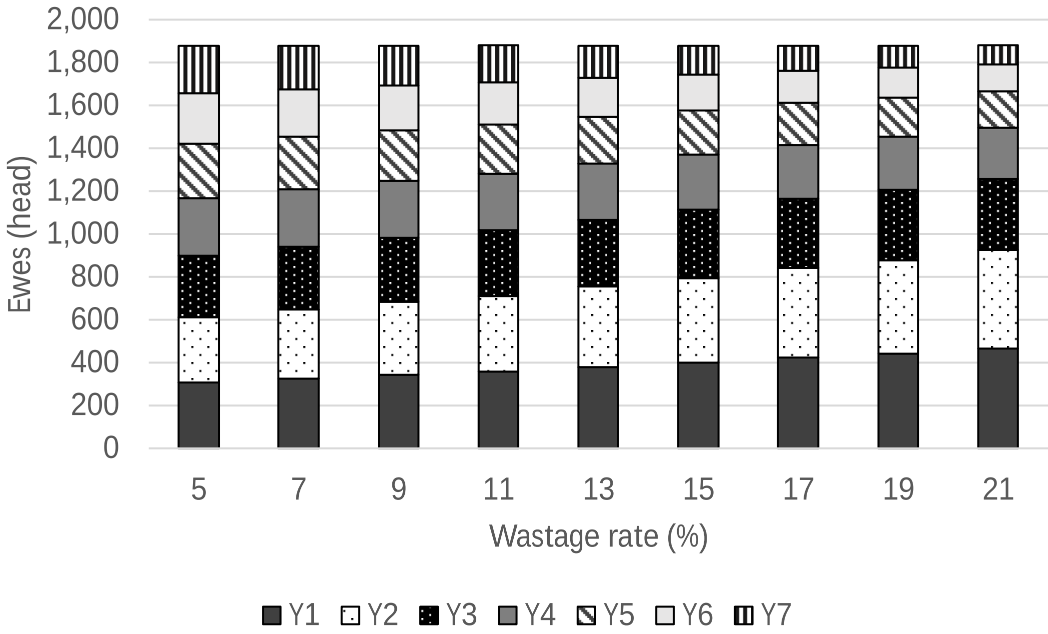
3.3.1 Ewe flock

Figure 3.4 shows the increase in the proportion of ewes in younger age classes with increasing WR, due to greater replacement requirements. Flock average age was 4.18 years when WR = 5%, decreasing to 3.54 years when WR = 21% (Figure 3.5). El-Shishiny *et al*. (1987) modelled a self-replacing flock of 500 ewes with different culling rates to assess impacts on meat production. With a greater average culling rate, average flock age also decreased, from 4.79 years with a cull rate of 20% to 4.77 years with a culling rate of 60%. Turner *et al*. (1968) found that for a 1,000 ewe self-replacing Australian Merino flock aged two to eight years with a replacement rate of 15.3%, the proportions of ewes in $Y_{1\ to\ 3}$ and in $Y_{4\ to\ 8}$ were 45.4% and 54.6%, respectively. Sumner and Henderson (2013) found that for three Merino flocks farmed in the North Island of New Zealand, 44 to 52% of adult ewes were in $Y_{4\ to\ 6}$, with ewes culled for age after Y_6. When WR = 5% in this study (replacement rate of 16.3%), the age distribution in the flock was similar to that of Turner *et al*. (1968) and Sumner and Henderson (2013) with 47.8% of ewes in $Y_{1\ to\ 3}$ and 52.2% of ewes in $Y_{4\ to\ 8}$. As WR and replacement rate increased, the proportion of ewes in $Y_{1\ to\ 3}$ increased to 66.8% when WR = 21%, similar to the findings of Hickey (1960) who found 66% of ewes to be in $Y_{1\ to\ 3}$ in a survey of 83,113 New Zealand breeding ewes on commercial farms. The proportion of ewe culls accounted for by Y_7 culls, not considered as wastage, decreased at a greater rate from 46% (WR = 5%) to 16% (WR = 21%). The reduction was due to greater losses from age classes $Y_{2\text{-}6}$, resulting in fewer ewes moving through to Y_7.

3.3.2 Flock productivity

As ewe flock age decreased, ensuing effects on flock productivity were an increase in wool production and reduction in reproductive rate. Wool production increased from 12.1 tonnes (WR = 5%), to 12.6 tonnes (WR = 21%) with a younger flock as ewe wool production peaked at Y_3 (Section 3.2.4). Ewe reproductive performance peaks at Y_5 (Section 3.2.2), hence the number of weaned lambs decreased from 2,478 lambs (WR = 5%) to 2,265 lambs (WR = 21%) as the number of lambs weaned per ewe presented for

Figure 3.4: The number of ewes in each age class (Y_i) from 1-year-old ewes (Y_1) to 7-year-old ewes (Y_7) with increasing ewe wastage.



breeding, including maiden ewes, decreased from 1.33 (WR = 5%) to 1.22 (WR = 21%; Figure 3.6). This concurs with previous research reporting that with greater ewe losses and subsequent reduction in average ewe age, the volume of meat produced by the flock deceased, and volume of wool produced increased (El-Shishiny *et al*., 1987). Requirements for replacement ewe lambs increased with increasing WR, from a replacement rate of 16% (WR = 5%) to 25% (WR = 21%) to maintain flock size. The proportion of lambs kept as replacements and therefore not available for sale increased from 12% to 21% of total lambs weaned across the WR range.

Figure 3.5: Average age of ewes in the ewe flock with increasing ewe wastage.

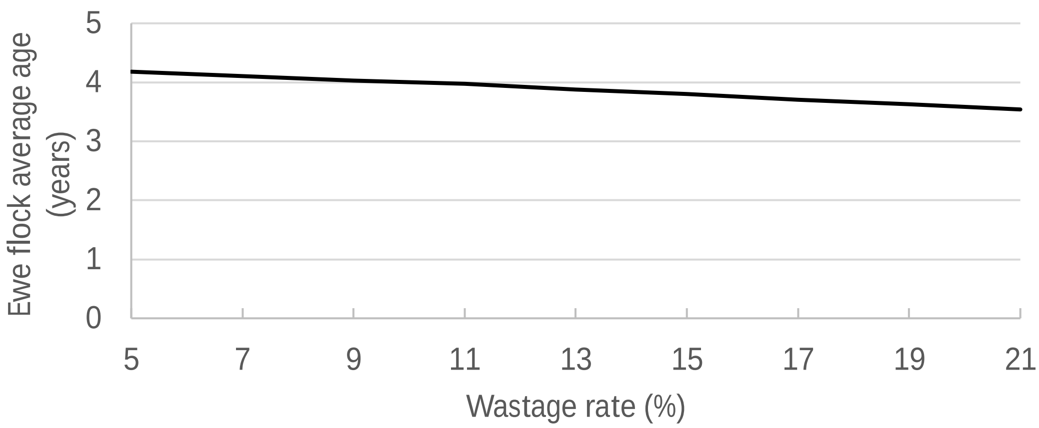
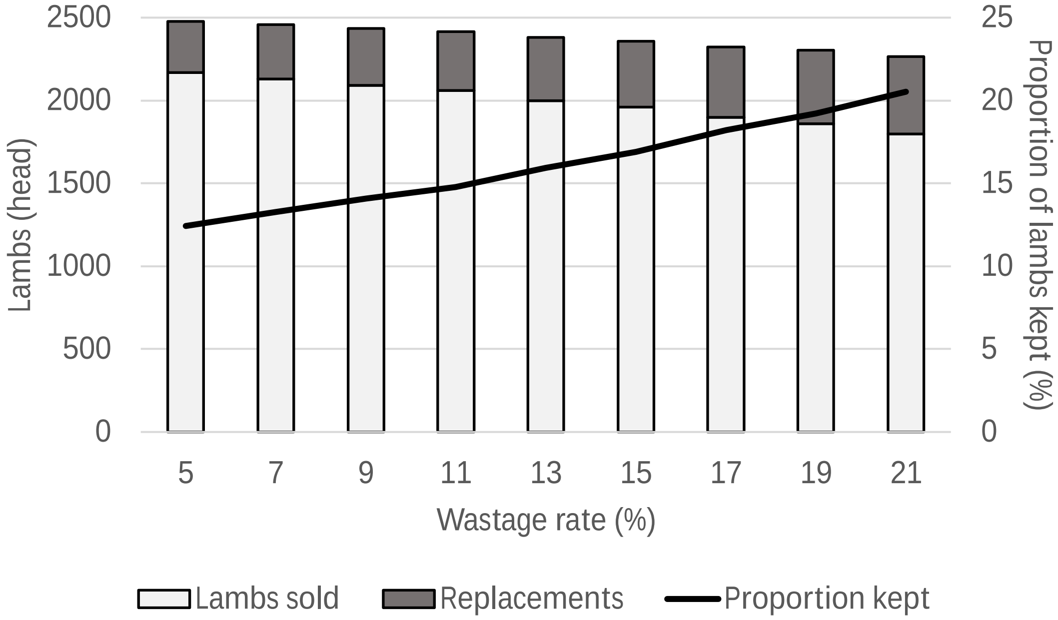


Figure 3.6: Number of weaned lambs that were available for sale or kept as replacements and proportion kept as replacements with increasing ewe wastage.



3.3.3 Farm profitability

Due to fewer lambs sold and more kept as replacements, income from stock sales decreased, resulting in lower total income for the sheep enterprise (Figure 3.7). Farm expenses were relatively constant with increasing WR, therefore, sheep enterprise COS deceased. COS decreased from $256/ha to $192/ha when WR increased from 5% to 21%, respectively. Similar to the mean published value of $265/ha (with quintiles ranging from $225/ha to $316/ha) for this type of farm (Beef + Lamb New Zealand Economic Service, 2018a). National average COS/ha of sheep and beef farms for production years from 2008/09 to 2012/13 ranged from $191/ha to $356/ha (Ministry for Primary Industries, 2012). Combined, these results suggest the farm modelled was representative of this farm system for the 2015/16 production year. COS for the total sheep enterprise (63% of 423 ha) decreased from $68,221 when WR = 5% to $51,166 when WR = 21% (Figure 3.7). Sheep COS reduced $1,069 per 1% increase in WR for the representative sheep enterprise where sheep consume 63% of feed on 423 ha.

As discussed in section 3.2.7, culled ewes constituted 81% of total ewe losses reflecting industry data (Beef + Lamb New Zealand Economic Service, 2018a). In a secondary analysis, when this ratio was altered to 50% of ewe losses from each of deaths and culls (50:50), respectively, the rate of decline in sheep COS averaged $1,299 per 1%

increase in ewe wastage (Figure 3.8). Total sheep COS decreased from $68,438 when WR = 7% to $50,259 when WR = 21% for this 423-ha representative farm where 63% of feed was consumed by sheep. The rate of change in COS as WR increased was greater than for the main analysis where the death to cull ratio was 19:81, with a sheep COS reduction of $1,299 compared with $1,069 in the original analysis, reflecting fewer culled ewes sold as more ewes died.

Figure 3.7: Cash income, expenses and sheep cash operating surplus (COS) with increasing ewe wastage.

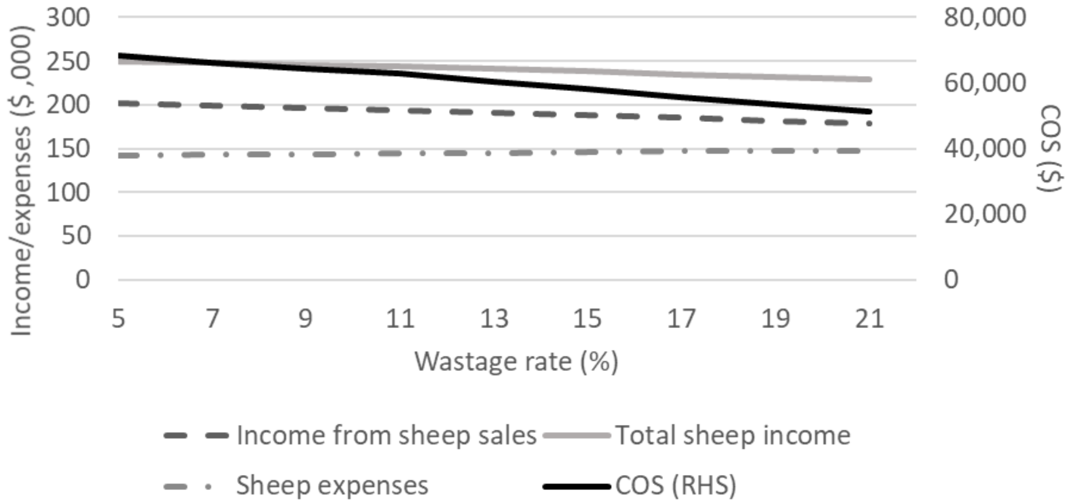
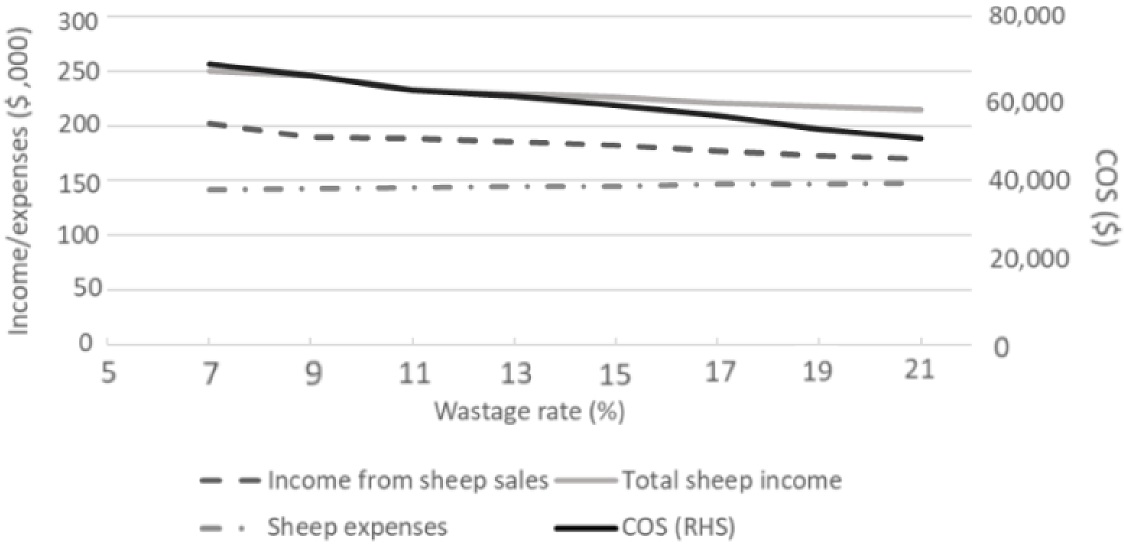


Figure 3.8: Cash income, expenses and sheep cash operating surplus (COS) with increasing ewe wastage when culled and dead ewes accounted for 50% each of ewe losses.

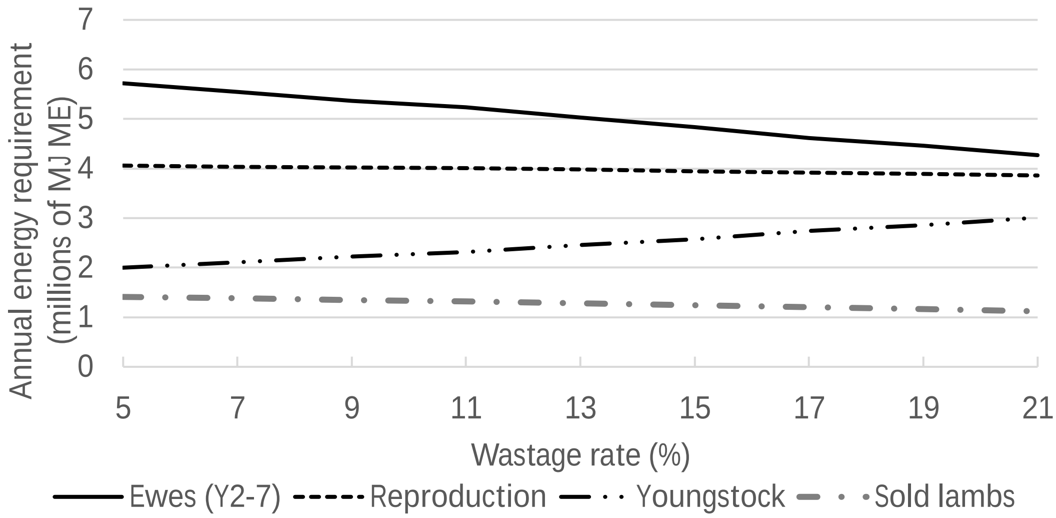


3.3.4 Sheep energy demand

Maximum total annual flock energy demand occurred when WR = 5% (13.43 million MJ ME). Total annual energy requirements decreased to 12.45 million MJ ME when WR = 21%, as greater numbers of ewes were wasted and fewer lambs produced leading to reduced nutritional demand for adult ewes, sold lambs, and gestation and lactation for all lambs (Figure 3.9). Total energy demand for young stock (replacement lambs from weaning until entering Y_2) increased with higher replacement rates and their energy demand accounted for an increasing proportion of total flock energy demand. Efficiency of pasture use in this study decreased from 162 lambs sold per million MJ ME consumed annually by the flock when WR = 5% (2,170 lambs sold in total) to 145 lambs sold per million MJ ME consumed annually when WR = 21% (1,800 lambs sold in total), indicating that pasture was used less efficiently with higher WR. (Figure 3.9).

The current study did not estimate changes in Greenhouse Gas emissions intensity with changes in WR but did explore changes in production efficiency from pasture. A previous modelling study used eight years of New Zealand sheep and lamb records to explore the influence of management change on methane emissions intensity, including the effect of delaying culling ewes for age by one year (Cruickshank *et al*., 2009). The study found methane production per lamb sold decreased 6.4% when ewes were culled for age at six years old compared with culling for age at five years,

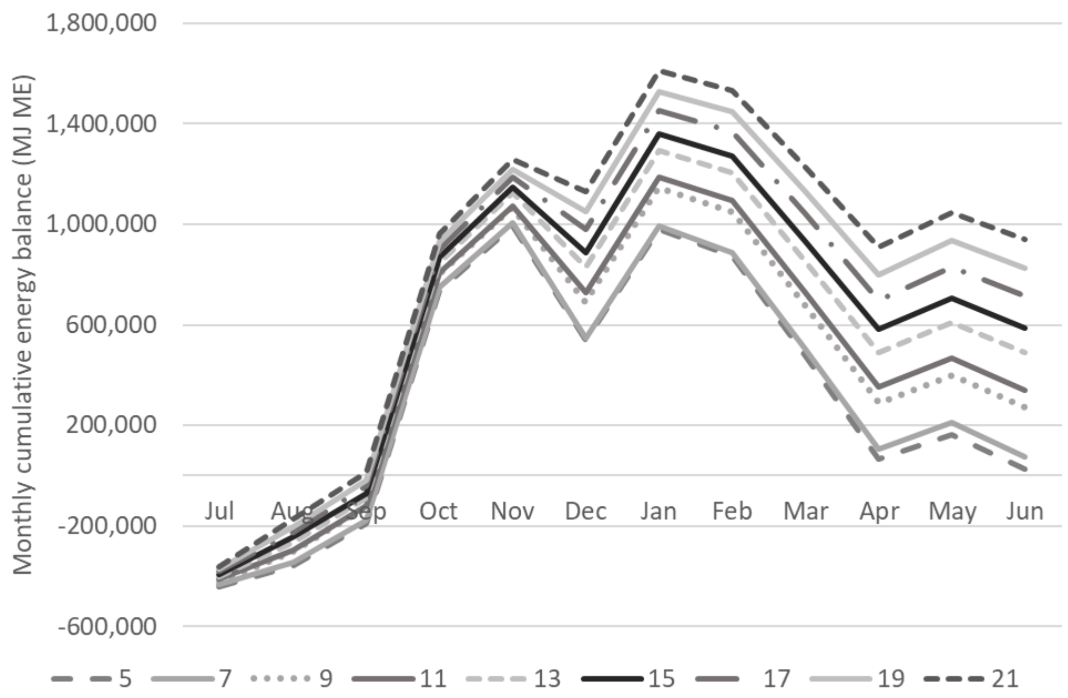
Figure 3.9: Annual energy requirements for $Y_{2\ to\ 7}$ (adult ewes); reproduction (pregnancy and lactation to weaning); young stock (replacement lambs from weaning until turning 2 years old); and sold lambs (non-replacement lambs from weaning until sale) with increasing ewe wastage.



explained by a lower replacement rate and older, more productive flock. Reductions in ewe death and culling rates of 10% resulted in relatively smaller reductions in emissions intensity, decreasing by 0.04% and 0.03% for death and culling rates, respectively, and ewe deaths and culling were already low in the research flock. Similarly, another study explored the impact of genetic selection in dairy cattle production systems in the United Kingdom on emissions intensity, including decreasing breeding stock WR (Wall *et al*., 2010). The emissions intensity of the dairy herd modelled decreased 4.42% when the herd average age was increased by six months from three to three and a half years, most of the reductions from decreasing WR were due to lower requirements for replacement stock. The improvements in production efficiency identified in the current study suggest that reducing WR would result in lower Greenhouse Gas emissions intensity of lamb production.

Higher ewe WR and subsequent lower total flock energy demand lead to greater monthly energy surpluses, resulting in a greater positive end of production year energy balance (Figure 3.10). Closing energy balance at the end of June was 24,107 MJ ME when WR = 5% and 939,017 MJ ME when WR = 21%. Potential changes in pasture quality and growth due to under-grazing were not included in this study, nor were alternative uses of the increased surplus of feed. In this study, the largest energy surplus occurred in mid to late-summer (Figure 3.10) when pastures are most vulnerable to maturing, and reproductive growth reducing pasture quality (Sheath *et al*., 1987). Possible alternative uses of the feed surplus for this farm system are to conserve and sell excess feed, though this farm system was on hill country which restricts the area that can be conserved; for greater weight gain in lambs, leading to a larger proportion sold as prime lambs for higher prices (Table 3.1); or to farm at a higher stocking rate, either increasing the size of the breeding ewe flock, the proportion of feed consumed by other species, or leasing pasture for grazing. Greater profitability gains and more efficient use of feed could likely occur from using this surplus feed to better feed existing stock to improve their performance and reduce WR (Young *et al*., 2011; Kenyon *et al*., 2014,). Young *et al*. (2011) identified improved pasture utilisation and adequate feeding of breeding ewes to increase farm profitability.

Figure 3.10: Monthly cumulative energy balance with increasing ewe wastage (wastage rates from 5% to 21%).



3.3.5 Implications

Operating profit losses with higher ewe WR have been quantified in this study, demonstrating a reduction in annual sheep COS of $1,069 per 1% increase in WR for a typical New Zealand North Island Hill Country farm. Average ewe death rate from the Beef + Lamb New Zealand Farm Survey Analysis for New Zealand North Island Hill Country farms is 4.2% and flock replacement rate is 21.7% (Beef + Lamb New Zealand Economic Service, 2018a). These values best match those when WR = 15% used in this study (Table 3.2) which had an annual sheep COS of $219/ha, where reducing ewe WR to 5% from 15% would increase the sheep enterprise COS by 17% (COS = $58,547 when WR = 15% and COS = $68,221 when WR = 5%). For farms of this type losing a large proportion of ewes prematurely, reducing flock WR from 21% to 5% would increase COS by 33% (COS = $51,166 when WR = 21% and COS = $68,221 when WR = 5%). Research currently underway aims to accurately determine the rate of ewe wastage on commercial New Zealand sheep farms (Griffiths, 2016). These findings, combined with those of this study, will provide clarity for sheep production industries around the productive and economic impact of premature on-farm ewe losses. The use of surplus feed resulting from greater ewe wastage was outside the scope of this study but could be included in strategies developed in future work to reduce ewe flock wastage.

3.4 Conclusion

The bio-economic system-dynamics model constructed for this study was useful in simulating the interactions across the sheep farming enterprise of occurring when different WR were applied to the ewe flock. Results of this study indicate that greater losses of breeding ewes due to wastage, including death and culling during their most productive years, increases requirements for replacement lambs and, reduces the average age of ewes in the flock and therefore the production of lambs for sale which is the major driver of profitability for sheep production systems. This study identified the operating profit of an average New Zealand North Island Hill Country sheep farm to increase by 33% for a farmer reducing WR from 21% to 5%, suggesting that strategies to reduce ewe wastage should have a positive impact on flock productivity and farm profitability. Such strategies may include changes to ewe management to improve reproductive performance and reduce deaths around lambing or due to climatic or disease events.

3.5 References

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Chapter Four

Quantifying sheep enterprise profitability with varying flock replacement rates, lambing rates, and breeding strategies in New Zealand.

4.1 Introduction

Revenue from sheep sales makes up the majority of the income for most New Zealand sheep farming enterprises (Beef + Lamb New Zealand Economic Service, 2016, 2018a). During the last 25 years New Zealand farmers have focused on increasing the total weight of lamb carcass produced per ewe, through increasing both the number of lambs weaned per ewe and individual lamb carcass weight (Mackay *et al*., 2012; Morris and Kenyon, 2014). The majority of breeding ewes in New Zealand are dual-purpose breeds with a Romney base, producing strong wool (diameter > 30 µm) and lambs for meat (Beef + Lamb New Zealand Economic Service, 2018b). Terminal sire breeds, such as Suffolk, Poll Dorset, and Texel have a focus on meat production and are associated with greater lamb growth rates and heavier liveweights (Clarke and Meyer, 1982; McEwan *et al*., 1995). Sires from such breeds are often bred with dual-purpose ewes to produce a faster growing crossbred lamb destined for slaughter (Carter and Kirton, 1975; Clarke and Meyer, 1982). A first cross lamb's growth superiority over the average performance of the two parental breeds, is referred to as heterosis or hybrid vigour (Donald *et al*., 1963). Advantages in lamb growth of up to 30% have been observed in crossbred lambs from terminal sires compared to purebred lambs in New Zealand flocks (Clarke and Meyer, 1982; McEwan *et al*., 1995). Improvements in birth weight, lamb survival, and carcass dressing percentage have also been reported (Carter and Kirton, 1975; Meyer *et al*., 1977; Kirton *et al*., 1995; Purchas *et al*., 2002; Shackelford *et al*., 2005; Jenkinson *et al*., 2007).

The average carcass weight of New Zealand lambs at slaughter is 18.5 kg, which, with a carcass dressing percentage of 41%, indicates an average lamb liveweight at slaughter of approximately 45 kg (Litherland *et al*., 2010; Beef + Lamb New Zealand Economic Service, 2018b; Ministry for Primary Industries, 2019). The price of lamb per kg of carcass weight that a farmer receives can vary greatly both within and between years, with prices traditionally peaking in late-spring (September to November), before declining in mid-summer and reaching their lowest point in early autumn (Beef + Lamb New Zealand Economic Service, 2018b). In New Zealand, lambing occurs predominantly between August and October (spring) with weaning ten to twelve weeks later (Morris *et al*., 2004). Lambs with faster growth rates can reach slaughter weight targets sooner and therefore can be sold at or near the highest per kg price.

Thompson *et al*. (2016) investigated the effect of increasing pre- and post-weaning lamb growth rates on farm profitability for a Gisborne (New Zealand East Coast) North Island Hill Country) farm using an optimisation model. They found that increasing lamb growth rates increased sheep enterprise profit and overall farm profitability. Further, faster growing lambs have lower total feed demand due to lower overall maintenance energy demand, allowing more feed and resources to be available for other stock classes on-farm, e.g. for the ewe flock to gain weight prior to breeding (Kemp *et al*., 2010). Lambs sold earlier also have reduced greenhouse gas emissions, health costs, and labour costs (Waghorn *et al*., 2002; Kemp *et al*., 2010).

In New Zealand the sheep breeding period is generally restricted to two to three oestrus cycles in total (i.e. two to three 17-day periods; Cranston *et al*., 2017). New Zealand farmers implement different strategies for use of terminal sires. One strategy is to use the same sire breed as the ewe (maternal sire breed) to produce sufficient numbers of purebred ewe lambs from which to choose replacements in the first 17-day period, then for the remainder of the breeding period use terminal sires. Typically, 70% of ewes presented for breeding will become pregnant in the first 17 days of breeding (Allison, 1975; Knight *et al*., 1980), therefore, using terminal sires during only the second and third 17-day cycles of breeding constrains their use to approximately 30% of the ewe flock. Alternatively, farmers may utilise terminal sires for the entire sheep breeding period with specific classes of ewes such as older ewes, from which they may not wish to produce replacements. Requirements for quality purebred ewe replacement lambs and higher mature ewe cull rates are constraining factors for use of terminal sires in New Zealand sheep farms (McEwan *et al*., 1995; Beef + Lamb New Zealand, 2019a). Published estimates of annual ewe wastage (i.e. premature death and culling of ewes prior to the end of their productive lifespan) rates in New Zealand commercial flocks range from 2.8% to more than 20%. Total flock replacement rates (enough to cover both ewe wastage and ewes being culled for age for a flock with a stable size) range from 20 to 35% (Cranston *et al*., 2017; Griffiths *et al*., 2017). The modelling by Thompson *et al*. (2016) did not investigate the impacts of either terminal sire use or ewe wastage and replacement rates on profitability gains from potential increases in lamb growth.

Bio-economic models can simulate bio-physical farm elements and interactions with the economic component of the farm system (Bohan *et al*., 2016), e.g. modelling changes to farm profit from changes in sire breed. Systems dynamics modelling is effective for modelling systems with numerous interconnected components and feedback processes (Walters *et al*., 2016) such as those existing in a breeding flock. Chapter Three modelled the effects of ewe flock wastage rates on ewe flock productivity and sheep enterprise operating profit. Greater wastage rates, which result in higher replacement requirements for a stable flock size, resulted in a flock with a greater proportion of young ewes with relatively lower lambing rates and reduced profit. They did not, however, consider the effect of wastage rate on breeding strategies i.e. terminal sire use. Lower ewe replacement rates would allow a greater proportion of the ewe flock to be bred with terminal sires, producing more crossbred lambs, potentially increasing sheep enterprise profitability. Therefore, the current study extended the model developed for Chapter Three to investigate the use of terminal sires across a purebred ewe flock with a range of lambing rates and ewe replacement rates.

4.2 Methods

System dynamics modelling was used to capture flock dynamics with the associated energy demand, production, and profitability implications. Recent research has revealed the utility of this approach in agricultural and livestock systems to test *ex ante* dynamic impacts of feedback from different scenarios and technical interventions (Hamza and Rich, 2015; Shane *et al*., 2017; Lie *et al*., 2018), including New Zealand farm systems (García, 2000). The base model developed for Chapter Three was extended to include the option of producing lambs from different sires with ewe age class differentiated breeding strategies to simulate production of purebred and crossbred lambs. Energy demand was calculated fortnightly (for each two-week period), rather than monthly, to investigate changes in energy demand with differing lamb sale dates. The base model structure has been reported in Chapter Three with detail of each component module. Therefore, this chapter only briefly outlines the model and identifies areas of difference in detail. The model was constructed using STELLA version 1.8.3 (isee systems, 2017) and was run for thirty consecutive years for each scenario with relevant model outputs from the final year interpreted and discussed in this paper. The model workings are explained in the following subsections.

4.2.1 Crossbred lamb performance from use of terminal sires

The range of published values for the production of Romney type lambs grazing traditional ryegrass and clover pastures in New Zealand is reported in Table 4.1. The approximate median values were used as base production parameters for the purebred lambs in this study, utilising values from North Island East Coast Hill Country or similar systems, where possible. Values for Romney lambs were chosen as the baseline parameters as this breed represents almost half of sheep in New Zealand and is the major breed in the North Island (Beef + Lamb New Zealand Economic Service, 2018b). In order to analyse the effect of terminal sire use on a number of lamb traits, the results of a number of crossbreeding studies were examined. Table 4.1 presents a summary of published comparisons of production parameters for purebred and crossbred lambs with the same dam breed (e.g. Romney, Merino, Cheviot, Romanov, Rambouillet, or Finnsheep) and either maternal or terminal sires (e.g. Suffolk, Poll Dorset, Dorset, or Texel). Crossbred lambs on average outperformed purebred lambs in terms of lamb survival, birth and weaning weights, post-weaning growth rates, and carcass dressing percentage. Relative parameters for crossbred lambs used in this study were informed by values from the published comparisons. For example, published weaning weights for New Zealand Romney type single-born lambs range from 23.9 kg to 37.5 kg (Table 4.1), an approximate median value of 28 kg was utilised for purebred lamb production in this model. In published comparisons between purebred and crossbred lambs, crossbred lambs from terminal sires had weaning weights 11 to 31% higher than purebred lambs (Table 4.1). The median crossbred production advantage value of 21% was used to adjust the single-born purebred lamb weaning weight to a single-born crossbred lamb weaning weight of 33.9 kg.

Table 4.1: Range of published values and parameters used in this study for New Zealand purebred (Romney type) lamb production, range of published values and median values for production advantage of crossbred lambs from a terminal sire compared with their purebred counterparts (%), and parameters used in this study for production of crossbred lambs. Purebred lamb production parameters were adjusted using the median value for crossbred advantage, to determine the crossbred lamb production parameters used in this study.

Parameter	Production for purebred (Romney lambs or similar)			Crossbred advantage (% increase)			Crossbred parameters used
	Range	Source	Parameters used	Range	Source	Median	
Lamb loss between scanning and weaning (%)	2 to 39.9	Dalton *et al*., 1980; Kelly, 1980; Geenty, 1997; Thomson *et al*., 2004; Beef + Lamb New Zealand, 2013; Thompson *et al*., 2016	16	4 to 12	Carter and Kirton, 1975; Meyer *et al*., 1977	8	14.7
Birth weight single (kg)	5.0 to 6.01	Kenyon *et al*., 2002a, b; Thomson *et al*., 2004; Jenkinson *et al*., 2007; Kenyon *et al*., 2009; Kenyon *et al*., 2011 Corner *et al*., 2013	5.5	8	Jenkinson *et al*., 2007	8	5.94
Birth weight multiple (kg)	3.9 to 4.88		4.5				4.86
Weaning weight single (kg)	23.9 to 37.5	Kenyon *et al*., 2002a, b; Thomson *et al*., 2004; Kenyon *et al*., 2009; Kenyon *et al*., 2011; Corner *et al*., 2013; Morris and Kenyon, 2014; Thompson *et al*., 2016	28	11 to 31	Carter and Kirton, 1975; Meyer *et al*., 1977; Hopkins *et al*., 2007	21	33.9
Weaning weight multiple (kg)	19.7 to 32.0		26				31.5
Post-weaning growth rate single (g/day)	56 to 322	Kemp *et al*., 2010; Golding *et al*., 2011; Somasiri *et al*., 2013	130	-2 to 31	Carter and Kirton, 1975; Clarke and Meyer, 1982; Kirton *et al*., 1995; Scales *et al*., 2000; Purchas *et al*., 2002; Shackelford *et al*., 2005; Hopkins *et al*., 2007; Ponnampalam *et al*., 2007	16	151
Post-weaning growth rate multiple (g/day)			100				116

Carcass dressing (%)	41	Purchas *et al*., 2002; Shackelford *et al*., 2005; Jenkinson *et al*., 2007; Litherland *et al*., 2010	41	0 to 8	Kirton *et al*., 1995; Purchas *et al*., 2002; Shackelford *et al*., 2005; Jenkinson *et al*., 2007	4	42.6

4.2.2 Representative farm

More than half of the North Island sheep population are farmed in the East Coast region (Beef + Lamb New Zealand Economic Service, 2018b). The model farm was based on an average New Zealand North Island East Coast Hill Country sheep and beef farm using mean 2016/17 production year data from the Beef + Lamb New Zealand Farm Survey Analysis (Beef + Lamb New Zealand Economic Service, 2018c). Sheep operations on a North Island Hill Country Sheep and Beef farm constitute the majority of total farm stock units (SU; Beef + Lamb New Zealand Economic Service, 2018c). A SU is defined as the equivalent feed consumption of a 55 kg ewe weaning one 28 kg lamb, equal to 550 kg DM (dry matter)/year (Trafford and Trafford, 2011). Commercial farms of this type usually also farm beef cattle and/or deer (Beef + Lamb New Zealand, 2012), therefore, the modelled representative farm had 60.8% of SU as sheep according to its farm type, with this fraction of pasture available for sheep only (Beef + Lamb New Zealand Economic Service, 2018c). It was assumed the 549-ha farm had a breeding flock of 2,182 mature purebred Romney ewes lambing annually in spring and grazing pasture year-round. The model only considered the sheep operations of the farm, i.e. sheep enterprise income, working expenses, and feed available for sheep (details in Sections 4.2.6 and 4.2.7 below).

4.2.3 Ewe flock dynamics

A simplified flow diagram of the flock is shown in Figure 4.1, showing movement between age classes, and sheep entering and leaving the flock. The ewe flock (Y) was divided into seven age (i) classes (Y_i), starting with Y_1 (maiden ewes; Equation 4.1). All ewes from the previous age class (Y_{i-1}), except deaths (D_i) and cull ewes (C_i), moved into the next age class at lambing, i.e. ewes entering Y_1 were 12 months of age (Equation 4.2).

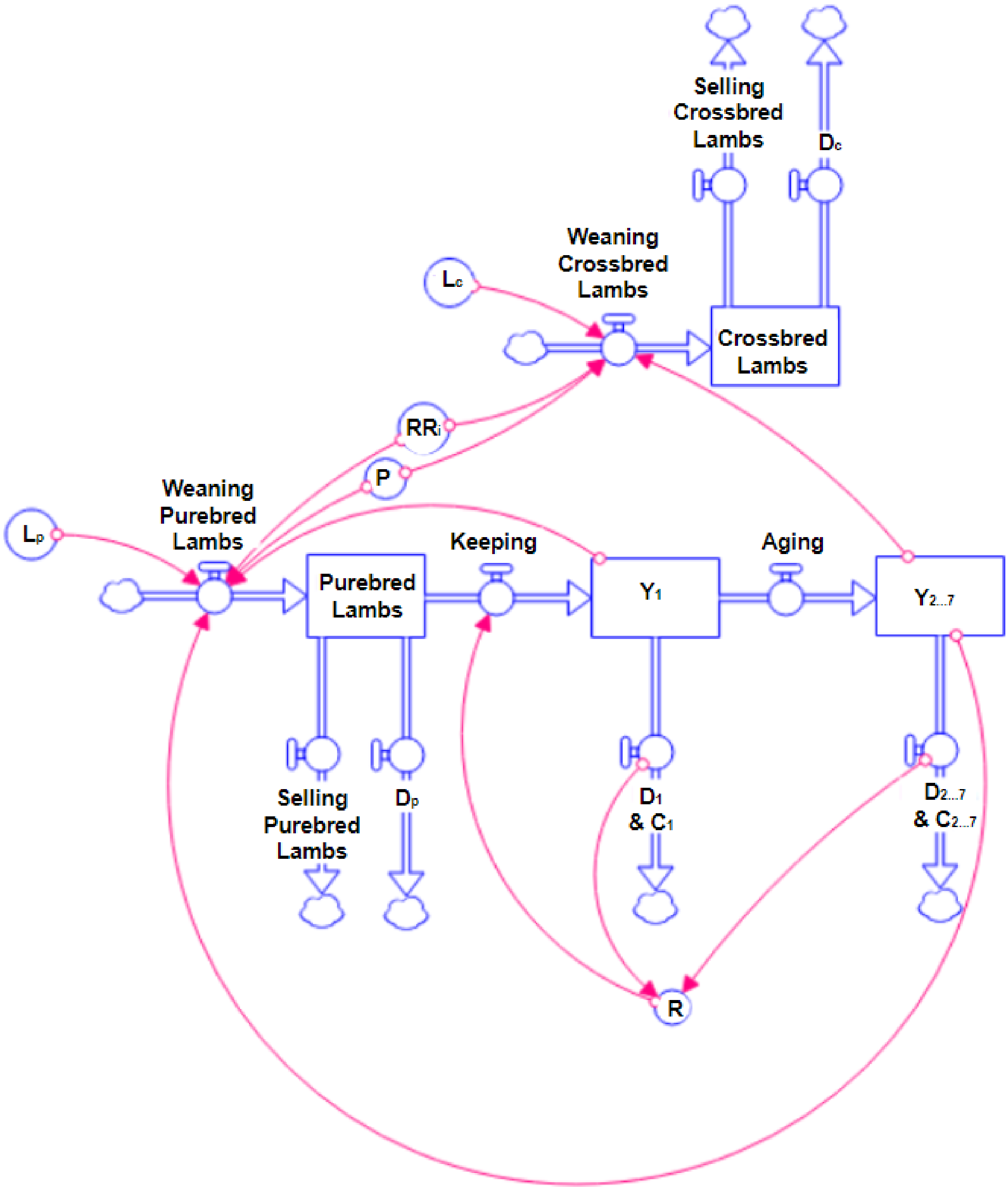
$$Y = \sum_{i=1}^{7} Y_i \quad [4.1]$$

Where

$$Y_i = Y_{i-1} - D_{i-1} - C_{i-1} \quad [4.2]$$

Mature ewes began lambing annually on 1st September (Beef + Lamb New Zealand, 2018) and maiden ewes (Y_1) lambed later at approximately 14 months of age (Cranston *et al*., 2017). Y_1 ewes were bred with maternal sires (to produce purebred lambs) at approximately nine months of age. In scenarios where use of terminal sires was

Figure 4.1: Simplified diagram of the flock dynamics module adapted from Chapter Three. Where each age class (Y_i) is depicted with movements between age classes, cull ewes (C_i) and deaths (D_i), replacement lamb requirements (R), sold lambs, and lambs weaned as a function of Y_i, relative reproductive performance for each ewe age class (RR_i), lambing rate for purebred (L_p) and crossbred (L_c) lambs, and the proportion of $Y_{2\text{-}7}$ bred with a terminal sire (P).



maximised for mature ewes, the proportion of age classes $Y_{2\text{-}7}$ bred with terminal sires (P) was increased until there was an insufficient number of purebred ewe lambs from which to choose replacements, as signalled by a drop in the number of maiden ewes in Y_1. The breeding strategy assumed in this study was maternal sires breeding with the youngest mature ewes to produce purebred replacements and terminal sires bred with ewes in the oldest age groups. For example, with a flock replacement rate of 20% and lambing rate of 130%, 58% (1,266 ewes) of the 2,182 ewes in the total mature flock were bred with terminal sires. In this scenario, ewes in Y_7 (298 ewes), Y_6 (321 ewes), Y_5 (346 ewes), and some of Y_4 (373 ewes) were bred with terminal sires (Table 4.2).

Table 4.2: Number of ewes and relative reproductive performance (RR_i) for each age (i) class (Y_i) for a flock of 2,182 mature ewes aged up to seven years bred with either maternal or terminal sires. With a lambing rate of 1.3 lambs weaned per ewe presented for breeding and replacement rate of 20%. Where the oldest ewes (58% of the mature flock, or 1,266 ewes) were bred with a terminal sire breed.

	Age class (Y_i)						
	Y_2	Y_3	Y_4		Y_5	Y_6	Y_7
Ewes (No.)	433	402	72	301	346	321	298
RR_i	0.85	0.97	1.04		1.09	1.06	0.99
Sire type	Maternal	Maternal	Maternal	Terminal	Terminal	Terminal	Terminal

Average flock lambing rate (lambs weaned per ewe presented for breeding) was varied to three levels: 110, 130, and 150%. The average flock lambing rate for North Island East Coast Hill Country farms in the 2016/17 production year was 123% (ranging from 110% to 131%) (Beef + Lamb New Zealand Economic Service, 2018c), with lambing rates of 110% and 150% being well within the range occurring on Hill Country farms nationally (Beef + Lamb New Zealand, 2019b). Lambing rate for purebred (L_p) and crossbred lambs (L_c), were in terms of lambs weaned per ewe presented for breeding. Number of lambs weaned (LM) was a function of ewes presented for breeding (Y_i), relative reproductive performance for each ewe age class (RR_i), LR_p or LR_c, and P (Equation 4.3), where RR_2 = 0.85, RR_3 = 0.97, RR_4 = 1.04, RR_5 = 1.09, RR_6 = 1.06, and RR_7 = 0.99 (Turner *et al*., 1968; Hight and Jury, 1970; Dickerson and Glimp, 1975; Thomson *et al*., 2004). In New Zealand ewe flocks, approximately 32% of eight to nine month old ewe lambs are presented to the ram, and these have an average lambing rate of 65% (Statistics New Zealand, 2018). In this study RR_1 = 0.24 to match survey data for North Island East Coast Hill Country farms (Beef + Lamb New Zealand Economic Service, 2018c).

$$LM = Y_1 \times RR_1 + \sum_{i=2}^{7}[Y_i \times L_p \times RR_i \times (P-1)] + \sum_{i=2}^{7}[Y_i \times L_c \times RR_i \times P] \qquad [4.3]$$

The number of lambs born as singles and twins depended on whole flock reproductive performance (Amer *et al*., 1999). All crossbred lambs and non-replacement purebred lambs (rams and ewes) were sold (timings of sale discussed later in Section 4.2.6).

Replacement ewe requirements (R) were the sum of all deaths (D_i) and culling (C_i) of $Y_{1\text{-}7}$ ewes to ensure a status quo size mature flock (Equation 4.4). Mature flock ewe deaths ($D_{2\text{-}7}$) and culling ($C_{2\text{-}7}$) were adjusted to reflect flock replacement rates (Table 4.3). D_1 = 1.9% (Beef + Lamb New Zealand Economic Service, 2018c), assuming ewes in this age class were not culled on reproductive performance for their first breeding and lambing.

$$R = \sum_{i=1}^{7}(D_i + C_i) \qquad [4.4]$$

All live Y_7 ewes were culled at weaning after their seventh lambing (assuming they first lambed at 14 months of age). On New Zealand sheep farms the majority of ewe deaths occur at or around lambing due to lambing difficulty or dystocia, metabolic disease, or pneumonia (Quinlivan and Martin, 1971; Davis, 1974; Tarbotton and Webby, 1999). Therefore, in this model all ewe deaths were assumed to occur at lambing and 20% of ewe culling in $Y_{2\text{–}7}$ occurred at pregnancy scanning, the remainder of ewes were culled at weaning, as in Chapter Three.

Table 4.3: Total deaths and cull ewes in a flock of 2,182 mature ewes on a New Zealand North Island Hill Country farm, with various replacement rates and at a ratio of 34:66 for deaths:cull ewes.

Flock replacement rate (%)	Deaths	Cull ewes
20	144	292
25	187	367
30	223	445

4.2.4 Replacement requirements

Replacement rates in commercial New Zealand ewe flocks range from 20 to 35% (Griffiths, 2016; Cranston *et al*., 2017). Rates of mature ewe loss, due to culling and death, in the model was included at three levels: 20, 25, and 30%, with matching flock replacement rates to maintain flock size (Table 4.3). The ratio of ewes leaving the flock due to death and culling was 34:66 according to survey data for North Island East Coast Hill Country farms (Beef + Lamb New Zealand Economic Service, 2018c). When selecting purebred ewe lambs to replace deaths and cull ewes, farmers often choose from more ewe lambs than they require. This buffer allows for culling of some potential replacement ewe lambs due to unwanted traits. As there were no published values on the size of this buffer, a rate of 30% was assumed. These additional buffer lambs were sold in autumn once replacements were selected, i.e. if 1,000 replacement lambs were required, these would be chosen from 1,300 purebred ewe lambs kept until breeding with 300 subsequently sold store (i.e. for another farm to grow for slaughter). This requirement for purebred ewe lambs from which to choose replacements affected the maximum proportion of the ewe flock that could be bred with a terminal sire.

4.2.5 Feed demand

Sheep energy demand was based on the number of sheep in each stock class and their respective energy demand in megajoules of metabolisable energy (MJ ME) according to production levels and equations from CSIRO (2007) and Nicol and Brookes (2007). These calculations did not differ from those described in Chapter Three but were calculated fortnightly instead of monthly. Energy demand for maintenance, liveweight change, pregnancy, lactation, and wool production were calculated. Sheep demand for daily maintenance energy (ME_m) were calculated from Equation 4.5 (CSIRO; 2007).

$$ME_m = \left[0.28 \times \frac{LW^{0.75} \times e^{-0.03 \times i}}{0.02 \times Q + 0.5}\right] \times 1.1 \qquad [4.5]$$

Where LW = liveweight (kg) and Q = pasture quality measured as MJ ME/kg DM, an average pasture quality value of 10 MJ ME/kg DM was assumed, considered a medium quality of pasture on New Zealand sheep and beef farms (Waghorn *et al.*, 2007). Mature ewe ($Y_{2\text{-}7}$) average liveweight was 65 kg, losing 2 kg in spring during lactation which was regained prior to autumn breeding, and liveweight for replacement ewes was assumed to average 45 kg when entering Y_1 at 12 months of age (Thomson *et al*., 2004). Liveweight values used to calculate maintenance demand for sheep younger than Y_2 were averages for that class of animal, for example single-born crossbred lambs were weaned at 33.9 kg (Table 4.1) and sold to slaughter at 41 kg liveweight, hence demand for maintenance between weaning and slaughter was based on an average liveweight of 37.45 kg. Energy demand for liveweight gain and loss were 55 MJ ME required for each kg of liveweight gain, and 35 MJ ME converted from each kg of liveweight loss (Nicol and Brookes, 2007).

Energy demand for gestation (ME_G) and lactation (ME_L) were calculated per lamb according to Equations 4.6 and 4.7 (Nicol and Brookes; 2007). The average New Zealand lamb loss rate (from scanning to weaning) of 16% (Dalton *et al*., 1980; Amer *et al*., 1999; Beef + Lamb New Zealand 2013) was used alongside lambing rate to estimate numbers of lamb foetuses for gestation requirement calculations. Lambs from $Y_{2\text{-}7}$ ewes were weaned at twelve weeks of age with average birth weights, weaning weights, and growth rates for purebred and crossbred lambs shown in Table 4.1. Energy demand for gestation of lambs from maiden ewes was calculated with those for purebred lambs from $Y_{2\text{-}7}$, where lambs from maiden ewes accounted for approximately 5% of total lambs weaned. Lambs from maiden ewes were weaned at ten weeks of age at 23 kg liveweight (Beef + Lamb New Zealand, 2014).

$$ME_G = 49 \times b + 7 \qquad [4.6]$$

and

$$ME_L = N \times [51.4 \times L + 134.7 \times \alpha - 1808] \qquad [4.7]$$

Where b was lamb birthweight (Table 4.1), N was the adjustment parameter for birth rank (N = 1 for single-born lambs and N = 1.35 for multiples), L = lamb liveweight at weaning (kg) (Table 4.1), and α = lamb age at weaning in weeks.

Average annual wool production per ewe was 4.64 kg according to survey data for North Island East Coast Hill Country farms (Beef + Lamb New Zealand Economic Service, 2018c) which was used to calculate flock daily wool growth (G) in g/sheep/day. Energy demand for wool growth (ME_W) was estimated using the wool growth equation from CSIRO (2007; Equation 4.8). The sheep enterprise produced an average of 14.37

tonnes of greasy (unscoured) wool per year from ewes in $Y_{1\text{-}7}$ and rams (Beef + Lamb New Zealand Economic Service, 2018c).

$$ME_w = 0.13 \times (G - 6) \qquad [4.8]$$

4.2.6 Economics

All economic data was in New Zealand Dollars, NZD$ 1 = EUR€ 0.59 = USD$ 0.65 as of 5th August 2019 (XE.com). Production, prices, and expenses were used to calculate the sheep enterprise cash operating surplus (COS) on a per ha basis. COS was used as an indicator of sheep enterprise profit and included cash income of the farm minus cash operating expenses. Expenses were $35.50 per sheep stock unit, average values from industry survey data (Beef + Lamb New Zealand Economic Service, 2018c). Expenses were comprised of variable costs and the enterprise share of fixed costs (including costs of repairs and maintenance, vehicles, administration, ACC, and insurance) while excluding drawings, tax, interest, depreciation, and rent (Shadbolt and Martin, 2005). Sheep sale prices were taken from survey data from the East Coast Hill Country of the North Island in 2016/17 (Beef + Lamb New Zealand Economic Service, 2018c) and prime lamb sale prices from weekly published schedule prices (per kg carcass weight) from lamb sales across the North Island (Inventas Media, 2017). Lamb sale timings, with cohorts of lambs sold at different times depending on their growth rates, and prices are shown in Table 4.4.

Table 4.4: Price[1] (NZD per kg carcass weight or $ per head) and timing for sheep sales with values from the 2016/17 production year.

Stock class	Timing of sale	Price (NZD)
Crossbred prime lambs	Mid - January	5.04 / kg
Crossbred prime lambs	Mid - February	4.98 / kg
Purebred prime lambs	Mid - March	4.98 / kg
Purebred prime lambs	Early May	5.63 / kg
Purebred store lambs	Early May	76.54 / head
Cull ewes (2 years)	Majority at weaning (early November)[2]	109.08 / head
Cull ewes (aged 3 to 7 years)	Majority at weaning (early November)[2]	74.45 / head

[1]Price data from Inventas Media (2017) and Beef + Lamb New Zealand Economic Service (2018c). [2]A minority of ewes were culled following pregnancy scanning in early winter.

All purebred lambs not required as replacement stock, including the excess purebred lambs which acted as a buffer (i.e. the 30% additional purebred ewe lambs) from which replacements had been selected, and all crossbred lambs were sold. The proportion of purebred lambs sold as prime lambs was maintained at 66.2% according to survey data for farms of this type (Beef + Lamb New Zealand Economic Service, 2018c). It was assumed all crossbred lambs were sold prime and all prime lambs were sold direct to slaughter. The timing of prime lamb sale depended on growth rates, thus, the time taken for lambs to reach the target average carcass weight of 17.5 kg. The average carcass weight at slaughter for prime lambs sold from North Island East Coast Hill Country farms is lower than the national average of 18.5 kg (Beef + Lamb New Zealand Economic Service, 2018c; Ministry for Primary Industries, 2019). The timings of sales are shown in Table 4.4, where prime lamb sales were split into groups representing lambs of each breed born as singles and multiples. For example, purebred prime lambs were sold in two cohorts according to the single- and multiple-born purebred lamb growth rates, the first sale of purebred prime lambs was in mid-March (Table 4.4). These lambs were weaned in late November with a liveweight of 28 kg and assumed to grow at a rate of 131 g/day to reach a slaughter liveweight of 42 kg, with a carcass dressing rate of 41% (Table 4.1), 107 days later in mid-March. For prime lambs, all lambs of each type, breed and birth rank, were sold as a group according to their average weaning weight and growth rate values in Table 4.1. Purebred lambs not sold prime, including all lambs from Y_1 ewes and excess purebred ewe lambs not selected as replacements, were sold store. The last prime lamb sale was in early May and all remaining lambs were then sold store at this time. Store lambs were lambs that failed to reach the target slaughter weight and were sold at an average liveweight of 33 kg, a weight too light for slaughter, in May. Wool from all sheep older than one year was sold for an average price of $2.54 per greasy kg (Beef + Lamb New Zealand Economic Service, 2018c).

The sheep enterprise working expenses (excluding rates, interest, rent, drawings, and depreciation) were based on sheep SU at $35.50 per SU according to 2016/17 average values in survey data from North Island East Coast Hill Country farms (Beef + Lamb New Zealand Economic Service, 2018c). Breeding costs were included in the working expenses, with one ram per 100 breeding ewes. SU included replacement ewes up to a year old, ewes in $Y_{1\text{-}7}$, and rams (Trafford and Trafford, 2011) Ewe ($Y_{1\text{-}7}$) SU were calculated based on their prolificacy and liveweight (Parker 1998). Dead ewes are disposed of on-farm in New Zealand so did not incur an additional cost. The prices for both dual-purpose and terminal breed rams varies greatly in New Zealand and it was assumed that the same number of rams were purchased at the same price, regardless of breed.

4.2.7 Feed supply

Although this farm type would typically have a small cropped area (i.e. 7 ha of the 549 ha farm; Beef + Lamb New Zealand Economic Service, 2018c), all feed consumed was assumed to be from pasture. A pasture growth curve representative of hill country in the Gisborne district (Trafford and Trafford, 2011) was integrated with average North Island Hill Country sheep and beef farm pasture quality data (Bown *et al*., 2013) to estimate the pattern of monthly energy supply from pasture. A feed adjustment parameter of 59% was assumed, as no published values for pasture utilisation rate were available and annual energy supply then matched the energy demand of the modelled scenario with a replacement rate of 25% and lambing rate of 130%, average rates for North Island East Coast Hill Country sheep farms (Beef + Lamb New Zealand Economic Service, 2018c). With 60.8% of feed available for sheep, the ewe flock had 20.46 million MJ ME available from annual pasture supply (Table 4.5).

Table 4.5: Pasture growth (Trafford and Trafford, 2011), quality (Bown et al., 2013), and resulting energy supply for a sheep flock on a 549 ha farm with a pasture utilisation rate of 59%, where 60.8% of pasture was available for sheep (Beef + Lamb New Zealand Economic Service, 2018c).

Month	Pasture growth (kg/ha/day)	Pasture quality (MJ ME / kg DM)	Monthly energy supply for sheep ('000 MJ ME)
September	25	9.9	1,487
October	46	10.0	2,856
November	52	9.8	3,062
December	52	8.5	2,744
January	52	8.2	2,647
February	38	7.2	1,534
March	39	8.5	2,058
April	29	8.3	1,446
May	15	9.5	885
June	10	10.0	601
July	8	9.7	482
August	14	11.5	1,000

4.2.8 Wool production

Total flock wool production (*WP;* Equation 4.9) was estimated using *W* (greasy fleece weight; Table 5.1) and an adjustment parameter (w_i) for wool production for each age class ($w_{0.5}$ = -3.5, w_1 = -1.8, w_2 = -0.09, w_3 = 0.42, w_4 = 0.28, w_5 = 0.05, w_6 = -0.14, and w_7 = -0.5; Brown *et al*., 1966; McLaughlin, 1973; Rose, 1974).

$$WP = \sum_{i=0.5}^{7} Y_i \times (W + w_i) \qquad [4.9]$$

4.2.9 Sensitivity analysis

A sensitivity analysis was performed for the scenario with an annual ewe flock replacement rate of 25% and lambing rate of 130%, representing the average North Island East Coast Hill Country sheep enterprise (Beef + Lamb New Zealand Economic Service, 2018c), with maximum use of terminal sires. Sheep (all lambs and cull ewes) sale base 2016/17 prices in Table 4.4 were adjusted to be either lower or higher by ± 20% to reflect inter-year changes in price (Beef + Lamb New Zealand Economic Service, 2018b). For example, the price for the first sale of lambs in January was adjusted from $5.04 per kg of carcass weight to $4.03 and $6.05 per kg carcass weight to reflect either reduced or increased prices, respectively.

There has been a wide range of levels reported for the production advantage of crossbred lambs from terminal sires over purebred lambs (Table 4.1). For this sensitivity analysis, the advantage of crossbred lambs for pre- and post-weaning growth rates over purebred lambs, median values shown in Table 4.1, were adjusted by ± 10%. For example, the base single-born lamb weaning weight for crossbred lambs was 33.9 kg, 21% greater than for purebred lambs at a 28 kg weaning weight. In the sensitivity analysis, crossbred lamb weaning weight was reduced to reflect a lower, 19%, advantage compared with purebred lambs (single-born crossbred lambs weaning weight of 33.3 kg) and increased to reflect a higher, 23%, advantage compared with purebred lambs (single-born crossbred lambs weaning weight of 34.5 kg). As the lamb pre- and post-weaning growth rates changed by ± 10%, timing of crossbred lamb sales was altered to reach the unchanged target carcass weight of 17.5 kg.

4.2.10 Changing flock structure from seven age classes to five age classes

New Zealand sheep flocks typically have five to seven age classes and the main analysis of this study modelled a ewe flock aged up to seven years (Y_{1-7}). For one scenario, the number of flock age classes was reduced to five age classes to investigate effects on lamb production and sheep COS. This was achieved through culling all live Y_5 ewes at weaning following the end of their fifth year, i.e. after their fifth lambing assuming they first lambed at 14 months of age, with no ewes entering Y_6 and Y_7. The same sized mature ewe flocks with either five or seven age classes were compared using the same wastage rate. In the flock with five age classes, it was expected there would be more ewes in each age class and a lower flock average age. Younger ewes have a lower reproductive performance (Section 4.2.3), so fewer lambs would be weaned per ewe. The higher number of ewes in each age class for the flock with five age classes would lead to higher numbers of ewes culled for age at five years old, resulting in an overall higher annual number of ewes leaving the flock. This increases replacement purebred ewe lamb requirements and, therefore, the proportion of the flock required to breed with maternal sires to produce purebred ewe lambs. This would reduce the proportion of ewes available to breed with terminal sires and therefore numbers of crossbred lambs produced.

4.3 Results and discussion

In general, the proportion of the mature ewe flock that could be bred with terminal sires was constrained by requirements for purebred ewe lambs from which replacements would be chosen. Therefore, fewer ewes could be bred with terminal sires when flock replacement rates were greater and/or lambing rates were lower. The effects on flock productivity, sheep enterprise operating profit (in the form of COS), and sheep energy demand from varying flock replacement rate, lambing rate, and terminal sire use are discussed separately in the following subsections. The modelled flock had seven age classes ($Y_{1\text{-}7}$) except for the scenario in section 4.3.2.3 where the flock was adjusted to have five age classes ($Y_{1\text{-}5}$).

4.3.1 Flock productivity

4.3.1.1 Use of terminal sires and flock productivity

When lambing rate was 150% and replacement rate was 20%, the maximum proportion of the mature ewe flock that could be bred with terminal sires was 65% (Table 4.6). As the lambing rate decreased to 130% and then 110%, the maximum proportion of the flock that could be bred with terminal sires also decreased. Further, due to the higher survival of crossbred lambs (Table 4.1), a greater number of lambs were weaned when a higher proportion of the ewe flock was bred with terminal sires (Table 4.6), effectively increasing the flock lambing rate. For example, for a flock with a base lambing rate of 130% and a replacement rate of 25%, 2,773 lambs were weaned in total when maternal sires only were used. However, when 58% of the flock were bred with terminal sires, 2,953 lambs were weaned. This indicates that farms with high lambing rates and low flock replacement rates (due to lower wastage rates) have the greatest potential for increased lamb production from the use of terminal sires.

4.3.1.2 Replacement rate and flock productivity

In the mature ewe flock when replacement rate increased from 20 to 30%, a greater number of young ewes entered the flock with a resultant reduction in flock average age, from 4.15 years (20%) to 3.64 years (30%; Table 4.7), similar to the findings of Chapter Three. Ewe reproductive performance was affected by age, peaking at five years of age, thus a younger flock results in a lower lambing rate and fewer lambs weaned. For example, in scenarios with no terminal sire use and a lambing rate of 130%, 2,805, 2,773, and 2,748 lambs were weaned from the mature flock (Y_{2-7}) with replacement rates of 20, 25, and 30%, respectively (Table 4.6). This effect of replacement rate and age structure on lamb production has been explored previously, with similar findings (El-Shishiny *et al*., 1987; Chapter Three).

4.3.1.3 Purebred ewe lamb requirements

The maximum proportion of the flock that could be bred with terminal sires was constrained not only by requirements for replacement lambs, but also the buffer of 30% additional purebred ewe lambs from which replacements were chosen. If this buffer were reduced, the proportion of ewes bred with terminal sires to produce crossbred lambs could be increased, increasing total lamb production and sheep enterprise COS, although this was not modelled in this study. Farmers prefer to have additional purebred ewe lambs to choose from when selecting replacements. They cull potential replacement lambs based on physical traits and/or those which display poor performance between weaning and final selection, i.e. in this model sold store in May at nine months of age.

Table 4.6: Lambs weaned from the mature ewe flock, sheep income, expenses, and cash operating surplus (COS) for a flock with varying lambing rates (lambs weaned per ewe presented for breeding), replacement rates, and use of terminal sires.

Replacement rate (%)	Proportion of ewes to terminal sires (%)	Lambs from mature flock (No.) Purebred	Crossbred	Total	Total sheep income ($ '000)	Sheep expenditure ($ '000)	COS ($/ha)
Lambing rate of 110%							
20	0	2,381	0	2,381	216	106	330
	25.5	1,769	726	2,495	230	110	360
	51	1,163	1,448	2,611	243	113	390
25	0	2,347	0	2,347	210	114	288
	17	1,923	479	2,402	217	116	303
	34	1,471	968	2,439	222	118	312
30	0	2,323	0	2,323	204	121	249
	9	2,073	256	2,329	206	122	252
	18	1,821	512	2,333	207	123	252
Lambing rate of 130%							
20	0	2,805	0	2,805	255	108	441
	29	1,991	960	2,951	272	112	480
	58	1,153	1,921	3,074	287	117	510
25	0	2,773	0	2,773	248	116	396
	22.5	2,109	760	2,869	259	119	420
	45	1,425	1,528	2,953	269	122	441
30	0	2,748	0	2,748	241	123	354
	16.5	2,264	550	2,814	254	126	384
	33	1,758	1,108	2,866	257	128	387

			Lambing rate of 150%				
	0	3,208	0	3,208	298	110	564
20	32.5	2,184	1,261	3,445	322	116	617
	65	1,134	2,521	3,655	343	121	665
	0	3,135	0	3,135	287	117	510
25	27	2,271	1,039	3,310	305	122	549
	54	1,397	2,099	3,496	324	127	590
	0	3,134	0	3,134	282	125	471
30	21.5	2,418	826	3,244	294	128	498
	43	1,688	1,667	3,355	306	132	522

Table 4.7: Ewes leaving the flock (including ewes culled for age and premature losses), replacement requirements, and average age for a flock with varying replacement rates.

Replacement rate (%)	Ewes culled for age (No.)	Premature ewe losses (No. [%])	Replacements required (No.)	Average age (years)
20	273	168 [7]	441	4.15
25	197	357 [13]	554	3.88
30	139	529 [19]	668	3.64

4.3.2 Sheep enterprise profitability

Quintile survey data for the 2016/17 production year indicates that average COS for a sheep enterprise only (excluding the beef enterprise) of North Island East Coast Hill Country farms ranges from less than \$212/ha to more than \$595/ha (Beef + Lamb New Zealand Economic Service, 2018c). The range of sheep enterprise COS for modelled scenarios in this study was slightly higher, at \$249/ha to \$665/ha (Table 4.6), indicating the modelled farm was representative of this type of farm in the 2016/17 production year.

4.3.2.1 Use of terminal sires and enterprise profitability

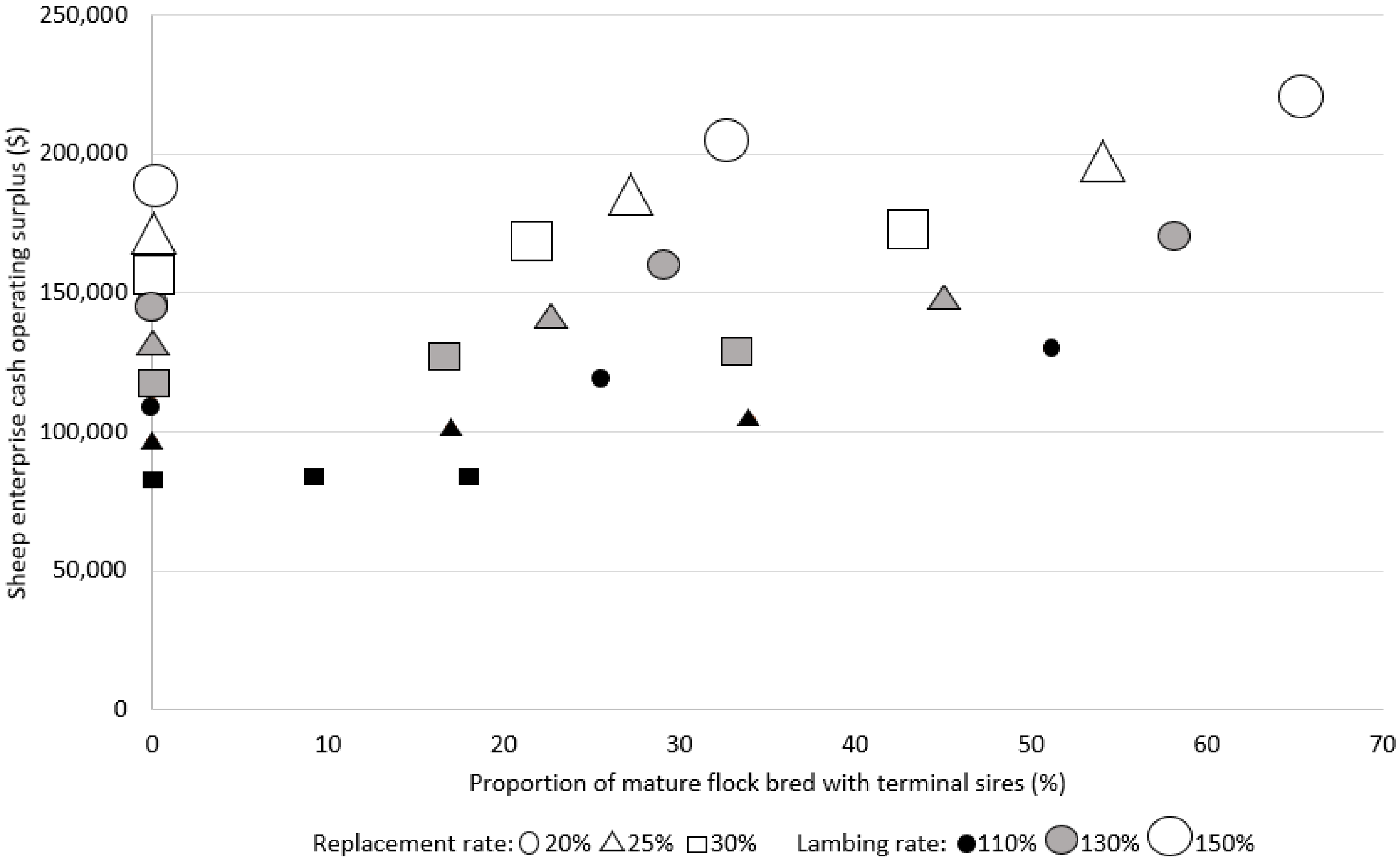
According to average survey data for New Zealand North Island East Coast Hill Country farms in the 2016/17 production year, income from the sale of live sheep (lambs sold store, prime lambs, and cull ewes) accounted for 48.4% of gross income, with 7.3% from wool (Beef + Lamb New Zealand Economic Service, 2018c). Improvements in lamb production levels and prices obtained drive the profitability of sheep enterprises in New Zealand (Cocks and Brown, 2005) and motivate New Zealand sheep farmers (McIvor and Aspin, 2001). It was, therefore, expected that sheep enterprise income and COS would increase with the increased lamb production and higher lamb prices from use of terminal sires. In this study, use of terminal sires increased sheep enterprise COS in all scenarios. The results indicated use of terminal sires to be advantageous in the lamb production system modelled, with the largest potential gains being made when lambing rate was highest and replacement rate lowest (where a larger proportion of the ewe flock may be bred with terminal sires; Figure 4.2). In the scenario with a lambing rate of 150% and replacement rate of 20% where 65% of mature ewes could be bred with terminal sires, sheep enterprise COS increased from \$564/ha, when terminal sires were not used, to \$665/ha with maximum use, an increase in COS of $101/ha. The increase in COS of 18% was driven primarily by greater income from lamb sales. Increased terminal sire use resulted in more lambs at weaning and faster lamb growth rates allowing lambs to be sold earlier, at higher prices. Expenses were estimated based on wintered SU, therefore, increased with lambing rate which increased ewe SU, and SU increased with replacement rate as more youngstock were retained on-farm. Expenses increased with greater use of terminal sires due to a higher rate of lambs weaned increasing sheep SU (through increasing ewe prolificacy), but this was at a lower rate relative to the increase in income observed. For a flock with a replacement rate of 25% and lambing rate of 130%, total sheep enterprise COS increased from $132,181 without terminal sires to $147,202 with maximum use of terminal sires (i.e. bred with 45% of the mature flock). Modelling by Thompson *et al*. (2016) showed improvements in lamb growth rates increased profitability on New Zealand North Island East Coast Hill Country farms. Interestingly, Thompson *et al*. (2016) found greater lamb growth rates to result in greater farm profit for sheep and beef farms in other areas of New Zealand but the maximum observed profit did not always occur with the fastest modelled lamb growth rates. This suggests that the advantages of higher lamb growth rates, from the use of terminal sires, may vary according to regional environmental conditions. Therefore, similar modelling exercises should be undertaken to account for varying conditions and lamb production systems across New Zealand to gain a broader understanding of the potential benefits from use of terminal sires.

4.3.2.2 Sensitivity analyses

4.3.2.2.1 Adjusted crossbred lamb growth rates and sheep sale prices

Sensitivity analyses with adjusted prices and levels of crossbred advantage for pre-and post-weaning lamb growth rates were also modelled. In these scenarios the flock had a replacement rate of 25% and lambing rate of 130% with use of terminal sire breeding maximised at 45% of mature ewes. Lower crossbred lamb growth rates, leading to later sale dates, reduced sheep enterprise COS but this reduction was relatively smaller than the gain in COS with a faster growth rate. For example, with base prices and slower growth rates COS was reduced $1/ha ($441/ha to $440/ha) from the base scenario, compared to the COS increase of $20/ha ($441/ha to $461/ha) with faster growth rates (Table 4.8). This indicates that, for the 2016/17 production year, there

Figure 4.2: Sheep enterprise annual Cash Operating Surplus with varying proportions of the mature ewe flock bred with terminal sires, flock annual replacement rates, and lambing rates. Annual replacement rates indicated by data point shape and lambing rates indicated by data point size.



was a small price penalty when selling lambs slightly later, but a significant advantage from selling earlier due to faster lamb growth rates. The 10% improvement in crossbred advantage for lamb growth rates could be achieved through use of a terminal ram bred to produce lambs with faster pre-and post- weaning growth rates. This sensitivity analysis did not take into account the extra cost of choosing to purchase terminal sires with above average lamb growth rate potential, which may negate the potential gains in COS from improved crossbred lamb production. Although at a ram to ewe ratio of 1:100 the farmer could afford to pay an additional $306 per animal for such a ram, even if the ram was only used for one breeding season.

Adjusting prices for all sheep sales (including cull ewes and store lambs) by ± 20% consistently changed the sheep enterprise income by 20% and, with unchanged enterprise working expenses, altered sheep enterprise COS by ± 31% (Table 4.8), i.e. either a COS reduction of $136/ha or an increase of $140/ha from the COS of $441/ha with base prices. These results show that, for the sheep enterprise modelled and 2016/17 production year, adjustments of 20% for sheep sale prices had relatively larger effects on COS than adjustments of 10% in crossbred advantage for lamb growth, when using terminal sires to produce crossbred lambs. However, farmers can choose which rams to purchase if they wish to improve lamb growth rates, whereas seasonal prices are largely outside of their control.

Table 4.8: Sensitivity analysis of the effects of varying sheep sale prices (2016/17 prices) and crossbred lamb growth rate on sheep enterprise cash operating surplus ($/ha) for a flock with an annual replacement rate of 25%, lambing rate of 130%, and terminal sires bred with 45% of the flock.

		Impact of crossbred lamb growth rates		
		10% lower value	Base value	10% higher value
Impact of price	20% lower prices	302	305	320
	Base prices	440	441	461
	20% higher prices	578	581	602

4.3.2.2.2 Adjusted sheep sale prices and varying lambing rate

A sensitivity analysis was undertaken for sheep enterprise COS with a flock replacement rate of 25% while varying lambing rate, proportion of ewes bred with terminal sires, and sheep sale prices (Table 4.9). When prices were decreased 20%, the reduction in COS from the scenario with base prices and without terminal sire use was somewhat mitigated by use of terminal sires. For example, with a lambing rate of 130% and sheep price decrease of 20%, there was a reduction from the base scenario COS ($396/ha) of $126/ha with no terminal sires and a reduction of $93/ha with maximum use of terminal sires ($396/ha to $303/ha). These results suggest that use of terminal sires can offset lower prices to some extent. This offset was greatest with a lambing rate of 150% where terminal sires were used over a larger proportion of the ewe flock, with the base COS of $510/ha reducing to $360/ha with no terminal sires and $60/ha greater (COS = $420/ha) with maximum use of terminal sires.

Table 4.9: Sensitivity analysis of the effects of varying sheep sale prices (2016/17 prices), lambing rate, and use of terminal sires on sheep enterprise cash operating surplus ($/ha) for a flock with an annual replacement rate of 25%.

Lambing rate (%)	Proportion of ewes to terminal sire (%)	20% lower prices	Base prices	20% higher prices
110	0	186	288	393
	17	195	303	411
	34	204	312	423
130	0	270	396	522
	22.5	288	420	549
	45	303	441	579
150	0	360	510	656
	27	390	549	707
	54	420	590	761

4.3.2.3 Changing flock structure from seven age classes to five age classes

With higher numbers of ewes in each age class for the flock with five age classes there were more ewes culled for age after five years, and flock replacement rate increased from 25% to 33%. Flock average age decreased from 3.88 years for a flock with seven age classes to 3.28 years with five age classes. Due to lower flock average age, fewer lambs were produced by the ewe flock with fewer age classes, e.g. 2,953 lambs weaned for the flock with seven age classes compared with 2,877 lambs weaned for the flock with five age classes, with maximum use of terminals sires. With fewer age classes, a lower proportion of the flock could be bred with terminal sires. For the flock with seven age classes, 45% of the flock could be bred with terminal sires and the sheep enterprise COS with maximum use of terminal sires was $441/ha. With five age classes, 30% of the flock could be bred with terminal sires with a resulting sheep COS of $381/ha. This was consistent with previous findings that flock age structure affects lamb production (El-Shishiny *et al*., 1987), and sheep enterprise COS (Chapter Three).

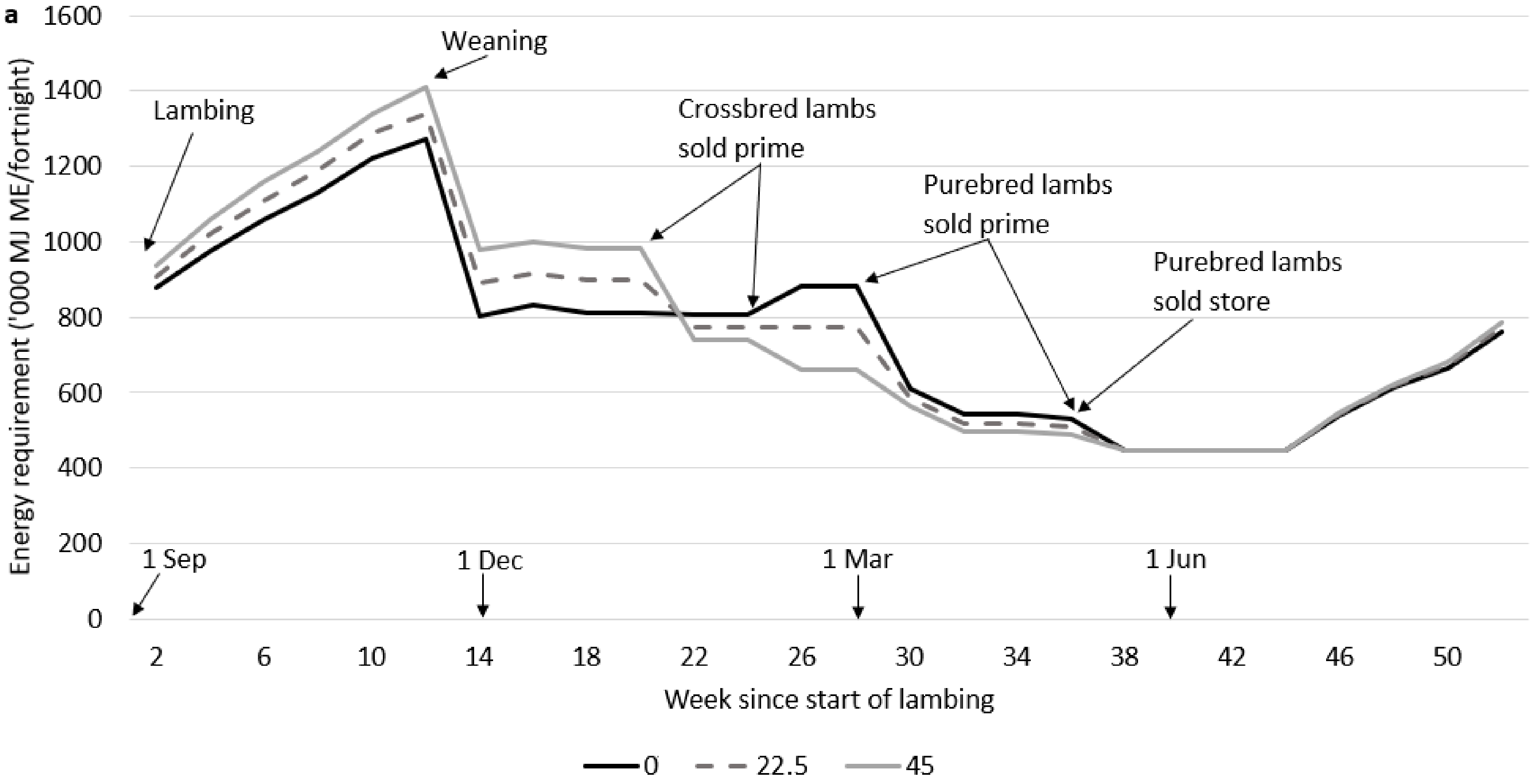
4.3.3 Sheep feed demand

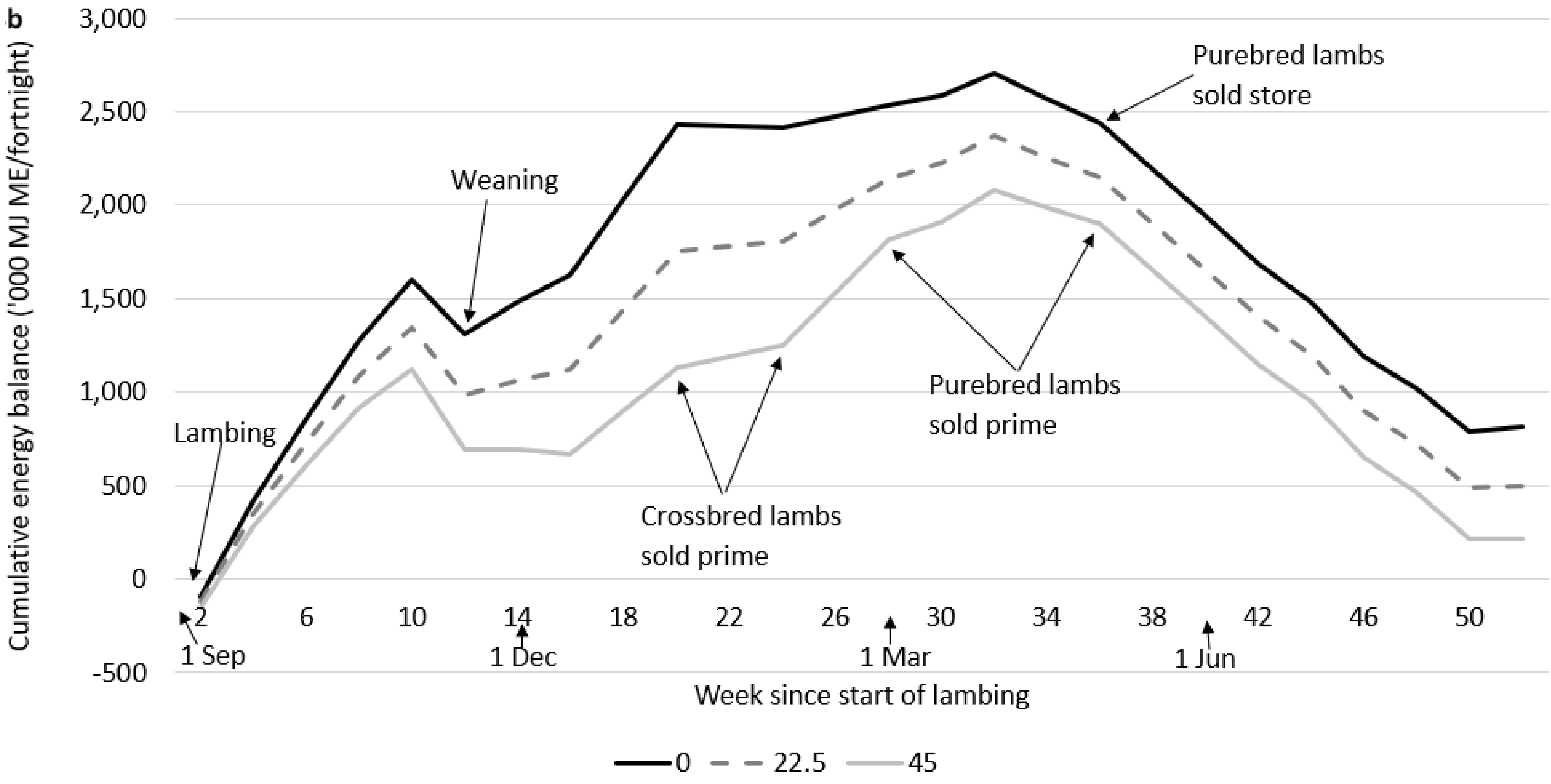
Total annual sheep energy demand increased with higher flock replacement rates, driven by greater numbers of replacement ewes, and also increased with higher lambing rates due to the resulting increased demand for gestation, lactation, and lamb growth (Table 4.10; Figure 4.3a). Figure 4.3b shows the fortnightly cumulative energy balance for a ewe flock on the East Coast of the North Island on Hill Country, with a lambing rate of 130% and a replacement rate of 25%, indicating how sheep enterprise energy demand and supply match across the production year. This scenario would most closely represent the average flock for farms of this type (Beef + Lamb New Zealand Economic Service, 2018c). The cumulative energy balance was in deficit in the period after the start of lambing on the 1st of September (week one), when pasture growth was relatively slow and energy demand was increasing due to requirements of ewes in late pregnancy and lactation. In this period mature ewes each lose an average of 2 kg of liveweight as their energy demand was partially met through mobilisation of body reserves to be regained in autumn (Kenyon *et al*., 2014). This liveweight loss is typical for ewes in New Zealand sheep farming systems and would not negatively affect production provided ewes were in good body condition at lambing (meet target energy reserve levels), did not lose more than 9 kg, and regained the liveweight loss prior to the subsequent breeding season (Beef + Lamb New Zealand, 2014, 2019c). Energy supply was greater than demand and the balance increased with the increased pasture growth from spring onwards. The greatest energy surplus occurred in weeks 32 and 34 (April) when energy demand was low once all lambs had been sold and ewes were in early pregnancy. Conserved pasture from times of surplus can be fed during energy balance deficits, however this farm system was on hill country, restricting the ability to mechanically harvest surplus pasture. Previously published work has found feeding the breeding flock to generally be the best use of surplus feed on pastoral sheep farms, due to the benefits of ewe weight and body condition gain between weaning and breeding, (Young *et al*., 2011; Kenyon *et al*., 2014).

Table 4.10: Sheep energy demand and cumulative energy balance for a flock with varying lambing rates (lambs weaned per ewe presented for breeding), replacement rates, and use of terminal sires.

Flock replacement rate (%)	Proportion of ewes to terminal sire (%)	Total annual energy demand ('000 MJ ME)	Final energy balance ('000 MJ ME)
Lambing rate of 110%			
20	0	18,116	2,339
	25.5	18,547	1,908
	51	18,886	1,569
25	0	18,775	1,680
	17	18,942	1,518
	34	19,088	1,367
30	0	19,164	1,291
	9	19,209	1,246
	18	19,250	1,205
Lambing rate of 130%			
20	0	19,260	1,195
	29	19,718	737
	58	20,081	374
25	0	19,779	676
	22.5	20,097	358
	45	20,374	81
30	0	20,251	204
	16.5	20,598	-143
	33	20,723	-263
Lambing rate of 150%			
20	0	20,470	-15
	32.5	21,108	-653
	65	21,630	-1,175
25	0	20,867	-412
	27	21,347	-892
	54	21,867	-1,412
30	0	21,410	-955
	21.5	21,738	-1,283
	43	22,062	-1,607

Figure 4.3: Fortnightly calculated a. sheep energy demand and b. energy balance on 549 ha on New Zealand North Island East Coast Hill Country where 60.8% of pasture was available for sheep (Beef + lamb New Zealand, 2018c) for a ewe flock with a lambing rate of 130% and a replacement rate of 25% with varying proportion of the flock (0, 22.5, and 45%) bred with terminal sires




b
3,000
2,500
2,000
1,500
1,000
500
0
-500
Cumulative energy balance ('000 MJ ME/fortnight)
Purebred lambs
sold store
Weaning
Lambing
Purebred lambs
sold prime
Crossbred lambs
sold prime
2
6
10
14
18
22
26
30
34
38
42
46
50
1 Sep
1 Dec
1 Mar
1 Jun
Week since start of lambing
0
22.5
45

4.3.3.1 Terminal sires

Figure 4.3b shows the energy balance to have greater surpluses without use of terminal sires, as energy demand was lower from week one (start of lambing) to week 22 with no terminal sire use due to fewer lambs weaned and lower lamb growth rates. For example, sheep energy demand post-weaning in week 20 was 812,000 MJ ME with no terminal sire use and 899,000 MJ ME with maximum use (Figure 4.3a). This difference was largest for the flock with a replacement rate of 20% and lambing rate of 150% when use of terminal sires was maximised to 65% of the flock (Table 4.10). From the time all crossbred lambs had been sold in week 24 (February) until all purebred lambs were sold in week 36 (May), sheep energy demand was lower in scenarios that utilised terminal sires (Figure 4.3a). Total annual sheep energy demand was increased up to 6% with highest terminal sire use (Table 4.10), indicating an overall small change in annual sheep feed demand. Increases in energy demand from crossbred lambs in weeks one to 22 were compensated for over the production year through reductions in feed demand from week 22 to 38 as crossbred lambs left the farm earlier. Availability of quality feed can be a major constraining factor for post-weaning growth rates of New Zealand lambs (Brown, 1990). In order to realise profitability gains from use of terminal sires there was a requirement for quality summer feed to achieve the potential increases in lamb growth, which may decrease production in another part of the farm system (Brown, 1990; Thompson *et al*., 2016). To achieve the potentially higher growth rate of crossbred lambs, farmers would need to ensure quality herbage is available which may include growing summer crops and/or alternative pasture species with high summer growth and quality such as herbs, or clovers (Kemp *et al*., 2010; Somasiri *et al*., 2015). The potential cost of growing additional feed has not been included in this analysis.

4.3.4 Alternative options for crossbred lamb sales

In this study, all crossbred lambs were finished on-farm, however, crossbreds from terminal sires could be sold sooner post-weaning as store lambs at heavier weights and for a premium per kg price compared to maternal breed lambs. This could be an alternative strategy for farmers to increase revenue through use of terminal sires while having greater flexibility in feed management. In this study all prime lambs were sold at a carcass weight of 17.5 kg, crossbred lambs could be sold later, at the same time as purebred prime lambs, at heavier weights for a higher price per head. This would, however, require more feed for crossbred lamb growth if remaining on-farm for a longer time.

4.4 General discussion

Lamb prices in the United Kingdom, Australia, and Ireland follow a similar pattern to those in New Zealand, lowest during summer and early autumn and higher in spring, winter, and late-autumn; terminal sires are used in these lamb production systems (Wolf *et al.,* 1980; Meat and Livestock Australia, 2018; Agriculture and Horticulture Development Board, 2019). Approximately 70% of lambs produced in Australia are crossbred from terminal sires (Banks and Ross, 2003). Terminal breed rams were present on 65% of 300 surveyed sheep farms in a Scottish study, mostly on lowland grasslands which can support higher production (Rodriguez-Ledesma *et al.,* 2011). In New Zealand, maternal breed sires make up at least 74% of rams bred with the national ewe flock (Beef + Lamb New Zealand Economic Service, 2018b). Terminal sires, therefore, are currently bred with up to 26% of the national New Zealand flock. The results of this study identified the proportion of the mature ewe flock that can be bred with terminal sires to be up to 65% with potential economic advantages, suggesting that terminal sires are currently underutilised in New Zealand lamb production systems. The sensitivity analysis in Table 4.9 of this study demonstrates that changes in prices of 20% have a relatively larger effect on COS compared with use of terminal sires, even with 65% of the flock bred with terminal sires. This degree of change in price occurs between years and the inability of terminal sire use to completely offset operating profit losses from reduced prices may contribute to the low rates of terminal sire use in New Zealand. Though these sensitivity analyses also highlighted the advantage of using terminal sires to increase production and take advantage of higher prices. The current study found small increases in COS when terminal sires are bred with a small proportion of the flock, i.e. 18% of the flock bred with terminal sires increased COS by $3/ha compared to no use of terminal sires (Table 4.6). The benefits of using terminal sires for some flocks may not outweigh the risks incurred, such as feed availability and price uncertainty, and the results of this study are specific to the system under consideration, including estimations of operating expenses.

In the current study operating expenses increased with use of terminal sires due to higher lamb survival rates raising ewe prolificacy and therefore wintered stock units on which expenses were based. There are potentially additional expenses incurred that could be significant for different farm systems. The sheep enterprise modelled in this study has sufficient pasture growth over summer to support crossbred lamb growth rates, but many lamb production systems without the same summer feed availability would require additional feed to be provided in the form of crops grown or bought-in supplements. In order to breed terminal sires with a specific segment of ewes in a flock, the flock would need to be separated into multiple groups for the breeding season. Managing multiple groups of ewes may increase labour and maintenance costs, particularly for smaller farms. Ewe flocks on New Zealand and Australian farms are relatively large compared to those in other nations, providing economies of scale for these costs. For smaller flocks this may not be feasible and terminal sires could be bred with ewes during the latter part of the breeding season, after maternal sires have been used, though additional costs may negate some of the benefits of crossbred lamb production.

Previous bio-economic modelling of sheep farming systems has explored the effects of increased lamb production on profit. Examples relevant to the current study include modelling in the United States with a single animal-based simulation model (Blackburn *et al.,* 1991), using a farm-level sheep production simulation model in Ireland (Bohan *et al.,* 2016), an optimisation model of a mixed-cropping system in Australia (Young *et al.,* 2010), and in New Zealand using an optimisation model for a mixed sheep and beef farm (Thompson *et al.,* 2016). System dynamics modelling has been used in the past to analyse systems characterised by information feedback, mutual interaction, circular causality, and interdependence, including analysis of small ruminant farming systems (Tedeschi *et al*., 2011). Our analysis investigated increased lamb production while varying factors that contribute to feedback loops in a breeding flock (e.g. annual flock replacement rate affecting flock age), for which systems dynamics is particularly appropriate. Therefore, the current study has demonstrated the value of system dynamics modelling to investigate the ewe flock dynamics which constrain use of terminal sires in self-replacing ewe flocks. The approach differs from previous sheep system modelling work as it investigates increasing lamb production for a subset of the ewe flock by employing a specific breeding strategy.

In conclusion, this study used an extended version of the bio-economic system-dynamics model developed for Chapter Three to investigate how flock lambing and replacement rates influence the proportion of the mature ewe flock that can be bred with terminal sires, while producing sufficient numbers of replacement ewe lambs. COS increases, through use of terminal sires compared to no use of terminal sires, ranged from $3/ha to $101/ha. For an average North Island East Coast Hill Country sheep enterprise, COS increased $15,021 with maximum use of terminal sires (bred with 45% of the flock), compared with no use. Despite the potential profit gains from crossbred lamb production from terminal sires, their use is low in New Zealand in comparison with international sheep farming systems. Varying feed supply, flock size, and lamb prices are factors that constrain the applicability of the study findings to lamb production systems in other regions and countries and may reduce the profit gains from use of terminal sires. Further work is needed to explore use of terminal sires for a sheep enterprise with differing seasonal prices and feed supply to those modelled in this study. Options to improve price and feed stability, i.e. supply contracts and forage species that can support crossbred lamb growth, are relevant research areas that could increase use of terminal sires in New Zealand.

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Chapter Five

Producing higher value wool: A transition from Romney to Merino cross

5.1 Introduction

The majority of wool produced in New Zealand is coarse wool (fibre diameter > 30 µm), for which the nominal price has fluctuated between \$2.50 and \$6.00 per kg clean since 1980 (Beef + Lamb New Zealand Economic Service, 2019a). This equates to a reduction in the real value of coarse wool alongside increased shearing costs, resulting in a lower proportion of farm income being derived from wool sales (Beef + Lamb New Zealand Economic Service, 2019b). The majority of income on most farms with sheep operations is from sales of sheep either direct to slaughter or to be grown for slaughter on another farm, therefore New Zealand sheep farmers have shifted their focus to lamb production (Beef + Lamb New Zealand Economic Service, 2019b).

In the last 30 years there has been an increasing price premium for mid-micron (fibre diameter between 25 and 29 µm) wool over coarse wool, and higher prices for fine wool (fibre diameter < 24 µm). Between 1980 and 2019, nominal mid-micron wool prices increased from \$3.50 to \$9.00 - 13.25 per kg clean, and nominal fine wool prices increased from \$5.00 to \$14.60 - 24.45 per kg clean (Beef + Lamb New Zealand Economic Service, 2019a; Carrfields Primary Wool, 2019). Fine wool only makes up approximately 8% of New Zealand wool exports, with mid-micron wool accounting for 15% (Beef + Lamb New Zealand Economic Service, 2019a). New Zealand farmers producing fine wool derive, on average, 28% of gross income from wool sales, while coarse wool producers only obtain 1 to 11% of gross income from wool sales (Beef + Lamb New Zealand Economic Service, 2019b). In New Zealand fine wool is predominantly produced on high altitude, steep, less fertile land in the South Island from Merino sheep, which make up around 6% of the national flock (Beef + Lamb New Zealand Economic Service, 2019a). The majority of the national breeding ewe flock, approximately 52%, are purebred Romney, a dual-purpose breed producing coarse wool (Beef + Lamb New Zealand Economic Service, 2019a).

Breeding a Merino ram with Romney ewes to produce offspring producing wool with a lower fibre diameter than their dam has been identified as a potential strategy to increase wool income while retaining the higher lamb production of the established Romney flock (Rae, 1967; BakerAg, 2019). Progeny born to Romney ewes (36 µm) bred with Merino rams (21 µm) produced wool with an approximate average fibre diameter of 28 µm in previous New Zealand studies (Dobbie *et al.*, 1985; Meikle *et al.*, 1988; Andrews *et al.*, 1995, 1998; Wuliji *et al.*, 1995; Scobie *et al.*, 2005; Muir and Thomson, 2013) and a second cross with Merino rams would produce lambs with an average fibre diameter that was again similar to the parental average, i.e. averaging 25 µm (Miekle *et al.*, 1988; Andrews *et al.*, 1995, 1998; Wuliji *et al.*, 1995). Combined, this indicates that within a few generations the average fibre diameter of an initially purebred Romney flock can be reduced through crossbreeding with Merino sires to increase wool income. Changes in sheep enterprise production and profit during such a breed transition period have not previously been quantified.

There is a lack of analyses examining the profitability of transitioning a sheep flock to a crossbred flock producing wool with a relatively lower average fibre diameter with potentially higher returns. Bio-economic models can simulate bio-physical farm elements and interactions with the economic component of the farm system (Bohan *et al.*, 2016; Chapter Three; Chapter Four), e.g. modelling changes to sheep enterprise operating profit as a result of changes in flock breed and production. Systems dynamics modelling is effective for modelling systems with numerous interconnected components and feedback processes (Walters *et al.*, 2016) such as those existing in a breeding flock that would determine numbers within each breed and age class during the breed transition period. The objective of this study was to simulate the transition period when using Merino sires with a Romney breeding flock to achieve a ¾ Merino ¼ Romney (¾M¼R) flock. The current study extends an existing bio-economic system-dynamics sheep farm model (from Chapter Three and Chapter Four) to quantify changes in sheep numbers, energy demand, and cashflow while determining potential strategies for selection intensity of Merino-Romney crossbred lambs and time taken to replace the base Romney flock with a ¾M¼R flock with approximately equivalent energy demand.

5.2 Methods

System dynamics modelling was used in the current analysis to capture flock dynamics and associated energy demand and production implications during the breed transition period. Recent research has revealed the efficacy of this approach in agricultural and livestock systems to test *ex ante* dynamic impacts of feedbacks from different scenarios and technical interventions (Hamza and Rich, 2015; Shane *et al.*, 2017; Lie *et al.*, 2018) including New Zealand pastoral farm systems (García, 2000). The model was constructed using STELLA version 1.9.3 (isee systems, 2017). Chapter Three used an earlier version of this model to explore changes in the productivity and operating profit of a ewe flock with varying rates of ewe wastage. The base model structure was reported in Chapter Three with the detail of each component model. This base model was then extended to include the option of producing lambs from different breed sires with ewe age class differentiated breeding strategies to investigate the use of terminal sires (Chapter Four). In the current study, the model has been further extended to include the option of crossbreeding to produce first (½ Merino ½ Romney; ½M½R) and second cross (¾M¼R) ewe flocks. In order to capture the impacts on wool fibre diameter of a Merino-Romney crossbreeding strategy under study, the wool production component model was extended to include prices for and production of wool with a range of fibre diameters and the effect of varying levels of lamb selection intensity on the average wool fibre diameter of the flock. The model workings are explained in the following subsections, with detail on the areas of difference from the base model in Chapter Three and Chapter Four.

5.2.1 Representative base farm with a Romney breed flock

The modelled farm (year zero of this analysis) was based on an average East Coast New Zealand North Island Hill Country sheep and beef farm using 2017/18 production year data (Beef + Lamb New Zealand Economic Service, 2019b). The farm was 530 ha with a self-replacing flock of 2,066 mature ewes lambing annually in spring and extensively grazing pasture year-round. Only the sheep operations of the farm were considered in this model; producing prime lambs and cull ewes for slaughter, store lambs to be finished on another farm, and coarse wool with > 30 µm fibre diameter. Sheep on an East Coast North Island Hill Country sheep and beef farm constitute the majority (i.e. 59.5% on average) of total farm stock units, the remaining being beef cattle and/or deer and/or non-lactating dairy cattle (see Section Error! Reference source not found.; B eef + Lamb New Zealand Economic Service, 2019b). A stock unit has been defined as the equivalent feed consumption of a 55 kg ewe weaning one 28 kg lamb, equal to 550 kg DM per year (DM = dry matter; Trafford and Trafford, 2011). Wintered stock units for each scenario included mature ewes (calculated based on ewe prolificacy and liveweight; Parker, 1998), replacement stock and those kept over winter, and rams.

5.2.2 Changes with Merino-Romney crossbred sheep

Published literature indicates that a Merino-Romney second cross flock, i.e. with 75% Merino genotypes (¾M¼R), would have the desired wool average fibre diameter in the 22-26 µm range that would increase wool value and be eligible for multi-year supply contracts through companies such as The New Zealand Merino Company (Wallace, 2018; The New Zealand Merino Company, n.d.). Figure 5.1 outlines the expected range of wool fibre diameter for sheep with varying levels of Merino genotypes in New Zealand Merino-Romney crossbred comparison studies. Further, Table 5.1 shows the published production parameters from Romney, ½M½R, and ¾M¼R flocks. These published values for Romney production from both industry and scientific data were used to inform the Romney production parameters. Studies comparing the production of purebred Romney sheep with Merino-Romney crossbreds were then used to adjust the Romney parameters and estimate Merino-Romney crossbred production based on the proportion of Merino genotypes. For example, a mature Romney ewe liveweight of 65 kg (Thomson *et al.*, 2004) was utilised and published comparisons showed first cross (½M½R) mature ewes on average were 7% lighter and second cross (¾M¼R) ewes a further 7% lighter (Dobbie *et al.*, 1985; Quirke *et al.*, 1987; Smith *et al.*, 1989). Therefore, mature ewe liveweights of 60 and 55 kg were used for ½M½R and ¾M¼R crossbred ewes in this study, respectively. For most production parameters there was a consistent change from Romney to ½M½R and ¾M¼R sheep (i.e. for liveweight, fleece weight, and post-weaning growth rate; Table 5.1). However, lamb weaning weight was found to be 11% lighter in ½M½R than purebred Romney lambs but only a further 3% lighter for ¾M¼R lambs (Meyer and Kirton, 1984; Dobbie *et al.*, 1985; Hinch, 1989; Montgomery *et al.*, 1989; Wuliji *et al.*, 1995; Everett-Hincks *et al.*, 1998; Scobie *et al.*, 2005; Muir and Thomson, 2013). Therefore, the Merino-Romney crossbred production parameters were adjusted accordingly based on the differences between individual parameters.

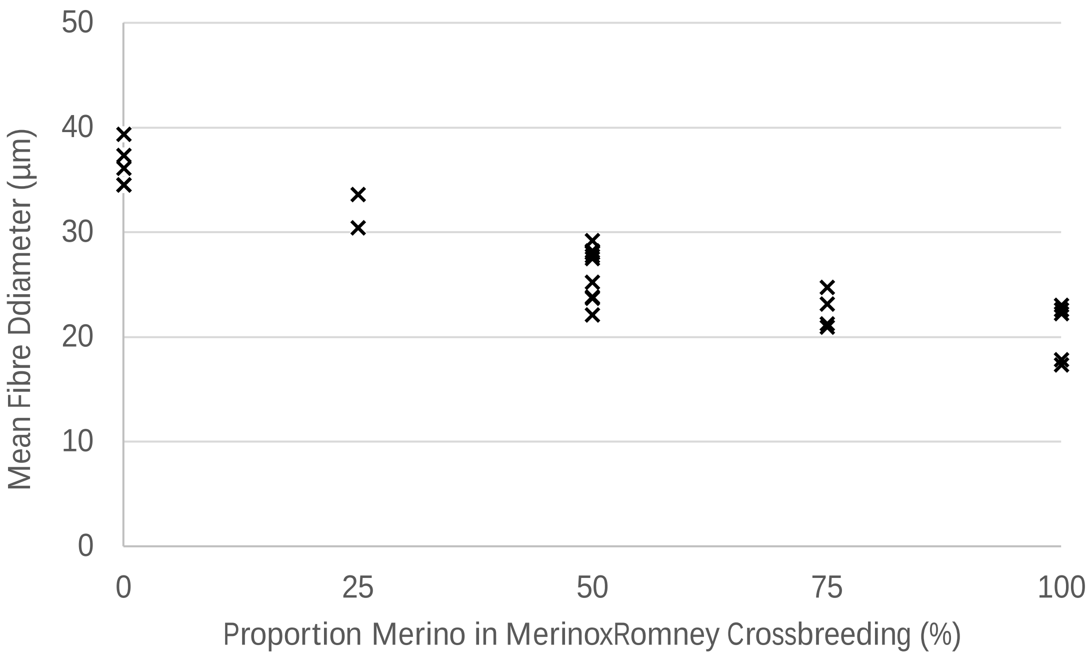
For some parameters, the comparison studies show no clear difference in the production of Romneys and Merino-Romney crossbred sheep (Table 5.1). This includes

Table 5.1: Production parameters for Romney, first cross (½ Merino ½ Romney), and second cross (¾ Merino ¼ Romney) flocks. Where published comparison studies of Merino-Romney crossbred sheep and their parental breeds were used to inform the change from Romney production values to ½M½R and ¾M¼R production.

Parameter	Romney		*½M½R*	*¾M¼R*	Comparison Romney vs. Merino-Romney Crossbred	
	Value	Reference	Value		Change (%)	Reference
Mature liveweight (kg)	65	Thomson *et al.*, 2004	60	55	-7	Dobbie *et al.*, 1985; Quirke *et al.*, 1987; Smith *et al.*, 1989
Lambing rate (%)*	132	Beef + Lamb New Zealand Economic Service, 2019b	132		0	Dobbie *et al.*, 1985; Quirke *et al.*, 1987; Everett-Hincks *et al.*, 1998; Scobie *et al.*, 2005
Mature greasy fleece weight (kg)	4.57	Beef + Lamb New Zealand Economic Service, 2019b	4.16	3.75	-9	Dobbie *et al.*, 1985; Meikle *et al.*, 1988; Wuliji *et al.*, 1995; Everett-Hincks *et al.*, 1998; Scobie *et al.*, 2005; Muir and Thomson, 2013
Birth weight - singles (kg)	5.5	Kenyon *et al.*, 2002a, b; Thomson *et al.*, 2004; Jenkinson *et al.*, 2007; Kenyon *et al.*, 2009; Kenyon *et al.*, 2011; Corner *et al.*, 2013	5.5		0	Hinch, 1989; Montgomery *et al.*, 1989
Birth weight - Multiples (kg)	4.5		4.5			
Weaning weight - singles (kg)	28	Kenyon *et al.*, 2002a, b; Thomson *et al.*, 2004; Kenyon *et al.*, 2009; Kenyon *et al.*, 2011 Corner *et al.*, 2013; Morris and Kenyon, 2014; Thompson *et al.*, 2016	25	24	-11 and	Meyer and Kirton, 1984; Dobbie *et al.*, 1985; Hinch, 1989; Montgomery *et al.*, 1989; Wuliji *et al.*, 1995; Everett-Hincks *et al.*, 1998; Scobie *et al.*, 2005; Muir and Thomson, 2013
Weaning weight - Multiples (kg)	26		23	23	-14	
Post-weaning growth - singles (g/day)	130	Kemp *et al.*, 2010; Golding *et al.*, 2011; Somasiri *et al.*, 2013	120	109	-8	Hinch, 1989; Everett-Hincks *et al.*, 1998; Scobie *et al.*, 2005
Post-weaning growth - multiples (g/day)	100		92	84		
Carcass dressing (%)	41	Purchas *et al.*, 2002; Shackelford *et al.*, 2005; Jenkinson *et al.*, 2007, Litherland *et al.*, 2010	41		0	Meyer and Kirton, 1984; Kirton *et al.*, 1995; Muir and Thompson, 2013
Fleece yield (%)	75.3	Wuliji and Dodds, 2011; Wuliji *et al.*, 2011; Scobie *et al.*, 2005	75.3		0	Wuliji *et al.*, 1995; Everett-Hincks *et al.*, 1998; Scobie *et al.*, 2005; Muir and Thomson, 2013

*Rate of lambs weaned per ewe presented for breeding.

Figure 5.1: Published values for wool average fibre diameter for sheep with varying proportion of Merino and Romney genotypes (Dobbie et al., 1985; Meikle et al., 1988; Andrews et al., 1995, 1998; Wuliji et al., 1995; Everett-Hincks et al., 1998; Scobie et al., 2005; Muir and Thomson, 2013).



carcass dressing percentage, where the comparison studies found similar values for Merino-Romney crossbred lambs therefore a value of 41% was used based on recent Romney data. Fleece yield was also similar across the Merino-Romney crossbred sheep and their purebred parent breeds, and an approximate median value of 75.3% was used for all animals. Lambing rates of the differing breeds showed no clear differences in the comparison studies and Romney flock average lambing rate of 1.32 lambs weaned per ewe presented for breeding was used for all flocks in part of this study (Table 5.1). However, it is unlikely that Merino-Romney crossbred ewes would maintain a lambing rate similar to the base Romney flock, therefore, lambing rate was also adjusted to a breed specific level in the modelled scenarios as described in Section 5.2.8.

5.2.3 Ewe flock dynamics

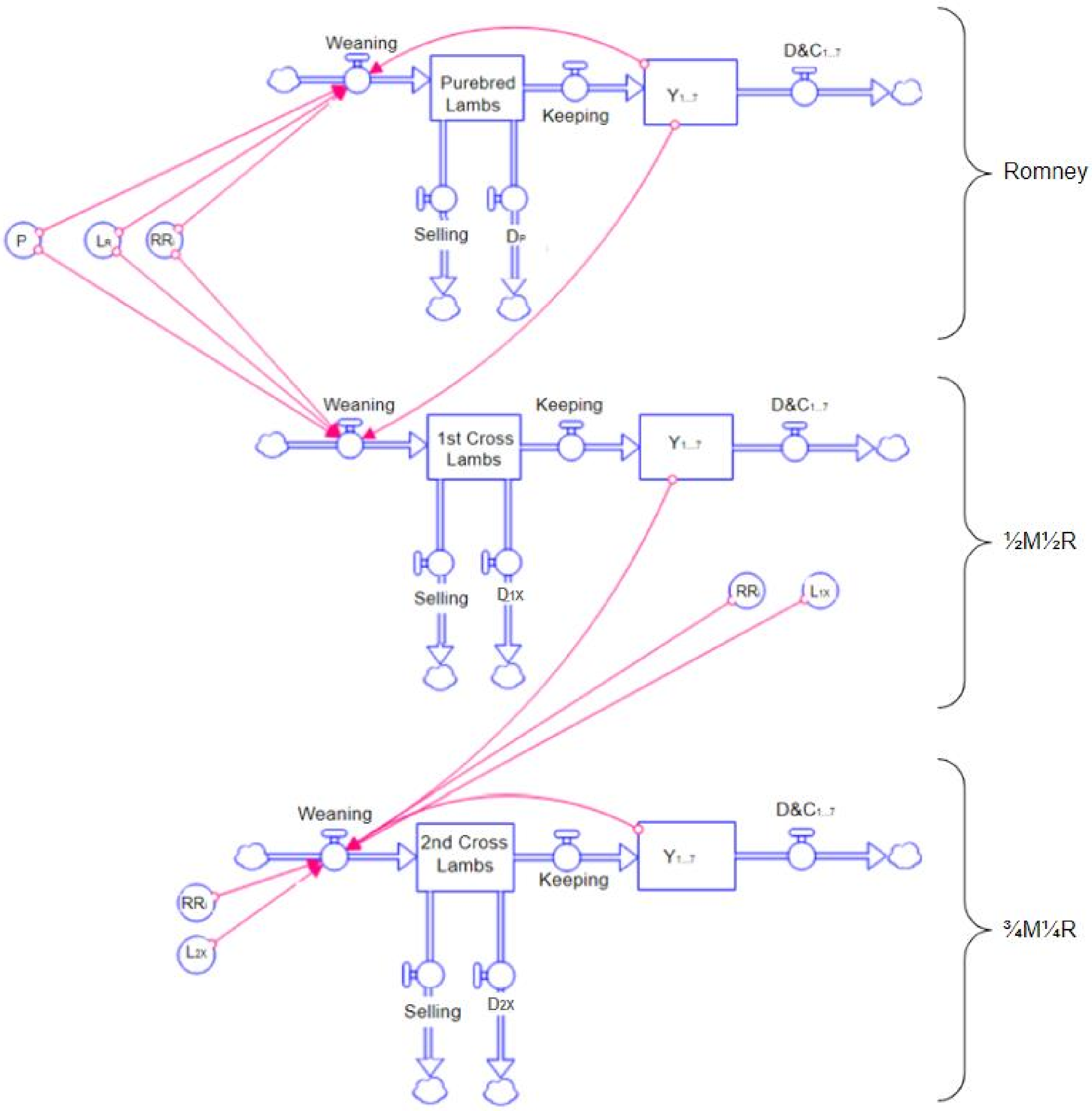
A simplified flow diagram of the flock dynamics component model is shown in Figure *5.2*, showing sheep movement between age classes, and entering and leaving each flock. The ewe flocks (Y) were each divided into seven age (i) classes (Y_i), starting with Y_1 (maiden ewes; Equation 5.1). All ewes from the previous age class (Y_{i-1}), except deaths (D_i) and cull ewes (C_i), moved into the next age class at lambing, i.e. ewes entering Y_1 were 12 months of age (Equation 5.2). Mature ewes ($Y_{2\text{-}7}$) began lambing annually on September 1 (Beef + Lamb New Zealand, 2018a).

$$Y = \sum_{i=1}^{7} Y_i \quad [5.1]$$

Where

$$Y_i = Y_{i-1} - D_{i-1} - C_{i-1} \quad [5.2]$$

Figure 5.2: Simplified diagram of flock dynamics module for crossbreeding of a ewe flock from purebred Romney to first (½M½R) and second cross (¾M¼R). Where numbers of lambs weaned of each type were a product of mature ewes in each age (i) class (Y_i), their relative reproductive rate (RR_i), lambing rate for each breed (L_x), the proportion of $Y_{1\ldots7}$ bred with maternal sires (P), selling of lambs, and deaths (D_i) and culling (C_i).



5.2.3.1 Romney flock

Before the breed transition scenarios were simulated, the model was run as a self-replacing Romney flock with all ewes bred with maternal sires to establish the base feed demand, production, and operating profit.

When the model was run with a self-replacing Romney flock, replacement ewe requirements (*R*) were the sum of all deaths (D_i) and culling (C_i) of $Y_{1\text{-}7}$ ewes to ensure a status quo size mature flock (Equation 5.3). Mature flock ewe deaths ($D_{2\text{-}7}$) and culling ($C_{2\text{-}7}$) were adjusted to reflect the flock replacement rate of 20.2% with a death:culling ratio of 26:74. Death rate (D_1) of ewes in Y_1 was D_1 1.9% (Beef + Lamb New Zealand Economic Service, 2019b), assuming ewes in this age class were not culled on reproductive performance for their first breeding and lambing.

$$R = \sum_{i=2}^{7}(D_i + C_i) \qquad [5.3]$$

All live Y_7 ewes were culled after their sixth or seventh lambing (depending on if their first lambing was as Y_1 or Y_2 ewes) at weaning. On New Zealand sheep farms the majority of ewe deaths occur at or around lambing due to lambing difficulty or dystocia, metabolic disease, or pneumonia (Quinlivan and Martin, 1971; Davis, 1974; Tarbotton and Webby, 1999). Therefore, in this model all ewe deaths were assumed to occur at lambing and 20% of ewe culling in $Y_{2\text{–}7}$ occurred at pregnancy scanning, the remaining ewe culling was assumed to occur at weaning, as in Chapter Three and Chapter Four.

Numbers of lambs weaned (*LM*) were estimated from Equation 5.4 as a function of ewes presented for breeding (Y_i), *LR* (lambing rate as lambs weaned per ewe presented for breeding), and *P* (proportion of ewes bred with a Merino sire, when modelling the self-replacing Romney flock $P = 0$), and, relative reproductive performance for each ewe age class (RR_i; $RR_2 = 0.85$, $RR_3 = 0.97$, $RR_4 = 1.04$, $RR_5 = 1.09$, $RR_6 = 1.06$, and $RR_7 = 0.99$; Turner *et al.*, 1968; Hight and Jury, 1970; Dickerson and Glimp, 1975; Thomson *et al.*, 2004). In New Zealand ewe flocks, approximately 32%, of eight to nine months old ewes are presented to the ram, and these have an average lambing rate of 65% (Statistics New Zealand, 2018), in this study $RR_1 = 0.24$ to match survey data for North Island East Coast Hill Country farms (Beef + Lamb New Zealand Economic Service, 2019b). Maiden ewes (Y_1) in the Romney flock were bred to lamb after the mature ewes at approximately 14 months of age (Cranston *et al.*, 2017).

Lambing rate (*LR*) in the current study was lambs weaned per ewe presented for breeding. The number of lambs born as singles and twins depended on whole flock reproductive performance (Amer *et al.*, 1999).

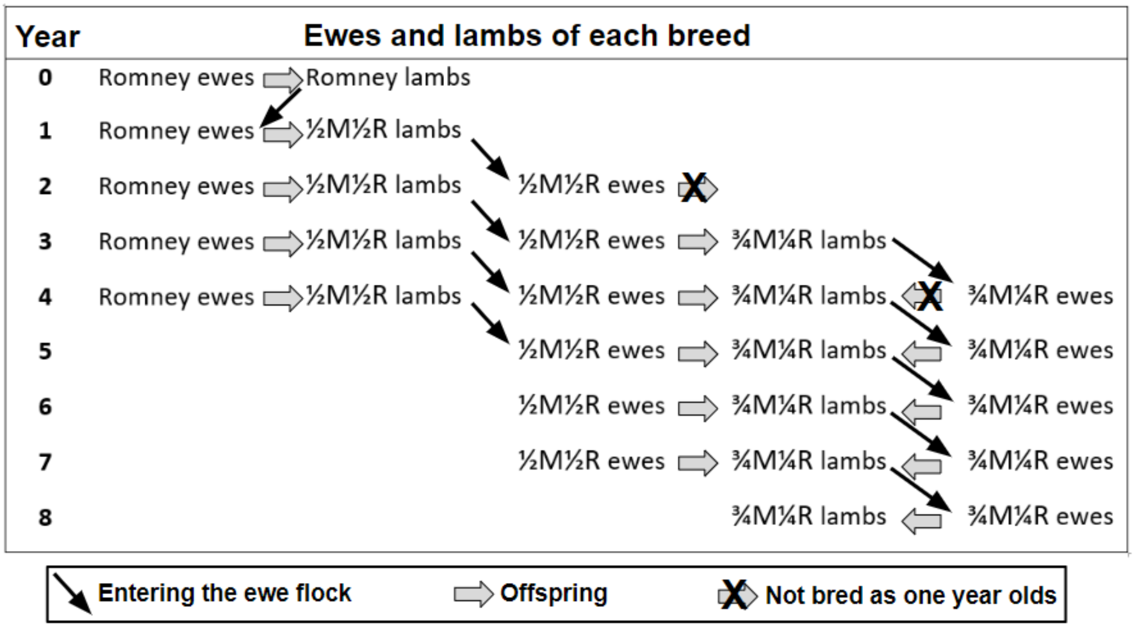
$$LM = \sum_{i=1}^{7}[Y_i \times LR \times RR_i \times (P-1)] + \sum_{i=1}^{7}[Y_i \times LR \times RR_i \times P] \qquad [5.4]$$

5.2.3.2 Crossbred flocks

To breed the Merino-Romney crossbred flocks the proportion of Romney ewes bred with Merino sires P = 1 (Equation 5.4). Therefore, all lambs produced were ½M½R (Figures 5.2 and 5.3). The resulting ½M½R ewes were bred with Merino rams producing ¾M¼R offspring. Romney Y_1 ewes were bred to lamb for the first time at 14 months of age, however, ½M½R and ¾M¼R crossbred ewes were not presented for breeding prior to Y_1 due to their lower predicted liveweight resulting in them not being suitable for mating. Numbers of ewe lambs entering Y_1 of the ½M½R and ¾M¼R flocks were determined by the number of ewe lambs remaining after two selection events ($Sort_w$ at weaning and $Sort_{10}$ at around ten months of age) for which selection intensity is discussed in Section 5.2.8. All ram lambs were sold prime prior to winter. $Sort_w$ was assumed to occur at weaning, where any ewe lambs that were visually identified with conformation issues (i.e. 24% or 35% in this study) were culled for subsequent sale as prime lambs. It was assumed that ewe lambs were not selected at $Sort_w$ stage according to wool fibre diameter characteristics, therefore, selection intensity was assumed not to affect the wool fibre diameter of remaining ewe lambs post- $Sort_w$. $Sort_{10}$ was assumed to occur at ten months of age when the remaining ewe lambs were shorn and wool samples sent for testing and those with the lowest wool fibre diameter retained. Ewe lambs not retained after selection at $Sort_{10}$ were sold prime at ten months of age.

Movement of $Y_{1\text{-}7}$ ewes between age classes as they aged was the same as in the Romney flock (Equation 5.2). The death rate of ½M½R and the ¾M¼R $Y_{2\text{-}7}$ ewes was 5.2% and Y_1 ewes 2% based on average farm survey values (Beef + Lamb New Zealand Economic Service, 2019b). It was assumed that the culling rate for crossbred ewe flocks was low in order to increase ewe numbers in the ¾M¼R crossbred flock, therefore the current study assumed only barren ewes were culled, assumed to be 4% of ewes (Kelly, 1980). Death and culling rates of Romney ewes were maintained at the pre-crossbreeding level until all remaining Romney ewes were culled either six or seven years after the start of breed transition depending on lamb selection intensity at $Sort_w$ and $Sort_{10}$. All remaining ½M½R ewes were subsequently culled two years after the last of the Romney ewes had been culled. After this time point only ¾M¼R ewes remained on farm and were assumed to be bred with a ¾M¼R sire with a similar average fibre diameter to the adult ewe flock in order to maintain the wool fibre diameter achieved at the end of the breed transition period.

Figure 5.3 : Simplified diagram of production of Romney and Merino-Romney crossbred lambs and lambs entering the ewe flocks (Y_{1-7}) each year from the start of breed transition, where the transition from Romney to ½ Merino ½ Romney (½M½R) and then to ¾ Merino ¼ Romney (¾M¼R) flock took seven years of crossbreeding.



5.2.4 Wool production

For the base Romney flock, all wool was assumed to be coarse wool type (averaging 36 µm) for which prices are flat across the range of fibre diameters above 33 µm (Carrfields Primary Wool, 2019), therefore micron variation was ignored. All Romney lambs on-farm in January were assumed to be shorn. Total flock wool production (*WP*) was estimated using average mature greasy fleece weight (*W* in kg; Table 5.1) and an adjustment parameter (w_i in kg) for wool production for each age class (Equation 5.5;

$w_{0.5}$ = -3.5, w_1 = -1.8, w_2 = -0.09, w_3 = 0.42, w_4 = 0.28, w_5 = 0.05, w_6 = -0.14, and w_7 = -0.5; Brown *et al.,* 1966; McLaughlin 1973; Rose 1974).

$$WP = \sum_{i=0.5}^{7} Y_i \times (W + w_i) \quad [5.5]$$

5.2.4.1 Wool production of Merino-Romney crossbred lambs and ewes

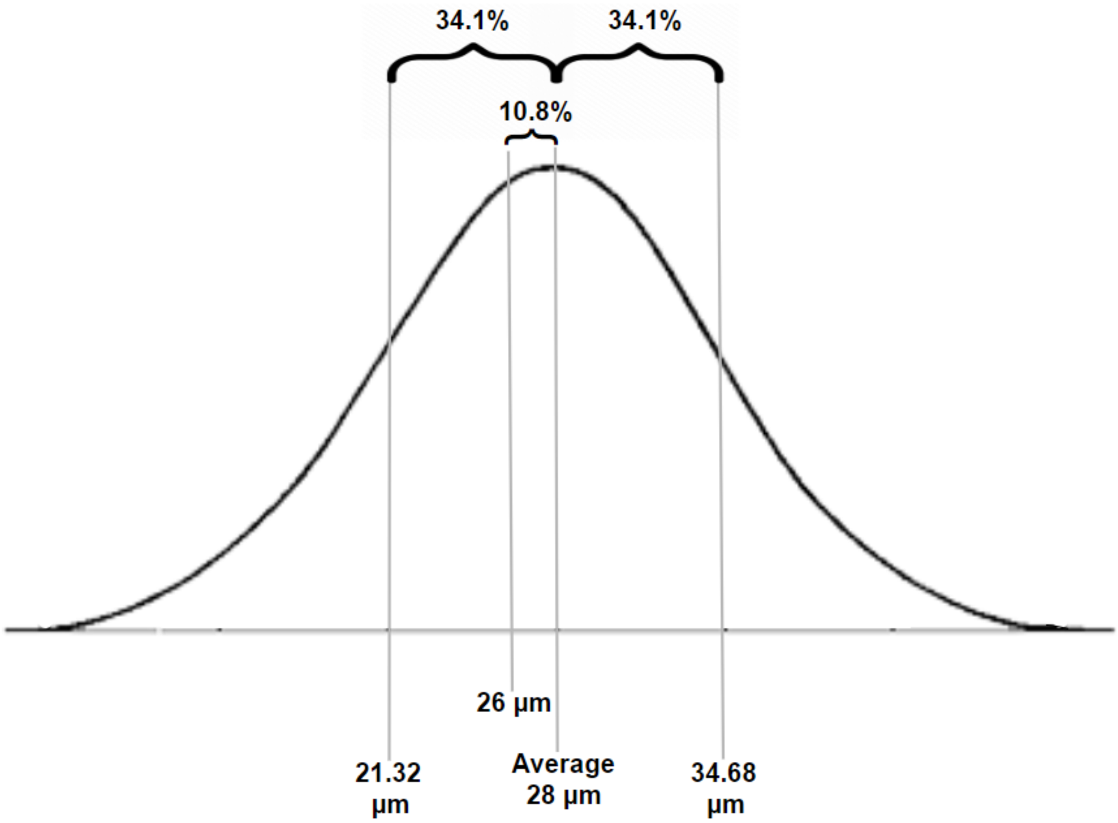
Published values for the fibre diameter of ½M½R lambs born to Romney (36 µm) ewes and Merino (21 µm) sires suggest an average fibre diameter of 28 µm with a standard deviation of 6.86 µm pre-$Sort_{10}$ (Figure 5.1). Published values for the fibre diameter of ¾M¼R crossbred lambs born to ½M½R ewes (e.g. 28 µm) and Merino rams (21 µm) suggest an average fibre diameter of lambs pre-$Sort_{10}$ similar to the parental average (e.g. 25 µm) and coefficient of variation of 25% (e.g. a standard deviation of 6.25 µm; Figure 5.1). As ¾M¼R lambs were bred from the ½M½R flock, the mature ¾M¼R ewe flock average fibre diameter was affected by ewe lamb selection intensity at $Sort_{10}$ events for both crossbred flocks. Average fibre diameter of the mature Merino-Romney sheep flocks was also influenced by the average age of the ewe flock. Fibre diameter varied with age for Merino-Romney crossbred flocks using an adjustment parameter (f_i in µm) for each age class (f_1 = 1.02, f_2 = 1.10, f_3 = 1.12, w_4 = 1.13, f_5 = 1.12, f_6 = 1.11, and f_7 = 1.10; Brown *et al.*, 1966; Turner *et al.*, 1968; Ponzoni *et al.*, 1995; Sumner *et al.*, 2001; Hatcher *et al.*, 2005; Thompson *et al.*, 2011). Wool fibre diameter for each age class (FD_i) was a product of the fibre diameter of ewe lambs post $Sort_{10}$ ($f_{0.5}$) and the adjustment parameter (f_i) as shown in Equation 5.6. For all Merino-Romney crossbred ewes in Y_{1-7} Equations 5.5 and 5.6 were used to calculate the production of wool of the appropriate fibre diameter of each age class of the mature flock, incorporating changes in flock wool production and fibre diameter with changing flock age structure.

$$FD_i = FD_{0.5} \times f_i \quad [5.6]$$

Merino-Romney crossbred ewe lambs were assumed not to be shorn until the wool testing prior to $Sort_{10}$, due to the lighter fleece weights and associated short fleece length. Therefore, the wool production of Merino-Romney crossbred lambs sold prime between $Sort_w$ and $Sort_{10}$ were not included in the sheep enterprise wool production and income of this analysis. Distribution of fibre diameter within crossbred ewe lambs after $Sort_w$ but prior to wool testing and selection for fibre diameter at $Sort_{10}$, was assumed to be normal. The normal distribution of fibre diameter, along with the mean and standard deviation, of the ewe lambs shorn prior to $Sort_{10}$ was used to estimate the production of wool of various fibre diameters from ten-month-old ewe lambs. In the model the proportion of wool within bands of two micron was sold for the same price. For example, wool from ten-month-old ½M½R ewe lambs pre-$Sort_{10}$ was assumed to be normally distributed with an average fibre diameter of 28 µm and standard deviation of 6.68 µm as shown in Figure 5.4. Therefore, wool with a fibre diameter of 26 µm to 28 µm accounted for 10.8% of wool shorn and this wool was sold for the 27 µm price. All ½M½R wool with a fibre diameter below 22 µm (six µm below average) was sold together. All ten-month-old ¾M¼R lambs' wool with a fibre diameter of more than eight µm greater than the mean was sold together for the coarse wool price. ¾M¼R lambs' wool with a fibre diameter of six µm lower than mean was sold together for the price appropriate for wool with a fibre diameter of six µm less than the mean. Wool of several fibre diameters were sold in groups in order to achieve the minimum bale size of 100 kg of greasy wool (New Zealand Wool Classers Association, 2016).

The normal distribution of wool fibre diameter in ewe lambs pre-$Sort_{10}$, as shown in Figure 5.4 for ½M½R lambs, was used to determine the change in mean fibre diameter after selection for wool fibre diameter at $Sort_{10}$. The cut-off point for ewe lambs with the coarsest wool culled post-$Sort_{10}$ was estimated according to the selection intensity (proportion of lambs culled) and the Z-score (number of standard deviations from the mean) corresponding to that proportion of area under the normal distribution curve. Ewe lambs producing wool with the highest fibre diameter (coarsest wool), i.e. the right-hand tail end of the distribution (Figure 5.4), were subsequently sold, shifting the mean fibre diameter to the left. The same protocol for determining the new mean fibre diameter post-$Sort_{10}$ was also used for ¾M¼R ewe lambs, for whom the pre-$Sort_{10}$ mean and standard deviation of fibre diameter were influenced by the mean fibre diameter of the dam (mature ½M½R flock and then the mature ¾M¼R flock) and ram. Merino rams with a fibre diameter of 21 µm were bred with ½M½R ewes. Rams producing wool with a similar fibre diameter to the ¾M¼R ewes were bred with ¾M¼R ewes to maintain wool fibre diameter.

Figure 5.4: Distribution of wool fibre diameter of ten month old ½ Merino ½ Romney lambs prior to selection. Mean and standard deviation from published values for New Zealand ½ Merino ½ Romney sheep (Meikle et al., 1988; Wuliji et al., 1995; Andrews et al., 1998; Scobie et al., 2005; Muir and Thomson, 2013).



5.2.4.2 Wool quality traits (excluding fibre diameter)

Published values for fleece staple length and yellowness (Y – Z) of Merino-Romney crossbred sheep in New Zealand ranged from 79.2 to 112 mm and 0.4 to 5.5, respectively (Dobbie *et al.*, 1985; Meikle *et al.*, 1988; Wuliji *et al.*, 1995; Everett-Hincks *et al.*, 1998; Muir and Thompson, 2013). These were within the range of staple lengths and yellowness values which would not receive a price discount (Cottle, 2010). Price penalties exist for very tender wool with a strength of less than 21 N/ktex (Newtons per kilotex; Cottle, 2010). New Zealand Merino-Romney crossbred sheep have been found to have sufficient strength, i.e. ¾M¼R sheep had a mean fibre strength of 32 N/ktex (Wuliji *et al.*, 1995). No published literature on the vegetable matter content of New Zealand Merino-Romney crossbred sheep fleece was found. The current study assumed there were no price discounts for wool quality characteristics aside from fibre diameter. Therefore, wool prices were estimated according to fibre diameter only.

5.2.5 Merino-Romney crossbred health issues in the North Island

In the available data, Merino and Merino-Romney crossbred sheep farmed in the North Island have not had health issues that were significantly different to Romney ewes or that negatively affected production. Including parasite burdens (Everett-Hincks *et al.*, 1998), flystrike (Muir and Thomson, 2013) and footrot (Dobbie *et al.*, 1985; Muir and Thomson, 2013). Farmers considering Merino-Romney crossbreeding could use Merino rams that have been selected for footrot resistance to mitigate the potential health issue (The New Zealand Merino Company, 2019a). The current study assumed animal health costs per stock unit for the Merino-Romney crossbred sheep did not differ from the industry averages for the Romney flock (Section 5.2.7.2).

5.2.6 Sheep energy demand

Total sheep energy demand was based on the number of sheep in each stock class and their respective individual energy demands in megajoules of metabolisable energy (MJ ME) according to production levels, and equations from CSIRO (2007) and Nicol and Brookes (2007). These calculations did not differ from those described in Chapter Three and Chapter Four. Energy demand for maintenance, liveweight change, pregnancy, lactation, and wool production was calculated. Sheep demand for daily maintenance energy (ME_m) were calculated from Equation 5.7 (CSIRO, 2007).

$$ME_m = \left[0.28 \times \frac{LW^{0.75} \times e^{-0.03 \times i}}{0.02 \times Q + 0.5}\right] \times 1.1 \qquad [5.7]$$

Where LW = liveweight (kg) and Q = pasture quality measured as MJ ME/kg DM and assumed to be 10 MJ ME/kg DM, considered a medium quality of pasture on New Zealand sheep and beef farms (Waghorn *et al.*, 2007). Mature ewe ($Y_{2\text{-}7}$) average liveweight varied according to breed as shown in Table 5.1, losing 2 kg in spring during lactation which was regained prior to autumn breeding. Liveweight of replacement ewes was assumed to average 70% of mature ewe liveweight when entering Y_1 at twelve months of age (Thomson *et al.*, 2004). Liveweight values used to calculate maintenance demand for sheep younger than Y_2 were averages for that class of animal. For example, single-born purebred Romney prime lambs were weaned at 28 kg (Table 5.1) and sold for slaughter at 43.6 kg liveweight, hence demand for maintenance between weaning and slaughter was based on an average liveweight of 35.8 kg. Energy demand for liveweight gain was 55 MJ ME required for each kg of liveweight gain, and 35 MJ ME converted from each kg of liveweight loss (Nicol and Brookes, 2007).

Energy demand for gestation (ME_G) and lactation (ME_L) were calculated per lamb according to Equations 5.8 and 5.9 (Nicol and Brookes, 2007). The average New Zealand lamb loss rate (from scanning to weaning) of 16% (Dalton *et al.*, 1980; Amer *et al.*, 1999; Beef + Lamb New Zealand, 2013) was used alongside lambing rate to estimate numbers of lamb foetuses for gestation requirement calculations. Lambs from $Y_{2\text{-}7}$ ewes were weaned at twelve weeks of age with average birth weights, weaning weights, and growth rates for purebred and crossbred lambs shown in Table 5.1. Energy demand for gestation of lambs from maiden Romney ewes was calculated with those for purebred lambs from $Y_{2\text{-}7}$, where lambs from maiden ewes accounted for approximately 5% of total lambs weaned from the status-quo base Romney flock. Lambs from maiden ewes were weaned at ten weeks of age at 23 kg liveweight (Beef + Lamb New Zealand, 2018b).

$$ME_G = 49 \times b + 7 \qquad [5.8]$$

and

$$ME_L = N \times [51.4 \times L + 134.7 \times \alpha - 1808] \qquad [5.9]$$

Where b was lamb birthweight (Table 5.1), N was the adjustment parameter for birth rank (N = 1 for single-born lambs and N = 1.35 for multiples), L = lamb liveweight at weaning (kg; Table 5.1), and α = lamb age at weaning in weeks.

Average annual wool production per ewe was used to calculate flock daily wool growth (G) in g/sheep/day adjusted from greasy fleece weight (Table 5.1). Energy demand for wool growth (ME_W) was estimated using the wool growth equation from CSIRO (2007) (Equation 5.10).

$$ME_w = 0.13 \times (G - 6) \qquad [5.10]$$

5.2.7 Economics

All economic values for this study were in New Zealand Dollars ($NZD; at 31st January 2020 $NZD 1 = $USD 0.65 = €EUR 0.59; xe.com). Production, prices, and expenses were used to calculate the sheep enterprise cash operating surplus (COS). COS was used as an indicator of sheep enterprise profit and included cash income of the farm minus cash operating expenses. In order to estimate sheep enterprise COS (COS_{Sheep}) on a per hectare basis, the area used in the calculation was adjusted according to changes in sheep feed requirements which changed the proportion of total farm feed consumed by sheep, i.e. when sheep feed requirements decreased the area over which the COS was spread was reduced accordingly. Industry survey data for New Zealand North Island Hill Country farms in the 2017/18 production year indicate that the average COS per ha of the sheep and cattle (COS_{Beef}) enterprises were approximately $390/ha and $280/ha, respectively (Beef + Lamb New Zealand Economic Service, 2019b). Therefore, changes in the sheep area of the farm adjusted the total sheep and beef COS to account for the effect of changes in the size of the beef cattle enterprise (Equation 5.11).

$$Total\ COS = Feed_{Sheep} \times COS_{Sheep} + (1 - Feed_{Sheep}) \times COS_{Beef} \qquad [5.11]$$

Where $Feed_{Sheep}$ was the proportion ($0 \leq Feed_{Sheep} \leq 1$) of total farm feed (Error! Reference source not found.) consumed by sheep (i.e. 59.5% for the base Romney flock; Beef + Lamb New Zealand Economic Service, 2019b).

5.2.7.1 Sheep enterprise income

The sheep enterprise income for the base Romney flock was calculated from production and average 2017/18 prices for wool (including wool from Romney lambs and Merino-Romney crossbred lambs on-farm after $Sort_W$) and sheep sales. Sale prices for store lambs and cull ewes were taken from the North Island East Coast Hill Country 2017/18 survey data (Beef + Lamb New Zealand Economic Service, 2019b) and prime lamb sale prices from weekly published schedule prices, a weighted average lamb price (per kg carcass weight) from lamb sales across the North Island (Table 5.2; Inventas Media, 2019). Romney lambs were sold in three groups, the timing of sales of prime lambs depended on average growth rates for single- and multiple-born lambs (Table 5.1). For this farm type, 65.40% of Romney lambs available for sale were sold prime and these were sold with a carcass weight of 17.87 kg (Beef + Lamb New Zealand Economic Service, 2019b). The remaining Romney lambs were assumed to have had slower growth and were sold store in early May with a liveweight of 32 kg, lighter than lambs usually sold prime in New Zealand (Inventas Media, 2019). Sheep sale timings and prices are shown in Table 5.2, with the majority of cull ewes (including two year olds) culled in December at weaning.

The Merino-Romney crossbred ram and ewe lambs available for sale post-$Sort_w$ were all sold prime when the target carcass weight of 17.87 kg was achieved according to their growth rates, therefore lamb birth rank and the resulting growth rate dictated their time of sale with the same schedule price data used for all prime lambs (Table 5.2). The Merino-Romney lambs sold prior to winter were all sold prime as the crossbred ewe flocks' lower energy requirements (due to their lower liveweight compared with Romney ewes) allowed more feed to be used for lamb growth. Prices for Merino-Romney culls, including ten-month-old ewe lambs sold after $Sort_{10}$, were adjusted from the industry survey average prices for Romney ewes according to their lower liveweight (Beef + Lamb New Zealand Economic Service, 2019b). Production parameters in Table 5.1 show the ½M½R and ¾M¼R crossbred ewes as 7% and 14% lighter than Romney ewes, respectively. For example, for cull ewes in Y_{3-7} the Romney price of $113.73 per head was adjusted to $105.77 per head for ½M½R crossbred ewes and to $98.37 per head for ¾M¼R crossbred ewes (Table 5.2). This price adjustment was validated through comparison of industry average prices in 2017/18 for ewe culls in the North Island Hill Country farming Romney ewes (e.g. $113.73 per head for mature cull Romney ewes) and South Island High Country farming Merino ewes (e.g. $105.85 per head for mature cull Merino ewes; Beef + Lamb New Zealand Economic Service, 2019b).

5.2.7.1.1 Wool prices

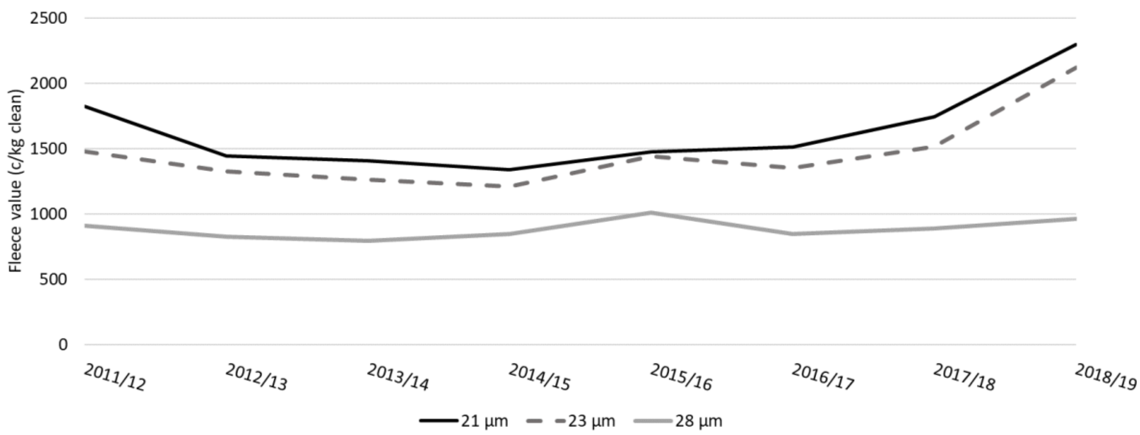
Real annual average values of New Zealand clean mid-micron and fine wool since 2011 are shown in Figure 5.5 (The New Zealand Merino Company, 2019b). Five-year averages from the 2014/15 to 2018/19 production years in this data were used as a basis for mid-micron and fine wool prices used in this study.

Table 5.2: Sheep sale prices used in model for Romney, ½ Merino ½ Romney, and ¾ Merino ¼ Romney flocks.

Breed	Sheep type	Timing	Price*	
Romney	First sale prime lambs	Late-December	\$5.70 / kg	Inventas Media, 2019
	Second sale prime lambs	Early-February	\$6.00 / kg	
	Store lambs	Early-May	\$99.44 / head	Beef + Lamb New Zealand Economic Service, 2019b
	Cull ewes < 3yo	December	\$134.64 / head	
	Mature cull ewes		\$113.73 / head	
½M½R	First sale prime lambs	Mid-January	\$6.06 / kg	Inventas Media, 2019
	Second sale prime lambs	Mid-March	\$6.13 / kg	
	Cull ewes < 3yo	December	\$125.22 / head	Beef + Lamb New Zealand Economic Service, 2019b
	Mature cull ewes		\$105.77 / head	
¾M¼R	First sale prime lambs	Mid-February	\$6.00 / kg	Inventas Media, 2019
	Second sale prime lambs	Start of May	\$6.31 / kg	
	Cull ewes < 3yo	December	\$116.45 / head	Beef + Lamb New Zealand Economic Service, 2019b
	Mature cull ewes		\$98.37 / head	

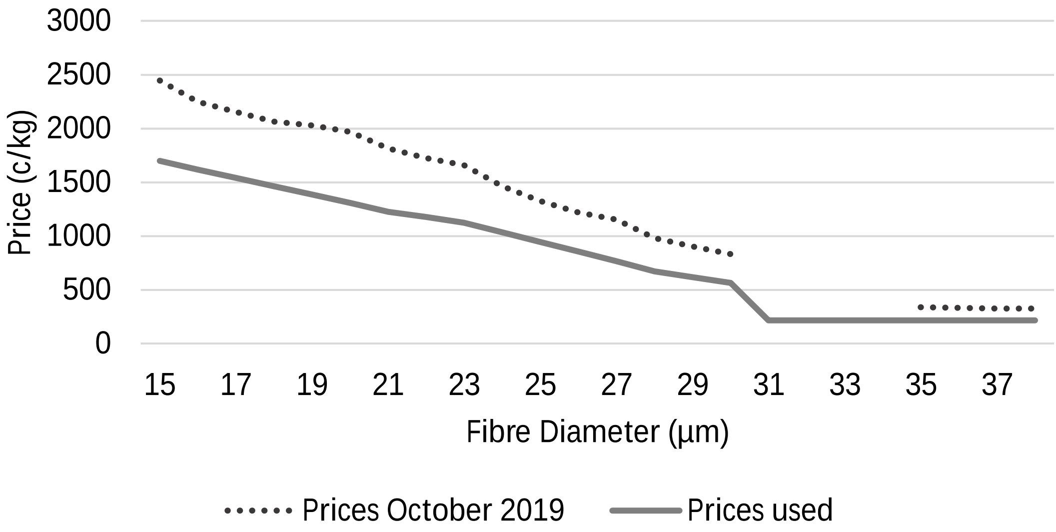
*prime lamb prices on per kg of carcass weight basis.

Figure 5.5: Real value for New Zealand wool of varying fibre diameter from 2011 to 2019 (The New Zealand Merino Company, 2019b).



Nominal clean prices for New Zealand wool of a range of fibre diameters in October 2019 are shown in Figure 5.6 (Carrfields Primary Wool, 2019) demonstrating the correlation between price and fibre diameter. Clean wool price and fibre diameter had a correlation coefficient of 0.993 up to 30 µm, with price reductions of $1.07 per kg for each 1 µm increase in fibre diameter until 30 µm. Above this diameter the price per kg was flat at approximately $3.25 per kg clean fleece.

Figure 5.6: Nominal prices for clean New Zealand wool of varying fibre diameter sold in October 2019 (Carrfields Primary Wool, 2019) and prices for greasy wool used in this analysis. Prices used were calculated from five year average real values (The New Zealand Merino Company, 2019b), correlation between price and micron (Carrfields Primary Wool, 2019), post-scouring fleece yield (Scobie et al., 2005; Wuliji and Dodds, 2011; Wuliji et al., 2011), proportion of fleece as skirtings (Cottle, 2010), and price discount of skirtings (The New Zealand Merino Company, 2019b).



The current study used five-year average wool prices from Figure 5.5 for the fibre diameters shown (21, 23, and 28 µm). The relationship between fibre diameter and price displayed in Figure 5.6 was then used to calculate prices for the remaining fibre diameters. The resulting prices were adjusted with 25% of the fleece as skirtings (Cottle, 2010), worth 10.7% less than the main fleece price (The New Zealand Merino Company, 2019b). The fleece yield from Table 5.1 of 75.3% was used to calculate price per kg of greasy wool for all breeds. For example, to calculate the price for one kg of greasy wool with a fibre diameter of 20 µm, the five-year average real value of clean wool with a fibre diameter of 21 µm ($16.73 per kg) was increased by $1.07 per kg to $17.81 per kg for 20 µm clean fleece. The price deduction for skirtings was applied, where 25% of the fleece received 89.3% of the main fleece price, and the resulting price was then adjusted by 75.3% to estimate pre-scouring (greasy) value of $13.05 per kg (Equation 5.12).

$$[17.81 \times 0.75 + 17.81 \times 0.25 \times 0.893] \times 0.753 = \$13.05\ /kg \qquad [5.12]$$

Wool price variation with fibre diameter used in the current study is shown in Figure 5.6. Wool production for ewes in each age class of the Merino-Romney crossbred $Y_{1\text{-}7}$ ewe flocks was calculated using Equation 5.5 and the fibre diameter using Equation 5.6 to determine wool income. Wool from the Romney flock was sold for the 2017/18 industry average price of $2.15 per kg greasy, which includes price discounts for skirtings (Beef + Lamb New Zealand Economic Service, 2019b).

5.2.7.2 Sheep enterprise expenses

Expenses were average values from industry survey data calculated on a per sheep stock unit basis (Beef + Lamb New Zealand Economic Service, 2019b; Table 5.3). Expenses were comprised of variable costs and the enterprise share of fixed costs (including costs of repairs and maintenance, vehicles, administration, ACC, and insurance) while excluding drawings, tax, interest, depreciation, and rent (Shadbolt and Martin, 2005). The cost of testing the fleeces of Merino-Romney lambs for wool fibre diameter prior to $Sort_{10}$ was based on the current industry price per fleece (New Zealand Wool Testing Authority Ltd, 2019). Operating expenses were consistent across breed types and were calculated on a per wintered stock unit basis (stock units are explained in Section 5.2.1), with wintered stock units including $Y_{1\text{-}7}$ ewes, lambs kept on farm prior to $Sort_{10}$ and those that remained on-farm afterwards, and rams that were on-farm at a ratio of one ram per one hundred ewes. Although shearing costs per kg of fleece are generally higher for Merino sheep, on a per stock unit and annual basis the industry survey data suggested they are similar to Romney (Beef + Lamb New Zealand Economic Service, 2019b). Dead sheep were disposed of on-farm which did not incur an additional cost. Breeding costs were included in the operating expenses and it was assumed that the price of Merino and Merino-Romney crossbred rams did not differ from Romney rams and the costs of annual ram purchases per sheep stock unit did not differ between ewe flock breeds.

Table 5.3: Sheep enterprise expenses

Breed	Expense*	Value ($ / stock unit)
All	Operating	47.79
	Shearing costs	9.00
	Animal health costs	6.00
Merino-Romney crossbred	Wool testing	$2.25 per fleece

*Operating, shearing, and animal health expenses were based on industry farm survey data per sheep stock unit (stock unit; Beef + Lamb New Zealand Economic Service, 2019b) except for the wool testing data which was based on numbers of ten month old Merino-Romney crossbred lambs (New Zealand Wool Testing Authority Ltd, 2019).

5.2.7.3 Net present value

In order to compare breed transition scenarios as alternative options for investment, a net present value (NPV) analysis was undertaken using Equation 5.13 from Robison and Barry (1996). The NPVs capture the time value of cashflow during the breed transition period, accounting for the timing of peak and low COS which differs between breed transition scenarios modelled. The NPV analysis was estimated for each breed transition scenario and the base Romney flock for twelve years which included the total time taken for the ¾M¼R flock of ewes in Y_{1-7} to reach desired size. Changes in numbers of ewes in each age class of the ¾M¼R flock occurred up until approximately thirty years from the beginning of bred transition, affecting flock productivity. Therefore, a NPV analysis was also conducted for a thirty-year period.

$$NPV = \sum_{T=1}^{12\ or\ 30} \frac{Total\ COS_t}{(1+r)^t} \qquad [5.13]$$

Where *Total COS* for the sheep and beef enterprises was calculated annually from Equation 5.11, T = each year during the breed transition period of twelve years or each year during and post-breed transition up to thirty years, and r was the discount rate for which both a rate of 10% to reflect long-term New Zealand business lending interest rates (Reserve Bank of New Zealand, 2020) and 6% to reflect current lower interest rates, i.e. 2017/18 (ASB, 2020), were used. Economic values in this analysis were all in real 2017/18 terms and the discount rates represented the real opportunity costs for farmers investing in the breed change strategies investigated.

5.2.8 Parameters varied in analysis

Analysis was performed with the lambing rates of the Merino-Romney crossbred ewes at two levels. The first level had the lambing rate of Merino-Romney crossbred ewes consistent with the Romney lambing rate of 132% (Beef + Lamb New Zealand Economic Service, 2019b) due to the lack of clear difference in the reproductive performance of Romney and Merino-Romney crossbred ewes in previous comparison studies (Table 5.1). However, the comparison studies provided relatively little data on the reproductive performance of Merino-Romney crossbred ewes compared with their parent breeds. Therefore, Merino-Romney crossbred lambing rates were varied in this analysis, with the crossbred flock lambing rates adjusted to be breed specific according to industry data. Merino and Romney purebred ewes generally exhibit differing lambing rates on commercial farms in New Zealand, with farm survey average lambing rates for the 2017/18 production year of 132% and 109% for Romney and Merino purebred ewe flocks, respectively (Beef + Lamb New Zealand Economic Service, 2019b). Therefore, Merino-Romney crossbred flock lambing rates were adjusted to 120% and 114% for the ½M½R and ¾M¼R crossbred flocks, respectively, as well as maintained at 132% in different modelled scenarios. In the results and discussion section of this paper these differing lambing rates are referred to as 'consistent' (i.e. 132% for all flocks) and 'breed specific' (132% for the Romney flock vs. 120% for the ½M½R flock vs. 114% for the ¾M¼R flock) lambing rates.

As well as adjusting the Merino-Romney crossbred ewe lambing rates, ewe lamb selection intensity at $Sort_w$ and $Sort_{10}$ was varied to explore the feasible levels for the breed transition scenarios modelled according to the time taken for the breed transition and resulting fibre diameter of the ¾M¼R crossbred flock. Selection intensity for ½M½R and ¾M¼R crossbred ewe lambs at $Sort_w$ and $Sort_{10}$ was consistent between the Merino-Romney crossbred flocks and selection events. Therefore, the selection intensity was effectively applied twice to each population of Merino-Romney crossbred ewe lambs. For illustration, from 1,000 weaned ¾M¼R ewe lambs, the low lamb selection intensity used in this analysis where 24% of ewe lambs were not selected would have 760 ewe lambs remaining on-farm over winter after $Sort_w$ and 577 ewe lambs would enter Y_1 of the ¾M¼R flock after $Sort_{10}$ (i.e. 24% of 760 ewe lambs not selected). From 1,000 weaned Merino-Romney crossbred ewe lambs, with the high lamb selection intensity (35% of ewe lambs not retained at each selection event) 423 ewe lambs would enter Y_1 of the ¾M¼R flock. The model was run until the ¾M¼R flock of $Y_{1\text{-}7}$ reached more than 2,500 ewes with a feed demand similar to that of the base purebred Romney flock in year zero (which took either seven or ten years of breed transition depending on selection intensity, i.e. ¾M¼R flock reached desired size eight or eleven years after transition start). The maximum feasible selection intensity was 35%, determined by the ¾M¼R crossbred flock achieving the desired size of more than 2,500 ewes in $Y_{1\text{-}7}$ after ten years of breed transition. The minimum feasible selection intensity was 24%, limited by the mean fibre diameter of the ¾M¼R crossbred flock once desired size was achieved. The desired mean fibre diameter of the ¾M¼R crossbred flock ($Y_{1\text{-}7}$) was ≤ 26 µm congruous with the upper range of fibre diameters reported in previous studies (Figure 5.1) and currently eligible for multi-year supply contracts (Wallace, 2018). The lamb selection intensity levels applied in the current analysis at each selection event for Merino-Romney crossbred ewe lambs were 24% and 35%.

5.2.9 The ¾M¼R crossbred flock at status quo flock size

Once the ¾M¼R crossbred flock reached more than 2,500 ewes the flock was modelled as status quo size, with replacement ewe lamb requirements calculated based on ewes in $Y_{1\text{-}7}$ age classes leaving the flock according to Equation 5.3, and $Y_{1\text{-}7}$ death and culling rates from Section 5.2.3.2 were maintained. Simulation of the status quo ¾M¼R crossbred flock was performed for each of the combinations of lambing rate and lamb selection intensity in the analysis.

5.3 Results and discussion

In all scenarios desired flock size (DFS), of at least 2,500, ¾M¼R ewes across Y_{1-7} producing wool with a fibre diameter of ≤ 26 µm and with an annual energy demand similar to that of the base Romney flock was achieved after a maximum of ten years of breed transition. Changes in sheep numbers, wool fibre diameter, sheep energy demand, lamb and wool production, sheep enterprise COS, and farm cash flow during the breed transition period are discussed in the following subsections. 'Merino-Romney crossbred' refers to both ½M½R and ¾M¼R sheep. Results are presented for thirty years from the beginning of breed transition, as ewe numbers in each age class of the ¾M¼R flock fluctuated due to flock dynamics until this time, after which time numbers were relatively stable (i.e. changed by up to ± 5% between years).

5.3.1 Wool fibre diameter

Lamb selection intensity was a greater influence on the mean fibre diameter of wool produced by the ¾M¼R flock at the DFS than lambing rate (Table 5.4). Fibre diameter of ½M½R ewe lambs pre-$Sort_{10}$ was assumed to be the same for all scenarios with lamb selection intensity determining the new mean fibre diameter post-$Sort_{10}$. This new mean fibre diameter carried through to the mature ½M½R flock from which the ¾M¼R lambs were bred. Low selection intensity (24% of crossbred ewe lambs not retained at each selection event) applied to all Merino-Romney crossbred ewe lambs resulted in a ¾M¼R flock mean fibre diameter of 25.7 µm and 26 µm after seven years of breed transition for consistent and breed specific lambing rates, respectively, which was a minor difference. High lamb selection intensity (35% of crossbred ewe lambs not retained at each selection event) achieved wool with a mean fibre diameter of 24 µm and 24.7 µm after ten years of transition for consistent and breed specific lambing rates, respectively, again only a small difference. The current study has demonstrated 24 µm to potentially be the lowest mean fibre diameter of the ¾M¼R flock achievable after ten years of breed transition from a Romney flock bred with Merino rams with a wool fibre diameter of 21 µm, when a consistent lamb selection intensity was applied at $Sort_w$ and $Sort_{10}$. A ¾M¼R flock producing wool with a mean fibre diameter of less than 24 µm may be achievable within a similar time period with sale of fewer Merino-Romney crossbred lambs after $Sort_w$ allowing greater selection for wool fibre diameter at $Sort_{10}$. However, this would require retention of more lambs over winter and would likely increase sheep energy demand, reducing feed available for other stock classes on-farm. This research assumed Merino rams with a mean wool fibre diameter of 21 µm were bred with Romney and ½M½R flocks, but the mean fibre diameter of wool from Merino sheep can be as low as 15 µm (Carrfields Primary Wool, 2019). Rams producing wool with fibre diameter lower than 21 µm could be used to decrease flock fibre diameter beyond the reductions estimated in this study and to further increase wool value. However, there may be associated reductions in lamb and wool production which would need to be considered.

5.3.2 Sheep numbers

Lamb selection intensity (low vs. high) at $Sort_w$ and $Sort_{10}$ had a greater effect on time taken to reach the DFS than lambing rate (Figure 5.7). Selection intensity was applied to all Merino-Romney crossbred lambs during the breed transition period of up to ten years. With lower selection intensity (i.e. more lambs retained after the two selection events) the DFS was achieved after seven years of breed transition compared with ten years of breed transition for the higher selection intensity (Figure 5.7). Total Y_{1-7} ewe numbers of all breeds peaked in the year prior to culling of the ½M½R flock, i.e. either year seven or eight depending on selection intensity. With lower lamb selection intensity, the entire Romney and ½M½R flocks could be culled earlier, leaving only ¾M¼R ewes on-farm, and the ¾M¼R DFS still achieved three years sooner than scenarios with higher selection intensity.

The model maintained the ¾M¼R flock size once the DFS was achieved. DFS ranged from 2,620 to 2,837 ¾M¼R ewes and was greater with lower crossbred ewe lamb selection intensity and consistent lambing rate, where greater numbers of ¾M¼R ewe lambs were available to enter the flock post-$Sort_{10}$. Once the DFS was achieved and ewe numbers in each age class remained relatively stable, flock average age was similar to the base Romney flock (4.13 years; Table 5.5) and replacement rate for the ¾M¼R flock was approximately 18%.

During breed transition there were up to seven different groups of sheep to be managed separately at shearing and breeding. For example, in year four there were Romney ewes, ½M½R lambs, ½M½R ewes, ¾M¼R lambs, and ¾M¼R ewes on-farm (Figure 5.3) as well as Merino and ¾M¼R rams. Some groups were small, such as the

Table 5.4: Wool fibre diameter (µm; mean with standard deviation where appropriate) during a breed transition from Romney to Merino-Romney crossbred for scenarios with differing lamb selection intensity (selected at weaning and selected according to wool fibre diameter at around ten months of age) and lambing rate.

Scenario*	½ Merino ½ Romney			¾ Merino ¼ Romney		
	Pre- $Sort_{10}$	Post- $Sort_{10}$	Mature flock	Pre- $Sort_{10}$	Post- $Sort_{10}$	Mature ewes
Low selection and consistent lambing rate	28.5 ± 6.9	26.2	30.0	24.8 ± 6.2	22.7	25.7
Low selection and breed specific lambing rate	28.5 ± 6.9	25.9	30.3	25.9 ± 6.3	22.6	26.0
High selection and consistent lambing rate	28.5 ± 6.9	25.3	29.0	24.1 ± 6.0	21.4	24.0
High selection and breed specific lambing rate	28.5 ± 6.9	25.5	29.0	24.3 ± 6.1	21.6	24.7

*Where low selection intensity was 24% of crossbred ewe lambs not retained at each selection event, high selection intensity was 35% of crossbred ewe lambs not retained, consistent lamb rate was 132% for all flocks, and breed specific lambing rate was 132% for Romney, 120% for ½ Merino ½ Romney, and 114% for ¾ Merino ¼ Romney flocks. $Sort_{10}$ = Ewe lambs selected for wool fibre diameter at ten months of age.

Figure 5.7: Flock size (ewes aged Y1-7) for each breed of flock (Romney, ½ Merino ½ Romney, and ¾ Merino ¼ Romney) during breed transition with a). low lamb selection (24% of Merino-Romney crossbred ewe lambs not retained at each selection event) and consistent lambing rate for all flocks (132%), b). low lamb selection and breed specific lambing rate between breeds (132% for Romney, 120% for ½M½R, and 114% for ¾M¼ flocks), c). high lamb selection (35% of Merino-Romney crossbred ewe lambs not retained at each selection event) and consistent lambing rate for all flocks, and d). high lamb selection and breed specific lambing rate between breeds. ↓ Where breed transition has finished and the ¾M¼R flock has reached the desired flock size.

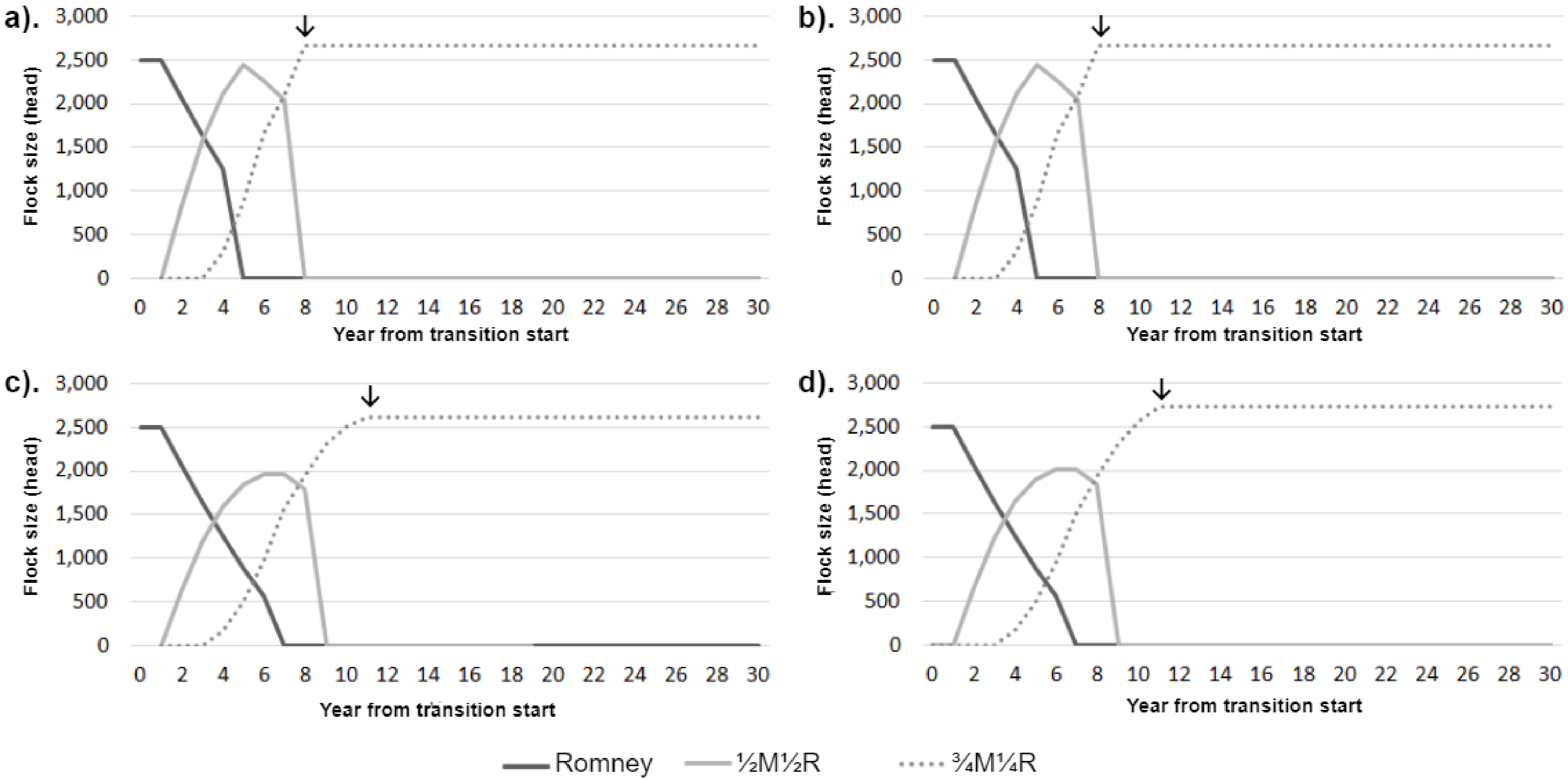


Table 5.5: Flock average age at key time points (T0 = Zero years since transition start) during breed transition scenarios from Romney to ¾ Merino ¼ Romney. Romney flock average age prior to the breed transition (T0) and when all ewes were culled (T4 or T6), ½ Merino ½ Romney average age when all ewes were culled (T7 or T8), and ¾M¼R average age once the desired flock size was achieved (T8 or T11).

Scenario*	Flock average age (years)						
	Romney			½M½R		¾M¼R	
	T0	T4	T6	T7	T8	T8	T11
Low selection and consistent lambing rate	4.13	5.19		4.24		3.20	
Low selection and breed specific lambing rate	4.13	5.19		4.61		3.16	
High selection and consistent lambing rate	4.13		6.00		4.73		4.15
High selection and breed specific lambing rate	4.13		6.00		4.73		4.08

*Where low selection intensity was 24% of crossbred ewe lambs not retained, high selection intensity was 35% of crossbred ewe lambs not retained at each selection event, consistent lamb rate was 132% for all flocks, and breed specific lambing rate was 132% for Romney, 120% for ½M½R, and 114% for ¾M¼ flocks.

approximately 500 older Romney ewes prior to flock culling (Figure 5.7). Management of numerous small groups of sheep may be operationally challenging when applying breed change strategies on commercial farms and needs to be considered when decisions are being made for breed transition planning.

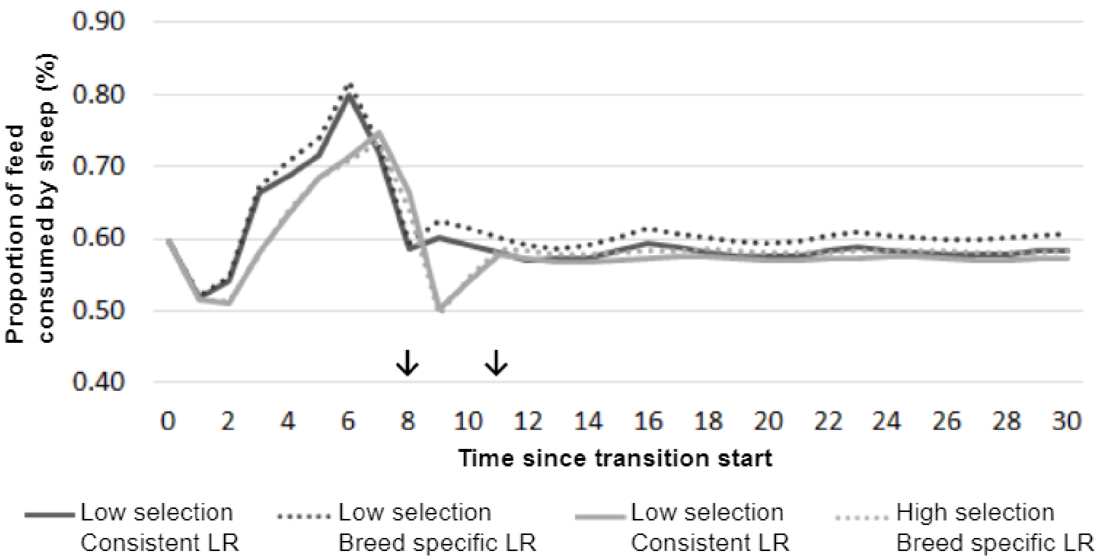
5.3.2.1 Ewe flock age

The base status quo Romney flock had a flock average age of 4.13 years in year zero (Table 5.5). Romney ewes leaving the flock due to death and culling were not replaced during the breed transition so average age of remaining Romney ewes increased to more than five years, i.e. 5.19 or 6.00 years, until the Romney flock was culled completely during years four or six. Timing of Romney and ½M½R flock culling was later with high lamb selection intensity (35% of crossbred ewe lambs not retained at each selection event; Figure 5.7). Age of ½M½R ewes at flock culling was therefore higher, at 4.73 years with high selection (35% of crossbred ewe lambs not retained at each selection event), compared with scenarios with low selection intensity (24% of crossbred ewe lambs not retained at each selection event) where ½M½R flock average age at culling was either 4.24 or 4.61 years depending on lambing rate (Table 5.5). Average age of the ½M½R flock was influenced by numbers of Y_1 ewes entering the flock, which were greater with lower lamb selection intensity and consistent lambing rate, reducing average age. The ¾M¼R flock average age at DFS was higher where selection intensity was higher with three additional years of breed transition resulting in more ewes in older age classes. In scenarios with high lamb selection intensity, there were ¾M¼R ewes in Y_7 when the DFS was achieved, and flock average ages were 4.15 and 4.08 years with consistent and breed specific lambing rates, respectively. However, for the scenarios with low lamb selection intensity, desired flock size was achieved earlier when ¾M¼R ewes had not yet aged into the Y_7 age class and the flock was therefore younger.

5.3.3 Energy demand

Energy demand of Merino-Romney crossbred mature ewes was lower than Romney ewes (e.g. daily mature ewe maintenance requirement of 10.3 MJ ME and 8.5 MJ ME for the 65 kg Romney and 55 kg ¾M¼R ewes, respectively). The base Romney flock had 2,490 ewes while the ¾M¼R flock DFS was more than 2,500 ewes total (2,620 to 2,837 ewes in Y_{1-7}; Figure 5.7). Approximately one third of Romney lambs were sold store in year zero (Beef + Lamb New Zealand Economic Service, 2019b). In comparison, all Merino-Romney crossbred lambs could be kept on-farm longer and sold prime due to the lower ewe flock energy demand compared with the heavier Romney ewes. The proportion of total farm feed consumed by sheep for the ¾M¼R flock once the DFS was achieved was similar to that of the base Romney flock (Figure 5.8). Peak total ewe numbers occurred in the year prior to ½M½R flock culling (where all ½M½R ewes remaining on-farm were culled) where the proportion of feed consumed by sheep also peaked at up to 82% of feed. The increased feed demand during breed transition demonstrates the impact changes in sheep numbers will have on whole-farm operations. The beef cattle herd consumed 40% of farm feed initially, this may increase to consume 51% of feed in year two and then reduce in feed consumption and herd size, potentially to 18% in year six. In the current analysis, selection intensity for Merino-Romney crossbred lambs and sale of all Merino-Romney crossbred lambs prime were consistent during transition. When undertaking a similar breed change strategy, farmers may implement more flexible inter-year lamb selection and sale policies, e.g. selling some Merino-Romney crossbred lambs earlier as store lambs in year six in order to mitigate the high sheep energy demand. Flexible lamb selection and sale policies may also be required to adapt to seasonal changes in feed supply.

Figure 5.8: Proportion of annual total farm feed supply (29.7 million MJ ME) consumed by sheep during a breed transition period for scenarios with differing Merino-Romney crossbred lamb selection intensity and lambing rate (LR), where the remaining feed was assumed to be consumed by beef cattle.



↓ Where breed transition has finished and the ¾ Merino ¼ Romney flock has reached desired flock size after either seven (low selection) or ten (high selection) years of transition. Where low selection intensity was 24% of crossbred ewe lambs not retained at each selection event, high selection intensity was 35% of crossbred ewe lambs not retained, consistent lamb rate was 132% for all flocks, and breed specific lambing rate was 132% for Romney, 120% for ½M½R, and 114% for ¾M¼ flocks.

In pastoral farming systems grazing intensity is varied across a production year to manage pasture composition and quality (Matthews *et al.*, 1999). Beef cattle on North Island Hill Country farms contribute to this grazing management, often grazing pasture subsequent to a higher priority stock class, such as growing lambs. This practice enables lambs to consume the high-quality pasture components and beef cattle then reduce post-grazing pasture covers to desired levels to best maintain pasture quality (Kenyon and Webby, 2007). It can therefore be assumed that reductions in the size of the beef cattle herd during transition to as low as consuming 18% of feed would have implications for pasture quality which may affect production (Figure 5.8). This was not included in the model and farmers may wish to take it into consideration when planning a similar breed transition.

Lamb selection intensity (24% vs. 35% of crossbred ewe lambs not retained at each selection event) had a greater effect on energy demand than lambing rate (consistently 132% across all breeds or breed specific/reduced for Merino-Romney crossbred flocks; Figure 5.8). Scenarios with lower lamb selection intensity generally had greater energy demand during transition with fewer lambs sold post-$Sort_w$ and therefore more lambs retained over winter until wool testing, with greater energy demand for their maintenance and growth. Lower lamb selection intensity (more crossbred ewe lambs retained) also enabled the Merino-Romney crossbred ewe flock size to grow at a faster rate, with greater energy demand compared with the higher lamb selection intensity in equivalent years during breed transition.

5.3.4 Wool and lamb production

Average mature fleece weight was 4.57 kg for Romney ewes and 3.75 kg for ¾M¼R ewes (Table 5.1). Therefore, despite up to 347 more ewes in the ¾M¼R flock at DFS, the base Romney flock produced 4.3 to 5.0 tonnes more wool (Figures 5.9 and 5.10).

Peak numbers of weaned lambs coincided with peak ewe numbers in year seven or eight of breed transition with up to 5,155 lambs weaned in those years (Figures 5.9 and 5.10). More lambs were weaned from the ¾M¼R flock at DFS in scenarios with higher lamb selection intensity. For example, with a consistent lambing rate (132%) there were 2,478 and 2,935 lambs weaned from the flock at DFS with low and high lamb selection intensity, respectively. The ¾M¼R ewe flock was older with high lamb selection intensity when the DFS was achieved later (Table 5.5), with an associated higher reproductive performance as age specific relative reproduction rate of ewes peaked in Y_5 (Section 5.2.3). Lamb selection intensity also influenced numbers of Merino-Romney crossbred lambs sold (all sold prime) during breed transition with higher selection intensity (fewer Merino-Romney crossbred ewe lambs retained) resulting in more lambs sold (Figure 5.10). For breed transition scenarios with consistent lambing rate, numbers of weaned lambs from the ¾M¼R flock at DFS were similar to the base Romney flock, while fewer lambs were weaned from the ¾M¼R flock at DFS with breed specific (and lower) lambing rate.

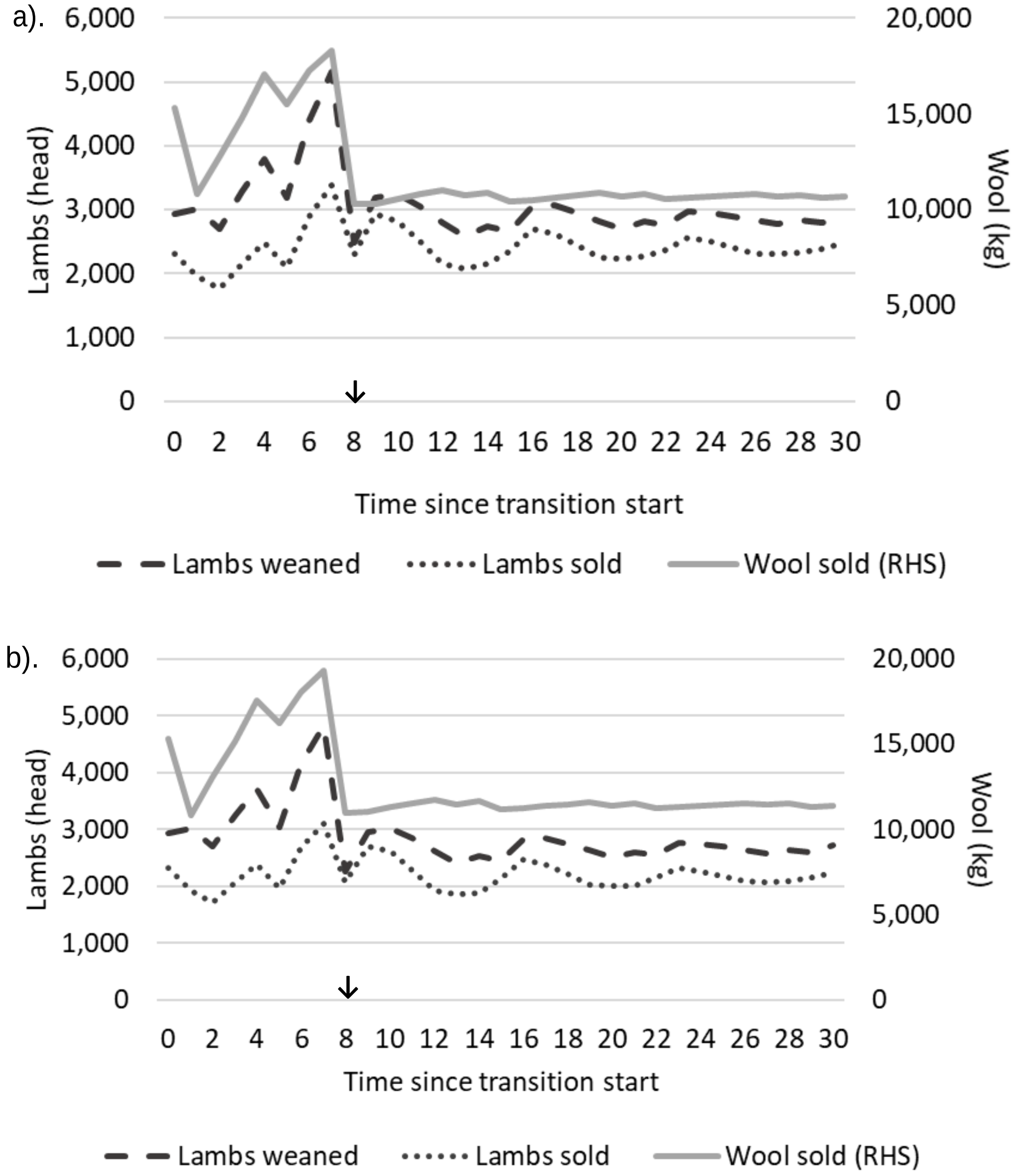
5.3.5 Profitability and cash flow of breed transition

Overall, production of wool with a lower fibre diameter by the ¾M¼R flock once the DFS was achieved, increased sheep enterprise income and sheep enterprise COS per ha compared with the base Romney flock. However, all breed transition strategies had lower cashflow than the base Romney flock during several years in the transition period (Figures 5.11 and 5.12), affecting the overall economic benefit of the breed change strategies modelled.

5.3.5.1 Base Romney flock vs. ¾M¼R flock at DFS

Wool income made up 11% of sheep enterprise income for the base Romney flock, within the range of industry averages for New Zealand coarse wool producers, and rose to 26% - 29% of income once ¾M¼R the DFS was achieved, similar to the range for farms in New Zealand South Island Hill Country farming Merino flocks producing fine wool (Beef + Lamb New Zealand Economic Service, 2019b; Figures 5.11 and 5.12). Wool income approximately tripled for the ¾M¼R flock at DFS compared with the base Romney flock, with an approximate fourfold increase in the value of wool on a per kg basis combined with an 18% reduction in mature greasy fleece weight of ewes (Table 5.1). The proportion of income from wool sales was greater for the flock at DFS in scenarios in which lambing rate was breed specific (and lower than the Romney flock) for ¾M¼R ewes as fewer lambs were produced and sheep sale income was lower than for the base Romney flock (Figures 5.11 and 5.12). Wool income was greater for the ¾M¼R flock at DFS with higher lamb selection intensity (35% of crossbred ewe lambs not retained at each selection event) as wool fibre diameter was lower (Table 5.4) and in this analysis, wool with a fibre diameter of 24 µm was valued at $1.79 per kg greasy more than wool with a fibre diameter of 26 µm (Figure 5.6). North Island Hill Country farmers currently derive the majority of gross income from sale of animals for meat, e.g. on average 46% and 39% from sheep and beef sales, respectively in 2017/18, while wool sales have accounted for a decreasing proportion of income, i.e. 12% in 2010/11 and 5% in 2017/18 (Beef + Lamb New Zealand Economic Service, 2019b). Increases in wool value and income from breed change strategies such as those examined in the current study would diversify farm income.

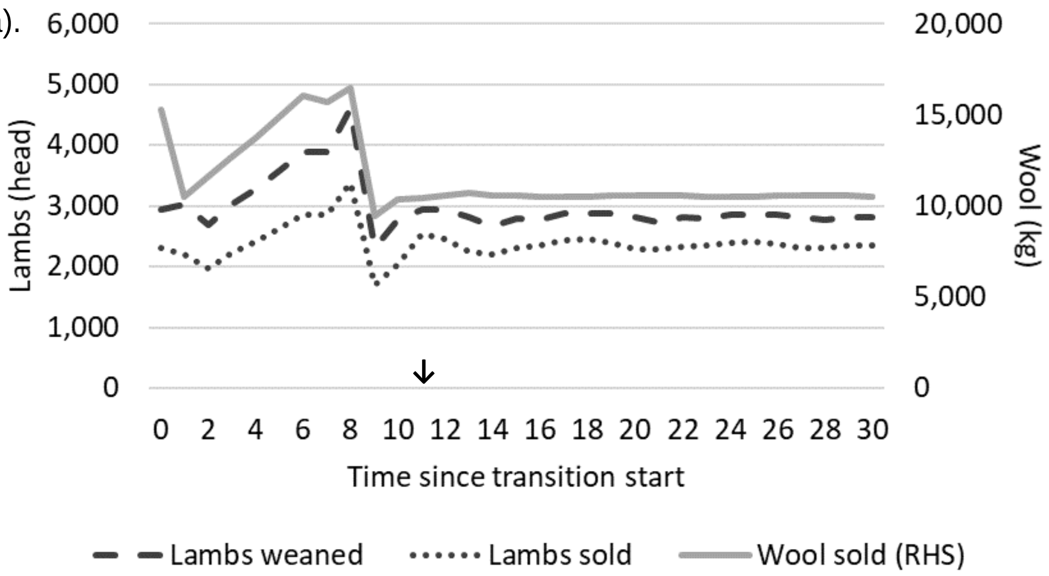
Figure 5.9: Lambs weaned, youngstock sold after selection at weaning and after selection at ten months of age, and wool sold each year during a breed transition period with low lamb selection intensity (24% of crossbred ewe lambs not retained at each selection event) and a). consistent lambing rate of 132% for all breeds, or b). breed specific lambing rate (lower for Merino-Romney crossbred flocks).



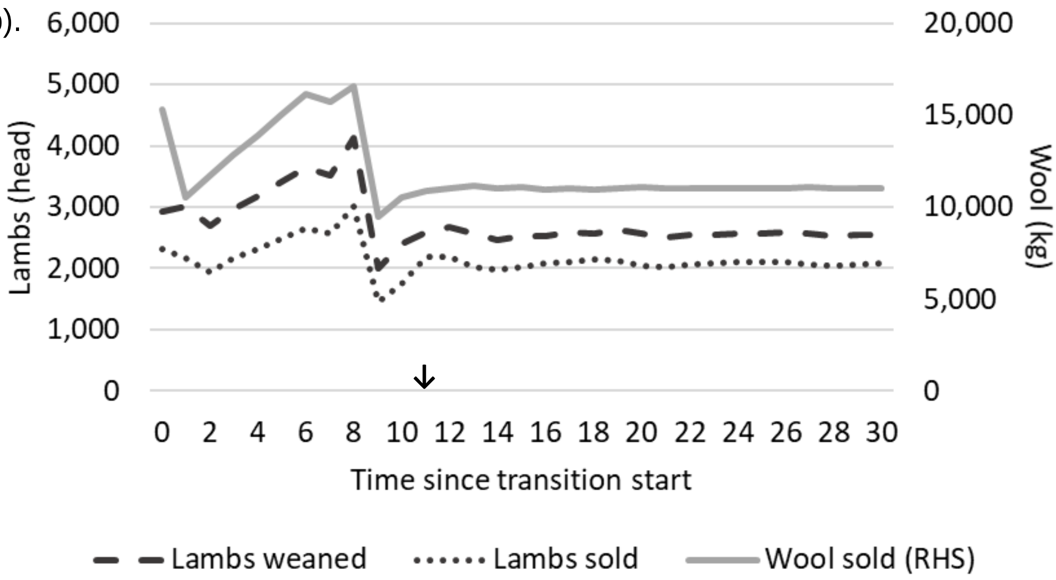
↓ Where breed transition has finished and the ¾ Merino ¼ Romney flock has reached desired flock size.

Figure 5.10: Lambs weaned, youngstock sold after selection at weaning and after selection at ten months of age, and wool sold each year during a breed transition period with high lamb selection (35% of crossbred ewe lambs not retained at each selection event) and a). consistent lambing rate of 132% for all breeds, or b). breed specific lambing rate (lower for Merino-Romney crossbred flocks).

a).



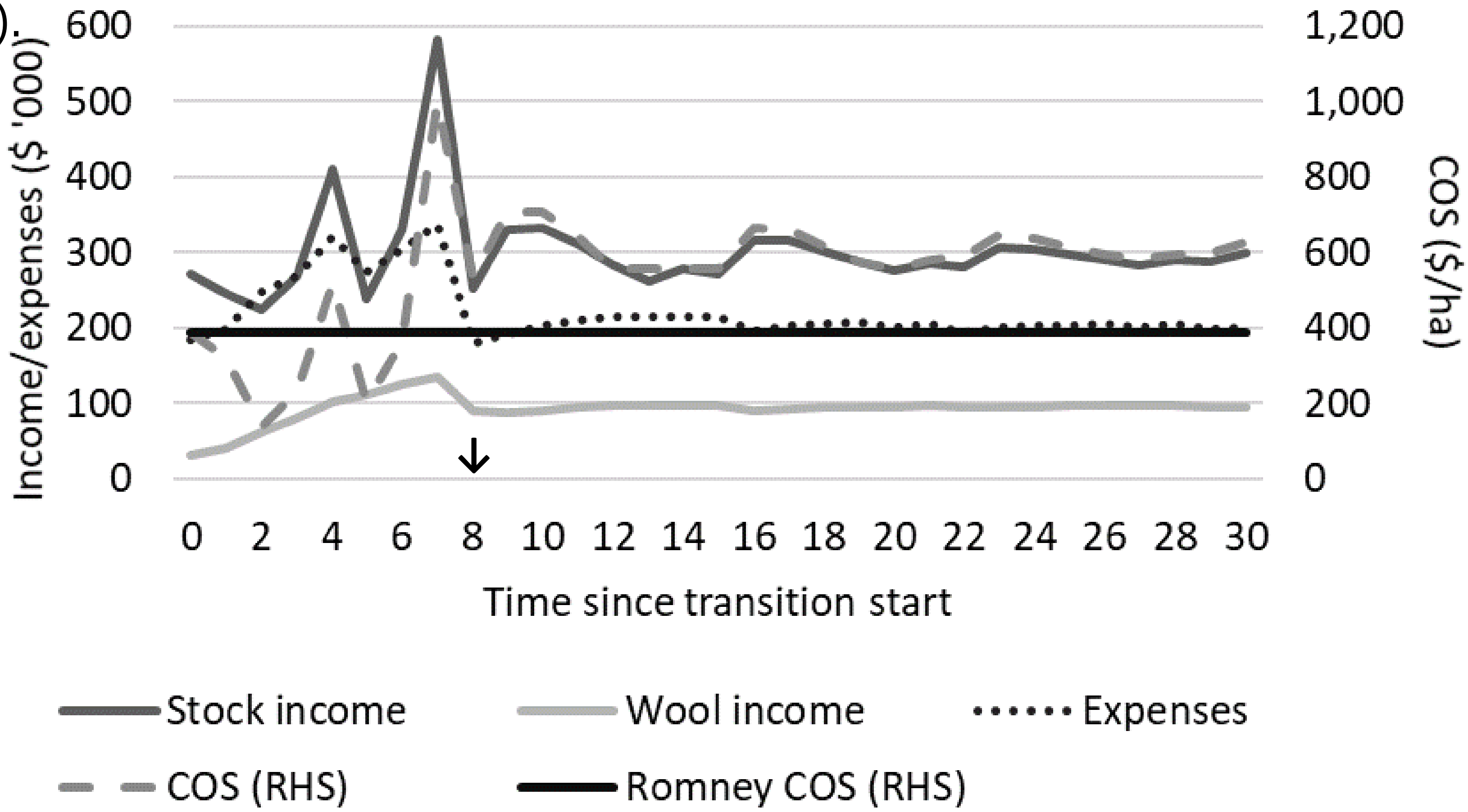
b).

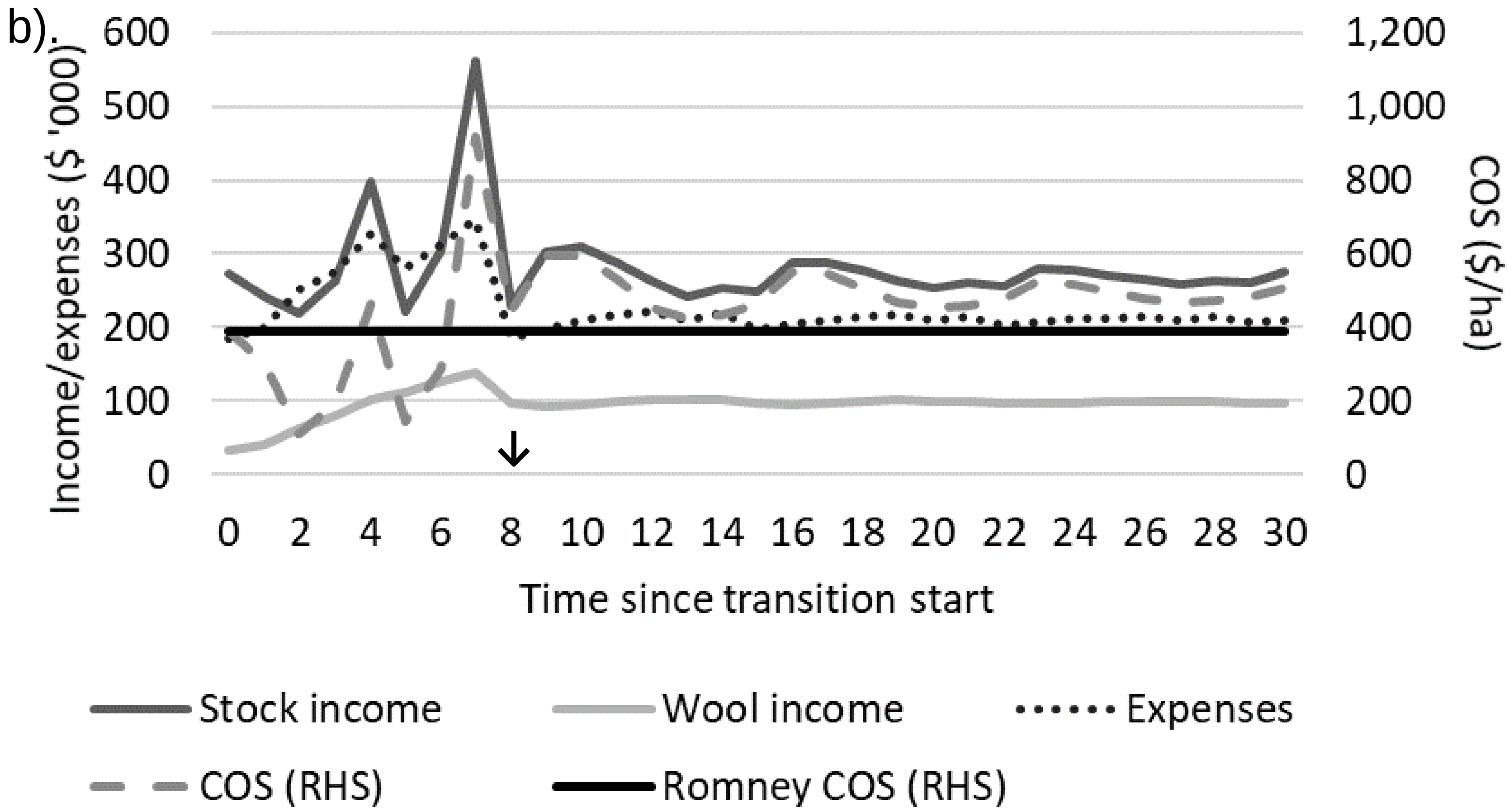


↓ Where breed transition has finished and the ¾ Merino ¼ Romney flock has reached desired flock size.

Figure 5.11: Sheep enterprise income, expenses, and cash operating surplus (COS) during a breed transition period with low lamb selection (24% of crossbred ewe lambs not retained at each selection event) and a). consistent lambing rate of 132% for all breeds, or b). breed specific lambing rate (lower for crossbred flocks).

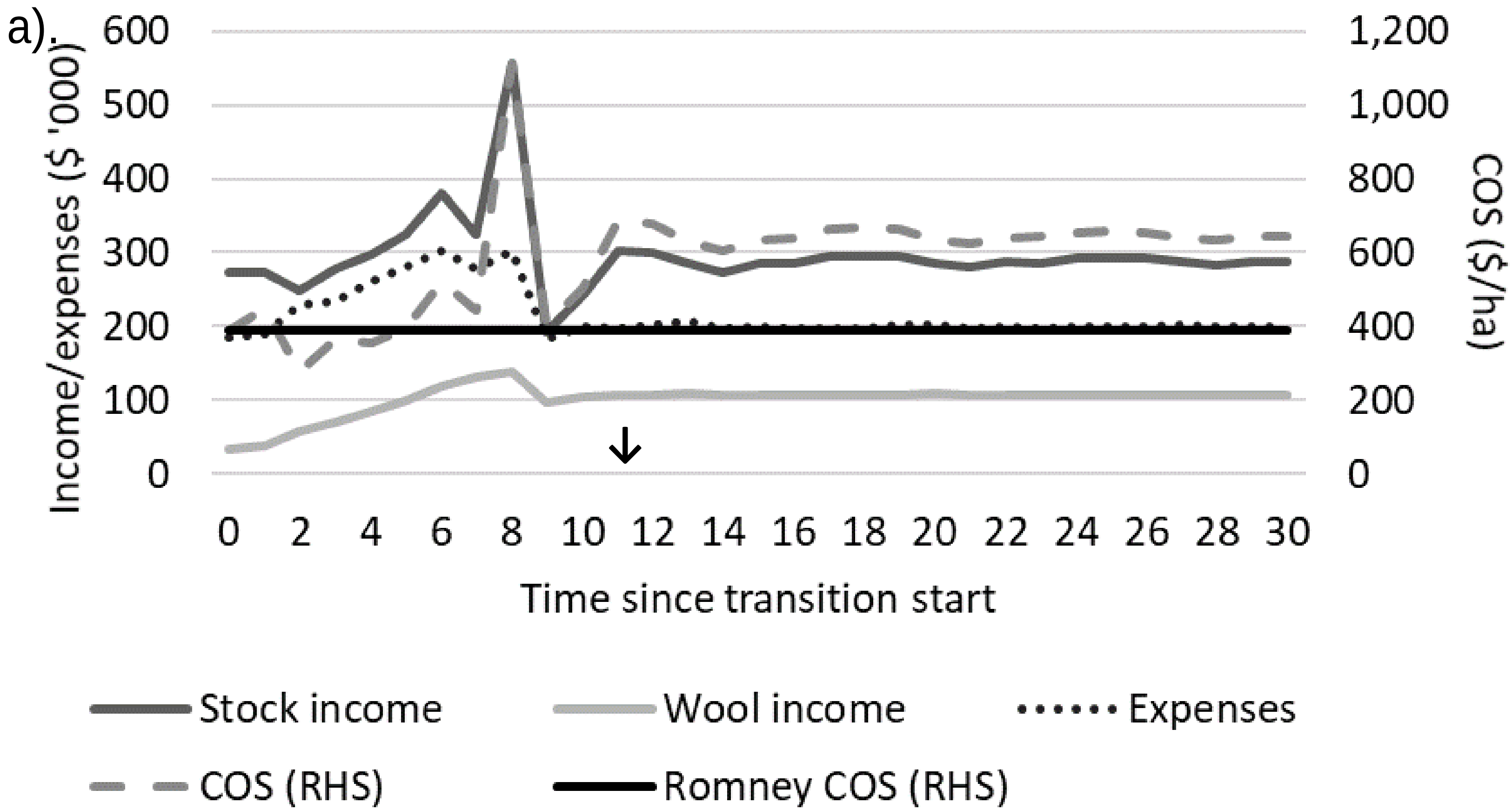
a).



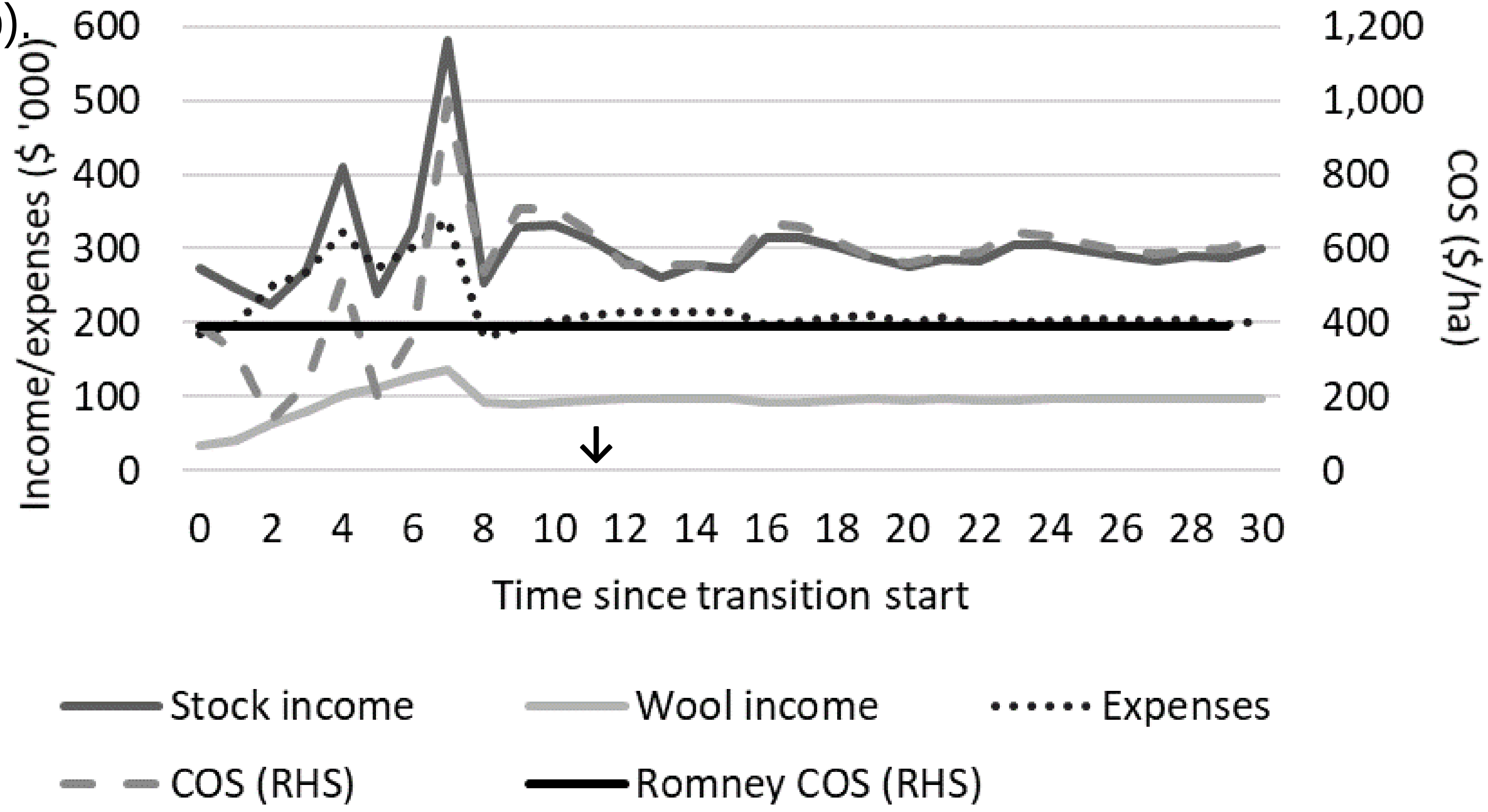


↓ Where breed transition has finished and the ¾ Merino ¼ Romney flock has reached desired flock size. Romney COS refers to the COS of the status quo Romney flock without to breed transition.

Figure 5.12: Sheep enterprise income, expenses, and cash operating surplus (COS) during a breed transition period with high lamb selection (35% of crossbred ewe lambs not retained at each selection event) and a). consistent lambing rate of 132% for all breeds, or b). breed specific lambing rate (lower for crossbred flocks).



b).



↓ Where breed transition has finished and the ¾ Merino ¼ Romney flock has reached desired flock size. Romney COS refers to the COS of the status quo Romney flock without to breed transition.

In most breed transition scenarios modelled, income from sheep sales was similar for the ¾M¼R flock at DFS compared with the base Romney flock (Figures 5.11 and 5.12). Lambing rate affected sheep sale income. For example, with high lamb selection intensity (35% of crossbred ewe lambs not retained at each selection event) and consistent lambing rate (132% lambing rate for all flocks) the ¾M¼R flock had a similar number of weaned lambs compared with the base Romney flock. The ¾M¼R lambs were sold for prime lamb prices and sheep sale income at DFS was $302,000 (Figure 5.12a). Selection intensity also influenced sheep sale income due to the younger ¾M¼R flocks at DFS in scenarios with low lamb selection intensity weaning fewer lambs. The current study used five year (2014/15 to 2018/19) average real values for mid-micron and fine wool (The New Zealand Merino Company, 2019b), during which time the wool value has increased. Similarly, lamb prices have increased since the 2017/18 values used in the current study (Beef + Lamb New Zealand Economic Serice, 2019c). Therefore, wool and lamb prices used in this study were relatively lower than those received by New Zealand commercial sheep farmers in years subsequent to 2017/18. Lamb carcasses from Merino genotypes can command a premium price in New Zealand when sold under the 'Silere' brand name, for example in 2019 Silere lamb sold for $7.10 - $7.20 per kg carcass weight in April 2019 (The Country, 2019) when average market New Zealand prices for lamb carcasses were $6.80 per kg carcass weight (Inventas Media, 2019). Therefore, the current study may be underestimating sheep enterprise income from the Merino-Romney crossbred flocks with a Merino crossbred premium. Chapter Four demonstrated the economic advantage of using terminal meat breed sires, which was not considered in the current study. Terminal sires are not likely to be used during the breed transition period when use of Merino sires producing Merino-Romney crossbred offspring would be maximised. However post-transition (i.e. once the DFS was achieved after seven or ten years of crossbreeding) terminal sires could produce faster growing lambs from the ¾M¼R flock, increasing lamb growth rates and potentially total carcass prices.

Total sheep enterprise expenses were relatively similar for the ¾M¼R flock at DFS compared with the base Romney flock, with similar expenses per stock unit (Table 5.3) and similar total sheep stock units (Figures 5.11 and 5.12). ¾M¼R ewes were lighter, with a mature liveweight of 55 kg contributing to a lower relative stock unit for the mature ewes compared with the heavier Romney ewes weighing 65 kg (Table 5.1). Ewe prolificacy also affected mature ewe stock units, which was lower for scenarios with breed specific Merino-Romney crossbred lambing rates. The ¾M¼R flock at DFS for all scenarios had an approximately equivalent energy demand to the base Romney flock, indicating similar sheep stock units and enterprise expenses. No difference in ram prices were assumed in the current study, however, prices for Merino and ¾M¼R rams may differ from Romney rams which would need to be considered by farmers. There may also be greater labour costs during the breed transition incurred by management of up to seven different groups of sheep during shearing and breeding. Industry survey data indicated similar health costs per stock unit for Merino flocks farmed in South Island High Country and Romney flocks farmed on North Island Hill Country, therefore health costs were assumed to be similar between breeds in the current study (Beef + Lamb New Zealand Economic Service, 2019b). Uncertainty around health costs is a farmer concern around managing Merino-Romney crossbred sheep in the North Island which tends to be a wetter environment than where Merino sheep are usually managed, which would need to be considered before making a breed change (BakerAg, 2019; Hoban, 2019).

On commercial farms, beef enterprise COS per ha may vary alongside changes in herd size and whole farm management during sheep breed transition, however, in the current study beef enterprise COS per ha was assumed to be consistent. Therefore, changes in sheep enterprise COS per ha caused proportional changes in total sheep and beef farm COS, while including changes in the sheep area of the farm. Sheep enterprise COS was higher for the ¾M¼R flock at DFS than the base Romney flock for all scenarios, with increases ranging from \$54/ha to \$296/ha (Figure 5.8; Figures 5.11 and 5.12). COS for the ¾M¼R flock at DFS differed with varied lamb selection intensity, where the greatest COS was achieved with high lamb selection intensity and consistent lambing rate (Figure 5.12a), driven by increased wool value and flock average age resulting in more lambs weaned. Previous work comparing the profitability of mid-micron and coarse wool producing flocks have similarly estimated greater profit from flocks producing mid-micron wool (Wright *et al.*, 1990; Hoban, 2019)

5.3.5.2 Cash flow and net present value

Sheep enterprise COS peaked at more than $900/ha in all scenarios (Figures 5.11 and 5.12), occurring when all remaining ½M½R ewes were sold in year seven or eight of scenarios with low and high lamb selection intensity, respectively (Figure 5.7). Sheep enterprise COS was less than that of the base Romney flock during several years of the breed transition for all scenarios. For scenarios with low lamb selection intensity (24% of crossbred ewe lambs not retained at each selection event), COS was less than the year zero COS of $390/ha during years one, two, three, five, and six by up to $280/ha (Figure 5.11). During years with lower COS, income from wool and sheep sales combined was higher than for the base Romney flock but total sheep enterprise expenses had relatively larger increases, reducing COS. Increased expenses during breed transition were driven by greater wintered stock units as Merino-Romney crossbred ewe flocks grew in size while Romney ewes were still present, alongside Merino-Romney crossbred ewe lambs remaining on-farm over winter until wool testing. COS did not include non-operating expenses of the farm, therefore, the impact of reductions in cashflow during breed transition on the scope of farm debt servicing or capital expenditure during these years was not estimated. COS did not decrease to the same extent with higher lamb selection intensity (35% of crossbred ewe lambs not retained at each selection event), where fewer lambs were wintered, but sheep and beef COS was still lower than that of the base Romney flock scenario during numerous years of breed transition.

The relatively smaller reduction in cashflow during breed transition with high lamb selection intensity may compensate for the additional time taken to achieve the ¾M¼R DFS. A NPV analysis was performed to summarise cashflow (combined sheep and beef total annual COS) for each breed transition scenario (Table 5.6). Twelve-year NPV was greatest with high lamb selection intensity (35% of crossbred ewe lambs not retained at each selection event) and consistent lambing rate (132% for all flocks), at $1.6 million with a discount rate of 10%, and this scenario also generated the highest sheep enterprise COS peak at $1,111/ha (Figure 5.12a). NPV was greater with high lamb selection intensity where the ¾M¼R DFS was achieved later, consistent with the findings of a previous modelling study where Merino sires were used to breed for lower fibre diameter for a Romney flock in the North Island and NPV was higher with a longer breed transition period (i.e. five vs. ten vs. fifteen years of breed change; Wright *et al.*, 1990).

Table 5.6: Net present value for combined sheep and beef farm cashflow for flock breed transition from Romney to Merino-Romney crossbred with differing crossbred lamb selection intensity and lambing rates. Discount rates of 6% and 10% were used to reflect 2017/18 and long-term New Zealand lending interest rates, respectively (ASB, 2020; Reserve Bank of New Zealand, 2020). Cash flow over twelve (breed transition period) and thirty (time taken to reach stable ewe numbers) years.

Scenario*	Net present value ($)			
	6% discount rate		10% discount rate	
	Twelve years	Thirty years	Twelve years	Thirty years
Status quo base Romney	1,627,085	2,703,271	1,372,259	1,909,048
Low selection and consistent lambing rate	1,832,397	3,274,267	1,498,730	2,215,396
Low selection and breed specific lambing rate	1,662,373	2,908,341	1,365,344	1,984,504
High selection and consistent lambing rate	1,878,644	3,400,111	1,552,333	2,311,038
High selection and breed specific lambing rate	1,742,588	3,077,844	1,448,610	2,114,836

*Where low selection intensity was 24% of Merino-Romney crossbred ewe lambs not retained at each selection event, high selection intensity was 35% of Merino-Romney crossbred ewe lambs not retained, consistent lamb rate was 132% for all flocks, and breed specific lambing rate was 132% for Romney, 120% for ½M½R, and 114% for ¾M¼ flocks.

Once the ¾M¼R flock achieved DFS there was ongoing variation in stock income from sheep sales, sheep enterprise COS, and, to a lesser degree, sheep expenses (Figures 5.11 and 5.12). The majority, i.e. approximately 70%, of sheep enterprise income post-breed transition was derived from sheep sales and lamb production was influenced by flock age structure as explained in Section 5.3.4. Ewe numbers in each age class of the ¾M¼R flock continued to fluctuate due to flock dynamics until achieving relatively stable numbers around 30 years after beginning breed transition. Therefore, stock income fluctuated with changes in flock age structure which drove the variation in sheep enterprise COS. Changes in lamb production with ewe flock age influenced sheep enterprise expenses through changing production with ewe flock age influenced sheep enterprise expenses through changing mature ewe stock units. Wool income was less affected by changes in flock age as relative differences in wool production and fibre diameter between age classes were smaller than for reproductive rate (Section 5.2.4.1).

The majority of breed transition scenarios had higher NPVs than the status quo base Romney flock (Table 5.6). Wright *et al.*, (1990) undertook an NPV analysis of use of Merino sires in a fifteen-year breed change strategy to replace a Romney flock in the North Island with mostly Merino ewes. They estimated the total fifteen-year value of cash flow to be 28% greater for the transition to a mostly Merino flock compared with the status quo base Romney flock, with wool produced by the Merino-Romney crossbred flock approximately double the value of coarse wool (Wright *et al.*, 1990). In the current analysis, thirty-year NPV with a 6% discount rate for the breed transition scenario with high lamb selection intensity (35% of crossbred ewe lambs not retained at each selection event) and consistent lambing rate (132% for all flocks) was $696,840 greater (26% greater) than for the base Romney flock ($2.703 million). The results demonstrate that Merino-Romney breed change strategies with greater Merino-Romney crossbred lamb selection intensity and higher lambing rates will generate the overall greatest cashflow during and subsequent to the transition period. The results suggest that similar breed transition strategies will likely be more profitable overall than maintaining the status quo Romney flock. Application of higher Merino-Romney crossbred ewe lamb selection intensity (fewer crossbred ewe lambs retained at each selection event), with an associated longer breed transition period, will be more profitable and achieve lower mean wool fibre diameter for the ¾M¼R flock.

The NPVs of breed transition scenarios were generally higher than the status quo Romney flock, with consistent relative values across the differing time periods and discount rates used (Table 5.6). However, some modelled scenarios with breed specific (lower lambing rate for crossbred ewes compared with Romney flock) lambing rate had relatively small or no economic benefit to total cashflow compared with the status quo base Romney flock, particularly where the NPV analysis focused on only the breed transition period of up to twelve years. For example, with a discount rate of 10% over twelve years the NPV of the breed transition scenario with low lamb selection intensity (24% of crossbred lambs retained) and breed specific lambing rate was $1.365 million, slightly lower than the status quo base flock value of $1.372 million (Table 5.6), due to low annual COS early in the breed transition period when cashflow was most valuable in the NPV analysis (Figure 5.11b). Relatively small long-term economic benefits of some breed transition strategies explored in the current analysis may discourage farmers from making such a breed change when combined with remaining uncertainty around health costs and potential effects on wool quality (outside of fibre diameter) which were not included in the current study. The ¾M¼R lambs continued to all be sold prime after the DFS was achieved, however, farmers with ¾M¼R flocks may choose to retain lambs over winter to harvest a fleece from them prior to sale. This would likely increase wool income but may reduce mature ewe flock size and/or the cattle herd size to compensate for the greater lamb energy demand. The effect of retaining lambs over winter on farm cashflow post-breed transition was not modelled and implications for the thirty-year NPVs were not estimated.

5.3.6 General discussion

Although there is increasing interest from North Island coarse wool producers to breed for wool with a lower fibre diameter, the specific management requirements of Merinos, such as grazing style, potential health issues around footrot and facial eczema, retention of lambs over winter, and potential production losses (specifically lambing rate, lamb growth rates, and carcass conformation) create uncertainty and are producer concerns (BakerAg, 2019). In recent years Merino sires have been used as a terminal sire across Romney, or similar coarse wool producing flocks as an alternative strategy for farmers to take advantage of increasing mid-micron wool prices from Merino-Romney crossbred lambs destined for slaughter and lamb carcass premiums. Where farmers have employed this strategy, the ½M½R lambs can remain on-farm over winter until a fleece is shorn and lambs subsequently sold (Muir and Thompson, 2013). Alternatively, they could be grazed off-farm or sold store for a premium after weaning to mitigate the effect of increased feed requirements incurred over winter. Impact on income, profit, and feed requirements of these types of strategies has not been examined or modelled.

Although two comparison studies that informed Merino-Romney crossbred production parameters used in this study were published in the current century, the majority were published in the 1980s and 1990s (Table 5.1). It was not clear how the performance of

Merino-Romney crossbred sheep relative to Romney sheep may have changed since these older studies were undertaken as breeds are continually evolving through selection. Data on reproductive performance was scarce for Merino-Romney ewes farmed on the North Island Hill Country, a key production parameter. The current study varied Merino-Romney crossbred lambing rate to reflect current industry averages of their parental breeds in scenarios with 'breed specific' lambing rate. Loss of lambs between birth and weaning is a major factor in flock lambing rates achieved in New Zealand, constituting the majority of potential lambs lost between scanning and weaning (Kelly, 1980). Merino ewes lose a relatively higher proportion of lambs between scanning and weaning, e.g. in a New Zealand study Merino ewes lost 29% of potential lambs while Romney ewes lost 19% (Geenty, 1997). Lamb survival is driven by variation in nutrition, breeding, and environment (Kenyon and Webby, 2007). While the breed specific lambing rates used in the current study have likely incorporated the effects of breeding by including the performance of modern commercial Merino flocks (although there is large within-breed variation), ewe nutrition and environment would potentially differ on North Island Hill Country from traditional Merino foraging environments in New Zealand and may affect overall lambing rate. Merino sheep generally scan at a slightly lower rate (i.e. lower rate of foetuses identified at trans-abdominal pregnancy scanning) than Romney ewes in New Zealand, and improved nutrition increases Merino scanning rates (Geenty, 1997).

The current study assumed that New Zealand North Island Hill Country farmers considering a breed change scenario from a purebred Romney flock to Merino-Romney crossbred would aim to have only ¾M¼R ewes on-farm after a maximum of ten years of transition. A longer breed transition period would potentially produce wool with lower fibre diameters than was achieved in the current study with further increases in wool value for the ¾M¼R flock, through applying greater Merino-Romney crossbred lamb selection intensity (i.e. more than 35% of crossbred ewe lambs not retained at each selection event). The maximum length of breed transition that would be worth considering by New Zealand farmers undertaking a similar breed change is not known. This study modelled a breed transition of the entire Romney flock to ¾M¼R, farmers may transition only part of their Romney flock which was not modelled. It was assumed the mean wool fibre diameter in the ¾M¼R flock would be maintained post-breed transition through use of ¾M¼R sires with similar fibre diameter. However, wool fibre diameter has a moderate heritability (Wuliji *et al.*, 2001) and farmers may continue to select for further reductions in fibre diameter in the ¾M¼R flock after the DFS was achieved, this was not included in the current analysis. The breed transition scenarios modelled all experienced changes in the size of the beef cattle operations on-farm varying from consuming 52% to 18% of total farm feed (Figure 5.8). If the size of the beef cattle operation was maintained at 40% of total farm feed consumed (or similar), then the time taken to achieve the ¾M¼R DFS would have been longer, likely with earlier culling of the whole Romney and ½M½R ewe flocks.

5.4 Conclusion

A breed transition strategy to replace a purebred Romney flock with ¾M¼R ewes on a North Island Hill Country farm through use of Merino sires may be achieved after seven to ten years of crossbreeding, largely influenced by Merino-Romney crossbred ewe lamb selection intensity. It appears the greatest economic benefit of this breed transition strategy compared with the status quo Romney flock occurred with high lamb selection intensity (i.e. 35% of crossbred ewe lambs not retained at each selection event) and lambing rates consistent with the base Romney flock (132%), with production of more lambs and higher value wool by the ¾M¼R flock. Where lambing rate and selection intensity were lower, the total value of cashflow during the breed transition period had little or no advantage over maintenance of the status quo Romney flock. Although farming of the ¾M¼R flock producing higher value mid-micron wool may diversify farm income and increase profit, uncertainties around Merino-Romney crossbred sheep performance in the North Island such as changes in lambing rate and animal health costs are unknown and require quantification, these may deter risk-averse farmers from making such a breed change. The current study has explored a Merino-Romney crossbreeding strategy with a range of potential breed transition scenarios represented. There remain numerous alternative options for farmers considering a similar breed change which could be explored in future research.

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Chapter Six

Overall Discussion

6.1 Introduction

Between 1980 and 2018, sheep numbers in New Zealand declined from 68 to 24 million (Beef + Lamb New Zealand Economic Service, 2019a). While between 1990 and 2012, the area of sheep and beef farmland decreased by 28% (Mackay *et al.*, 2012), with remaining sheep and beef farms increasingly being situated on steeper, less fertile land (Cranston *et al.*, 2017). Despite reductions in sheep numbers and farmed area, production of sheep meat remained relatively stable (FAOSTAT, 2017) due to successful efforts to increase lambing rates (lambs weaned per ewe presented for breeding) and lamb carcass weights (Mackay *et al.*, 2012; Morris and Kenyon, 2014). Conversely, production of wool has declined from 380 kt of greasy wool in 1980 to 139 kt in 2018 (Beef + Lamb New Zealand Economic Service, 2019a). The majority of sheep in New Zealand are dual-purpose breeds such as the Romney, producing coarse wool with a fibre diameter of > 30 µm and relatively low value (Beef + Lamb New Zealand Economic Service, 2019a). Export revenue in 2018 from sheep meat totalled $3.35 billion and wool exports earned $543 million (Beef + Lamb New Zealand Economic Service, 2019a). Individual sheep and beef farm operating profit in 2018 ranged from $0/ha to more than $1,500/ha, averaging $450/ha and lambing rates ranged from 80% to 180%, averaging 132% (Beef + Lamb New Zealand, 2020a), indicating many farms have potential for improvement. Several strategic and system changes were identified in the literature review to have the potential to increase sheep enterprise production and profit. These have not previously been investigated at a farm systems level. Bio-economic farm systems modelling has been recognized as an appropriate method for investigating the impact of changes on productivity and profitability at a farm or enterprise level (McCall *et al.*, 1994). The scenarios chosen for investigation in the current research each include changes to flock dynamics. i.e. flock age structure and varying annual flock replacement rates, with one scenario involving a flock in a transition state.

6.1.1 Research objectives

Having identified several profitability scenarios for New Zealand sheep farming systems and the appropriate modelling technique to explore them, the specific objectives of this thesis were to:

1. Use STELLA (isee Systems, 2019) to develop a bio-economic system-dynamics model of a New Zealand sheep farming enterprise focused around ewe flock dynamics.
2. Test the steady state, annual model by investigating the impacts of varying rates of ewe wastage.
3. Use the model in a steady-state, annual form to investigate scenarios where income from lamb sales increased through use of terminal sires.
4. Use the model in a multi-year transition form to investigate a scenario where wool fibre diameter decreased and income increased through a gradual flock breed change.

The results of this research provide relevant information to New Zealand farmers that could be considered during decision making around these issues, potentially contributing to improvements in the production and profitability of sheep farming systems in New Zealand.

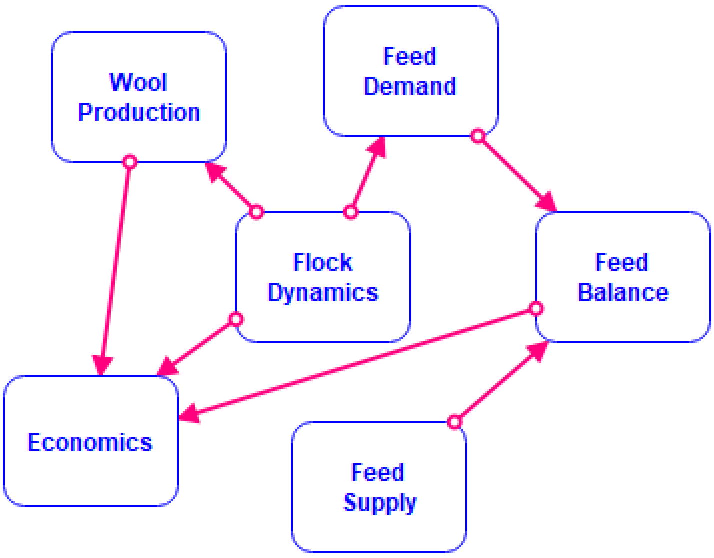
6.2 Findings

6.2.1 The model developed

A bio-economic system-dynamics model of a sheep enterprise was developed using the software 'STELLA' (isee Systems, 2017). The component modules represented flock dynamics, wool production, and economics with calculation of COS (cash operating surplus) based on income from lamb and wool sales less expenses based on sheep stock units (Figure 6.1). Component modules also included sheep energy demand in the form of metabolizable energy calculated monthly (Chapter Three) or fortnightly (Chapters Four and Five), feed supply in the form of metabolizable energy from pasture growth, cumulative energy balance as a monthly (Chapter Three) or fortnightly (Chapter Four) surplus or deficit of metabolizable energy.

Key inputs for the flock dynamics component module included desired size of ewe flock, rates of ewe death and premature (prior to Y_7) culling, lambing rate, and proportion of ewes bred with differing breed sires (maternal vs. terminal vs. Merino). Key input parameters for other component modules include liveweights and growth rates, wool type and production, a pasture growth curve from the area of New Zealand under study, operating expenses, and sheep sale and wool prices. Key model outputs included replacement ewe lamb requirements, numbers of lambs of each breed weaned and sold, ewes culled for age, feed demand and supply, feed surpluses and deficits, total sheep enterprise income and expenses, and COS. Model output aligned with previously published industry data and was therefore considered a realistic representation of a New Zealand North island Hill Country sheep farming system.

Figure 6.1: Schematic diagram of component modules.



6.2.2 Ewe wastage

Annual replacement rates for commercial breeding ewe flocks in New Zealand vary from 20% to 35% (Griffiths, 2016; Cranston *et al.*, 2017). Ewes leaving the flock and requiring replacement are made up of ewes culled for age and ewe wastage, defined as ewe deaths and premature culling prior to the end of their potential productive lifespan (Griffiths, 2016). A reduction in ewe wastage was one strategic change identified in Chapter Two with the potential to increase production and profit of New Zealand sheep farming systems. Previous studies have estimated the cost of increased replacement requirements from greater herd/flock loss rates (Bailey and Currin, 1999; Tozer and Heinrichs, 2001; Dawson and Carson, 2002; McHugh, 2012). Chapter Three examined this issue from another perspective: reduced production and profit for in New Zealand sheep enterprises with high ewe wastage rates (WR). Although it was not accurately known what the average, or typical rates of wastage are in New Zealand commercial breeding ewe flocks, they range from less than 5% to more than 20% of ewes (Anderson and Heuer, 2017; Griffiths *et al.*, 2017). Results of the current study indicate that greater losses of breeding ewes due to wastage increased requirements for replacement ewe lambs, reduced ewe flock average age, and reduced production of lambs for sale. As lamb sales are a major driver of profitability for the majority of New Zealand sheep production systems (Beef + Lamb New Zealand Economic Service, 2019b), sheep enterprise COS was reduced with greater WR. COS for the total sheep enterprise decreased from $68,221, when WR = 5%, to $51,166, when WR = 21%. Sheep enterprise COS was reduced by $1,069 per 1% increase in WR for the representative sheep enterprise. This suggests that strategies to reduce wastage rates should have a positive impact on flock productivity and sheep enterprise operating profit, highlighting ewe wastage in New Zealand as a significant issue warranting further investigation.

The impact of ewe wastage had not been previously quantified at a farm systems level and system dynamics was found to be suitable for modelling the feedback loops involved in calculating replacement requirements and the effect of changes in flock age structure on productivity and operating profit. This research was one of the first sheep farm system models to incorporate the effects of changes in age structure on production in a farm system focused around capital breeding stock. System dynamics allowed ewes in each age class to be represented as 'stocks' with movements between age classes as 'flows'. The model was run until stable numbers in each age class were achieved for each WR. As ewe-flock age decreased there were ensuing effects on flock productivity. These was an increase in wool production as ewe wool production peaks at three years of age (Brown *et al.,* 1966; McLaughlin 1973; Rose 1974,) and a reduction in reproductive rate, as ewe reproductive performance peaks at five years of age (Hickey, 1960; Turner *et al.*, 1968; Hight and Jury, 1970; Dickerson and Glimp, 1975; Thomson *et al.*, 2004). Therefore, the overall outcomes of this research demonstrated how production losses from greater ewe flock WR were compounded by the lower reproductive performance of younger ewe flocks.

6.2.3 Use of terminal sires

New Zealand North Island Hill Country sheep enterprises derive the majority of gross income from lamb sales, therefore profit is driven by lamb production and price (Beef + Lamb New Zealand Economic Service, 2019b). There was a relatively consistent trend in lamb price within production years, generally highest in spring (September to November) and lowest in autumn (March to May; Beef + Lamb New Zealand Economic Service, 2019a). Sales of lambs sooner after weaning in November or December should therefore increase the price per kg of lamb carcass weight that farmers receive. Lamb growth rates are influenced by factors such as health, feed, and breed, where crossbred lambs from terminal sires have demonstrated consistently higher growth rates than their purebred counterparts (Clarke and Meyer, 1982; McEwan *et al.*, 1995). Therefore, use of terminal sires to produce crossbred lambs allowing earlier sale of lambs for higher prices per kg of carcass weight was investigated in Chapter Four. In a self-replacing breeding flock, requirements for purebred ewe lambs was the major constraint for terminal sire use, therefore flock replacement rate was an integral factor. Replacement rate and numbers of ewe lambs retained were calculated in the model based on numbers of ewes leaving the flock due to death or culling, forming a loop as displayed in Figure 4.1. The proportion of ewes bred with terminal sires to produce crossbred lambs was increased until numbers of purebred maternal breed ewe lambs required were no longer met.

This research identified the upper limit for terminal breeding to range from 18% to 65% of the ewe flock, dependent on flock replacement and lambing rates. This upper limit was higher with lower replacement rates and higher lambing rates as these influenced the proportion of the ewe flock required to breed with maternal sires to produce purebred ewe lambs. Sheep enterprise operating profit was higher with greater use of terminal sires, with COS increases of up to $101/ha with maximum use of terminal sires compared to the COS with no terminal sire use (Table 4.6). This was due to the higher survival rate of crossbred lambs from terminal sires (Carter and Kirton, 1975; Meyer *et al.*, 1977) and faster pre- and post-weaning growth rates (Carter and Kirton, 1975; Clarke and Meyer, 1982; Kirton *et al.*, 1995; Scales *et al.*, 2000; Purchas *et al.*, 2002; Shackelford *et al.*, 2005; Hopkins *et al.*, 2007; Ponnampalam *et al.*, 2007) enabling crossbred lambs to reach target carcass weight sooner after weaning when prices were higher. Use of terminal sires increased sheep energy demand over summer to support the crossbred lambs' higher growth rates. This increased demand was mostly compensated for by lambs leaving the farm earlier, having less overall energy demand for maintenance. Thus, use of terminal sires altered the sheep energy demand profile, with greater demand in summer but similar demand over the whole production year.

Although absolute numbers were not available, information for national ewe flocks indicates New Zealand sheep farmers' use of terminal sires to be relatively low (Beef + Lamb New Zealand Economic Service, 2019a) compared to their use in other countries with pastoral sheep production systems such as Australia (Banks and Ross, 2013) or Scotland (Rodriguez-Ledesma *et al.*, 2011). The sensitivity analyses conducted in the current study demonstrated the relatively greater impact of lamb price on operating profit compared with changes in crossbred lamb production, indicating that lamb prices were more important factors for profit than increased production from terminal sire use. The findings of this research provide information on the potential scope for terminal sire use in New Zealand's self-replacing breeding ewe flocks, associated increases in feed demand in summer when finishing crossbred lambs on-farm, and potential increases in profit.

6.2.4 Crossbreeding to reduce wool fibre diameter

New Zealand sheep and beef farms with dual-purpose breed flocks producing coarse wool such as Romney derived approximately 5% to 11% of gross income from wool sales in 2018, as the real value of coarse wool has declined since 1980 (Beef + Lamb New Zealand Economic Service, 2019a, b). The real values of fine and mid-micron wool have increased during the same period and multi-year supply contracts offering guaranteed prices are available for these types of wool (Wallace, 2018; The New Zealand Merino Company, n.d.; Beef + Lamb New Zealand Economic Service, 2019a). A breed transition to a Merino-Romney crossbred flock to reduce wool fibre diameter on North Island Hill Country farms through breeding a purebred Romney ewe flock with Merino sires may allow producers to take advantage of these higher mid-micron wool prices and supply contracts. Previous New Zealand Merino-Romney crossbreeding studies have demonstrated the expected reductions in wool fibre diameter (Dobbie *et al.*, 1985; Meikle *et al.*, 1988; Andrews *et al.*, 1995, 1998;; Wuliji *et al.*, 1995; Everett-Hincks *et al.*, 1998; Muir and Thomson, 2013), indicating the potential increase in wool value which may increase sheep enterprise profit. However, uncertainty around the time taken to replace a purebred Romney flock with a Merino-Romney flock producing mid-micron wool through crossbreeding is a deterrent to undertaking this breeding strategy from a farmer perspective, as well as changes in lamb production and cashflow during the breed transition period (BakerAg, 2019).

System dynamics was an appropriate technique to model this strategy in Chapter Five. Sheep in each age class represented as a 'stock' and their movements as 'flows' demonstrated how numbers of ewes and lambs of each breed changed during the gradual breed transition. The purebred Romney ewe flock was bred with Merino sires to produce ½ Merino ½ Romney (½M½R) lambs of which some ewe lambs then entered the ½M½R flock and were bred with Merino sires to produce ¾ Merino ¼ Romney (¾M¼R) lambs of which some ewe lambs then populated the ¾M¼R flock. Numbers of Merino-Romney crossbred ewe lambs entering the ½M½R and ¾M¼R flocks were determined by selection intensity at weaning and after wool testing (at around ten months of age). Sheep numbers were used to estimate sheep enterprise production and operating profit each year during and subsequent to the breed transition period, with Merino-Romney crossbred lamb selection intensity and Merino-Romney crossbred flock lambing rates varied between scenarios.

Selection intensity for Merino-Romney crossbred ewe lambs was the major determinant of time taken to achieve the ¾M¼R desired flock size (DFS) and average fibre diameter of wool produced by the ¾M¼R flock. With the high level of lamb selection intensity, 35% of crossbred ewe lambs not retained at each selection event (weaning and wool testing at ten months of age), this was the maximum selection intensity that still achieved ¾M¼R DSF within ten years of breed transition. The low lamb selection intensity did not retain 24% of crossbred ewe lambs at each selection event, the lowest level with which ¾M¼R flock wool average fibre diameter was ≤ 26 µm, congruous with the upper range of fibre diameter reported in previous studies (Figure 5.1) and currently eligible for a multi-year supply contracts (Wallace, 2018). With lower lamb selection intensity, the ¾M¼R DFS could be achieved three years earlier (seven years of breed transition) while also culling all of the remaining ½M½R and Romney ewes earlier. The low lamb selection intensity had more ewe lambs retained on-farm over winter and grew Merino-Romney flock ewe numbers faster, with a greater proportion of total farm feed consumed by sheep and the size of the beef cattle operations on-farm decreasing from 40% of stock units to as low as 18% during the breed transition period (once the ¾M¼R DFS was achieved the sheep feed demand was maintained at the pre-breed transition level). Sheep feed demand increased alongside increases in sheep enterprise expenses which reduced sheep enterprise COS below that of the base Romney flock, during the breed transition period, with greater COS reductions in scenarios with low lamb selection intensity. Sheep enterprise COS and total farm COS were greater once the ¾M¼R DFS had been achieved compared with the original Romney flock. COS was generally greater with higher lamb selection intensity (35% of ewe lambs not selected) where a ¾M¼R flock lower average wool fibre diameter was achieved and consistent lambing rate between flocks (no reduction in Merino-Romney crossbred flock lambing rate from the Romney level of 132%). Similarly, net present value (NPV) analyses for twelve and thirty years showed there was almost always an overall economic benefit of the breed change strategy compared with the status quo Romney flock, i.e. up to 26% greater value, despite reductions in COS during breed transition. However, for scenarios where lambing rate and lamb selection intensity were lower, the breed change NPV had relatively small or no advantage over maintenance of the status quo Romney flock. Although the results inform farmers of expected production and cashflow during the breed transition with potentially large economic benefits, remaining uncertainties around animal health costs and lambing rate when farming ¾M¼R ewes on North Island Hill Country may deter risk-adverse farmers from making such a breed change.

Bio-economic sheep farm models currently in use in New Zealand model the system in a steady state (Marshall *et al.*, 1991; Rendel *et al.*, 2013). The bio-economic system-dynamics model developed in this research can simulate the farm in both steady and transition states. The original Romney flock was modelled in steady state, i.e. maintaining Romney ewe numbers, to investigate the ‘status quo’ scenario and inform the initial values for the breed transition. The model was then used in a transition state where the Romney flock no longer produced purebred lambs from which to choose replacements, but instead produced Merino-Romney crossbred lambs to populate the first cross ewe flock. When simulating this breed change the model requires input of the DFS for ¾M¼R ewes, and the ¾M¼R flock was modelled with a stable size after the DFS was achieved. The ability to simulate the sheep farming enterprise in a transition state from one system to another was novel and the results provide insight currently relevant to New Zealand coarse wool producers.

6.3 Limitations

The bio-economic system-dynamics sheep enterprise model developed and used in this research quantified several profitability scenarios not previously explored in New Zealand at a farm system level and for which the current available models were not suitable, i.e. FARMAX and AgInform are both steady state, optimisation models (Marshall *et al.*, 1991; Rendel *et al.*, 2013). Output of the model developed in this study provided insights into the issues of ewe wastage, terminal sire breeding, and a breed transition to produce higher value wool to inform decisions made by New Zealand sheep farmers and industry members. While the model developed was effective and appropriate for the research undertaken, there are limitations in its application that are acknowledged in the following subsections.

6.3.1 Estimating profitability changes using Cash Operating Surplus

This research explored sheep enterprise profit in the form of COS, ignoring expenses related to interest, tax, rent, depreciation, and rates (Shadbolt and Martin, 2005) in order to exclude assumptions about farm financial structure, e.g. ownership structure and business debt. The scenarios investigated in this research were operational changes with likely greater implications for operating (or 'working') expenses than those excluded. However, there were possibly some effects on non-operating expenses that have not been explored. One example is the effect of lamb sale date on interest paid on farm overdraft. Income and expenses were calculated on an annual basis in the model, however, in reality they are not evenly spread across the year and farmers rely on a bank overdraft account to facilitate cash flow (Federated Farmers, 2017). Survey data for East Coast North Island Hill Country farms in the 2017/18 season shows annual total interest payments range from $53.35/ha to $190.30/ha, averaging $143.53/ha, a significant expense across a farm type with an average area of 530 ha (Beef + Lamb New Zealand Economic Service, 2019b). Earlier lamb sales occurring through use of terminal sires to produce faster growing crossbred lambs in

Chapter Four would generate farm income earlier in the production year allowing farmers to reduce their overdraft at an earlier date and potentially lessen interest expenses paid that year. Conversely, lambs were sold later when using Merino sires in Chapter Five, potentially delaying overdraft payments and accruing greater interest costs to the farm business. COS also decreased during the breed transition period compared to the COS of the base Romney flock which may have limited debt servicing. There are a wide range of financial structures present in New Zealand North Island Hill Country farms, partially illustrated by the range of interest expense values presented in the survey data. Inclusion of these with the variation necessary to capture relevant profitability data for New Zealand sheep farmers would constitute a separate piece of work.

6.3.2 Exclusion of beef cattle enterprise

This research focused on the sheep operations and enterprise of the farm. It was acknowledged that sheep and beef operations are typically carried out on the same farms in New Zealand and the implications for feed supply and working expenses were compensated for through use of a constant ratio of sheep to beef stock units for Chapters Three and Four, then the proportions of sheep and beef stock units were adjusted in Chapter Five. This approach constitutes a limitation in the research as most of the possible implications for the beef enterprise of scenarios investigated were not explored. Chapter Three included the increased feed demand of the sheep enterprise with increased ewe wastage from greater replacement ewe lamb demand, focusing only on changes to the sheep enterprise production and operating profit. Use of terminal sires in Chapter Four increased feed requirements in summer to support the high growth rates of crossbred lambs. It was assumed that the proportion of feed/pasture consumed by sheep was constant across the year, however, this would likely vary across the production year, with the complimentary feed demand and grazing styles of sheep and cattle managed to maximise pasture growth and quality for animal performance (Cranston *et al.*, 2017). In Chapter Five, when Merino sires were used to transition the breeding flock from purebred Romney to ¾M¼R crossbred, the overall farm operating profit (sheep and beef enterprise operating profit combined) was adjusted to reflect changes in the proportion of feed consumed by sheep (stock units). It was assumed in Chapter Five that beef enterprise operating profit was consistent on a per hectare basis despite changes in size (i.e. the proportion of feed consumed by beef cattle changed from 40% to as low as 18% during the breed transition). The model could be adapted in the future to include the beef cattle herd dynamics with implications for production and profit.

6.3.3 Use of experimental and benchmarking data

Results of this research were general findings around impacts on production, operating profit, and feed balance for New Zealand sheep farming enterprises due to changes in ewe wastage, use of terminal sires, and a flock breed transition to produce higher value wool. Model input was informed by benchmarking data from industry surveys (Beef + Lamb New Zealand Economic Service, 2019b) to construct a representative 'average' sheep enterprise for North Island Hill Country rather than data from an individual case study farm. Where industry survey data averages were not available or appropriate, experimental data was used to estimate production. For example, data from historic (i.e. published from 1975 to 2007) New Zealand studies comparing crossbred lambs from terminal sires with purebred lambs were combined with current lamb production levels to estimate crossbred lamb production in Chapter Four. It was unknown how achievable the estimated production levels would be on commercial farms e.g. weaning lambs at 34 kg liveweights on a Gisborne Hill Country farm. Similarly, Chapter Five used historic (i.e. published from 1985 to 2013) comparison studies of Merino-Romney crossbreeding to inform production parameters of ½M½R and ¾M¼R ewes and lambs. For some parameters there was a lack of data to inform model input, including lambing rate, fleece yield, and lamb carcass dressing percentage. Where the parameter would likely be a large factor affecting the results, such as lambing rate, it was altered between scenarios. For example, between modelled scenarios lambing rate was either 'consistent' at 132% for all flocks or 'breed specific' and adjusted to be lower for Merino-Romney crossbred flocks to reflect 2017/18 commercial farm survey data for each parent breed. Otherwise these production parameters were maintained between the breeds.

It is unlikely that the findings would be directly applicable to all New Zealand commercial sheep farmers and caution should be taken when extrapolating results to regions and farm systems other than those modelled. There is currently no published industry data available to validate the accuracy of model output for the specific scenarios investigated. Ewe wastage data are currently being collected from several New Zealand research ewe flocks (Griffiths *et al.*, 2017) and in future this data can be compared with the results from Chapter Three. There was insufficient data on terminal sire use on individual New Zealand farms to indicate how it is influenced by purebred ewe lamb requirements or the impact of their use on operating profit. Crossbreeding using Merino sires with a Romney ewe flock to transition to a Merino-Romney flock producing wool with lower fibre diameter in the North Island has gained commercial interest in recent years due to changes in the value of mid-micron wool (BakerAg, 2019). However, there was no available industry data on the changes in production, energy demand, and profit occurring during the breed change period or the production and profit of an appropriately sized ¾M¼R flock in the North Island with which the model output can be compared. Therefore, although the information provided from this analysis is valuable for farmer decision making and aligns with industry data, the applicability to a specific farming situation is limited.

6.3.4 Assumptions

This modelling research was based around assumptions informing the behaviour of the modelled system. Where possible, industry survey averages and published experimental data were used directly or as a basis for the assumptions in the modelling of this thesis. However, there were some parameters for which limited or no data were available and this was stated alongside the approach taken in the relevant methods sections of Chapters Three, Four, and Five. For example, although there was published data on annual ewe flock replacement rates, none exists on the requirements for purebred ewe lambs from which to choose replacements (referred to as ‘buffer’ lambs in Chapter Four) which was an important factor in the scope for use of terminal sires to produce crossbred lambs. For example, were 1,000 ewe lambs required as replacement to maintain flock size, a total of 1,300 purebred ewe lambs would be required from which to choose the 1,000 replacement lambs. Conversations with farmers indicated an approximate additional requirement of 30%, therefore, this level of purebred ewe lamb requirements was included in the analysis. Another area with a lack of knowledge was the lambing rate of Merino-Romney crossbred ewes farmed in the North Island which was integral to the analysis in Chapter Five. This study used differing lambing rates in the analysis to compensate for the knowledge gap, i.e. a consistent lambing rate of 132% for all flocks according to the few data points offered in the historic comparison studies vs. varying Merino-Romney lambing rate based on current industry data for their purebred parent breeds. Ideally it would be preferable to have accurate industry data on total purebred ewe lamb requirements from which to choose replacements and production of Merino-Romney crossbred sheep but in this research available data were extrapolated, or varied, in the analysis.

6.3.5 Simulation modelling

Optimisation models are highly suitable for farm planning during a production year, such as determining the optimal mix of stock and feed types on-farm to maximise profit (Kennedy, 1986). It is therefore an appropriate modelling approach for exploration of farm resource allocation (AgInform; Rendel *et al.*, 2013) and feed budgeting (Farmax; Marshall *et al.*, 1991) on New Zealand sheep farms. Optimisation models are usually developed to maximise a specified parameter, i.e. operating profit, within a defined set of constraints (Flichman and Jacquet, 2003), and may be less suited to investigating the impact of a wide range of changes in the sheep production system. A simulation modelling approach, specifically system dynamics, was appropriate for the scenarios investigated in this research as they were focused around exploring profitability implications from changes to flock dynamics including numerous feedback loops, such as flock replacement requirements, and a ewe flock in a transition state (Walters *et al.*, 2016). Development and use of an optimisation model would estimate the optimal scenario for enterprise profit, which is not known when using a simulation model. For example, an optimisation model may have found maximum profit to occur at a certain stage of the transition to a ¾M¼R flock in Chapter Five, with differing sheep sale decisions to what was modelled in this thesis. This could involve the model determining the best culling policy for the whole Romney and ½M½R ewe flocks which maybe earlier or later in the breed transition period than what was modelled.

The size and complexity of dynamic models increase exponentially with increases in numbers of states and decision variables (Kennedy, 1986). The model developed in this study had numerous feedback loops, inter-connected components, and non-linearities in order to effectively explore the chosen scenarios. Therefore, it is possible that an optimisation model may struggle to find the global maximum profit for the scenarios, and instead identify local optima among the large set of potential solutions. Although there are mitigation methods for avoiding this 'curse of dimensionality', they may involve reducing the numbers of variables in the model and a resulting loss of precision (Kennedy, 1986). Therefore, the system dynamics simulation modelling technique used in this study was appropriate to modelling the scenarios investigated in this research.

6.3.6 Environmental factors

Environmental regulations are a major current issue facing New Zealand farmers, with recent policies limiting nutrient losses to ground and surface water and forthcoming restrictions on greenhouse gas emissions (Beef +Lamb New Zealand, 2020b). The model developed and used in this research does not estimate the environmental impact of changes made, although potential changes in emissions intensity per unit of product were discussed. The largest contributors to nutrient losses in New Zealand pastoral animal production systems are urinary nitrogen and enteric methane which are closely related to feed intake (Decau *et al.*, 2004; Clark *et al.*, 2011). Therefore, changes in feed demand estimated by the model may provide some insight into resultant nutrient losses from different production levels modelled. The research used industry averages and experimental data to inform the model which does not predict outcomes for individual farms. Physical and production input data used could also be utilised in the nutrient budgeting model Overseer, which incorporates data specific to nutrient losses such as soil type and rainfall (Wheeler *et al.*, 2006), to estimate the environmental impact of modelled scenarios. This would be a worthwhile addition to the findings of the current study.

6.4 Implications for farmers

The research has developed and used a bio-economic system-dynamics model of a sheep farming system to provide estimates of changes in production, feed demand, and profitability that could be expected with changes in ewe wastage rates, use of terminal sires, and breed transition to produce higher value wool. The results are relevant to current New Zealand sheep farming and could alleviate some uncertainty for farmers and consultants when making strategic decisions such as changing breeding policies.

Although the New Zealand sheep farming industry is aware of the lower reproductive performance of younger ewes (Beef + Lamb New Zealand, 2013), the effect of flock age on productivity and profit has not previously been quantified in New Zealand. Results from Chapter Three demonstrate the effect on lamb production of greater premature ewe losses (wastage) and the resultant higher proportion of younger replacement ewes in the flock, highlighting the value of ewe retention. Reductions in operating profit from increasing ewe wastage rates quantified in this study indicate to farmers appropriate costs for management practices to mitigate ewe wastage i.e. approximately up to $1,069 for each 1% reduction in wastage achieved. Such mitigation may include providing additional feed and management strategies to improve flock lambing rate as poor reproductive performance has been identified as a major driver of ewe culling contributing to wastage (Griffiths *et al.*, 2017).

Terminal sires are bred with up to 26% of the New Zealand national ewe flock (Beef + Lamb New Zealand Economic Service, 2019a). Results of Chapter Four suggest this proportion could be increased to increase sheep enterprise operating profit. Quantification of how flock annual replacement and lambing rates limit the scope for using terminal sires provided in Figure 4.2 and resulting sheep enterprise operating profit can be compared with farmers' own flocks and terminal sire use. The results suggest that terminal sires are underutilised in New Zealand ewe flocks, however, the sensitivity analysis performed demonstrated how changes in lamb prices have a relatively larger impact on profit than changes in lamb production through use of terminal sires. This identifies price uncertainty as a potential major deterrent to terminal sire breeding. With the outcomes of this research and forecast prices combined, farmers can make informed choices around use of terminal sires in their breeding policies.

The increasing value of mid-micron wool and estimated profit when farming mid-micron wool producing sheep compared with coarse wool producing flocks such as Romney are appealing to New Zealand farmers (Baker Ag, 2019; Hoban, 2020). Results from Chapter Five demonstrate likely large changes in the size of the sheep operations during breed transition, from consuming 60% of total farm feed to consuming up to 82% (i.e. beef cattle feed consumption reduced to as little as 18% of total farm feed), indicating the significant effect that undertaking a breed change strategy would have on farm operations. The reduced cashflow during breed transition may limit debt servicing and capital expenditure during the breed transition period and the overall economic benefit of breed change ranged from no benefit to 26% greater than maintenance of the status quo Romney flock. These results indicate use of Merino sires with a Romney flock to transition to a flock producing wool with a lower fibre diameter diversifies and increases sheep enterprise income, increasing farm operating profit. The results also indicate an appropriate range of Merino-Romney crossbred lamb section intensities of 24% to 35% of Merino-Romney crossbred ewe lambs not retained after each selection event, which may be an appropriate initial assumption for farmers considering a similar breed change strategy. Farmers can include these results in their decision making while also considering remaining uncertainties around lamb and wool prices, Merino-Romney crossbred sheep production, the length of breed transition period they would tolerate, and their desired reductions in wool fibre diameter.

6.4.1 Lamb and wool prices

Lamb prices received by farmers are a major driver of income and profit for New Zealand North Island sheep farming enterprises (Beef + Lamb New Zealand Economic Service, 2019b), therefore the findings of this research are sensitive to lamb price changes. The research modelled sheep farming systems in the 2016/17 and 2017/18 production years and therefore used sheep sale prices from these periods. Since 2016, New Zealand lamb prices have increased each year. i.e. from an export value of 510 c/kg carcass weight in 2015/16 to a forecast value of 773 c/kg carcass weight in 2019/20 (Beef + Lamb New Zealand Economic Service, 2019c), a real value gain of 43% over the five-year period. With higher lamb prices, the impact of ewe wastage on sheep enterprise operating profit, estimated in Chapter Three to be $1,069 per 1% increase in ewe wastage for an average Manawatu North Island Hill Country farm in 2016/17, would have been even larger. Chapter Four explored use of terminal sires to increase lamb production and prices for an average East Coast North Island Hill County farm in 2017/18, the sensitivity analysis performed in this chapter demonstrated how higher lamb prices further increased sheep enterprise profit gains from use of terminal sires. With higher lamb prices, the reduction in lamb income for breed transition scenarios in Chapter Five with lower Merino-Romney crossbred flock lambing rates would change the relative economic benefit of breed change compared with maintaining the status quo Romney flock.

Similarly, prices for mid-micron wool have risen during the past decade, for example, the real value of New Zealand wool with a fibre diameter of 23 µm has risen from $15 /kg clean in 2011 to $21 /kg clean in 2019 (The New Zealand Merino Company, 2019). During the same time the value of coarse wool has decreased to where many producers consider shearing a welfare necessity rather than source of revenue (Bootsma and Searle, 2019). The breed transition analysis in Chapter Five used five-year average values from 2014 to 2019 to inform wool prices in the model which may not reflect current or future prices. Higher mid-micron wool prices such as those received by farmers in 2018/19 would increase the economic benefit of making the breed change compared with continued production of coarse wool. Lamb and wool prices are two of numerous uncertainties for farmers considering strategic changes such as those examined in this research which should be included in their decision making.

6.5 Future use of model

The bio-economic system-dynamics model developed was a 'skeleton' model, where input data can change to investigate scenarios such as a flock breed change for a specific farm or type of farm (McCown and Parton, 2006). It was not envisaged that the model will be used as a tactical decision support tool for within-production year decision making, but can be utilised to inform strategic, farm system level decision making and possibly adapted for scenarios not explored in this research. Several sheep research questions outside the scope of this research could be addressed using the current model, such as the implications of varying proportions of ewes having their maiden lambing at around one year old. The model could be adapted to simulate other small ruminant production systems, for example, could model goat production systems by setting the average fleece weight to zero. The beef cattle herd dynamics could be added to the model in the future to explore effects of system changes across the whole sheep and beef farm.

6.6 Overall conclusion

Most New Zealand sheep farming enterprises derive the majority of their income from sales of animals for meat, i.e. income from sales of lambs and cull ewes make up 46.2% of North Island Hill Country total sheep and beef gross farm income (Beef + Lamb New Zealand Economic Service, 2019b), and 92% of sheep meat produced in New Zealand is exported (Morris and Dymond, 2013). The productivity of New Zealand farmers has increased in the last 30 years, with national average lambing rate increasing from 101% in 1990 to 132% by 2018, (Beef + Lamb New Zealand Economic Service, 2019a; Davidson, 2012), but the range of operating profit achieved across New Zealand sheep and beef farms indicates the potential for increases in production and profit amongst many farms. Ewe wastage, use of terminal sires, and a breed transition to produce higher value wool are issues currently pertinent to the profitability of New Zealand sheep farm enterprises. Associated changes have the potential to improve sheep enterprise profitability through reducing lamb production losses caused by ewe wastage, production of crossbred lambs with faster growth rates to be sold when per kg prices are higher through use of terminal sires, and production of wool with a lower fibre diameter to be sold for higher prices.

The bio-economic system-dynamics sheep farming model developed to explore these issues was novel in its inclusion of the effect of flock age on productivity, incorporation of multiple feedback loops within the flock, and modelling inter-year changes during a transition period. The results provide information beneficial to the New Zealand sheep farming industry and farmer decision making.

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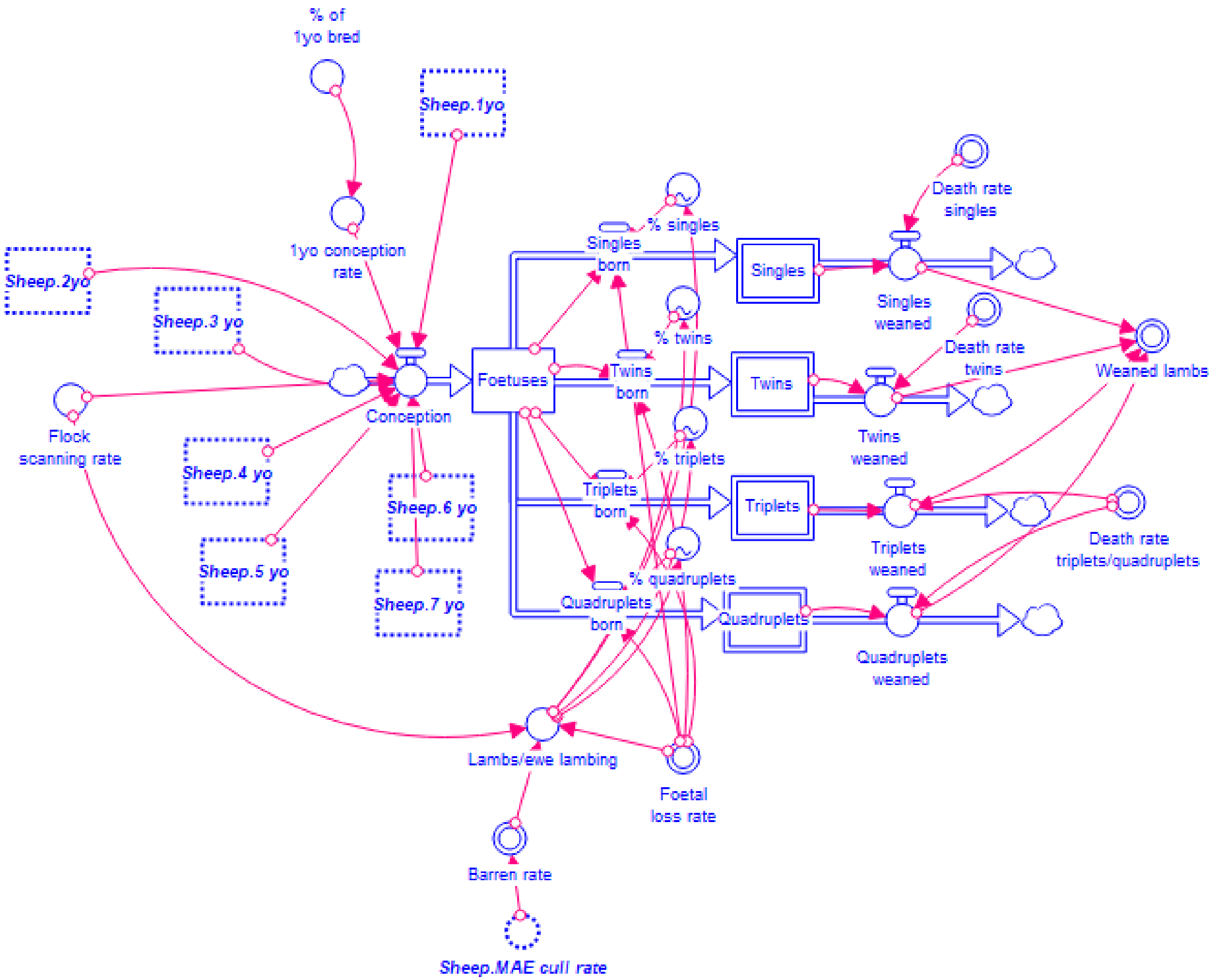
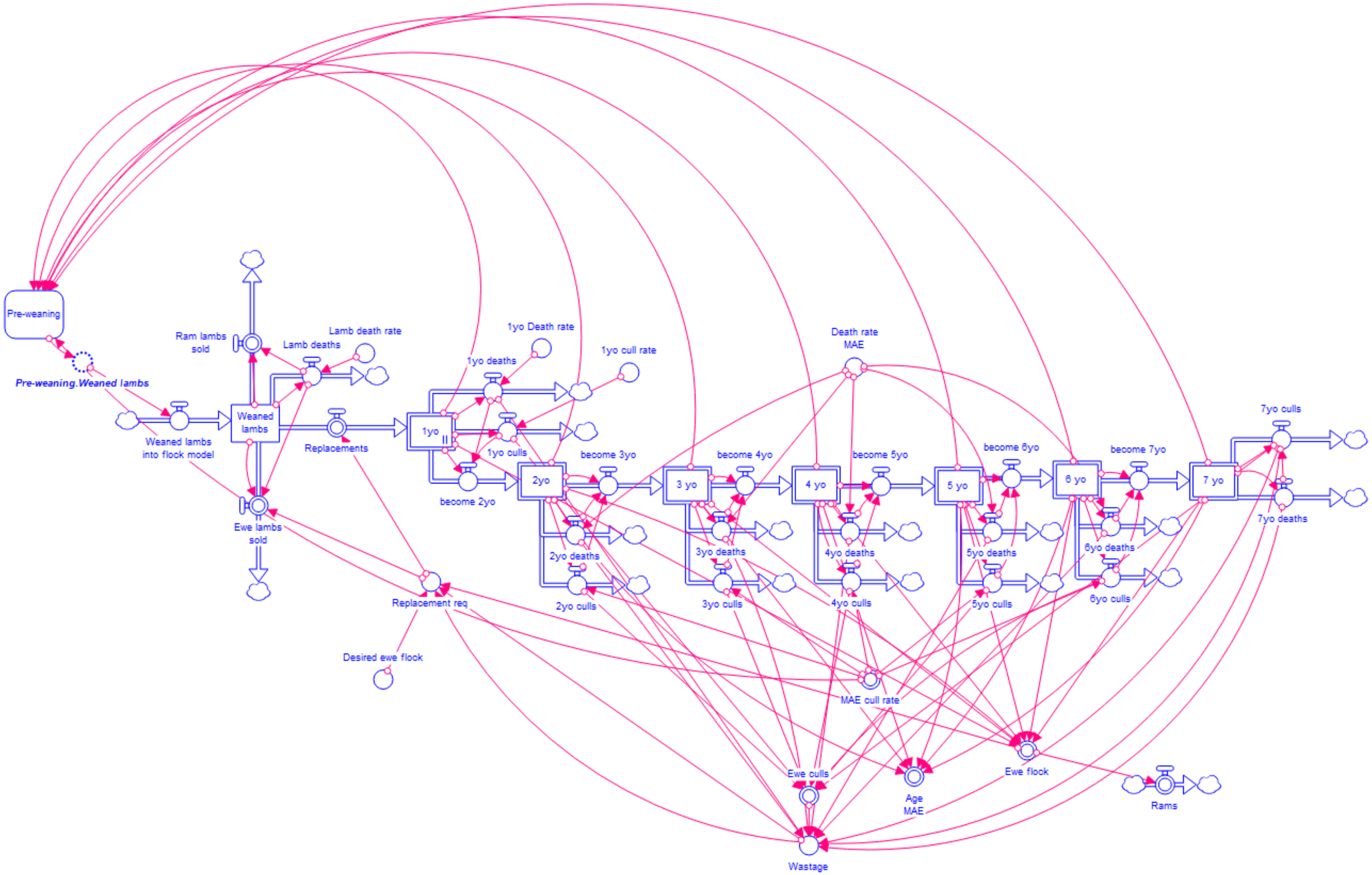
Appendix One: Screenshot of flock dynamics model used in Chapter Three




Pre-weaning
Pre-weaning.Weaned lambs
Weaned lambs into flock model
Ram lambs sold
Lamb deaths
Lamb death rate
Weaned lambs
Ewe lambs sold
Replacements
Replacement req
Desired ewe flock
1yo
1yo deaths
1yo Death rate
1yo cull rate
1yo culls
become 2yo
2yo
become 3yo
2yo deaths
2yo culls
3 yo
become 4yo
3yo deaths
3yo culls
4 yo
become 5yo
4yo deaths
4yo culls
Death rate MAE
5 yo
become 6yo
5yo deaths
5yo culls
6 yo
become 7yo
6yo deaths
6yo culls
7 yo
7yo culls
7yo deaths
MAE cull rate
Ewe culls
Age MAE
Ewe flock
Rams
Wastage

Appendix Two: Glossary for equations

Term	Units	Definition
% culled at tailing	%	Proportion of cull ewes culled at tailing rather than weaning (where tailing occurs eight weeks after the start of lambing)
% lambs prime	%	Proportion of lambs sold prime
% MAE to Merino	%	Proportion of mature ewes (aged two to seven years) bred with Merino sires
% Sheep SU	%	Proportion of total farm feed (stock units) consumed by sheep
% singles	%	Proportion of lambs born as singles
% to Terminal	%	Proportion of mature ewes (aged two to seven years) bred with terminal sires
(sold) lambs a	head	Group of sold maternal lambs
.		Indicates which component module the equation/parameter was from
_		Separates words in label
1&2yo cull price	$/head	Price for one and two-year old cull ewes
10mo		Ten months old
1X		1/2 Merino 1/2 Romney crossbred
1yo	head	One-year old ewes
1yo Culls	head	Ewes culled annual from that stock class
1yo Deaths	head	Ewes dying annual from that stock class
2X		3/4 Merino 1/4 Romney crossbred
6mo ??		Choosing to shear lambs on-farm at shearing
Activity		Relating to type of country (1 for hill country)
Age	years	
Age MAE	years	Average age of ewe flock (one to seven-year old ewes)
Animal health	$ /stock unit	Animal health costs
April ME	MJ /month	Metabolisable energy available for sheep from pasture for the month of April
April ME req	MJ /month	Energy demand of all sheep in April
April PGR	kg dry matter (DM) /ha/day	April pasture growth rate
April qual	MJ ME/kg DM (dry matter)	Pasture quality (energy content) for that month
Ave 1X lamb FD	micron	Average lamb fibre diameter pre-Sort10mo
Bal April	MJ	Cumulative balance of metabolisable energy
Barren rate	%	Ewes not pregnant at scanning
Become 2yo	head	The INFLOW of ewes into the subsequent flock age class
Birth weight	kg	
Breed 1yo 1or2 months later?		Choose how long after start of mature ewe lambing the 1yo ewes will start lambing
Carcass WT	kg	Empty carcass weight
Cold		0 if sheep not under cold stress
Conception	head	INFLOW of foetuses
COS per ha	$/ha	Cash operating surplus on a per hectare basis
Cull all	sheep	Culling all f flock if these conditions met
Cull rate	%	Proportion of sheep in stock class culled annually
Cull rate exclu barren	%	Ewe flock culling rate excluding barren ewes
Death rate	%	Proportion of sheep in stock class dying annually
Desired ewe flock	head	Size of ewe flock set by user
Dressing %	%	Carcass dressing out rate
Eaten 1	MJ/fortnight	Energy consumed by sheep according to their energy requirements
Effective ha	ha	Combined area of pasture, forage, and crops on-farm

Eradicate	sheep	Culling all of flock if size below this threshold (and other conditions met)
Ewe lambs sold	head	Weaned ewe lambs excluding those retained as replacements
F 1	MJ /fortnight	Energy requirements of all sheep for that fortnight after start of lambing
FB 1		Cumulative fortnightly feed balance
FD	Micron µm	Fibre diameter
Feed adjustment	%	In place of utilisation
Flush length	days	Length of time for pre-breeding liveweight gain
Flush??		1 if ewes gain weight prior to breeding
Foetal loss rate	%	Foetuses lost between scanning and birth
Foetuses	head	Lamb foetuses at scanning
FT 1	MJ	Transfer of feed from one fortnight to another
FWE	$/stock unit	Farm working expenses (exclude tax, interest, rent, depreciation)
GFW	kg	Greasy fleece weight
GR		Choice of which pasture growth rate curve to use
GRAPH		Where parameter used in model depends on another input parameter (x, y)
Growth rate	kg/day	Growth rate of lambs post-weaning
INFLOW		Entering a stock
INIT		Initial value of stock
Italics & grey		Units for equations
kg wool +/- 2 micron	kg	Wool from 10mo shearing with fibre diameter within two micron of the average
Lamb income	$	Income from sales of all lambs
Lambing date		Choice of which month feed supply
Lambing rate	%	Lambs weaned per ewe presented for breeding
Lambs a 5	MJ /fortnight	Energy demand of group of lambs in fortnight 5 after start of lambing
Lambs from 1yo sale LW	kg	Lambs born to 1yo ewes' liveweight at sale
Lambs terminal singles 5	MJ /fortnight	Energy demand of group of lambs in fortnight 5 after start of lambing
Lambs/ewe lambing	%	Rate of lambs born from the ewe flock (excluding barren ewes). Used to determine proportion of lambs for each birth rank
Leave	weeks after weaning	When that group of lambs was sold
Length of cold	days	Time the ewe flock experiences cold stress
Loss rate	%	Death rate of lambs between birth and weaning
LW	kg	Liveweight
LW flushing	kg	Liveweight of ewes aged two to seven during flushing
LWC		Liveweight change
LWC flushing	kg	Liveweight change of ewes aged two to seven during flushing
M/D	MJ MJ/kg DM	Pasture quality
MAE	head	Mixed age ewes (aged two years or older)
MAE kg LWG	kg	Daily liveweight gain
MAE kg LWL	kg	Daily liveweight loss
Maternal lambs	head	Purebred lambs
Maternal singles scan	head	Option to calculate lambs weaned from scanning numbers rather than lambing rate
ME	MJ	Metabolisable energy
ME req	MJ	Total annual energy requirement of this stock class
Multiple		Lamb born as multiple (twin, triplet, etc)

Mutton	$/head	Price for cull ewes aged three years or older
NON-NEGATIVE		The stock cannot be a negative value
OUTFLOW		Leaving a stock
Prime	head	Lamb sold directly to slaughter
Prime on-farm at shearing	days after weaning	Date prime lambs were sold
Prolificacy	%	Rate of lambs weaned from the flock
R		Romney
Rams	head	Rams according to mating ratio
Replacement req	head	Requirement for replacement ewe lambs entering the flock to maintain ewe flock size
Replacements	head	Ewe lambs that will enter the ewe flock as replacements
Scanning culls	head	Ewes culled at scanning
Scanning rate	%	Rate of foetuses at scanning from ewe flock
Shearing	$ /stock unit	Shearing costs
Shearing date	days after weaning	
Single		Lamb born as single
Singles born	head	Single lambs born
Sold lambs	head	All lambs not retained as replacements
Sort10mo cull rate	%	Proportion of Merino-Romney crossbred ewe lambs culled at sorting event at ten months of age
Sortweaning cull rate	%	Proportion of Merino-Romney crossbred ewe lambs culled at sorting event at weaning
Std dev		Standard deviation
Stock income	$	Income from sales of all sheep
Store	head	lamb sold to another farmer to grow for slaughter
Terminal lambs	head	Crossbred lambs from terminal (meat breed) sires
UNIFLOW		IN/OUTFLOWS can only move in one direction
Wastage	head	Premature deaths and culling of ewes (all ewes leaving flock excluding 7yo culling)
Weaned lambs into flock model	head	bringing weaned lambs from Pre-weaning component module into main flock dynamics component module
Weaning age	weeks	Week after start of lambing that lambs from mature ewes (aged two to seven years) are weaned
Weaning culls	head	Ewe culls (excluding scanning culls) occur at weaning
Weaning weight	kg	Liveweight of lambs at weaning
Wool produced at 10mo	kg	Worn shorn at ten months old at wool testing
Wool production <1yo	kg	Wool produced from lambs on-farm at shearing
WT	kg	Weight e.g. birth weight
Z score new average FD		Ratio of standard deviation to average

Appendix Three: Model equations

Equations for Chapter Three

Economics:
"%_lambs_prime" = 0.821 *%*
Animal_health = 5 *$/SU*
COS_per_ha = (Income-Costs)/Feed."Effective_ha" *$*
Expenses = (Expenses_per_Stock_Unit*Sheep_stock_units) *$*
Expenses_per_Stock_Unit = Animal_health+FWE+Shearing *$/SU*
"Expenses/ha" = Costs/Feed."Effective_ha" *$/ha*
FWE = 46.18 *$/SU*
Income = Wool_price*Wool_production.Total_greasy_wool+Stock_income *$*
MAE_SU = 0.12679+0.011357*ME_req.MAE_LW+0.002179*(Prolificacy*100) *SU*
Mutton_price = 61.35 *$/head*
Prime_lamb_price = 87.04 *$/head*
Prolificacy = "Pre-weaning".Weaned_lambs/Sheep.Ewe_flock *%*
Shearing = 5.64 *$/SU*
Sheep_stock_units = Sheep.Ewe_flock*MAE_SU+Sheep.Rams+Sheep.Replacements *SU*
Stock_income = (Sheep.Ram_lambs_sold+Sheep.Ewe_lambs_sold)*Store_Lamb_price*(1-"%_lambs_prime")+(Sheep.Ram_lambs_sold+Sheep.Ewe_lambs_sold)*Prime_lamb_price*"%_lambs_prime"+Sheep.Ewe_culls*Mutton_price *$*
Store_Lamb_price = 73.91 *$/head*
Wool_price = 4.03 *$/head*

Feed:
"Effective_ha" = 423 *ha*
"%_SU_sheep" = 0.632 *%*
April_ME = 8.3*April_PGR*30*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
April_PGR = 10 *kgDM/ha/day*
Aug_ME = 11.5*Aug_PGR*31*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Aug_PGR = 20 *kgDM/ha/day*
Dec_ME = 8.5*Dec_PGR*31*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Dec_PGR = 35 *kgDM/ha/day*
Feb_ME = 7.2*Feb_PGR*28*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Feb_PGR = 15 *kgDM/ha/day*
Feed_adjustment = 0.7 *%*
Jan_ME = 8.2*Jan_PGR*31*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Jan_PGR = 25 *kgDM/ha/day*
July_ME = 9.7*July_PGR*31*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
July_PGR = 10 *kgDM/ha/day*
June_ME = 10*June_PGR*30*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
June_PGR = 10 *kgDM/ha/day*
Mar_ME = 8.5*Mar_PGR*31*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Mar_PGR = 10 *kgDM/ha/day*
May_ME = 9.5*May_PGR*31*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
May_PGR = 15 *kgDM/ha/day*
Nov_ME = 9.8*Nov_PGR*30*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Nov_PGR = 40 *kgDM/ha/day*
Oct_ME = 10*Oct_PGR*31*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Oct_PGR = 45 *kgDM/ha/day*
Sept_ME = 9.9*Sept_PGR*30*Feed_adjustment*"Effective_ha"*"%_SU_sheep" *MJ ME*
Sept_PGR = 30 *kgDM/ha/day*
Total_ME_for_sheep = July_ME+Aug_ME+Sept_ME+Oct_ME+April_ME+May_ME+Nov_ME+Dec_ME+Jan_ME+Feb_ME+Mar_ME+June_ME *MJ ME*

Feed_balance:

Bal_April = Feed.April_ME-Monthly_FD.Apr+Bal_Mar *MJ ME*
Bal_Aug = Feed.Aug_ME-Monthly_FD.Aug+Bal_Jul *MJ ME*
Bal_Dec = Feed.Dec_ME-Monthly_FD.Dec+Bal_Nov *MJ ME*
Bal_Feb = Feed.Feb_ME-Monthly_FD.Feb+Bal_Jan *MJ ME*
Bal_Jan = Feed.Jan_ME-Monthly_FD.Jan+Bal_Dec *MJ ME*
Bal_Jul = Feed.July_ME-Monthly_FD.Jul *MJ ME*
Bal_Jun = Feed.June_ME-Monthly_FD.Jun+Bal_May *MJ ME*
Bal_Mar = Feed.Mar_ME-Monthly_FD.Mar+Bal_Feb *MJ ME*
Bal_May = Feed.May_ME-Monthly_FD.May+Bal_April *MJ ME*
Bal_Nov = Feed.Nov_ME-Monthly_FD.Nov+Bal_Oct *MJ ME*
Bal_Oct = Feed.Oct_ME-Monthly_FD.Oct+Bal_Sept *MJ ME*
Bal_Sept = Feed.Sept_ME-Monthly_FD.Sept+Bal_Aug *MJ ME*

ME_req:
"1y_wool_GFW" = 3.2 *kg*
"1yo_LW" = MAE_LW*0.70 *kg*
"1yo_ME_LWG" = 55*(MAE_LW-"1yo_LW") *MJ ME*
"1yo_ME_Maintenance" = ((0.28*(MEAN("1yo_LW", MAE_LW)^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(0))) *MJ ME*
"1yo_ME_req" = ("1yo_wool_ME"+"1yo_ME_Maintenance"*365+"1yo_ME_LWG")*Sheep."1yo" *MJ ME*
"1yo_wool_ME" = 0.13*("1y_wool_GFW"*1000/365-6)+0.13*("6m_wool_GFW"*1000/365-6) *MJ ME*
"6m_wool_GFW" = 1.5 *kg*
Activity = 1
Carcass_WT = 18 *kg*
Cold = 0
Dressing_% = 0.5 *%*
Flush_?? = 1
Flush_Length = 42 *days*
Length_of_cold = 0 *days*
"M/D" = *10 MJME/kgDM*
MAE_kg_LWG = 0.1 *kg*
MAE_kg_LWL = 0.15 *kg*
MAE_Length_LWL = 28 *days*
MAE_LW = 65 *kg*
MAE_ME_LWC = (IF(Flush_??=1)THEN(55*MAE_kg_LWG*Flush_Length)ELSE(0))+MAE_kg_LWL*(-35)*MAE_Length_LWL *MJ ME*
MAE_ME_Maintenance = ((0.28*(MAE_LW^0.75)*EXP(-0.03*Sheep.Age_MAE))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(0))) *MJ ME*
MAE_ME_req =
(MAE_ME_LWC++MAE_ME_Maintenance*365+MAE_ME_Maintenance*(IF(Cold=1)THEN(0.2*Length_of_cold)ELSE(0))+MAE_ME_Wool*365)*(Sheep.Ewe_flock-Sheep."1yo"-Weaning_culls-Scanning_culls)+(Weaning_culls*((Weaning_age*7)*(MAE_ME_Maintenance+MAE_ME_Wool)+MAE_kg_LWL*MAE_Length_LWL))+Scanning_culls*((MAE_ME_Wool+MAE_ME_Maintenance)*287+MAE_ME_LWC) *MJ ME*
MAE_ME_Wool = 0.13*(Wool_production.Ave_wool_GFW_MAE*1000/365-6) *MJ ME*
ME_gestation = ("Pre-weaning".Singles*Single_ME_req_gestation+("Pre-weaning".Twins*Multiple_ME_req_gestation)+("Pre-weaning".Triplets*Multiple_ME_req_gestation/2)+("Pre-weaning".Quadruplets*Multiple_ME_req_gestation/2))*(1+"Pre-weaning".Foetal_loss_rate) *MJ ME*
ME_Lactation = ("Pre-weaning".Singles*Single_ME_req_lactation+("Pre-weaning".Twins*Multiple_ME_req_lactation/2*1.35)+("Pre-weaning".Triplets*Multiple_ME_req_lactation/3*1.45)+("Pre-weaning".Quadruplets*Multiple_ME_req_lactation/4*1.45)) *MJ ME*
Multiple_birth_weight = 4.5 *kg*
Multiple_ME_req_gestation = GRAPH(Multiple_birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJ ME*
Multiple_ME_req_lactation = -1808+51.4*Multiple_Weaning_weight+134.7*Weaning_age *MJ ME*

Multiple_prime_growth_rate = 0.11 *g/day*
Multiple_prime_lamb_ME_req = (Carcass_WT/Dressing_%-Multiple_Weaning_weight)*55+((((0.28*(MEAN(Multiple_Weaning_weight, Carcass_WT/Dressing_%)^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(0))))*((Carcass_WT/Dressing_%-Multiple_Weaning_weight)/Multiple_prime_growth_rate)) *MJ ME*
Multiple_store_growth_rate = 0.08 *g/day*
Multiple_store_lamb_ME_req = Multiple_store_growth_rate*Stores_leave*55+(((0.28*(MEAN(Multiple_Weaning_weight, (Multiple_store_growth_rate*Stores_leave+Multiple_Weaning_weight))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))))*Stores_leave *MJ ME*
Multiple_Weaning_weight = 28 *kg*
Prime_lambs_ME_req = Single_prime_lamb_ME_req*("Pre-weaning".Singles*(1-"Pre-weaning".Death_rate_singles)-Sheep.Replacements/2)*Economics."%_lambs_prime"+Multiple_prime_lamb_ME_req*("Pre-weaning".Twins*(1-"Pre-weaning".Death_rate_twins)-Sheep.Replacements/2)*Economics."%_lambs_prime"+Multiple_prime_lamb_ME_req*(("Pre-weaning".Quadruplets+"Pre-weaning".Triplets)*(1-"Pre-weaning"."Death_rate_triplets/quadruplets"))*Economics."%_lambs_prime" *MJ ME*
Ram_Age = 4 *years*
Ram_LW = 70 *kg*
Ram_ME_Maintenance = (((0.28*(Ram_LW^0.75)*EXP(-0.03*Ram_Age))/(0.02*"M/D"+0.5))*(IF(Activity=1)THEN(1.1)ELSE(0))*1.15) *MJ ME*
Ram_ME_req = (Ram_ME_Maintenance*365+Ram_wool_ME*365+IF(Cold=1)THEN(Ram_ME_Maintenance*0.2*Length_of_cold)ELSE(0))*Sheep.Rams *MJ ME*
Ram_wool_ME = 0.13*(Wool_production.Ave_wool_GFW_MAE*1000/365-6) *MJ ME*
Replacements_ME_req = (("1yo_LW"-Single_Weaning_weight)*55+(((0.28*(MEAN(Single_Weaning_weight, "1yo_LW")^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))))*(365-Weaning_age*7))*Sheep.Replacements *MJ ME*
Scanning_culls = ROUND(Sheep.Ewe_flock*"Pre-weaning".Barren_rate) *sheep*
Single_Birth_weight = 6 *kg*
Single_ME_req_gestation = GRAPH(Single_Birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJ ME*
Single_ME_req_lactation = -1808+51.4*Single_Weaning_weight+134.7*Weaning_age *MJ ME*
Single_prime_growth_rate = 0.15 *g/day*
Single_prime_lamb_ME_req = (Carcass_WT/Dressing_%-Single_Weaning_weight)*55+((((0.28*(MEAN(Single_Weaning_weight, Carcass_WT/Dressing_%)^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))))*((Carcass_WT/Dressing_%-Single_Weaning_weight)/Single_prime_growth_rate)) *MJ ME*
Single_store_growth_rate = 0.09 *g/day*
Single_store_lamb_ME_req = Single_store_growth_rate*Stores_leave*55+(((0.28*(MEAN(Single_Weaning_weight, (Single_store_growth_rate*Stores_leave+Single_Weaning_weight))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))))*Stores_leave *MJ ME*
Single_Weaning_weight = 30 *kg*
Sold_lambs_ME_req = Store_lambs_ME_req+Prime_lambs_ME_req *MJ ME*
Store_lambs_ME_req = Single_store_lamb_ME_req*("Pre-weaning".Singles*(1-"Pre-weaning".Death_rate_singles)-Sheep.Replacements/2)*(1-Economics."%_lambs_prime")+Multiple_store_lamb_ME_req*("Pre-weaning".Twins*(1-"Pre-weaning".Death_rate_twins)-Sheep.Replacements/2)*(1-Economics."%_lambs_prime")+Multiple_store_lamb_ME_req*(("Pre-weaning".Quadruplets+"Pre-weaning".Triplets)*(1-"Pre-weaning"."Death_rate_triplets/quadruplets"))*(1-Economics."%_lambs_prime") *MJ ME*
Stores_leave = 36 *weeks after weaning*

Total_ME_req =
Ram_ME_req+"1yo_ME_req"+MAE_ME_req+ME_Lactation+ME_gestation+Replacements_ME_req+Sold_lambs_ME_req *MJ ME*
Weaning_age = 12 *weeks after weaning*
Weaning_culls = IF((Sheep.Ewe_flock*Sheep.MAE_cull_rate)-Scanning_culls)>0THEN((Sheep.Ewe_flock*Sheep.MAE_cull_rate)-Scanning_culls)ELSE(0) *sheep*

Monthly_FD:
Apr =
ME_req.Ram_ME_req/12+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*30*("Y2-7"-ME_req.Weaning_culls)+LWG/2*("Y2-7"-ME_req.Weaning_culls) *MJ ME*
Aug =
ME_req.Ram_ME_req/12+ME_req.ME_gestation*.631+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*31*("Y2-7"-ME_req.Weaning_culls-ME_req.Scanning_culls) *MJ ME*
Dec =
ME_req.Ram_ME_req/12+ME_req.Store_lambs_ME_req+ME_req.Prime_lambs_ME_req+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*31*("Y2-7"-ME_req.Weaning_culls) *MJ ME*
Feb =
ME_req.Ram_ME_req/12+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*28*("Y2-7"-ME_req.Weaning_culls) *MJ ME*
Jan =
ME_req.Ram_ME_req/12+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*31*("Y2-7"-ME_req.Weaning_culls) *MJ ME*
Jul =
ME_req.Ram_ME_req/12+ME_req.ME_gestation*.369+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*31*("Y2-7"-ME_req.Weaning_culls-ME_req.Scanning_culls) *MJ ME*
Jun =
ME_req.Ram_ME_req/12+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*30*("Y2-7"-ME_req.Weaning_culls)
LWG = (IF(ME_req.Flush_??=1)THEN(55*ME_req.MAE_kg_LWG*ME_req.Flush_Length)ELSE(0))
LWL = ME_req.MAE_kg_LWL*(-35)*ME_req.MAE_Length_LWL *MJ ME*
Mar =
ME_req.Ram_ME_req/12+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*31*("Y2-7"-ME_req.Weaning_culls)+LWG/2*("Y2-7"-ME_req.Weaning_culls) *MJ ME*
May =
ME_req.Ram_ME_req/12+ME_req.Replacements_ME_req/9+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*31*("Y2-7"-ME_req.Weaning_culls) *MJ ME*
Nov =
ME_req.Ram_ME_req/12+ME_req.ME_Lactation*.406+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*30*"Y2-7"+"Y2-7"*LWL/3 *MJ ME*
Oct =
ME_req.Ram_ME_req/12+ME_req.ME_Lactation*.317+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*31*"Y2-7"+"Y2-7"*LWL/3 *MJ ME*
Sept =
ME_req.Ram_ME_req/12+ME_req.ME_Lactation*.277+ME_req."1yo_ME_req"/12+(ME_req.MAE_ME_Maintenance+ME_req.MAE_ME_Wool)*30*"Y2-7"+LWL/3*"Y2-7" *MJ ME*
Total_req = Jul+Aug+Sept+Oct+Nov+Dec+Jan+Feb+Mar+Apr+May+Jun *MJ ME*
"Y2-7" = Sheep.Ewe_flock-Sheep."1yo" *sheep*

Sheep:
"1yo"(t) = "1yo"(t - dt) + (Replacements - "1yo_culls" - become_2yo - "1yo_deaths") * dt {NON-NEGATIVE} *sheep*

INIT "1yo" = 320 *sheep*
INFLOWS:
Replacements = Replacement_req {UNIFLOW} *sheep/year*
OUTFLOWS:
"1yo_culls" = "1yo_cull_rate"*"1yo" {UNIFLOW} *sheep/year*
"1yo_deaths" = "1yo_Death_rate"*"1yo" {UNIFLOW} *sheep/year*
"2yo"(t) = "2yo"(t - dt) + (become_2yo - become_3yo - "2yo_deaths" - "2yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "2yo" = 306 *sheep*
INFLOWS:
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
"2yo_deaths" = "2yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"2yo_culls" = "2yo"*MAE_cull_rate {UNIFLOW} *sheep/year*
"3_yo"(t) = "3_yo"(t - dt) + (become_3yo - become_4yo - "3yo_deaths" - "3yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "3_yo" = 285 *sheep*
INFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
"3yo_deaths" = "3_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"3yo_culls" = "3_yo"*MAE_cull_rate {UNIFLOW} *sheep/year*
"4_yo"(t) = "4_yo"(t - dt) + (become_4yo - become_5yo - "4yo_deaths" - "4yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "4_yo" = 265 *sheep*
INFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
"4yo_deaths" = "4_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"4yo_culls" = MAE_cull_rate*"4_yo" {UNIFLOW} *sheep/year*
"5_yo"(t) = "5_yo"(t - dt) + (become_5yo - become_6yo - "5yo_deaths" - "5yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "5_yo" = 245 *sheep*
INFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
"5yo_culls" = MAE_cull_rate*"5_yo" {UNIFLOW} *sheep/year*
"6_yo"(t) = "6_yo"(t - dt) + (become_6yo - become_7yo - "6yo_deaths" - "6yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "6_yo" = 255 *sheep*
INFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep /year*
OUTFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
"6yo_deaths" = "6_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"6yo_culls" = MAE_cull_rate*"6_yo" {UNIFLOW} *sheep/year*
"7_yo"(t) = "7_yo"(t - dt) + (become_7yo - "7yo_deaths" - "7yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "7_yo" = 203 *sheep*
INFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep /year*
OUTFLOWS:
"7yo_deaths" = "7_yo"*0.15 {UNIFLOW} *sheep/year*
"7yo_culls" = "7_yo"-"7yo_deaths" {UNIFLOW} *sheep/year*

Weaned_lambs(t) = Weaned_lambs(t - dt) + (Weaned_lambs_into_flock_model - Ram_lambs_sold - Replacements - Ewe_lambs_sold - Lamb_deaths) * dt {NON-NEGATIVE} sheep
INIT Weaned_lambs = 0 sheep
INFLOWS:
Weaned_lambs_into_flock_model = "Pre-weaning".Weaned_lambs {UNIFLOW} sheep/year
OUTFLOWS:
Ram_lambs_sold = Weaned_lambs*0.5-(Lamb_deaths*0.5) {UNIFLOW} sheep/year
Replacements = Replacement_req {UNIFLOW} sheep/year
Ewe_lambs_sold = (Weaned_lambs*0.5)-(Lamb_deaths*0.5)-Replacement_req {UNIFLOW} sheep/year
Lamb_deaths = Weaned_lambs*Lamb_death_rate {UNIFLOW} sheep/year
Rams = ROUND(Ewe_flock/100) {UNIFLOW} sheep/year
"1yo_cull_rate" = 0.005 %
"1yo_Death_rate" = 0.005 %
Age_MAE = ("2yo"*2+"3_yo"*3+"4_yo"*4+"5_yo"*5+("6_yo"+"7_yo")*6)/("2yo"+"3_yo"+"4_yo"+"5_yo"+"6_yo"+"7_yo") years
Death_rate_MAE = 0.04 %
Desired_ewe_flock = 1879 sheep
Ewe_culls = "1yo_culls"+"2yo_culls"+"3yo_culls"+"4yo_culls"+"5yo_culls"+"6yo_culls"+"7yo_culls" sheep
Ewe_flock = "7_yo"+"6_yo"+"5_yo"+"4_yo"+"3_yo"+"2yo"+"1yo" sheep
Lamb_death_rate = 0.01 %
MAE_cull_rate = 0.153 %
Replacement_req = IF((Ewe_flock+Wastage+"7yo_culls")<Desired_ewe_flock)THEN(Desired_ewe_flock-Ewe_flock+Wastage+"7yo_culls")ELSE(Wastage+"7yo_culls") sheep
Wastage = "2yo_deaths"+"3yo_deaths"+"4yo_deaths"+"5yo_deaths"+"1yo_deaths"+"6yo_deaths"+"7yo_deaths"+Ewe_culls-"7yo_culls" sheep

Wool_production:
"\"4.5y_GFW" = (Sheep."4_yo"*(1-Sheep.MAE_cull_rate*0.8))*(Ave_wool_GFW_MAE+0.284) kg
"\"5.5y_GFW" = (Sheep."5_yo"*(1-Sheep.MAE_cull_rate*0.8))*(Ave_wool_GFW_MAE+0.054) kg
"\"6.5y_GFW" = (Sheep."6_yo"*(1-Sheep.MAE_cull_rate*0.8))*(Ave_wool_GFW_MAE-0.136) kg
"\"7.5y_GFW" = (Sheep."7_yo"*(1-Sheep.MAE_cull_rate*0.8))*(Ave_wool_GFW_MAE-0.496) kg
"1.5y_GFW" = (Ave_wool_GFW_MAE-0.225)*Sheep."1yo" kg
"2.5y_GFW" = (Ave_wool_GFW_MAE+0.094)*(Sheep."2yo"*(1-Sheep.MAE_cull_rate*0.8)) kg
"3.5y_GFW" = (Sheep."3_yo"*(1-Sheep.MAE_cull_rate*0.8))*(Ave_wool_GFW_MAE+0.424) kg
"6m_GFW" = IF("6mo_??"=1)THEN((Ave_wool_GFW_MAE-3.5)*(Sheep."1yo"))ELSE(0)+IF("Prime_on-farm_at_shearing">Shearing_date)THEN((Ave_wool_GFW_MAE-3.5)*(Sheep.Ram_lambs_sold+Sheep.Ewe_lambs_sold)*Economics."%_lambs_prime")ELSE(0)+IF(ME_req.Stores_leave>Shearing_date)THEN((Ave_wool_GFW_MAE-3.5)*(Sheep.Ram_lambs_sold+Sheep.Ewe_lambs_sold)*(1-Economics."%_lambs_prime"))ELSE(0) kg
"6mo_??" = 1
Ave_wool_GFW_MAE = 6 kg
"Prime_on-farm_at_shearing" = (ME_req.Carcass_WT/ME_req.Dressing_%-MEAN(ME_req.Single_Weaning_weight, ME_req.Multiple_Weaning_weight))/MEAN(ME_req.Single_prime_growth_rate, ME_req.Multiple_prime_growth_rate)
Shearing_date = 35 weeks after start of lambing
Total_greasy_wool = "6m_GFW"+"1.5y_GFW"+"2.5y_GFW"+"3.5y_GFW"+"\"4.5y_GFW"+"\"5.5y_GFW"+"\"6.5y_GFW"+Sheep.Rams*Ave_wool_GFW_MAE kg

"Pre-weaning":
Foetuses(t) = Foetuses(t - dt) + (Conception - Twins_born - Triplets_born - Singles_born - Quadruplets_born) * dt {NON-NEGATIVE} sheep
INIT Foetuses = 0 sheep

INFLOWS:
Conception =
"1yo_conception_rate"*Sheep."1yo"+Flock_scanning_rate*(Sheep."2yo"*0.85+Sheep."3_yo"*0.97+Sheep."4_yo"*1.04+Sheep."5_yo"*1.09+Sheep."6_yo"*1.06+Sheep."7_yo"*0.99) {UNIFLOW} *sheep/year*
OUTFLOWS:
Twins_born = (Foetuses*(1-Foetal_loss_rate))*"%_twins" {UNIFLOW} *sheep/year*
Triplets_born = (Foetuses*(1-Foetal_loss_rate))*"%_triplets" {UNIFLOW} *sheep/year*
Singles_born = (Foetuses*(1-Foetal_loss_rate))*"%_singles" {UNIFLOW} *sheep/year*
Quadruplets_born = (Foetuses*(1-Foetal_loss_rate))*"%_quadruplets" {UNIFLOW} *sheep/year*
Quadruplets(t) = Quadruplets(t - dt) + (Quadruplets_born - Quadruplets_weaned) * dt {NON-NEGATIVE} *sheep*
INIT Quadruplets = 0 *sheep*
INFLOWS:
Quadruplets_born = (Foetuses*(1-Foetal_loss_rate))*"%_quadruplets" {UNIFLOW} *sheep /year*
OUTFLOWS:
Quadruplets_weaned = Quadruplets*(1-"Death_rate_triplets/quadruplets") {UNIFLOW} *sheep/year*
Singles(t) = Singles(t - dt) + (Singles_born - Singles_weaned) * dt {NON-NEGATIVE} *sheep*
INIT Singles = 0 *sheep*
INFLOWS:
Singles_born = (Foetuses*(1-Foetal_loss_rate))*"%_singles" {UNIFLOW} *sheep/year*
OUTFLOWS:
Singles_weaned = Singles*(1-Death_rate_singles) {UNIFLOW} *sheep/year*
Triplets(t) = Triplets(t - dt) + (Triplets_born - Triplets_weaned) * dt {NON-NEGATIVE} *sheep*
INIT Triplets = 0 *sheep*
INFLOWS:
Triplets_born = (Foetuses*(1-Foetal_loss_rate))*"%_triplets" {UNIFLOW} *sheep/year*
OUTFLOWS:
Triplets_weaned = Triplets*(1-"Death_rate_triplets/quadruplets") {UNIFLOW} *sheep/year*
Twins(t) = Twins(t - dt) + (Twins_born - Twins_weaned) * dt {NON-NEGATIVE} *sheep*
INIT Twins = 0 *sheep*
INFLOWS:
Twins_born = (Foetuses*(1-Foetal_loss_rate))*"%_twins" {UNIFLOW} *sheep/year*
OUTFLOWS:
Twins_weaned = Twins*(1-Death_rate_twins) {UNIFLOW} *sheep/year*
"%_of_1yo_bred" = 1 *%*
"%_quadruplets" = GRAPH("Lambs/ewe_lambing")
(1.000, 0.000), (1.100, 0.000), (1.200, 0.000), (1.300, 0.000), (1.400, 0.000), (1.500, 0.000), (1.600, 0.000), (1.700, 0.010), (1.800, 0.010), (1.900, 0.010), (2.000, 0.010), (2.100, 0.010), (2.200, 0.030), (2.300, 0.040), (2.400, 0.060), (2.500, 0.100) *%*
"%_singles" = GRAPH("Lambs/ewe_lambing")
(1.000, 1.000), (1.100, 0.950), (1.200, 0.800), (1.300, 0.700), (1.400, 0.600), (1.500, 0.500), (1.600, 0.400), (1.700, 0.320), (1.800, 0.280), (1.900, 0.220), (2.000, 0.200), (2.100, 0.180), (2.200, 0.170), (2.300, 0.140), (2.400, 0.120), (2.500, 0.120) *%*
"%_triplets" = GRAPH("Lambs/ewe_lambing")
(1.000, 0.000), (1.100, 0.000), (1.200, 0.000), (1.300, 0.000), (1.400, 0.000), (1.500, 0.000), (1.600, 0.020), (1.700, 0.060), (1.800, 0.070), (1.900, 0.100), (2.000, 0.200), (2.100, 0.290), (2.200, 0.370), (2.300, 0.450), (2.400, 0.460), (2.500, 0.450) *%*
"%_twins" = GRAPH("Lambs/ewe_lambing")
(1.000, 0.000), (1.100, 0.100), (1.200, 0.200), (1.300, 0.300), (1.400, 0.400), (1.500, 0.500), (1.600, 0.600), (1.700, 0.670), (1.800, 0.690), (1.900, 0.660), (2.000, 0.630), (2.100, 0.600), (2.200, 0.510), (2.300, 0.470), (2.400, 0.400), (2.500, 0.390) *%*
"1yo_scanning_rate" = IF("%_of_1yo_bred">0)THEN(0.52)ELSE(0) *%*
Barren_rate = Sheep.MAE_cull_rate/5 *%*
Death_rate_singles = 0.15 *%*
"Death_rate_triplets/quadruplets" = 0.35 *%*
Death_rate_twins = 0.15 *%*
Flock_scanning_rate = 1.5 *%*

Foetal_loss_rate = 0.01 *%*
"Lambs/ewe_lambing" = (Flock_scanning_rate*(1-Foetal_loss_rate-Barren_rate*Flock_scanning_rate))
%
Weaned_lambs = Singles_weaned+Twins_weaned+Triplets_weaned+Quadruplets_weaned *sheep*

Equations for Chapter Four

Economics:
"1&2yo_cull_price" = 109 *$/head*
Animal_health = 5.5 *$/SU*
COS_per_ha = (Income-Expenses)/(Feed.Effective_Ha*Feed."%_sheep_Stock_units") *$/ha*
Expenses = (Expenses_per_SU*Sheep_stock_units) *$*
Expenses_per_SU = Animal_health+FWE+Shearing *$/SU*
"Expenses/ha" = Expenses/Feed. Effective_Ha *$/ha*
FWE = 25.4 *$/SU*
Income = Wool_production.Wool_income+Stock_income *$*
Lamb_income =
ME_req.Sold_lambs_a*Maternal_lambs_price_a+ME_req.Sold_lambs_c*Maternal_lambs_price_c+ME_req.Sold_lambs_d*Maternal_lambs_price_d+Sheep.Terminal_multiples_weaned*Terminal_multiples_price+Sheep.Terminal_singles_weaned*Terminal_singles_price+ME_req.Sold_lambs_b*Maternal_lambs_price_b+Lambs_from_hoggets_price*ME_req.Lambs_from_1yo *$*
Lambs_from_hoggets_price = 76.54 *$/head*
MAE_Stock_Units =
0.12679+0.011357*Fortnightly_feed_demand.MAE_LW_Summer+0.002179*(Prolificacy*100) *SU*
Maternal_lambs_price_a = 87.15 *$/head*
Maternal_lambs_price_b = 98.54 *$/head*
Maternal_lambs_price_c = 76.54 *$/head*
Maternal_lambs_price_d = 0 *$/head*
Mutton_price = 74 *$/head*
Prolificacy =
(Sheep.Terminal_singles_weaned+Sheep.Maternal_Female_multiples_weaned+Sheep.Maternal_Female_singles_weaned+Sheep.Terminal_multiples_weaned)/Sheep.Ewe_flock *%*
Shearing = 4.56 *$/SU*
Sheep_stock_units = Sheep.Ewe_flock*MAE_Stock_Units+Sheep.Rams+Sheep.Replacements *SU*
Stock_income = (Sheep.Ewe_culls-Sheep."1yo_culls"-Sheep."2yo_culls")*Mutton_price+(Sheep."2yo_culls"+Sheep."1yo_culls")*"1&2yo_cull_price"+Lamb_income *$*
Terminal_multiples_price = 87.15 *$/head*
Terminal_singles_price = 88.23 *$/head*

Feed:
"%_sheep_Stock_units" = 0.608 *SU*
Apr_ME = 30*Apr_PGR*Apr_qual*"%_sheep_Stock_units"* Effective_Ha *MJME*
Apr_PGR = GRAPH(GR)
(1.00, 10.000), (2.00, 41.000), (3.00, 29.000), (4.00, 29.000), (5.00, 28.000), (6.00, 25.000), (7.00, 26.000), (8.00, 21.000), (9.00, 14.000), (10.00, 20.000), (11.00, 13.000), (12.00, 5.000), (13.00, 0.000), (14.00, 16.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Apr_qual = 8.3 *MJ ME/kg DM*
Effective_Ha = 549 *ha*
Aug_ME = 31*Aug_PGR*Aug_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Aug_PGR = GRAPH(GR)
(1.00, 20.000), (2.00, 0.000), (3.00, 33.000), (4.00, 14.000), (5.00, 18.000), (6.00, 15.000), (7.00, 32.000), (8.00, 7.000), (9.00, 9.000), (10.00, 11.000), (11.00, 0.000), (12.00, 0.000), (13.00, 0.000), (14.00, 9.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Aug_qual = 11.5 *MJ ME/kg DM*
Dec_ME = 31*Dec_PGR*Dec_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Dec_PGR = GRAPH(GR)
(1.00, 35.000), (2.00, 73.000), (3.00, 37.000), (4.00, 52.000), (5.00, 44.000), (6.00, 60.000), (7.00, 30.000), (8.00, 34.000), (9.00, 19.000), (10.00, 48.000), (11.00, 52.000), (12.00, 12.000), (13.00, 16.000), (14.00, 44.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*

Dec_qual = 8.5 *MJ ME/kg DM*
Feb_ME = 28*Feb_PGR*Feb_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Feb_PGR = GRAPH(GR)
(1.00, 15.000), (2.00, 61.000), (3.00, 30.000), (4.00, 38.000), (5.00, 26.000), (6.00, 35.000), (7.00, 12.000), (8.00, 35.000), (9.00, 14.000), (10.00, 43.000), (11.00, 35.000), (12.00, 7.000), (13.00, 8.000), (14.00, 28.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Feb_qual = 7.2 *MJ ME/kg DM*
Feed_adjustment = .7
GR = 3
Jan_ME = 31*Jan_PGR*Jan_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Jan_PGR = GRAPH(GR)
(1.00, 25.000), (2.00, 59.000), (3.00, 29.000), (4.00, 52.000), (5.00, 38.000), (6.00, 45.000), (7.00, 15.000), (8.00, 36.000), (9.00, 13.000), (10.00, 48.000), (11.00, 42.000), (12.00, 12.000), (13.00, 14.000), (14.00, 36.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day* Jan_qual = 8.2 *MJ ME/kg DM*
Jul_ME = 31*Jul_PGR*Jul_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Jul_PGR = GRAPH(GR)
(1.00, 10.000), (2.00, 24.000), (3.00, 19.000), (4.00, 8.000), (5.00, 12.000), (6.00, 5.000), (7.00, 16.000), (8.00, 3.000), (9.00, 5.000), (10.00, 5.000), (11.00, 0.000), (12.00, 0.000), (13.00, 0.000), (14.00, 5.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Jul_qual = 9.7 *MJ ME/kg DM*
Jun_ME = 30*Ha*Feed_adjustment*"%_sheep_Stock_units"*Jun_qual*Jun_PGR *MJME*
Jun_PGR = GRAPH(GR)
(1.00, 10.000), (2.00, 25.000), (3.00, 18.000), (4.00, 10.000), (5.00, 11.000), (6.00, 5.000), (7.00, 16.000), (8.00, 5.000), (9.00, 5.000), (10.00, 5.000), (11.00, 0.000), (12.00, 0.000), (13.00, 0.000), (14.00, 5.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Jun_qual = 10 *MJ ME/kg DM*
Mar_ME = 31*Mar_PGR*Mar_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Mar_PGR = GRAPH(GR)
(1.00, 10.000), (2.00, 50.000), (3.00, 32.000), (4.00, 39.000), (5.00, 30.000), (6.00, 35.000), (7.00, 21.000), (8.00, 34.000), (9.00, 16.000), (10.00, 31.000), (11.00, 27.000), (12.00, 7.000), (13.00, 7.000), (14.00, 24.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day* Mar_qual = 8.5 *MJ ME/kg DM*
May_ME = 31*May_PGR*May_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
May_PGR = GRAPH(GR)
(1.00, 15.000), (2.00, 32.000), (3.00, 24.000), (4.00, 15.000), (5.00, 20.000), (6.00, 15.000), (7.00, 25.000), (8.00, 8.000), (9.00, 8.000), (10.00, 10.000), (11.00, 3.000), (12.00, 1.000), (13.00, 0.000), (14.00, 9.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day* May_qual = 9.5 *MJ ME/kg DM*
Nov_ME = 30*Nov_PGR*Nov_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Nov_PGR = GRAPH(GR)
(1.00, 40.000), (2.00, 63.000), (3.00, 38.000), (4.00, 52.000), (5.00, 46.000), (6.00, 50.000), (7.00, 51.000), (8.00, 51.000), (9.00, 27.000), (10.00, 41.000), (11.00, 48.000), (12.00, 17.000), (13.00, 20.000), (14.00, 47.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Nov_qual = 9.8 *MJ ME/kg DM*
Oct_ME = 31*Oct_PGR*Oct_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Oct_PGR = GRAPH(GR)
(1.00, 45.000), (2.00, 58.000), (3.00, 47.000), (4.00, 46.000), (5.00, 46.000), (6.00, 55.000), (7.00, 70.000), (8.00, 51.000), (9.00, 37.000), (10.00, 40.000), (11.00, 39.000), (12.00, 24.000), (13.00, 18.000), (14.00, 46.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day* Oct_qual = 10 *MJ ME/kg DM*
Sep_ME = 30*Sep_PGR*Sep_qual*"%_sheep_Stock_units"*Feed_adjustment* Effective_Ha *MJME*
Sep_PGR = GRAPH(GR)
(1.00, 30.000), (2.00, 50.000), (3.00, 47.000), (4.00, 25.000), (5.00, 36.000), (6.00, 40.000), (7.00, 56.000), (8.00, 32.000), (9.00, 30.000), (10.00, 31.000), (11.00, 16.000), (12.00, 15.000), (13.00, 1.000),

(14.00, 25.000), (15.00, 0.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Sep_qual = 9.9 *MJ ME/kg DM*

Feed_balance:
FB_1(t) = FB_1(t - dt) + (- FT_1 - Eaten_1) * dt {NON-NEGATIVE} *MJME*
INIT FB_1 = 0 *MJME*
OUTFLOWS:
FT_1 =
IF(Lambing_date=1)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Oct_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_1 = Fortnightly_feed_demand.F_1 {UNIFLOW} *MJME/fortnight*
FB_10(t) = FB_10(t - dt) + (FT_9 - FT_10 - Eaten_10) * dt {NON-NEGATIVE} *MJME*
INIT FB_10 = 0 *MJME*
INFLOWS:
FT_9 =
IF(Lambing_date=1)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Feb_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_10 =
IF(Lambing_date=1)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Feb_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_10 = Fortnightly_feed_demand.F_10 {UNIFLOW} *MJME/fortnight*
FB_11(t) = FB_11(t - dt) + (FT_10 - FT_11 - Eaten_11) * dt {NON-NEGATIVE} *MJME*
INIT FB_11 = 0 *MJME*
INFLOWS:
FT_10 =
IF(Lambing_date=1)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Feb_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_11 =
IF(Lambing_date=1)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Mar_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_11 = Fortnightly_feed_demand.F_11 {UNIFLOW} *MJME/fortnight*
FB_12(t) = FB_12(t - dt) + (FT_11 - FT_12 - Eaten_12) * dt {NON-NEGATIVE} *MJME*
INIT FB_12 = 0 *MJME*
INFLOWS:
FT_11 =
IF(Lambing_date=1)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Mar_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_12 =
IF(Lambing_date=1)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing

_date=5)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Mar_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_12 = Fortnightly_feed_demand.F_12 {UNIFLOW} *MJME/fortnight*
FB_13(t) = FB_13(t - dt) + (FT_12 - FT_13 - Eaten_13) * dt {NON-NEGATIVE} *MJME*
INIT FB_13 = 0 *MJME*
INFLOWS:
FT_12 =
IF(Lambing_date=1)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Mar_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_13 =
IF(Lambing_date=1)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Apr_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_13 = Fortnightly_feed_demand.F_13 {UNIFLOW} *MJME/fortnight*
FB_14(t) = FB_14(t - dt) + (FT_13 - FT_14 - Eaten_14) * dt {NON-NEGATIVE} *MJME*
INIT FB_14 = 0 *MJME*
INFLOWS:
FT_13 =
IF(Lambing_date=1)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Apr_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_14 =
IF(Lambing_date=1)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Apr_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_14 = Fortnightly_feed_demand.F_14 {UNIFLOW} *MJME/fortnight*
FB_15(t) = FB_15(t - dt) + (FT_14 - FT_15 - Eaten_15) * dt {NON-NEGATIVE} *MJME*
INIT FB_15 = 0 *MJME*
INFLOWS:
FT_14 =
IF(Lambing_date=1)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Apr_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_15 =
IF(Lambing_date=1)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.May_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_15 = Fortnightly_feed_demand.F_15 {UNIFLOW} *MJME/fortnight*
FB_16(t) = FB_16(t - dt) + (FT_15 - FT_16 - Eaten_16) * dt {NON-NEGATIVE} *MJME*
INIT FB_16 = 0 *MJME*
INFLOWS:
FT_15 =
IF(Lambing_date=1)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.May_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:

FT_16 =
IF(Lambing_date=1)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Mar_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_da
te=7)THEN(Feed.May_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_16 = Fortnightly_feed_demand.F_16 {UNIFLOW} *MJME/fortnight*
FB_17(t) = FB_17(t - dt) + (FT_16 - FT_17 - Eaten_17) * dt {NON-NEGATIVE} *MJME*
INIT FB_17 = 0 *MJME*
INFLOWS:
FT_16 =
IF(Lambing_date=1)THEN(Feed.Feb_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Mar_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_da
te=7)THEN(Feed.May_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_17 =
IF(Lambing_date=1)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Mar_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing
_date=5)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jun_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_17 = Fortnightly_feed_demand.F_17 {UNIFLOW} *MJME/fortnight*
FB_18(t) = FB_18(t - dt) + (FT_17 - FT_18 - Eaten_18) * dt {NON-NEGATIVE} *MJME*
INIT FB_18 = 0 *MJME*
INFLOWS:
FT_17 =
IF(Lambing_date=1)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Mar_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing
_date=5)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jun_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_18 =
IF(Lambing_date=1)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Apr_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.May_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jun_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_18 = Fortnightly_feed_demand.F_18 {UNIFLOW} *MJME/fortnight*
FB_19(t) = FB_19(t - dt) + (FT_18 - FT_19 - Eaten_19) * dt {NON-NEGATIVE} *MJME*
INIT FB_19 = 0 *MJME*
INFLOWS:
FT_18 =
IF(Lambing_date=1)THEN(Feed.Mar_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Apr_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.May_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jun_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_19 =
IF(Lambing_date=1)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Apr_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.May_ME)ELSE(0)+IF(Lambi
ng_date=5)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_da
te=7)THEN(Feed.Jun_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_19 = Fortnightly_feed_demand.F_19 {UNIFLOW} *MJME/fortnight*
FB_2(t) = FB_2(t - dt) + (FT_1 - FT_2 - Eaten_2) * dt {NON-NEGATIVE} *MJME*
INIT FB_2 = 0 *MJME*
INFLOWS:
FT_1 =
IF(Lambing_date=1)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Aug_ME)ELSE(0)+IF(Lam
bing_date=3)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_

date=5)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Oct_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_2 =
IF(Lambing_date=1)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Nov_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_2 = Fortnightly_feed_demand.F_2 {UNIFLOW} *MJME/fortnight*
FB_20(t) = FB_20(t - dt) + (FT_19 - FT_20 - Eaten_20) * dt {NON-NEGATIVE} *MJME*
INIT FB_20 = 0 *MJME*
INFLOWS:
FT_19 =
IF(Lambing_date=1)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Jun_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_20 =
IF(Lambing_date=1)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Jul_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_20 = Fortnightly_feed_demand.F_20 {UNIFLOW} *MJME/fortnight*
FB_21(t) = FB_21(t - dt) + (FT_20 - FT_21 - Eaten_21) * dt {NON-NEGATIVE} *MJME*
INIT FB_21 = 0 *MJME*
INFLOWS:
FT_20 =
IF(Lambing_date=1)THEN(Feed.Apr_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Jul_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_21 =
IF(Lambing_date=1)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Jul_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_21 = Fortnightly_feed_demand.F_21 {UNIFLOW} *MJME/fortnight*
FB_22(t) = FB_22(t - dt) + (FT_21 - FT_22 - Eaten_22) * dt {NON-NEGATIVE} *MJME*
INIT FB_22 = 0 *MJME*
INFLOWS:
FT_21 =
IF(Lambing_date=1)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Jul_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_22 =
IF(Lambing_date=1)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Aug_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_22 = Fortnightly_feed_demand.F_22 {UNIFLOW} *MJME/fortnight*
FB_23(t) = FB_23(t - dt) + (FT_22 - FT_23 - Eaten_23) * dt {NON-NEGATIVE} *MJME*
INIT FB_23 = 0 *MJME*
INFLOWS:

FT_22 =
IF(Lambing_date=1)THEN(Feed.May_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Aug_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_23 =
IF(Lambing_date=1)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Aug_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_23 = Fortnightly_feed_demand.F_23 {UNIFLOW} *MJME/fortnight*
FB_24(t) = FB_24(t - dt) + (FT_23 - FT_24 - Eaten_24) * dt {NON-NEGATIVE} *MJME*
INIT FB_24 = 0 *MJME*
INFLOWS:
FT_23 =
IF(Lambing_date=1)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Aug_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_24 =
IF(Lambing_date=1)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Sep_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_24 = Fortnightly_feed_demand.F_24 {UNIFLOW} *MJME/fortnight*
FB_25(t) = FB_25(t - dt) + (FT_24 - FT_25 - Eaten_25) * dt {NON-NEGATIVE} *MJME*
INIT FB_25 = 0 *MJME*
INFLOWS:
FT_24 =
IF(Lambing_date=1)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Sep_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_25 =
IF(Lambing_date=1)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Sep_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_25 = Fortnightly_feed_demand.F_25 {UNIFLOW} *MJME/fortnight*
FB_26(t) = FB_26(t - dt) + (FT_25 - FT_26 - Eaten_26) * dt {NON-NEGATIVE} *MJME*
INIT FB_26 = 0 *MJME*
INFLOWS:
FT_25 =
IF(Lambing_date=1)THEN(Feed.Jun_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Sep_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_26 =
IF(Lambing_date=1)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Jul_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Oct_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_26 = Fortnightly_feed_demand.F_26 {UNIFLOW} *MJME/fortnight*

FB_3(t) = FB_3(t - dt) + (FT_2 - FT_3 - Eaten_3) * dt {NON-NEGATIVE} *MJME*
INIT FB_3 = 0 *MJME*
INFLOWS:
FT_2 =
IF(Lambing_date=1)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Nov_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_3 =
IF(Lambing_date=1)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Nov_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_3 = Fortnightly_feed_demand.F_3 {UNIFLOW} *MJME/fortnight*
FB_4(t) = FB_4(t - dt) + (FT_3 - FT_4 - Eaten_4) * dt {NON-NEGATIVE} *MJME*
INIT FB_4 = 0 *MJME*
INFLOWS:
FT_3 =
IF(Lambing_date=1)THEN(Feed.Aug_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Nov_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_4 =
IF(Lambing_date=1)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Dec_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_4 = Fortnightly_feed_demand.F_4 {UNIFLOW} *MJME/fortnight*
FB_5(t) = FB_5(t - dt) + (FT_4 - FT_5 - Eaten_5) * dt {NON-NEGATIVE} *MJME*
INIT FB_5 = 0 *MJME*
INFLOWS:
FT_4 =
IF(Lambing_date=1)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Dec_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_5 =
IF(Lambing_date=1)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Dec_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_5 = Fortnightly_feed_demand.F_5 {UNIFLOW} *MJME/fortnight*
FB_6(t) = FB_6(t - dt) + (FT_5 - FT_6 - Eaten_6) * dt {NON-NEGATIVE} *MJME*
INIT FB_6 = 0 *MJME*
INFLOWS:
FT_5 =
IF(Lambing_date=1)THEN(Feed.Sep_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=5)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=7)THEN(Feed.Dec_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_6 =
IF(Lambing_date=1)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=3)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambin

g_date=5)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Dec_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_6 = Fortnightly_feed_demand.F_6 {UNIFLOW} *MJME/fortnight*
FB_7(t) = FB_7(t - dt) + (FT_6 - FT_7 - Eaten_7) * dt {NON-NEGATIVE} *MJME*
INIT FB_7 = 0 *MJME*
INFLOWS:
FT_6 =
IF(Lambing_date=1)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Oct_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Dec_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_7 =
IF(Lambing_date=1)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Nov_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jan_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_7 = Fortnightly_feed_demand.F_7 {UNIFLOW} *MJME/fortnight*
FB_8(t) = FB_8(t - dt) + (FT_7 - FT_8 - Eaten_8) * dt {NON-NEGATIVE} *MJME*
INIT FB_8 = 0 *MJME*
INFLOWS:
FT_7 =
IF(Lambing_date=1)THEN(Feed.Oct_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Nov_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jan_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_8 =
IF(Lambing_date=1)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Nov_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jan_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_8 = Fortnightly_feed_demand.F_8 {UNIFLOW} *MJME/fortnight*
FB_9(t) = FB_9(t - dt) + (FT_8 - FT_9 - Eaten_9) * dt {NON-NEGATIVE} *MJME*
INIT FB_9 = 0 *MJME*
INFLOWS:
FT_8 =
IF(Lambing_date=1)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Nov_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_dat
e=7)THEN(Feed.Jan_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
OUTFLOWS:
FT_9 =
IF(Lambing_date=1)THEN(Feed.Nov_ME)ELSE(0)+IF(Lambing_date=2)THEN(Feed.Dec_ME)ELSE(0)+IF(La
mbing_date=3)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambing_date=4)THEN(Feed.Dec_ME)ELSE(0)+IF(Lambin
g_date=5)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date=6)THEN(Feed.Jan_ME)ELSE(0)+IF(Lambing_date
=7)THEN(Feed.Feb_ME)ELSE(0) {UNIFLOW} *MJME/fortnight*
Eaten_9 = Fortnightly_feed_demand.F_9 {UNIFLOW} *MJME/fortnight*
Lambing_date = 1

Fortnightly_feed_demand:
"Cull_rate_exclu._barren" = (Sheep.Ewe_culls-Sheep.Ewe_flock*MEAN(Sheep.Maternal_barren_rate,
Sheep.Terminal_barren_rate))/(Sheep.Ewe_flock-
Sheep.Ewe_flock*MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate)) *%*
"%_Culled_tailing" = .1 *%*
Breed_1yo_1or2_months_later? = 2

F_1 =
ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+ME_req.ME_Lactation*0.084+MAE_Lactation_maintenance/6+IF(Breed_1yo_1or2_months_later?=0)THEN(ME_req.ME_Gestation*0.1188)ELSE(0)+IF(Breed_1yo_1or2_months_later?=1)THEN(ME_req.ME_Gestation*0.1188*(1-Sheep."%_Lambs_from_1yo")+Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.2486)ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)THEN(ME_req.ME_Gestation*0.1188*(1-Sheep."%_Lambs_from_1yo")+Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.098)ELSE(0)
MJME/fortnight
F_10 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_10+Lambs_b_10+Lambs_c_10+Lambs_Terminal_multiples_10+Lambs_Terminal_singles_10+Lambs_from_1yo_10 *MJME/fortnight*
F_11 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_11+Lambs_b_11+Lambs_c_11+Lambs_Terminal_multiples_11+Lambs_Terminal_singles_11+Lambs_from_1yo_11 *MJME/fortnight*
F_12 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26++MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_12+Lambs_b_12+Lambs_c_12+Lambs_Terminal_multiples_12+Lambs_Terminal_singles_12+Lambs_from_1yo_12 *MJME/fortnight*
F_13 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_13+Lambs_b_13+Lambs_c_13+Lambs_Terminal_multiples_13+Lambs_Terminal_singles_13+Lambs_from_1yo_13 *MJME/fortnight*
F_14 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_14+Lambs_b_14+Lambs_c_14+Lambs_Terminal_multiples_14+Lambs_Terminal_singles_14+Lambs_from_1yo_14 *MJME/fortnight*
F_15 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_15+Lambs_b_15+Lambs_c_15+Lambs_Terminal_multiples_15+Lambs_Terminal_singles_15+Lambs_from_1yo_15 *MJME/fortnight*
F_16 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_16+Lambs_b_16+Lambs_c_16+Lambs_Terminal_multiples_16+Lambs_Terminal_singles_16+Lambs_from_1yo_16 *MJME/fortnight*
F_17 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_17+Lambs_b_17+Lambs_c_17+Lambs_Terminal_multiples_17+Lambs_Terminal_singles_17+Lambs_from_1yo_17 *MJME/fortnight*
F_18 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_18+Lambs_b_18+Lambs_c_18+Lambs_Terminal_multiples_18+Lambs_Terminal_singles_18+Lambs_from_1yo_18 *MJME/fortnight*
F_19 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_19+Lambs_b_19+Lambs_c_19+Lambs_Terminal_multiples_19+Lambs_Terminal_singles_19+Lambs_from_1yo_19 *MJME/fortnight*
F_2 =
ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+ME_req.ME_Lactation*0.1304+MAE_Lactation_maintenance/6+IF(Breed_1yo_1or2_months_later?=0)THEN(ME_req.ME_Gestation*0.016)ELSE(0)+IF(Breed_1yo_1or2_months_later?=1)THEN(ME_req.ME_Gestation*0.016*(1-Sheep."%_Lambs_from_1yo")+Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.3609)ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)THEN(ME_req.ME_Gestation*0.016*(1-

Sheep."%_Lambs_from_1yo")+Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.1778)ELSE(0) *MJME/fortnight*
F_20 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_20+Lambs_b_20+Lambs_c_20+Lambs_Terminal_multiples_20+Lambs_Terminal_singles_20+Lambs_from_1yo_20 *MJME/fortnight*
F_21 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_21+Lambs_b_21+Lambs_c_21+Lambs_Terminal_multiples_21+Lambs_Terminal_singles_21+Lambs_from_1yo_21 *MJME/fortnight*
F_22 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_22+Lambs_b_22+Lambs_c_22+Lambs_Terminal_multiples_22+Lambs_Terminal_singles_22+Lambs_from_1yo_22 *MJME/fortnight*
F_23 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+ME_req.ME_Gestation*0.098+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_23+Lambs_b_23+Lambs_c_23+Lambs_Terminal_multiples_23+Lambs_Terminal_singles_23+Lambs_from_1yo_23 *MJME/fortnight*
F_24 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+ME_req.ME_Gestation*0.1778+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_24+Lambs_b_24+Lambs_c_24+Lambs_Terminal_multiples_24+Lambs_Terminal_singles_24+Lambs_from_1yo_24 *MJME/fortnight*
F_25 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_25+Lambs_b_25+Lambs_c_25+Lambs_Terminal_multiples_25+Lambs_Terminal_singles_25+Lambs_from_1yo_25 *MJME/fortnight*
F_26 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Sheep.Maternal_barren_rate, Sheep.Terminal_barren_rate))+ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_26+Lambs_b_26+Lambs_c_26+Lambs_Terminal_multiples_26+Lambs_Terminal_singles_26+Lambs_from_1yo_26 *MJME/fortnight*
F_3 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+ME_req.ME_Lactation*0.1546+MAE_Lactation_maintenance/6+IF(Breed_1yo_1or2_months_later?=1)THEN(Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.1188+ME_req.ME_Lactation_Lambs_from_1yo*0.084)ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)THEN(Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.2486)ELSE(0) *MJME/fortnight*
F_4 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+ME_req.ME_Lactation*0.172+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing")+IF(Breed_1yo_1or2_months_later?=1)THEN(Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.016+ME_req.ME_Lactation_Lambs_from_1yo*0.1304)ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)THEN(Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.3609)ELSE(0) *MJME/fortnight*
F_5 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+IF(ME_req.MAE_weaning_age=8)OR(ME_req.MAE_weaning_age<8)THEN(ME_req.Replacements_ME_req/(52-ME_req.MAE_weaning_age)*2+Lambs_a_5+Lambs_b_5+Lambs_c_5+Lambs_Terminal_multiples_5+Lambs_Terminal_singles_5+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"))ELSE(ME_req.ME_Lactation*0.195+MAE_Lactation_maintenance/6*(1-

"Cull_rate_exclu._barren"*"%_Culled_tailing")+IF(Breed_1yo_1or2_months_later?=1)THEN(ME_req.ME
_Lactation_Lambs_from_1yo*0.1546)ELSE(0))+IF(Breed_1yo_1or2_months_later?=2)THEN(Sheep."%_L
ambs_from_1yo"*ME_req.ME_Gestation*0.1188+ME_req.ME_Lactation_Lambs_from_1yo*0.084)ELSE(
0) *MJME/fortnight*
F_6 =
ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+IF(ME_req.MAE_weaning_age=10)OR(ME_req.M
AE_weaning_age<10)THEN(ME_req.Replacements_ME_req/(52-
ME_req.MAE_weaning_age)*2+Lambs_a_6+Lambs_b_6+Lambs_c_6+Lambs_Terminal_multiples_6+La
mbs_Terminal_singles_6+MAE_Lactation_maintenance/6*(1-
"Cull_rate_exclu._barren"))ELSE(ME_req.ME_Lactation*0.2082+MAE_Lactation_maintenance/6*(1-
"Cull_rate_exclu._barren"*"%_Culled_tailing"))+Lambs_from_1yo_6 *MJME/fortnight*
F_7 =
ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+Lambs_from_1yo_7+IF(ME_req.MAE_weaning_a
ge=12)OR(ME_req.MAE_weaning_age<12)THEN(ME_req.Replacements_ME_req/(52-
ME_req.MAE_weaning_age)*2+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren")+Lambs_a_7+Lambs_b_7+Lambs_c_7+Lambs_Terminal_multiples_7+Lambs_
Terminal_singles_7)ELSE(ME_req.ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren"*"%_Culled_tailing")) *MJME/fortnight*
F_8 =
IF(ME_req.MAE_weaning_age=14)OR(ME_req.MAE_weaning_age<14)THEN(ME_req.Replacements_ME
_req/(52-
ME_req.MAE_weaning_age)*2+Lambs_a_8+Lambs_b_8+Lambs_c_8+Lambs_Terminal_multiples_8+La
mbs_Terminal_singles_8+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren")+Lambs_from_1yo_8+ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26)E
LSE(ME_req.ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren"*"%_Culled_tailing")+Lambs_from_1yo_8+ME_req."1yo_ME_req"/26+ME_re
q.Ram_ME_req/26) *MJME/fortnight*
F_9 = ME_req."1yo_ME_req"/26+ME_req.Ram_ME_req/26+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren")+ME_req.Replacements_ME_req/(52-
ME_req.MAE_weaning_age)*2+Lambs_a_9+Lambs_b_9+Lambs_c_9+Lambs_Terminal_multiples_9+La
mbs_Terminal_singles_9+Lambs_from_1yo_9 *MJME/fortnight*
Lambs_a_10 = IF(ME_req.a_Leave>18)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_11 = IF(ME_req.a_Leave>20)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_12 = IF(ME_req.a_Leave>22)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_13 = IF(ME_req.a_Leave>24)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_14 = IF(ME_req.a_Leave>26)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_15 = IF(ME_req.a_Leave>28)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_16 = IF(ME_req.a_Leave>30)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_17 = IF(ME_req.a_Leave>32)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_18 = IF(ME_req.a_Leave>34)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_19 = IF(ME_req.a_Leave>36)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_20 = IF(ME_req.a_Leave>38)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_21 = IF(ME_req.a_Leave>40)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_22 = IF(ME_req.a_Leave>42)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_23 = IF(ME_req.a_Leave>44)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_24 = IF(ME_req.a_Leave>46)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_25 = IF(ME_req.a_Leave>48)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_26 = IF(ME_req.a_Leave>50)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_5 = IF(ME_req.a_Leave>8)THEN (ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_6 = IF(ME_req.a_Leave>10)THEN (ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_7 = IF(ME_req.a_Leave>11)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_8 = IF(ME_req.a_Leave>14)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_a_9 = IF(ME_req.a_Leave>16)THEN(ME_req.Lambs_a_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_10 = IF(ME_req.b_Leave>18)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_11 = IF(ME_req.b_Leave>20)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_12 = IF(ME_req.b_Leave>22)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_13 = IF(ME_req.b_Leave>24)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*

Lambs_b_14 = IF(ME_req.b_Leave>26)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_15 = IF(ME_req.b_Leave>28)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_16 = IF(ME_req.b_Leave>30)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_17 = IF(ME_req.b_Leave>32)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_18 = IF(ME_req.b_Leave>34)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_19 = IF(ME_req.b_Leave>36)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_20 = IF(ME_req.b_Leave>38)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_21 = IF(ME_req.b_Leave>40)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_22 = IF(ME_req.b_Leave>42)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_23 = IF(ME_req.b_Leave>44)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_24 = IF(ME_req.b_Leave>46)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_25 = IF(ME_req.b_Leave>48)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_26 = IF(ME_req.b_Leave>50)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_5 = IF(ME_req.b_Leave>8)THEN (ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_6 = IF(ME_req.b_Leave>10)THEN (ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_7 = IF(ME_req.b_Leave>11)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_8 = IF(ME_req.b_Leave>11)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_b_9 = IF(ME_req.b_Leave>16)THEN(ME_req.lambs_b_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_10 = IF(ME_req.c_Leave>18)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_11 = IF(ME_req.c_Leave>20)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_12 = IF(ME_req.c_Leave>22)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_13 = IF(ME_req.c_Leave>24)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_14 = IF(ME_req.c_Leave>26)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_15 = IF(ME_req.c_Leave>28)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_16 = IF(ME_req.c_Leave>30)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_17 = IF(ME_req.c_Leave>32)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_18 = IF(ME_req.c_Leave>34)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_19 = IF(ME_req.c_Leave>36)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_20 = IF(ME_req.c_Leave>38)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_21 = IF(ME_req.c_Leave>40)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_22 = IF(ME_req.c_Leave>42)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_23 = IF(ME_req.c_Leave>44)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_24 = IF(ME_req.c_Leave>46)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_25 = IF(ME_req.c_Leave>48)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_26 = IF(ME_req.c_Leave>50)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_5 = IF(ME_req.c_Leave>8)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_6 = IF(ME_req.c_Leave>10)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_7 = IF(ME_req.c_Leave>12)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_8 = IF(ME_req.c_Leave>14)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_9 = IF(ME_req.c_Leave>16)THEN (ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_from_1yo_10 =
+IF(Breed_1yo_1or2_months_later?=1)AND(ME_req.Lambs_from_1yo_leave>14)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)AND(ME_req.Lambs_from_1yo_weaning_age>9)THEN(ME_req.ME_Lactation_Lambs_from_1yo*0.2082)ELSE(IF(ME_req.Lambs_from_1yo_leave<10)THEN(0)ELSE(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))) *MJME/fortnight*
Lambs_from_1yo_11 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_12 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_13 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_14 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_15 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*

Lambs_from_1yo_16 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_17 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_18 = ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_19 =
IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>32)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave- *MJME/fortnight*
ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>28)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_20 =
IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>34)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>30)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_21 =
IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>36)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>32)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_22 =
IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>38)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>34)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_23 =
IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>40)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>36)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_24 =
IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>42)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>38)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_25 =
IF(Breed_1yo_1or2_months_later?=0)THEN(ME_req.ME_Gestation*0.2486)ELSE(0)+IF(Breed_1yo_1or2_months_later?=1)THEN(ME_req.ME_Gestation*0.2486*(1-Sheep."%_Lambs_from_1yo")+Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.098)ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)THEN(ME_req.ME_Gestation*0.2486*(1-Sheep."%_Lambs_from_1yo"))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>44)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>40)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_26 =
IF(Breed_1yo_1or2_months_later?=0)THEN(ME_req.ME_Gestation*0.3609)ELSE(0)+IF(Breed_1yo_1or2_months_later?=1)THEN(ME_req.ME_Gestation*0.3609*(1-Sheep."%_Lambs_from_1yo")+Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.1778)ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)THEN(ME_req.ME_Gestation*0.3609*(1-

Sheep."%_Lambs_from_1yo"))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=1)AND(ME_req.Lambs_from_1yo_leave>46)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(ME_req.ME_Lactation_Lambs_from_1yo=2)AND(ME_req.Lambs_from_1yo_leave>42)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*

Lambs_from_1yo_6 = IF(Breed_1yo_1or2_months_later?=1)THEN(ME_req.ME_Lactation_Lambs_from_1yo*0.172)ELSE(0)+IF(Breed_1yo_1or2_months_later?=2)THEN(Sheep."%_Lambs_from_1yo"*ME_req.ME_Gestation*0.016+ME_req.ME_Lactation_Lambs_from_1yo*0.1304)ELSE(0) *MJME/fortnight*

Lambs_from_1yo_7 = IF(Breed_1yo_1or2_months_later?=2)THEN(ME_req.ME_Lactation_Lambs_from_1yo*0.1546)ELSE(0)+IF(Breed_1yo_1or2_months_later?=1)AND(ME_req.Lambs_from_1yo_weaning_age>7)THEN(ME_req.ME_Lactation_Lambs_from_1yo*0.195)ELSE(IF(ME_req.Lambs_from_1yo_leave<10)AND(Breed_1yo_1or2_months_later?=1)THEN(0)ELSE(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))) *MJME/fortnight*

Lambs_from_1yo_8 = IF(Breed_1yo_1or2_months_later?=1)AND(ME_req.Lambs_from_1yo_weaning_age>9)THEN(ME_req.ME_Lactation_Lambs_from_1yo*0.2082)ELSE(IF(ME_req.Lambs_from_1yo_leave<12)THEN(0)ELSE(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2)))+IF(Breed_1yo_1or2_months_later?=2)THEN(ME_req.ME_Lactation_Lambs_from_1yo*0.172)ELSE(0) *MJME/fortnight*

Lambs_from_1yo_9 = IF(Breed_1yo_1or2_months_later?=2)AND(ME_req.Lambs_from_1yo_weaning_age>7)THEN(ME_req.ME_Lactation_Lambs_from_1yo*0.195)ELSE(IF(ME_req.Lambs_from_1yo_leave<8)THEN(0)ELSE(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2)))+IF(Breed_1yo_1or2_months_later?=1)AND(ME_req.Lambs_from_1yo_leave>12)THEN(ME_req.Lambs_from_1yo_MEreq/((ME_req.Lambs_from_1yo_leave-ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_10 = IF(ME_req.Terminal_multiple_Leave>18)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_11 = IF(ME_req.Terminal_multiple_Leave>20)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_12 = IF(ME_req.Terminal_multiple_Leave>22)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_13 = IF(ME_req.Terminal_multiple_Leave>24)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_14 = IF(ME_req.Terminal_multiple_Leave>26)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_15 = IF(ME_req.Terminal_multiple_Leave>28)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_16 = IF(ME_req.Terminal_multiple_Leave>30)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_17 = IF(ME_req.Terminal_multiple_Leave>32)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_18 = IF(ME_req.Terminal_multiple_Leave>34)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_19 = IF(ME_req.Terminal_multiple_Leave>36)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_20 = IF(ME_req.Terminal_multiple_Leave>38)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_21 = IF(ME_req.Terminal_multiple_Leave>40)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_22 = IF(ME_req.Terminal_multiple_Leave>42)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_23 = IF(ME_req.Terminal_multiple_Leave>44)THEN(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_multiples_24 = IF(ME_req.Terminal_multiple_Leave>46)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_multiples_25 = IF(ME_req.Terminal_multiple_Leave>48)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_multiples_26 = IF(ME_req.Terminal_multiple_Leave>50)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_multiples_5 = IF(ME_req.Terminal_multiple_Leave>8)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_multiples_6 = IF(ME_req.Terminal_multiple_Leave>10)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_multiples_7 = IF(ME_req.Terminal_multiple_Leave>12)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_multiples_8 = IF(ME_req.Terminal_multiple_Leave>14)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_multiples_9 = IF(ME_req.Terminal_multiple_Leave>16)THEN
(ME_req.Terminal_multiple_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_10 = IF(ME_req.Terminal_single_Leave>18)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_11 = IF(ME_req.Terminal_single_Leave>20)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_12 = IF(ME_req.Terminal_single_Leave>22)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_13 = IF(ME_req.Terminal_single_Leave>24)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_14 = IF(ME_req.Terminal_single_Leave>26)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_15 = IF(ME_req.Terminal_single_Leave>28)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_16 = IF(ME_req.Terminal_single_Leave>30)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_17 = IF(ME_req.Terminal_single_Leave>32)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_18 = IF(ME_req.Terminal_single_Leave>34)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_19 = IF(ME_req.Terminal_single_Leave>36)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_20 = IF(ME_req.Terminal_single_Leave>38)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_21 = IF(ME_req.Terminal_single_Leave>40)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_22 = IF(ME_req.Terminal_single_Leave>42)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_23 = IF(ME_req.Terminal_single_Leave>44)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_24 = IF(ME_req.Terminal_single_Leave>46)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_25 = IF(ME_req.Terminal_single_Leave>48)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_26 = IF(ME_req.Terminal_single_Leave>50)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_5 = IF(ME_req.Terminal_single_Leave>8)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_6 = IF(ME_req.Terminal_single_Leave>10)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_7 = IF(ME_req.Terminal_single_Leave>12)THEN
(ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*

Lambs_Terminal_singles_8 = IF(ME_req.Terminal_single_Leave>14)THEN (ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
Lambs_Terminal_singles_9 = IF(ME_req.Terminal_single_Leave>16)THEN (ME_req.Terminal_single_lambs_MEreq)ELSE(0) *MJME/fortnight*
LWC_Flushing = 2 *kg*
LWC_Gestation = 0 *kg*
LWC_Lactation = -2 *kg*
LWC_Summer = 0 *kg*
MAE_Flushing_maintenance = (((0.28*(MAE_LW_Flushing^0.75)*EXP(-0.03*Sheep.Age_MAE))/(0.02*ME_req."M/D"+0.5)*(IF(ME_req.Activity=1)THEN(1.1)ELSE(1)))*42+(IF(LWC_Flushing>0)THEN(LWC_Flushing*55)ELSE(LWC_Flushing*(-35)))+ME_req.MAE_ME_Wool*42)*"Y2-7" *MJME*
MAE_Gestation_maintenance = (((0.28*(ME_req.MAE_LW_Gestation^0.75)*EXP(-0.03*Sheep.Age_MAE))/(0.02*ME_req."M/D"+0.5)*(IF(ME_req.Activity=1)THEN(1.1)ELSE(1)))*155+(IF(LWC_Gestation>0)THEN(LWC_Gestation*55)ELSE(LWC_Gestation*(-35)))+ME_req.MAE_ME_Wool*155)*"Y2-7" *MJME*
MAE_Lactation_maintenance = (((0.28*(MAE_LW_Lactation^0.75)*EXP(-0.03*Sheep.Age_MAE))/(0.02*ME_req."M/D"+0.5)*(IF(ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Lactation>0)THEN(LWC_Lactation*55)ELSE(LWC_Lactation*(-35)))+ME_req.MAE_ME_Wool*84)*"Y2-7" *MJME*
MAE_LW_Flushing = 66 *kg*
MAE_LW_Lactation = 66 *kg*
MAE_LW_Summer = 65 *kg*
MAE_Summer_maintenance = (((0.28*(MAE_LW_Summer^0.75)*EXP(-0.03*Sheep.Age_MAE))/(0.02*ME_req."M/D"+0.5)*(IF(ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Summer>0)THEN(LWC_Summer*55)ELSE(LWC_Summer*(-35)))+ME_req.MAE_ME_Wool*84)*"Y2-7"
"Y2-7" = Sheep.Ewe_flock-Sheep."1yo" *MJME*

ME_req:
Maternal_lamb_sold(t) = Maternal_lamb_sold(t - dt) + (Maternal_lambs_sold - Sold_lambs_a - Sold_lambs_d - Sold_lambs_b - Sold_lambs_c) * dt {NON-NEGATIVE} *sheep*
INIT Maternal_lamb_sold = 0 *sheep*
INFLOWS:
Maternal_lambs_sold = Sheep.Maternal_Female_multiples_sold+Sheep.Maternal_Female_singles_sold+Sheep.Maternal_Male_multiples_sold+Sheep.Maternal_Male_singles_sold-Sheep."%_Lambs_from_1yo"*All_lambs {UNIFLOW} *sheep/year*
OUTFLOWS:
Sold_lambs_a = IF(Maternal_lamb_sold>Sold_maternal_lambs_a)OR(Maternal_lamb_sold=Sold_maternal_lambs_a)THEN(Sold_maternal_lambs_a)ELSE(Maternal_lamb_sold) {UNIFLOW} *sheep/year*
Sold_lambs_d = Maternal_lamb_sold-Sold_lambs_a-Sold_lambs_b-Sold_lambs_c {UNIFLOW} *sheep/year*
Sold_lambs_b = IF(Maternal_lamb_sold>(Sold_maternal_lambs_a+Sold_maternal_lambs_b))OR(Maternal_lamb_sold=(Sold_maternal_lambs_a+Sold_maternal_lambs_b))THEN(Sold_maternal_lambs_b)ELSE(Maternal_lamb_sold-Sold_maternal_lambs_a) {UNIFLOW} *sheep/year*
Sold_lambs_c = IF(Maternal_lamb_sold>(Sold_maternal_lambs_a+Sold_maternal_lambs_b+Sold_maternal_lambs_c))OR(Maternal_lamb_sold=(Sold_maternal_lambs_a+Sold_maternal_lambs_b+Sold_maternal_lambs_c))THEN(Sold_maternal_lambs_c)ELSE(Maternal_lamb_sold-Sold_maternal_lambs_a-Sold_maternal_lambs_b) {UNIFLOW} *sheep/year*
Lambs_from_1yo = Sheep."%_Lambs_from_1yo"*All_lambs {UNIFLOW} *sheep/year*
"1y_GFW" = 3.2 *kg*
"1yo_LW" = MAE_LW_Gestation*0.70 *kg*
"1yo_ME_LWG" = 55*(MAE_LW_Gestation-"1yo_LW") *kg*

"1yo_ME_Maintenance" = ((0.28*(MEAN("1yo_LW", MAE_LW_Gestation)^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))) *MJME*
"1yo_ME_req" = ("1yo_wool_ME"+"1yo_ME_Maintenance"*365+"1yo_ME_LWG")*Sheep."1yo" *MJME*
"1yo_wool_ME" = 0.13*("1y_GFW"*1000/365-6)+0.13*("6m_GFW"*1000/365-6) *MJME*
"6m_GFW" = 1.5 *kg*
Lambs_a_CW = 17.5 *kg*
Lambs_a_Dressing% = .41
Lambs_a_Leave = 28 *weeks after weaning*
Activity = 1
All_lambs = Sheep.Maternal_Female_singles_weaned+Sheep.Maternal_Female_multiples_weaned+Sheep.Terminal_singles_weaned+Sheep.Terminal_multiples_weaned+Sheep.Maternal_male_singles_weaned+Sheep.Maternal_male_multiples_weaned *sheep*
Lambs_b_CW = 17.5 *kg*
Lambs_b_Dressing% = .41 *%*
Lambs_b_Leave = 36 *weeks after weaning*
Lambs_c_CW = 32.52 *kg*
Lambs_c_Dressing% = 1 *%*
Lambs_c_Leave = 36 *weeks after weaning*
Cold = 0
Lambs_d_CW = 18 *kg*
Lambs_d_Dressing% = .5 *%*
Lambs_d_Leave = 16 *weeks after weaning*
Lambs_a_MEreq = (0.13*((Wool_production.Ave_GFW_MAE+(1.87*(a_Leave/52)-3.74))*1000/(a_Leave*7)-6)*Sold_lambs_a*((a_Leave-MAE_weaning_age)*7)+(a_CW/a_Dressing%-Maternal_single_Weaning_wt)*55*Sold_lambs_a+(0.28*(MEAN(Maternal_single_Weaning_wt, (a_CW/a_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((a_Leave-MAE_weaning_age)*7)*Sold_lambs_a)/((a_Leave-MAE_weaning_age)/2) *MJME*
lambs_b_MEreq = (0.13*((Wool_production.Ave_GFW_MAE+(1.87*(b_Leave/52)-3.74))*1000/(b_Leave*7)-6)*Sold_lambs_b*((b_Leave-MAE_weaning_age)*7)+(b_CW/b_Dressing%-Maternal_multiple_Weaning_wt)*55*Sold_lambs_b+(0.28*(MEAN(Maternal_multiple_Weaning_wt, (b_CW/b_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((b_Leave-MAE_weaning_age)*7)*Sold_lambs_b)/((b_Leave-MAE_weaning_age)/2) *MJME*
lambs_c_MEreq = (0.13*((Wool_production.Ave_GFW_MAE+(1.87*(c_Leave/52)-3.74))*1000/(c_Leave*7)-6)*Sold_lambs_c*((c_Leave-MAE_weaning_age)*7)+(c_CW/c_Dressing%-Maternal_multiple_Weaning_wt)*55*Sold_lambs_c+(0.28*(MEAN(Maternal_multiple_Weaning_wt, (c_CW/c_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((c_Leave-MAE_weaning_age)*7)*Sold_lambs_c)/((c_Leave-MAE_weaning_age)/2) *MJME*
lambs_d_MEreq = (0.13*((Wool_production.Ave_GFW_MAE+(1.87*(d_Leave/52)-3.74))*1000/(d_Leave*7)-6)*Sold_lambs_d*((d_Leave-MAE_weaning_age)*7)+(d_CW/d_Dressing%-Maternal_single_Weaning_wt)*55*Sold_lambs_d+(0.28*(MEAN(Maternal_single_Weaning_wt, (d_CW/d_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((d_Leave-MAE_weaning_age)*7)*Sold_lambs_d)/((d_Leave-MAE_weaning_age)/2) *MJME*
Lambs_from_1yo_leave = 28 *weeks after weaning*
Lambs_from_1yo_MEreq = (Lambs_from_1yo_sale_LW-Lambs_from_1yo_single_Weaning_WT)*55*Lambs_from_1yo+(0.28*(MEAN(Lambs_from_1yo_single_Weaning_WT, Lambs_from_1yo_sale_LW)^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Lambs_from_1yo_leave-Lambs_from_1yo_weaning_age)*7)*Lambs_from_1yo *MJME*
Lambs_from_1yo_sale_LW = 32.52 *kg*
Lambs_from_1yo_single_Weaning_WT = 23 *kg*
Lambs_from_1yo_weaning_age = 10 *weeks after weaning*
Length_of_cold = 0
"M/D" = 10 *MJME/kgDM*
MAE_LW_Gestation = 67 *kg*

MAE_ME_Maintenance = ((0.28*(MAE_LW_Gestation^0.75)*EXP(-0.03*Sheep.Age_MAE))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))) *MJME*
MAE_ME_req = (MAE_ME_Maintenance*365+MAE_ME_Maintenance*(IF(Cold=1)THEN(0.2*Length_of_cold)ELSE(0))+MAE_ME_Wool*365)*Sheep.Ewe_flock *MJME*
MAE_ME_Wool = 0.13*(Wool_production.Ave_GFW_MAE*1000/365-6) *MJME*
MAE_weaning_age = 12 *weeks after weaning*
Maternal_Multiple_birth_wt = 4.5 *kg*
Maternal_multiple_Weaning_wt = 26 *kg*
Maternal_Single_Birth_wt = 5.5 *kg*
Maternal_single_Weaning_wt = 28 *kg*
ME_Gestation = (((Sheep.Maternal_Female_singles_weaned+Sheep.Maternal_male_singles_weaned)/(1-Sheep.Maternal_singles_loss_rate)+Sheep.Terminal_singles_weaned/(1-Sheep.Terminal_singles_loss_rate))*Single_ME_req_gestation+((Sheep.Maternal_Female_multiples_weaned+Sheep.Maternal_male_multiples_weaned)/(1-Sheep.Maternal_multiples_loss_rate)+Sheep.Terminal_multiples_weaned/(1-Sheep.Tmultiples_loss_rate))*Multiple_ME_req_gestation) *MJME*
ME_Lactation = ((Sheep.Maternal_Female_singles_weaned+Sheep.Maternal_male_singles_weaned)/(1-Sheep.Maternal_singles_loss_rate)*(1-Sheep."%_Lambs_from_1yo")+Sheep.Terminal_singles_weaned/(1-Sheep.Terminal_singles_loss_rate))*Single_ME_req_lactation+(Multiple_ME_req_lactation/2*1.35)*(Sheep.Terminal_multiples_weaned/(1-Sheep.Tmultiples_loss_rate)+(Sheep.Maternal_Female_multiples_weaned+Sheep.Maternal_male_multiples_weaned)/(1-Sheep.Maternal_multiples_loss_rate)*(1-Sheep."%_Lambs_from_1yo")) *MJME*
ME_Lactation_Lambs_from_1yo = Single_ME_req_lactation_Lambs_from_1yo*Sheep."%_Lambs_from_1yo"*All_lambs *MJME*
Multiple_ME_req_gestation = GRAPH(Maternal_Multiple_birth_wt*(1-Terminal_lambs_%)+Terminal_multiple_birth_wt*Terminal_lambs_%)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*
Multiple_ME_req_lactation = -1808+51.4*(Maternal_multiple_Weaning_wt*(1-Terminal_lambs_%)+Terminal_multiple_Weaning_wt*Terminal_lambs_%)+134.7*MAE_weaning_age *MJME*
Ram_Age = 4 *years*
Ram_LW = 70 *kg*
Ram_ME_Maintenance = (((0.28*(Ram_LW^0.75)*EXP(-0.03*Ram_Age))/(0.02*"M/D"+0.5))*(IF(Activity=1)THEN(1.1)ELSE(1))*1.15) *MJME*
Ram_ME_req = (Ram_ME_Maintenance*365+Ram_wool_ME*365+IF(Cold=1)THEN(Ram_ME_Maintenance*0.2*Length_of_cold)ELSE(0))*Sheep.Rams *MJME*
Ram_wool_ME = 0.13*(Wool_production.Ave_GFW_MAE*1000/365-6) *MJME*
Replacements_ME_req = (("1yo_LW"-Maternal_single_Weaning_wt)*55+(((0.28*(MEAN(Maternal_single_Weaning_wt, "1yo_LW")^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))))*(365-MAE_weaning_age*7)+(0.13*((Wool_production.Ave_GFW_MAE-1.86)*1000/(365-MAE_weaning_age*7)-6)))*Sheep.Replacements *MJME*
Single_ME_req_gestation = GRAPH(Maternal_Single_Birth_wt*(1-Terminal_lambs_%)+Terminal_single_birth_wt*Terminal_lambs_%)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*
Single_ME_req_lactation = -1808+51.4*(Maternal_single_Weaning_wt*(1-Terminal_lambs_%)+Terminal_single_Weaning_wt*Terminal_lambs_%)+134.7*MAE_weaning_age
Single_ME_req_lactation_Lambs_from_1yo = -1808+51.4*Lambs_from_1yo_single_Weaning_WT+134.7*Lambs_from_1yo_weaning_age *MJME*
Sold_maternal_lambs_a = 698 *sheep*
Sold_maternal_lambs_b = 0 *sheep*
Sold_maternal_lambs_c = 1000 *sheep*

Terminal_lambs_% =
Sheep.Terminal_lambs_weaned/(Sheep.Maternal_lambs_weaned+Sheep.Terminal_lambs_weaned) *%*
Terminal_multiple_birth_wt = 4.86 *kg*
Terminal_multiple_CW = 17.5 *kg*
Terminal_multiple_Dressing% = .426 *%*
Terminal_multiple_lambs_MEreq =
(0.13*((Wool_production.Ave_GFW_MAE+(1.87*(Terminal_multiple_Leave/52)-
3.74))*1000/(Terminal_multiple_Leave*7)-
6)*Sheep.Terminal_singles_weaned*((Terminal_multiple_Leave-
MAE_weaning_age)*7)+(Terminal_multiple_CW/Terminal_multiple_Dressing%-
Maternal_single_Weaning_wt)*55*Sheep.Terminal_singles_weaned+(0.28*(MEAN(Maternal_single_W
eaning_wt, (Terminal_multiple_CW/Terminal_multiple_Dressing%))^0.75)*EXP(-
0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Terminal_multiple_Leave-
MAE_weaning_age)*7)*Sheep.Terminal_singles_weaned)/((Terminal_multiple_Leave-
MAE_weaning_age)/2) *MJME*
Terminal_multiple_Leave = 19 *weeks after weaning*
Terminal_multiple_Weaning_wt = 31.5 *kg*
Terminal_single_birth_wt = 5.94 *kg*
Terminal_single_CW = 17.5 *kg*
Terminal_single_Dressing% = .426 *%*
Terminal_single_lambs_MEreq =
(0.13*((Wool_production.Ave_GFW_MAE+(1.87*(Terminal_single_Leave/52)-
3.74))*1000/(Terminal_single_Leave*7)-
6)*Sheep.Terminal_multiples_weaned*((Terminal_single_Leave-
MAE_weaning_age)*7)+(Terminal_single_CW/Terminal_single_Dressing%-
Maternal_multiple_Weaning_wt)*55*Sheep.Terminal_multiples_weaned+(0.28*(MEAN(Maternal_mult
iple_Weaning_wt, (Terminal_single_CW/Terminal_single_Dressing%))^0.75)*EXP(-
0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Terminal_single_Leave-
MAE_weaning_age)*7)*Sheep.Terminal_multiples_weaned)/((Terminal_single_Leave-
MAE_weaning_age)/2) *MJME*
Terminal_single_Leave = 24 *weeks after weaning*
Terminal_single_Weaning_wt = 33.9 *kg*

Sheep:
"1yo"(t) = "1yo"(t - dt) + (Replacements - "1yo_culls" - become_2yo - "1yo_deaths") * dt {NON-
NEGATIVE} *sheep*
INIT "1yo" = 668 *sheep*
INFLOWS:
Replacements = (Maternal_Female_singles_kept+Maternal_Female_multiples_kept)*(1-
Replacements_Buffer) {UNIFLOW} *sheep/year*
OUTFLOWS:
"1yo_culls" = "1yo_cull_rate"*"1yo" {UNIFLOW} *sheep/year*
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
"1yo_deaths" = "1yo_Death_rate"*"1yo" {UNIFLOW} *sheep/year*
"2yo"(t) = "2yo"(t - dt) + (become_2yo - become_3yo - "2yo_deaths" - "2yo_culls") * dt {NON-
NEGATIVE} *sheep*
INIT "2yo" = 655 *sheep*
INFLOWS:
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
"2yo_deaths" = "2yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"2yo_culls" = "2yo"*MAE_cull_rate {UNIFLOW} *sheep/year*
"3_yo"(t) = "3_yo"(t - dt) + (become_3yo - become_4yo - "3yo_deaths" - "3yo_culls") * dt {NON-
NEGATIVE} *sheep*
INIT "3_yo" = 493 *sheep*
INFLOWS:

become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
"3yo_deaths" = "3_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"3yo_culls" = "3_yo"*MAE_cull_rate {UNIFLOW} *sheep/year*
"4_yo"(t) = "4_yo"(t - dt) + (become_4yo - become_5yo - "4yo_deaths" - "4yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "4_yo" = 372 *sheep*
INFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
"4yo_deaths" = "4_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"4yo_culls" = MAE_cull_rate*"4_yo" {UNIFLOW} *sheep/year*
"5_yo"(t) = "5_yo"(t - dt) + (become_5yo - become_6yo - "5yo_deaths" - "5yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "5_yo" = 280 *sheep*
INFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
"5yo_deaths" = "5_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"5yo_culls" = MAE_cull_rate*"5_yo" {UNIFLOW} *sheep/year*
"6_yo"(t) = "6_yo"(t - dt) + (become_6yo - become_7yo - "6yo_deaths" - "6yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "6_yo" = 211 *sheep*
INFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
"6yo_deaths" = "6_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"6yo_culls" = MAE_cull_rate*"6_yo" {UNIFLOW} *sheep/year*
"7_yo"(t) = "7_yo"(t - dt) + (become_7yo - "7yo_deaths" - "7yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "7_yo" = 159 *sheep*
INFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
"7yo_deaths" = "7_yo"*(Death_rate_MAE+0.02) {UNIFLOW} *sheep/year*
"7yo_culls" = "7_yo"-"7yo_deaths" {UNIFLOW} *sheep/year*
maternal_female_multiples(t) = maternal_female_multiples(t - dt) + (Maternal_Female_multiples_weaned - Maternal_Female_multiples_kept - Maternal_Female_multiples_sold) * dt {NON-NEGATIVE} *sheep*
INIT maternal_female_multiples = 0 *sheep*
INFLOWS:
Maternal_Female_multiples_weaned = IF(Maternal_multiple_scan>0)THEN(Maternal_multiple_scan*(1-Maternal_multiples_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_multiples*0.5) {UNIFLOW} *sheep/year*
OUTFLOWS:
Maternal_Female_multiples_kept = IF(Maternal_female_singles<Replacement_req)THEN(Replacement_req-Maternal_Female_singles_kept)ELSE(0) {UNIFLOW} *sheep/year*
Maternal_Female_multiples_sold = maternal_female_multiples-Maternal_Female_multiples_kept {UNIFLOW} *sheep/year*
Maternal_female_singles(t) = Maternal_female_singles(t - dt) + (Maternal_Female_singles_weaned - Maternal_Female_singles_sold - Maternal_Female_singles_kept) * dt {NON-NEGATIVE} *sheep*
INIT Maternal_female_singles = 0 *sheep*
INFLOWS:

Maternal_Female_singles_weaned = IF(Maternal_single_scan>0)THEN(Maternal_single_scan*(1-Maternal_singles_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_singles*0.5) {UNIFLOW} *sheep/year*
OUTFLOWS:
Maternal_Female_singles_sold = Maternal_female_singles-Maternal_Female_singles_kept {UNIFLOW} *sheep/year*
Maternal_Female_singles_kept = IF(Maternal_female_singles>Replacement_req)OR(Maternal_female_singles=Replacement_req)THEN(Replacement_req)ELSE(Maternal_female_singles) {UNIFLOW} *sheep/year*
maternal_male_multiples(t) = maternal_male_multiples(t - dt) + (Maternal_male_multiples_weaned - Maternal_Male_multiples_sold) * dt {NON-NEGATIVE} *sheep*
INIT maternal_male_multiples = 0 *sheep*
INFLOWS:
Maternal_male_multiples_weaned = IF(Maternal_multiple_scan>0)THEN(Maternal_multiple_scan*(1-Maternal_multiples_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_multiples*0.5) {UNIFLOW} *sheep/year*
OUTFLOWS:
Maternal_Male_multiples_sold = maternal_male_multiples {UNIFLOW} *sheep/year*
Maternal_male_singles(t) = Maternal_male_singles(t - dt) + (Maternal_male_singles_weaned - Maternal_Male_singles_sold) * dt {NON-NEGATIVE} *sheep*
INIT Maternal_male_singles = 0 *sheep*
INFLOWS:
Maternal_male_singles_weaned = IF(Maternal_single_scan>0)THEN(Maternal_single_scan*(1-Maternal_singles_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_singles*0.5) {UNIFLOW} *sheep/year*
OUTFLOWS:
Maternal_Male_singles_sold = Maternal_male_singles {UNIFLOW} *sheep/year*
Rams = ROUND(Ewe_flock/Ram_ratio) {UNIFLOW} *sheep/year*
Terminal_multiples_weaned = IF(Terminal_multiple_scan>0)THEN(Terminal_multiple_scan*(1-Tmultiples_loss_rate))ELSE(Terminal_lambs_weaned*Terminal_multiples) {UNIFLOW} *sheep/year*
Terminal_singles_weaned = IF(Terminal_single_scan>0)THEN(Terminal_single_scan*(1-Terminal_singles_loss_rate))ELSE(Terminal_lambs_weaned*Terminal_singles) {UNIFLOW} *sheep/year*
"%_Lambs_from_1yo" = ("1yo"*"1yo_lambing_rate")/(Maternal_lambs_weaned+Terminal_lambs_weaned) *sheep*
"%_MAE_to_Terminal" = 0.18 *%*
"1yo_cull_rate" = 0 *%*
"1yo_Death_rate" = 0.019 *%*
"1yo_lambing_rate" = .28 *%*
Age_MAE = ("2yo"*2+"3_yo"*3+"4_yo"*4+"5_yo"*5+("6_yo"+"7_yo")*6)/("2yo"+"3_yo"+"4_yo"+"5_yo"+"6_yo"+"7_yo") *years*
Death_rate_MAE = 0.102 *%*
Deaths = Wastage+"7yo_culls"-Ewe_culls-"1yo_deaths" *sheep*
Ewe_culls = "2yo_culls"+"3yo_culls"+"4yo_culls"+"5yo_culls"+"6yo_culls"+"7yo_culls" *sheep*
Ewe_flock = "7_yo"+"6_yo"+"5_yo"+"4_yo"+"3_yo"+"2yo"+"1yo" *sheep*
MAE_cull_rate = 0.145 *%*
Maternal_barren_rate = .03 *%*
Maternal_lambing_rate = 1.1 *%*
"Maternal_lambs_born/_ewe_lambing" = Maternal_lambs_weaned*(1+MEAN(Maternal_multiples_loss_rate, Maternal_singles_loss_rate))/(Ewe_flock*(1-Maternal_barren_rate-"%_MAE_to_Terminal")) *%*
Maternal_lambs_weaned = "1yo_lambing_rate"*"1yo"+(1-"%_MAE_to_Terminal")*Maternal_lambing_rate*("2yo"*0.85+"3_yo"*0.97+"4_yo"*1.04+"5_yo"*0.92+"6_yo"*0.92+"7_yo"*0.92) *sheep*
Maternal_multiple_scan = 0 *sheep*
Maternal_multiples = GRAPH("Maternal_lambs_born/_ewe_lambing")

(1.000, 0.000), (1.100, 0.050), (1.200, 0.200), (1.300, 0.300), (1.400, 0.400), (1.500, 0.480), (1.600, 0.600), (1.700, 0.680), (1.800, 0.720), (1.900, 0.780), (2.000, 0.800), (2.100, 0.820), (2.200, 0.830), (2.300, 0.860), (2.400, 0.880), (2.500, 0.880) *sheep*
Maternal_multiples_loss_rate = .16 *%*
Maternal_single_scan = 0 *sheep*
Maternal_singles = GRAPH("Maternal_lambs_born/_ewe_lambing")
(1.000, 1.000), (1.100, 0.950), (1.200, 0.800), (1.300, 0.700), (1.400, 0.600), (1.500, 0.500), (1.600, 0.400), (1.700, 0.320), (1.800, 0.280), (1.900, 0.220), (2.000, 0.200), (2.100, 0.180), (2.200, 0.170), (2.300, 0.140), (2.400, 0.120), (2.500, 0.120) *sheep*
Maternal_singles_loss_rate = .16 *%*
Ram_ratio = 100
Replacement_req = 668/(1-Replacements_Buffer) *sheep*
Replacements_Buffer = 0.3 *%*
Terminal_barren_rate = .03 *%*
Terminal_lambing_rate = 1.1 *%*
"Terminal_lambs_born/_ewe_lambing" = Terminal_lambs_weaned*(1+MEAN(Tmultiples_loss_rate, Terminal_singles_loss_rate))/(Ewe_flock*(1-Terminal_barren_rate)*("%_MAE_to_Terminal"+0.00001))
Terminal_lambs_weaned =
"%_MAE_to_Terminal"*Terminal_lambing_rate*(1+MEAN(Terminal_singles_loss_rate, Tmultiples_loss_rate))*("2yo"*1.03+"3_yo"*1.03+"4_yo"*1.03+"5_yo"*1.09+"6_yo"*1.06+"7_yo"*0.99)
Terminal_multiple_scan = 0 *sheep*
Terminal_multiples = GRAPH("Terminal_lambs_born/_ewe_lambing")
(1.000, 0.000), (1.100, 0.050), (1.200, 0.200), (1.300, 0.300), (1.400, 0.400), (1.500, 0.480), (1.600, 0.600), (1.700, 0.680), (1.800, 0.720), (1.900, 0.780), (2.000, 0.800), (2.100, 0.820), (2.200, 0.830), (2.300, 0.860), (2.400, 0.880), (2.500, 0.880) *sheep*
Terminal_single_scan = 0 *sheep*
Terminal_singles = GRAPH("Terminal_lambs_born/_ewe_lambing")
(1.000, 1.000), (1.100, 0.950), (1.200, 0.800), (1.300, 0.700), (1.400, 0.600), (1.500, 0.500), (1.600, 0.400), (1.700, 0.320), (1.800, 0.280), (1.900, 0.220), (2.000, 0.200), (2.100, 0.180), (2.200, 0.170), (2.300, 0.140), (2.400, 0.120), (2.500, 0.120) *sheep*
Terminal_singles_loss_rate = .147 *%*
Tmultiples_loss_rate = .147 *%*
Wastage =
"2yo_deaths"+"3yo_deaths"+"4yo_deaths"+"5yo_deaths"+"1yo_deaths"+"6yo_deaths"+"7yo_deaths"+ Ewe_culls-"7yo_culls" *sheep*

Wool_production:
Ave_GFW_MAE = 5.6 *kg*
Shearing_date = 15 *weeks after start of lambing*
Strong_wool_price = 2.54 *$/kg*
Wool_income = (Sheep.Rams*Ave_GFW_MAE++Sheep."1yo"*(Ave_GFW_MAE-0.23)+Sheep."2yo"*(Ave_GFW_MAE-0.09)+Sheep."3_yo"*(Ave_GFW_MAE+0.42)+Sheep."4_yo"*(Ave_GFW_MAE+0.28)+Sheep."5_yo"*(Ave_GFW_MAE+0.05)+Sheep."6_yo"*(Ave_GFW_MAE-0.14)+Sheep."7_yo"*(Ave_GFW_MAE-0.5)+"Wool_production_<1yo")*Strong_wool_price *$*
"Wool_production_<1yo" = (Ave_GFW_MAE+(1.8743*0.5-3.7371))*(IF(Shearing_date<ME_req.c_Leave)THEN(ME_req.Sold_lambs_c)ELSE(0)+IF(Shearing_date<ME_req.d_Leave)THEN(ME_req.Sold_lambs_d)ELSE(0)+IF(Shearing_date<ME_req.a_Leave)THEN(ME_req.Sold_lambs_a)ELSE(0)+IF(Shearing_date<ME_req.b_Leave)THEN(ME_req.Sold_lambs_b)ELSE(0)+IF(Shearing_date<ME_req.Terminal_multiple_Leave)THEN(Sheep.Terminal_singles_weaned)ELSE(0)+IF(Shearing_date<ME_req.Terminal_single_Leave)THEN(Sheep.Terminal_multiples_weaned)ELSE(0)) *kg*

Equations for Chapter Five

"1st_X":
"1yo"(t) = "1yo"(t - dt) + (replacements - "1yo_culls" - become_2yo - "1yo_deaths") * dt {NON-NEGATIVE} *sheep*
INIT "1yo" = 0 *sheep*
INFLOWS:
replacements = (Maternal_Female_multiples_kept+Maternal_Female_singles_kept) {UNIFLOW} *sheep/year*
OUTFLOWS:
"1yo_culls" = (cull_all+"1yo_cull_rate")*"1yo" {UNIFLOW} *sheep/year*
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
"1yo_deaths" = "1yo_Death_rate"*"1yo" {UNIFLOW} *sheep/year*
"2yo"(t) = "2yo"(t - dt) + (become_2yo - become_3yo - "2yo_deaths" - "2yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "2yo" = 0 *sheep*
INFLOWS:
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
"2yo_deaths" = "2yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"2yo_culls" = "2yo"*(MAE_cull_rate+cull_all) {UNIFLOW} *sheep/year*
"3_yo"(t) = "3_yo"(t - dt) + (become_3yo - become_4yo - "3yo_deaths" - "3yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "3_yo" = 0 *sheep*
INFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
"3yo_deaths" = "3_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"3yo_culls" = "3_yo"*(MAE_cull_rate+cull_all) {UNIFLOW} *sheep/year*
"4_yo"(t) = "4_yo"(t - dt) + (become_4yo - become_5yo - "4yo_deaths" - "4yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "4_yo" = 0 *sheep*
INFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
"4yo_deaths" = "4_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"4yo_culls" = (MAE_cull_rate+cull_all)*"4_yo" {UNIFLOW} *sheep/year*
"5_yo"(t) = "5_yo"(t - dt) + (become_5yo - become_6yo - "5yo_deaths" - "5yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "5_yo" = 0 *sheep*
INFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
"5yo_deaths" = "5_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"5yo_culls" = (MAE_cull_rate+cull_all)*"5_yo" {UNIFLOW} *sheep/year*
"6_yo"(t) = "6_yo"(t - dt) + (become_6yo - become_7yo - "6yo_deaths" - "6yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "6_yo" = 0 *sheep*
INFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
"6yo_deaths" = "6_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*

"6yo_culls" = (MAE_cull_rate+cull_all)*"6_yo" {UNIFLOW} *sheep/year*
"7_yo"(t) = "7_yo"(t - dt) + (become_7yo - "7yo_deaths" - "7yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "7_yo" = 0 *sheep*
INFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
"7yo_deaths" = "7_yo"*(Death_rate_MAE+0.02) {UNIFLOW} *sheep/year*
"7yo_culls" = "7_yo"-"7yo_deaths" {UNIFLOW} *sheep/year*
"2X_multiples_weaned" = IF((IF("2X_multiple_scan">0)THEN("2X_multiple_scan"*(1-"2X_multiples_loss_rate"))ELSE("2X_lambs_weaned"*"2X_multiples"))<10)THEN(0)ELSE(IF("2X_multiple_scan">0)THEN("2X_multiple_scan"*(1-"2X_multiples_loss_rate"))ELSE("2X_lambs_weaned"*"2X_multiples")) {UNIFLOW} *sheep/year*
"2X_singles_weaned" = IF((IF("2X_single_scan">0)THEN("2X_single_scan"*(1-MxR_singles_loss_rate))ELSE("2X_lambs_weaned"*"2X_singles"))<10)THEN(0)ELSE(IF("2X_single_scan">0)THEN("2X_single_scan"*(1-MxR_singles_loss_rate))ELSE("2X_lambs_weaned"*"2X_singles")) {UNIFLOW} *sheep/year*
Maternal_Female_multiples_kept = Maternal_Female_multiples*(1-Sortweaning_cull_rate)*(1-Sort10mo_cull_rate) {UNIFLOW} *sheep/year*
Maternal_Female_multiples_sold = Maternal_Female_multiples*Sortweaning_cull_rate {UNIFLOW} *sheep/year*
Maternal_Female_singles_kept = Maternal_Female_singles*(1-Sortweaning_cull_rate)*(1-Sort10mo_cull_rate) {UNIFLOW} *sheep/year*
Maternal_Female_singles_sold = Maternal_Female_singles*Sortweaning_cull_rate {UNIFLOW} *sheep/year*
Maternal_Male_multiples_finished = Maternal_male_multiples {UNIFLOW} *sheep/year*
Multiples_Male_singles_finished = Maternal_male_singles {UNIFLOW} *sheep/year*
Rams = ROUND(Ewe_flock/Ram_ratio) {UNIFLOW} *sheep/year*
"%_MAE_to_Merino" = 1 *%*
"10mo_culls" = (Maternal_Female_multiples+Maternal_Female_singles)*Sortweaning_cull_rate*Sort10mo_cull_rate *sheep*
"1yo_cull_rate" = 0 *%*
"1yo_Death_rate" = 0.02 *%*
"2X_barren_rate" = .03 *%*
"2X_lambing_rate" = 1.2015 *%*
"2X_lambs_born/_ewe_lambing" = "2X_lambs_weaned"*(1+MEAN("2X_multiples_loss_rate", MxR_singles_loss_rate))/(Ewe_flock*(1-"2X_barren_rate")*("%_MAE_to_Merino"+0.0001)+0.0001) *%*
"2X_lambs_weaned" = "%_MAE_to_Merino"*"2X_lambing_rate"*(1+MEAN(MxR_singles_loss_rate, "2X_multiples_loss_rate"))*("2yo"*0.85+"3_yo"*0.97+"4_yo"*1.04+"5_yo"*1.09+"6_yo"*1.06+"7_yo"*0.99) *sheep*
"2X_multiple_scan" = 0 *sheep*
"2X_multiples" = GRAPH("2X_lambs_born/_ewe_lambing")
(1.000, 0.000), (1.100, 0.050), (1.200, 0.200), (1.300, 0.300), (1.400, 0.400), (1.500, 0.480), (1.600, 0.600), (1.700, 0.680), (1.800, 0.720), (1.900, 0.780), (2.000, 0.800), (2.100, 0.820), (2.200, 0.830), (2.300, 0.860), (2.400, 0.880), (2.500, 0.880) *sheep*
"2X_multiples_loss_rate" = 0.16 *%*
"2X_single_scan" = 0 *sheep*
"2X_singles" = GRAPH("2X_lambs_born/_ewe_lambing")
(1.000, 1.000), (1.100, 0.950), (1.200, 0.800), (1.300, 0.700), (1.400, 0.600), (1.500, 0.500), (1.600, 0.400), (1.700, 0.320), (1.800, 0.280), (1.900, 0.220), (2.000, 0.200), (2.100, 0.180), (2.200, 0.170), (2.300, 0.140), (2.400, 0.120), (2.500, 0.120) *sheep*
Age_MAE = ("2yo"*2+"3_yo"*3+"4_yo"*4+"5_yo"*5+("6_yo"+"7_yo")*6)/("2yo"+"3_yo"+"4_yo"+"5_yo"+"6_yo"+"7_yo"+0.0001) *years*
cull_all = IF(Ewe_flock<Eradicate)AND(Eradicate>0)AND("2nd_X".Ewe_flock>1800)THEN(1)ELSE(0) *sheep*
Death_rate_MAE = 0.052 *%*
Deaths = Wastage+"7yo_culls"-Ewe_culls-"1yo_deaths" *sheep*

Eradicate = 2200 *sheep*
Ewe_culls = "2yo_culls"+"3yo_culls"+"4yo_culls"+"5yo_culls"+"6yo_culls"+"7yo_culls"+"1yo_culls" *sheep*
Ewe_flock =
IF(("7_yo"+"6_yo"+"5_yo"+"4_yo"+"3_yo"+"2yo"+"1yo")<10)THEN(0)ELSE("7_yo"+"6_yo"+"5_yo"+"4_yo"+"3_yo"+"2yo"+"1yo") *sheep*
MAE_cull_rate = 0.04 *%*
Maternal_Female_multiples = Romney."1Xmultiples_weaned"*0.5 *sheep*
Maternal_Female_singles = Romney."1X_singles_weaned"*0.5 *sheep*
Maternal_male_multiples = Romney."1Xmultiples_weaned"*0.5 *sheep*
Maternal_male_singles = Romney."1X_singles_weaned"*0.5 *sheep*
MxR_singles_loss_rate = 0.16 *%*
Ram_ratio = 100
Sort10mo_cull_rate = 0.23 *%*
Sortweaning_cull_rate = 0.23 *%*
Wastage =
"2yo_deaths"+"3yo_deaths"+"4yo_deaths"+"5yo_deaths"+"1yo_deaths"+"6yo_deaths"+"7yo_deaths"+Ewe_culls-"7yo_culls" *sheep*

"1st_X_fortnightly_feed_demand":
"Cull_rate_exclu._barren" = ("1st_X".Ewe_culls-"1st_X".Ewe_flock*MEAN(Romney."1X_barren_rate"))/("1st_X".Ewe_flock-"1st_X".Ewe_flock*MEAN(Romney."1X_barren_rate")+0.00001) *%*
"%_Culled_tailing" = .1 *%*
"10mo_cull_a_1" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_10" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_11" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_12" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_13" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_14" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_15" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_16" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_17" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_18" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_19" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_2" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_20" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_21" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_22" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_23" =
IF("10mo_cull_leave_a">44)THEN("1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2))ELSE(0) *MJME/fortnight*

"10mo_cull_a_24" =
IF("10mo_cull_leave_a">46)THEN("1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_a_25" =
IF("10mo_cull_leave_a">48)THEN("1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_a_26" =
IF("10mo_cull_leave_a">50)THEN("1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_a_3" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_4" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_5" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_6" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_7" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_8" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_9" = "1st_X_ME_req"."10mo_cull_ME_req_a"/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_b_1" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_10" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_11" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_12" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_13" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_14" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_15" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_16" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_17" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_18" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_19" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_2" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_20" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_21" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_22" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_23" = IF
("10mo_cull_leave_b">44)THEN("1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_24" = IF
("10mo_cull_leave_b">46)THEN("1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_25" = IF
("10mo_cull_leave_b">48)THEN("1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_26" = IF
("10mo_cull_leave_b">50)THEN("1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_3" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*

"10mo_cull_b_4" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_5" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_6" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_7" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_8" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_b_9" = "1st_X_ME_req"."10mo_cull_ME_req_b"/("10mo_cull_leave_b"/2) *MJME/fortnight*
"10mo_cull_leave_a" = 44 *weeks after start of lambing*
"10mo_cull_leave_b" = 44 *weeks after start of lambing*
F_1 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+"1st_X_ME_req".ME_Lactation*0.084+MAE_Lactation_maintenance/6+"1st_X_ME_req".ME_Gestation*0.1188+"10mo_cull_a_1"+"10mo_cull_b_1" *MJME/fortnight*
F_10 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_10+Lambs_b_10+Lambs_c_10+"10mo_cull_a_10"+"10mo_cull_b_10" *MJME/fortnight*
F_11 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_11+Lambs_b_11+Lambs_c_11+"10mo_cull_a_11"+"10mo_cull_b_11" *MJME/fortnight*
F_12 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26++MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_12+Lambs_b_12+Lambs_c_12+"10mo_cull_a_12"+"10mo_cull_b_12" *MJME/fortnight*
F_13 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_13+Lambs_b_13+Lambs_c_13+"10mo_cull_a_13"+"10mo_cull_b_13" *MJME/fortnight*
F_14 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_14+Lambs_b_14+Lambs_c_14+"10mo_cull_a_14"+"10mo_cull_b_14" *MJME/fortnight*
F_15 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_15+Lambs_b_15+Lambs_c_15+"10mo_cull_a_15"+"10mo_cull_b_15" *MJME/fortnight*
F_16 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_16+Lambs_b_16+Lambs_c_16+"10mo_cull_a_16"+"10mo_cull_b_16" *MJME/fortnight*
F_17 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_17+Lambs_b_17+Lambs_c_17+"10mo_cull_a_17"+"10mo_cull_b_17" *MJME/fortnight*
F_18 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-

"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_18+Lambs_b_18+Lambs_c_18+"10mo_cull_a_18"+"10mo_cull_b_18" *MJME/fortnight*
F_19 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_19+Lambs_b_19+Lambs_c_19+"10mo_cull_a_19"+"10mo_cull_b_19" *MJME/fortnight*
F_2 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+"1st_X_ME_req".ME_Lactation*0.1304+MAE_Lactation_maintenance/6+"1st_X_ME_req".ME_Gestation*0.016+"10mo_cull_a_2"+"10mo_cull_b_2"
F_20 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_20+Lambs_b_20+Lambs_c_20+"10mo_cull_a_20"+"10mo_cull_b_20" *MJME/fortnight*
F_21 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_21+Lambs_b_21+Lambs_c_21+"10mo_cull_a_21"+"10mo_cull_b_21" *MJME/fortnight*
F_22 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_22+Lambs_b_22+Lambs_c_22+"10mo_cull_a_22"+"10mo_cull_b_22" *MJME/fortnight*
F_23 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+"1st_X_ME_req".ME_Gestation*0.098+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_23+Lambs_b_23+Lambs_c_23+"10mo_cull_a_23"+"10mo_cull_b_23" *MJME/fortnight*
F_24 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+"1st_X_ME_req".ME_Gestation*0.1778+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_24+Lambs_b_24+Lambs_c_24+"10mo_cull_a_24"+"10mo_cull_b_24" *MJME/fortnight*
F_25 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_25+Lambs_b_25+Lambs_c_25+"10mo_cull_a_25"+"10mo_cull_b_25"+"1st_X_ME_req".ME_Gestation*0.2486 *MJME/fortnight*
F_26 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney."1X_barren_rate"))+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_26+Lambs_b_26+Lambs_c_26+"10mo_cull_a_26"+"10mo_cull_b_26"+"1st_X_ME_req".ME_Gestation*0.3609 *MJME/fortnight*
F_3 =
"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+"1st_X_ME_req".ME_Lactation*0.1546+MAE_Lactation_maintenance/6+"10mo_cull_a_3"+"10mo_cull_b_3" *MJME/fortnight*

F_4 = "1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+"1st_X_ME_req".ME_Lactation*0.172+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing")+"10mo_cull_a_4"+"10mo_cull_b_4" *MJME/fortnight*

F_5 = "1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+IF("1st_X_ME_req".MAE_weaning_age=8)OR("1st_X_ME_req".MAE_weaning_age<8)THEN("1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_5+Lambs_b_5+Lambs_c_5+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"))ELSE("1st_X_ME_req".ME_Lactation*0.195+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing"))+"10mo_cull_a_5"+"10mo_cull_b_5" *MJME/fortnight*

F_6 = "1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+IF("1st_X_ME_req".MAE_weaning_age=10)OR("1st_X_ME_req".MAE_weaning_age<10)THEN("1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_6+Lambs_b_6+Lambs_c_6+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"))ELSE("1st_X_ME_req".ME_Lactation*0.2082+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing"))+"10mo_cull_a_6"+"10mo_cull_b_6" *MJME/fortnight*

F_7 = "1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+IF("1st_X_ME_req".MAE_weaning_age=12)OR("1st_X_ME_req".MAE_weaning_age<12)THEN("1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+Lambs_a_7+Lambs_b_7+Lambs_c_7)ELSE("1st_X_ME_req".ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing"))+"10mo_cull_a_7"+"10mo_cull_b_7" *MJME/fortnight*

F_8 = IF("1st_X_ME_req".MAE_weaning_age=14)OR("1st_X_ME_req".MAE_weaning_age<14)THEN("1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_8+Lambs_b_8+Lambs_c_8+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26)ELSE("1st_X_ME_req".ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing")+"1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26)+"10mo_cull_a_8"+"10mo_cull_b_8" *MJME/fortnight*

F_9 = "1st_X_ME_req"."1yo_ME_req"/26+"1st_X_ME_req".Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"1st_X_ME_req".Replacements_ME_req/(52-"1st_X_ME_req".MAE_weaning_age)*2+Lambs_a_9+Lambs_b_9+Lambs_c_9+"10mo_cull_a_9"+"10mo_cull_b_9" *MJME/fortnight*

Lambs_a_10 = IF("1st_X_ME_req".lambs_a_Leave>18)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0) *MJME/fortnight*

Lambs_a_11 = IF("1st_X_ME_req".lambs_a_Leave>20)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0) *MJME/fortnight*

Lambs_a_12 = IF("1st_X_ME_req".lambs_a_Leave>22)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0) *MJME/fortnight*

Lambs_a_13 = IF("1st_X_ME_req".lambs_a_Leave>24)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0) *MJME/fortnight*

Lambs_a_14 = IF("1st_X_ME_req".lambs_a_Leave>26)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0) *MJME/fortnight*

Lambs_a_15 = IF("1st_X_ME_req".lambs_a_Leave>28)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0) *MJME/fortnight*

Lambs_a_16 = IF("1st_X_ME_req".lambs_a_Leave>30)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0) *MJME/fortnight*

Lambs_a_17 = IF("1st_X_ME_req".lambs_a_Leave>32)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_18 = IF("1st_X_ME_req".lambs_a_Leave>34)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_19 = IF("1st_X_ME_req".lambs_a_Leave>36)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_20 = IF("1st_X_ME_req".lambs_a_Leave>38)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_21 = IF("1st_X_ME_req".lambs_a_Leave>40)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_22 = IF("1st_X_ME_req".lambs_a_Leave>42)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_23 = IF("1st_X_ME_req".lambs_a_Leave>44)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_24 = IF("1st_X_ME_req".lambs_a_Leave>46)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_25 = IF("1st_X_ME_req".lambs_a_Leave>48)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_26 = IF("1st_X_ME_req".lambs_a_Leave>50)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_5 = IF("1st_X_ME_req".lambs_a_Leave>8)THEN ("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_6 = IF("1st_X_ME_req".lambs_a_Leave>10)THEN ("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_7 = IF("1st_X_ME_req".lambs_a_Leave>11)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_8 = IF("1st_X_ME_req".lambs_a_Leave>14)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_9 = IF("1st_X_ME_req".lambs_a_Leave>16)THEN("1st_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_10 = IF("1st_X_ME_req".lambs_b_Leave>18)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_11 = IF("1st_X_ME_req".lambs_b_Leave>20)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_12 = IF("1st_X_ME_req".lambs_b_Leave>22)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_13 = IF("1st_X_ME_req".lambs_b_Leave>24)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_14 = IF("1st_X_ME_req".lambs_b_Leave>26)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_15 = IF("1st_X_ME_req".lambs_b_Leave>28)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_16 = IF("1st_X_ME_req".lambs_b_Leave>30)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_17 = IF("1st_X_ME_req".lambs_b_Leave>32)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_18 = IF("1st_X_ME_req".lambs_b_Leave>34)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_19 = IF("1st_X_ME_req".lambs_b_Leave>36)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_20 = IF("1st_X_ME_req".lambs_b_Leave>38)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_21 = IF("1st_X_ME_req".lambs_b_Leave>40)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_22 = IF("1st_X_ME_req".lambs_b_Leave>42)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_23 = IF("1st_X_ME_req".lambs_b_Leave>44)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_24 = IF("1st_X_ME_req".lambs_b_Leave>46)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_25 = IF("1st_X_ME_req".lambs_b_Leave>48)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_26 = IF("1st_X_ME_req".lambs_b_Leave>50)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_5 = IF("1st_X_ME_req".lambs_b_Leave>8)THEN ("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_6 = IF("1st_X_ME_req".lambs_b_Leave>10)THEN ("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_7 = IF("1st_X_ME_req".lambs_b_Leave>11)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_8 = IF("1st_X_ME_req".lambs_b_Leave>11)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_9 = IF("1st_X_ME_req".lambs_b_Leave>16)THEN("1st_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_10 = IF("1st_X_ME_req".lambs_c_Leave>18)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_11 = IF("1st_X_ME_req".lambs_c_Leave>20)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_12 = IF("1st_X_ME_req".lambs_c_Leave>22)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_13 = IF("1st_X_ME_req".lambs_c_Leave>24)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_14 = IF("1st_X_ME_req".lambs_c_Leave>26)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_15 = IF("1st_X_ME_req".lambs_c_Leave>28)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_16 = IF("1st_X_ME_req".lambs_c_Leave>30)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_17 = IF("1st_X_ME_req".lambs_c_Leave>32)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_18 = IF("1st_X_ME_req".lambs_c_Leave>34)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_19 = IF("1st_X_ME_req".lambs_c_Leave>36)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_20 = IF("1st_X_ME_req".lambs_c_Leave>38)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_21 = IF("1st_X_ME_req".lambs_c_Leave>40)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_22 = IF("1st_X_ME_req".lambs_c_Leave>42)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_23 = IF("1st_X_ME_req".lambs_c_Leave>44)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_24 = IF("1st_X_ME_req".lambs_c_Leave>46)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_25 = IF("1st_X_ME_req".lambs_c_Leave>48)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_26 = IF("1st_X_ME_req".lambs_c_Leave>50)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_5 = IF("1st_X_ME_req".lambs_c_Leave>8)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_6 = IF("1st_X_ME_req".lambs_c_Leave>10)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_7 = IF("1st_X_ME_req".lambs_c_Leave>12)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_8 = IF("1st_X_ME_req".lambs_c_Leave>14)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_9 = IF("1st_X_ME_req".lambs_c_Leave>16)THEN ("1st_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
LWC_Flushing = 2 *kg*
LWC_Gestation = 0 *kg*
LWC_Lactation = -2 *kg*
LWC_Summer = 0 *kg*
MAE_Flushing_maintenance = (((0.28*(MAE_LW_Flushing^0.75)*EXP(-0.03*"1st_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*42+(IF(LWC_Flushing>0)THEN(LWC_Flushing*55)ELSE(LWC_Flushing*(-35)))+"1st_X_ME_req".MAE_ME_Wool*42)*"Y2-7" *MJME*
MAE_Gestation_maintenance = (((0.28*("1st_X_ME_req".MAE_LW_Gestation^0.75)*EXP(-0.03*"1st_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*155+(IF(LWC_Gestation>0)THEN(LWC_Gestation*55)ELSE(LWC_Gestation*(-35)))+"1st_X_ME_req".MAE_ME_Wool*155)*"Y2-7" *MJME*
MAE_Lactation_maintenance = (((0.28*(MAE_LW_Lactation^0.75)*EXP(-0.03*"1st_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Lactation>0)THEN(LWC_Lactation*55)ELSE(LWC_Lactation*(-35)))+"1st_X_ME_req".MAE_ME_Wool*84)*"Y2-7" *MJME*
MAE_LW_Flushing = 60.45 *kg*
MAE_LW_Lactation = 58.45 *kg*
MAE_LW_Summer = 58.45 *kg*
MAE_Summer_maintenance = (((0.28*(MAE_LW_Summer^0.75)*EXP(-0.03*"1st_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Summer>0)THEN(LWC_Summer*55)ELSE(LWC_Summer*(-35)))+"1st_X_ME_req".MAE_ME_Wool*84)*"Y2-7" *MJME*
"Y2-7" = "1st_X".Ewe_flock-"1st_X"."1yo" *sheep*

"1st_X_ME_req":
Maternal_lambs_finished = "1st_X".Maternal_Female_singles_sold+"1st_X".Multiples_Male_singles_finished+"1st_X".Maternal_Female_multiples_sold+"1st_X".Maternal_Male_multiples_finished {UNIFLOW} *sheep/year*
"10mo_cull_a_%" = 1 *%*
"10mo_cull_ME_req_a" = "10mo_cull_ME_req_total"*"10mo_cull_a_%" *MJME*
"10mo_cull_ME_req_b" = "10mo_cull_ME_req_total"*(1-"10mo_cull_a_%") *MJME*
"10mo_cull_ME_req_total" = (("1yo_LW"-Maternal_single_Weaning_wt)*55+(((0.28*(MEAN(Maternal_single_Weaning_wt, "1yo_LW")^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))))*(365-MAE_weaning_age*7)+(0.13*((Wool_1st_X.MAE_GFW-1.86)*1000/(365-MAE_weaning_age*7)-6)))*"1st_X"."10mo_culls" *MJME*
"1y_wool_GFW" = 3.2 *kg*
"1yo_LW" = MAE_LW_Gestation*0.70 *kg*
"1yo_ME_LWG" = 55*(MAE_LW_Gestation-"1yo_LW") *MJME*
"1yo_ME_Maintenance" = ((0.28*(MEAN("1yo_LW", MAE_LW_Gestation)^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))) *MJME*
"1yo_ME_req" = ("1yo_wool_ME"+"1yo_ME_Maintenance"*365+"1yo_ME_LWG")*"1st_X"."1yo" *MJME*
"1yo_wool_ME" = 0.13*("1y_wool_GFW"*1000/365-6)+0.13*("6m_wool_GFW"*1000/365-6) *MJME*
"6m_wool_GFW" = 1.5 *kg*
Cold = 0
lambs_a_CW = 17.87 *kg*
lambs_a_Dressing% = .41 *%*
lambs_a_Leave = 22 *weeks after weaning*

Lambs_a_MEreq = (0.13*((Wool_1st_X.MAE_GFW+(1.87*(lambs_a_Leave/52)-3.74))*1000/(lambs_a_Leave*7)-6)*"1st_X".Maternal_Female_singles_sold*((lambs_a_Leave-MAE_weaning_age)*7)+(lambs_a_CW/lambs_a_Dressing%-Maternal_single_Weaning_wt)*55*"1st_X".Maternal_Female_singles_sold+(0.28*(MEAN(Maternal_single_Weaning_wt, (lambs_a_CW/lambs_a_Dressing%))^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((lambs_a_Leave-MAE_weaning_age)*7)*"1st_X".Maternal_Female_singles_sold)/((lambs_a_Leave-MAE_weaning_age)/2) *MJME*
lambs_b_CW = 17.87 *kg*
lambs_b_Dressing% = .41*%*
lambs_b_Leave = 30 *weeks after weaning*
lambs_b_MEreq = (0.13*((Wool_1st_X.MAE_GFW+(1.87*(lambs_b_Leave/52)-3.74))*1000/(lambs_b_Leave*7)-6)*"1st_X".Maternal_Female_multiples_sold*((lambs_b_Leave-MAE_weaning_age)*7)+(lambs_b_CW/lambs_b_Dressing%-Maternal_multiple_Weaning_wt)*55*"1st_X".Maternal_Female_multiples_sold+(0.28*(MEAN(Maternal_multiple_Weaning_wt, (lambs_b_CW/lambs_b_Dressing%))^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((lambs_b_Leave-MAE_weaning_age)*7)*"1st_X".Maternal_Female_multiples_sold)/((lambs_b_Leave-MAE_weaning_age)/2) *MJME*
lambs_c_CW = 17.87 *kg*
lambs_c_Dressing% = .41 *%*
lambs_c_Leave = 22 *weeks after weaning*
lambs_c_MEreq = (0.13*((Wool_1st_X.MAE_GFW+(1.87*(lambs_c_Leave/52)-3.74))*1000/(lambs_c_Leave*7)-6)*"1st_X".Multiples_Male_singles_finished*((lambs_c_Leave-MAE_weaning_age)*7)+(lambs_c_CW/lambs_c_Dressing%-Maternal_single_Weaning_wt)*55*"1st_X".Multiples_Male_singles_finished+(0.28*(MEAN(Maternal_single_Weaning_wt, (lambs_c_CW/lambs_c_Dressing%))^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((lambs_c_Leave-MAE_weaning_age)*7)*"1st_X".Multiples_Male_singles_finished)/((lambs_c_Leave-MAE_weaning_age)/2) *MJME*
lambs_d_CW = 17.87 *kg*
lambs_d_Dressing% = .41 *%*
lambs_d_Leave = 30 *weeks after weaning*
lambs_d_MEreq = (0.13*((Wool_1st_X.MAE_GFW+(1.87*(lambs_d_Leave/52)-3.74))*1000/(lambs_d_Leave*7)-6)*"1st_X".Maternal_Male_multiples_finished*((lambs_d_Leave-MAE_weaning_age)*7)+(lambs_d_CW/lambs_d_Dressing%-Maternal_multiple_Weaning_wt)*55*"1st_X".Maternal_Male_multiples_finished+(0.28*(MEAN(Maternal_multiple_Weaning_wt, (lambs_d_CW/lambs_d_Dressing%))^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((lambs_d_Leave-MAE_weaning_age)*7)*"1st_X".Maternal_Male_multiples_finished)/((lambs_d_Leave-MAE_weaning_age)/2) *MJME*
Length_of_cold = 0
MAE_LW_Gestation = 60.45 *kg*
MAE_ME_Maintenance = ((0.28*(MAE_LW_Gestation^0.75)*EXP(-0.03*"1st_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))) *MJME*
MAE_ME_req = (MAE_ME_Maintenance*365+MAE_ME_Maintenance*(IF(Cold=1)THEN(0.2*Length_of_cold)ELSE(0))+MAE_ME_Wool*365)*"1st_X".Ewe_flock *MJME*
MAE_ME_Wool = 0.13*(Wool_1st_X.MAE_GFW*1000/365-6) *MJME*
MAE_weaning_age = 12 *weeks after start of lambing*
Maternal_Multiple_birth_weight = 4.5 *kg*
Maternal_multiple_Weaning_wt = 23.14 *kg*
Maternal_Single_Birth_weight = 5.5 *kg*
Maternal_single_Weaning_wt = 24.92 *kg*

ME_Gestation = (((Romney."1X_singles_weaned")/(1-Romney."1X_singles_loss_rate"))*Single_ME_req_preg+((Romney."1Xmultiples_weaned")/(1-Romney."1X_multiples_loss_rate"))*Multiple_ME_req_preg) *MJME*
ME_Lactation = ((Romney."1X_singles_weaned")/(1-Romney."1X_singles_loss_rate"))*Single_ME_req_lact+(Multiple_ME_req_lact/2*1.35)*((Romney."1Xmultiples_weaned")/(1-Romney."1X_multiples_loss_rate")) *MJME*
Multiple_ME_req_lact = -1808+51.4*Maternal_multiple_Weaning_wt*+134.7*MAE_weaning_age *MJME*
Multiple_ME_req_preg = GRAPH(Maternal_Multiple_birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*
Ram_Age = 4 *years*
Ram_LW = 70 *kg*
Ram_ME_Maintenance = (((0.28*(Ram_LW^0.75)*EXP(-0.03*Ram_Age))/(0.02*Romney_ME_req."M/D"+0.5))*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*1.15) *MJME*
Ram_ME_req = (Ram_ME_Maintenance*365+Ram_wool_ME*365+IF(Cold=1)THEN(Ram_ME_Maintenance*0.2*Length_of_cold)ELSE(0))*(Romney."%_MAE_to_Merino"*Romney.Rams) *MJME*
Ram_wool_ME = 0.13*(Wool_1st_X.MAE_GFW*1000/365-6) *MJME*
Replacements_ME_req = (("1yo_LW"-Maternal_single_Weaning_wt)*55+(((0.28*(MEAN(Maternal_single_Weaning_wt, "1yo_LW")^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))))*(365-MAE_weaning_age*7)+(0.13*((Wool_1st_X.MAE_GFW-1.86)*1000/(365-MAE_weaning_age*7)-6)))*"1st_X".replacements *MJME*
Single_ME_req_lact = -1808+51.4*Maternal_single_Weaning_wt+134.7*MAE_weaning_age *MJME*
Single_ME_req_preg = GRAPH(Maternal_Single_Birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*

"2nd_X":
"1yo"(t) = "1yo"(t - dt) + (Replacements - "1yo_culls" - become_2yo - "1yo_deaths") * dt {NON-NEGATIVE} *sheep*
INIT "1yo" = 0 *sheep*
INFLOWS:
Replacements = IF(Ewe_flock<Desired_ewe_flock)THEN("2X_Female_Single_kept_GROWING"+"2X_Female_Multiples_kept_GROWING")ELSE("2X_Female_Single_kept_STABLE"+"2X_Female_Multiples_kept_STABLE") {UNIFLOW} *sheep/year*
OUTFLOWS:
"1yo_culls" = "1yo_cull_rate"*"1yo" {UNIFLOW} *sheep/year*
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
"1yo_deaths" = "1yo_Death_rate"*"1yo" {UNIFLOW} *sheep/year*
"2yo"(t) = "2yo"(t - dt) + (become_2yo - become_3yo - "2yo_deaths" - "2yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "2yo" = 0 *sheep*
INFLOWS:
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
"2yo_deaths" = "2yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"2yo_culls" = "2yo"*MAE_cull_rate {UNIFLOW} *sheep/year*
"3_yo"(t) = "3_yo"(t - dt) + (become_3yo - become_4yo - "3yo_deaths" - "3yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "3_yo" = 0 *sheep*
INFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:

become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
"3yo_deaths" = "3_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"3yo_culls" = "3_yo"*MAE_cull_rate {UNIFLOW} *sheep/year*
"4_yo"(t) = "4_yo"(t - dt) + (become_4yo - become_5yo - "4yo_deaths" - "4yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "4_yo" = 0 *sheep*
INFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
"4yo_deaths" = "4_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"4yo_culls" = MAE_cull_rate*"4_yo" {UNIFLOW} *sheep/year*
"5_yo"(t) = "5_yo"(t - dt) + (become_5yo - become_6yo - "5yo_deaths" - "5yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "5_yo" = 0 *sheep*
INFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
"5yo_deaths" = "5_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"5yo_culls" = MAE_cull_rate*"5_yo" {UNIFLOW} *sheep/year*
"6_yo"(t) = "6_yo"(t - dt) + (become_6yo - become_7yo - "6yo_deaths" - "6yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "6_yo" = 0 *sheep*
INFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
"6yo_deaths" = "6_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"6yo_culls" = MAE_cull_rate*"6_yo" {UNIFLOW} *sheep/year*
"7_yo"(t) = "7_yo"(t - dt) + (become_7yo - "7yo_deaths" - "7yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "7_yo" = 0 *sheep*
INFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
"7yo_deaths" = "7_yo"*(Death_rate_MAE+0.02) {UNIFLOW} *sheep/year*
"7yo_culls" = "7_yo"-"7yo_deaths" {UNIFLOW} *sheep/year*
"2X_Female_multiples_finished" = IF(Ewe_flock<Desired_ewe_flock)THEN("2X_Female_Multiples_weaned"*Sortweaning_cull_rate)ELSE("2X_Female_Multiples_weaned"-"2X_Female_Multiples_kept_STABLE") {UNIFLOW} *sheep/year*
"2X_Female_Multiples_kept_STABLE" = IF("2X_Female_singles_weaned"<Replacement_req)THEN(IF("2X_Female_Multiples_weaned">(Replacement_req-"2X_Female_Single_kept_STABLE"))THEN(Replacement_req-"2X_Female_Single_kept_STABLE")ELSE("2X_Female_Multiples_weaned"))ELSE(0) {UNIFLOW} *sheep/year*
"2X_Female_singles_finished" = IF(Ewe_flock<Desired_ewe_flock)THEN("2X_Female_singles_weaned"*Sortweaning_cull_rate)ELSE("2X_Female_singles_weaned"-"2X_Female_Single_kept_STABLE") {UNIFLOW} *sheep/year*
"2X_Female_singles_weaned" = IF("2X_single_scan">0)THEN("2X_single_scan"*(1-"2X_singles_loss_rate")*0.5)ELSE(("2X_lambs_weaned"*"2X_singles"+"1st_X"."2X_singles_weaned")*0.5) {UNIFLOW} *sheep/year*
"2X_male_multiples_weaned" = IF("2X_multiple_scan">0)THEN("2X_multiple_scan"*(1-"2X_multiples_loss_rate")*0.5)ELSE("2X_lambs_weaned"*"2X_multiples"*0.5)+"1st_X"."2X_multiples_weaned"*0.5 {UNIFLOW} *sheep/year*
"2X_male_singles_weaned" = IF("2X_single_scan">0)THEN("2X_single_scan"*(1-"2X_singles_loss_rate")*0.5)ELSE("2X_lambs_weaned"*"2X_singles"*0.5)+"1st_X"."2X_singles_weaned"*0.5 {UNIFLOW} *sheep/year*

Rams = ROUND(Ewe_flock/Ram_ratio) {UNIFLOW} *sheep/year*
"%_lambs_from_2X" =
"2X_lambs_weaned"/("2X_lambs_weaned"+"1st_X"."2X_singles_weaned"+"1st_X"."2X_multiples_weaned"+0.0001) *sheep*
"1yo_cull_rate" = 0 *%*
"1yo_Death_rate" = 0.02 *%*
"2X_barren_rate" = .03 *%*
"2X_Female_Multiples_kept_GROWING" = "2X_Female_Multiples_kept_STABLE"*(1-Sortweaning_cull_rate)*(1-Sort10mo_cull_rate) *sheep*
"2X_Female_Multiples_weaned" = IF("2X_multiple_scan">0)THEN("2X_multiple_scan"*(1-"2X_multiples_loss_rate")*0.5)ELSE(("2X_lambs_weaned"*"2X_multiples"+"1st_X"."2X_multiples_weaned")*0.5)
"2X_Female_Single_kept_GROWING" = "2X_Female_singles_weaned"*(1-Sortweaning_cull_rate)*(1-Sort10mo_cull_rate) *sheep*
"2X_Female_Single_kept_STABLE" =
IF("2X_Female_singles_weaned">Replacement_req)OR("2X_Female_singles_weaned"=Replacement_req)THEN(Replacement_req)ELSE("2X_Female_singles_weaned") *sheep*
"2X_lambing_rate" = 1.1443 *%*
"2X_lambs_born/_ewe_lambing" = "2X_lambs_weaned"*(1+MEAN("2X_multiples_loss_rate", "2X_singles_loss_rate"))/(Ewe_flock*(1-"2X_barren_rate")+0.0001) *%*
"2X_lambs_weaned" = (1-"%_MAE_to_Terminal")*"2X_lambing_rate"*("2yo"*0.85+"3_yo"*0.97+"4_yo"*1.04+"5_yo"*1.09+"6_yo"*1.06+"7_yo"*0.99) *sheep*
"2X_multiple_scan" = 0 *sheep*
"2X_multiples" = GRAPH("2X_lambs_born/_ewe_lambing")
(1.000, 0.000), (1.100, 0.050), (1.200, 0.200), (1.300, 0.300), (1.400, 0.400), (1.500, 0.480), (1.600, 0.600), (1.700, 0.680), (1.800, 0.720), (1.900, 0.780), (2.000, 0.800), (2.100, 0.820), (2.200, 0.830), (2.300, 0.860), (2.400, 0.880), (2.500, 0.880) *sheep*
"2X_multiples_loss_rate" = 0.16 *%*
"2X_single_scan" = 0 *sheep*
"2X_singles" = GRAPH("2X_lambs_born/_ewe_lambing")
(1.000, 1.000), (1.100, 0.950), (1.200, 0.800), (1.300, 0.700), (1.400, 0.600), (1.500, 0.500), (1.600, 0.400), (1.700, 0.320), (1.800, 0.280), (1.900, 0.220), (2.000, 0.200), (2.100, 0.180), (2.200, 0.170), (2.300, 0.140), (2.400, 0.120), (2.500, 0.120) *sheep*
"2X_singles_loss_rate" = 0.16 *%*
Age_MAE =
("2yo"*2+"3_yo"*3+"4_yo"*4+"5_yo"*5+("6_yo"+"7_yo")*6)/("2yo"+"3_yo"+"4_yo"+"5_yo"+"6_yo"+"7_yo"+0.00001) *years*
Culled_10mo =
IF(Desired_ewe_flock>Ewe_flock)THEN(("2X_lambs_weaned"+"1st_X"."2X_singles_weaned"+"1st_X"."2X_multiples_weaned")*0.5*Sort10mo_cull_rate*Sortweaning_cull_rate)ELSE(0) *sheep*
Death_rate_MAE = 0.052 *%*
Deaths = Wastage+"7yo_culls"-Ewe_culls-"1yo_deaths" *sheep*
Desired_ewe_flock = 2300 *sheep*
Ewe_culls = "2yo_culls"+"3yo_culls"+"4yo_culls"+"5yo_culls"+"6yo_culls"+"7yo_culls"+"1yo_culls" *sheep*
Ewe_flock = "7_yo"+"6_yo"+"5_yo"+"4_yo"+"3_yo"+"2yo"+"1yo" *sheep*
MAE_cull_rate = 0.04 *%*
Ram_ratio = 100
Replacement_Buffer = 0 *sheep*
Replacement_req = (IF((Ewe_flock+Wastage+"7yo_culls")<Desired_ewe_flock)THEN(Desired_ewe_flock-Ewe_flock+Wastage+"7yo_culls")ELSE(Wastage+"7yo_culls"))/(1-Replacement_Buffer) *sheep*
Sort10mo_cull_rate = 0.23 *%*
Sortweaning_cull_rate = 0.23 *%*
Wastage =
"2yo_deaths"+"3yo_deaths"+"4yo_deaths"+"5yo_deaths"+"1yo_deaths"+"6yo_deaths"+"7yo_deaths"+Ewe_culls-"7yo_culls" *sheep*

"2nd_X_fortnightly_feed_demand":
"Cull_rate_exclu._barren" = ("2nd_X".Ewe_culls-"2nd_X".Ewe_flock*MEAN("2nd_X"."2X_barren_rate"_1))/("2nd_X".Ewe_flock-"2nd_X".Ewe_flock*MEAN("2nd_X"."2X_barren_rate"_1)+0.00001) *%*
"%_Culled_tailing" = .1 *%*
"10mo_cull_a_1" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_10" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_11" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_12" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_13" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_14" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_15" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_16" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_17" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_18" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_19" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_2" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_20" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_21" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_22" = "2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2) *MJME/fortnight*
"10mo_cull_a_23" = IF ("10mo_cull_leave_a">44)THEN("2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2))ELSE (0) *MJME/fortnight*
"10mo_cull_a_24" = IF ("10mo_cull_leave_a">46)THEN("2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2))ELSE (0) *MJME/fortnight*

"10mo_cull_a_25" = IF
("10mo_cull_leave_a">48)THEN("2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2))ELSE (0) *MJME/fortnight*
"10mo_cull_a_26" = IF
("10mo_cull_leave_a">50)THEN("2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2))ELSE (0) *MJME/fortnight*
"10mo_cull_a_3" =
"2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2)
MJME/fortnight
"10mo_cull_a_4" =
"2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2)
MJME/fortnight
"10mo_cull_a_5" =
"2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2)
MJME/fortnight
"10mo_cull_a_6" =
"2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2)
MJME/fortnight
"10mo_cull_a_7" =
"2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2)
MJME/fortnight
"10mo_cull_a_8" =
"2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2)
MJME/fortnight
"10mo_cull_a_9" =
"2nd_X_ME_req"."10mo_cull_ME_req_a"*(("10mo_cull_leave_a"/2)/26)/("10mo_cull_leave_a"/2)
MJME/fortnight
"10mo_cull_b_1" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_10" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_11" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_12" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_13" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_14" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_15" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_16" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_17" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_18" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight

"10mo_cull_b_19" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_2" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_20" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_21" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_22" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_23" = IF
("10mo_cull_leave_b">44)THEN("2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_24" = IF
("10mo_cull_leave_b">46)THEN("2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_25" = IF
("10mo_cull_leave_b">48)THEN("2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_26" = IF
("10mo_cull_leave_b">50)THEN("2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2))ELSE(0) *MJME/fortnight*
"10mo_cull_b_3" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_4" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_5" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_6" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_7" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_8" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_b_9" =
"2nd_X_ME_req"."10mo_cull_ME_req_b"*(("10mo_cull_leave_b"/2)/26)/("10mo_cull_leave_b"/2)
MJME/fortnight
"10mo_cull_leave_a" = 44 *weeks after start of lambing*
"10mo_cull_leave_b" = 44 *weeks after start of lambing*
F_1 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+"2nd_X_ME_req".ME_Lactation*0.084+MAE_Lactation_maintenance/6+"2nd_X_ME_req".ME_Gestation*0.1188+"10mo_cull_a_1"+"10mo_cull_b_1"
F_10 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-

"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_10+Lambs_b_10+Lambs_c_10+"10mo_cull_a_10"+"10mo_cull_b_10" *MJME/fortnight*
F_11 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_11+Lambs_b_11+Lambs_c_11+"10mo_cull_a_11"+"10mo_cull_b *MJME/fortnight* _11"
F_12 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26++MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_12+Lambs_b_12+Lambs_c_12+"10mo_cull_a_12"+"10mo_cull_b_12" *MJME/fortnight*
F_13 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_13+Lambs_b_13+Lambs_c_13+"10mo_cull_a_13"+"10mo_cull_b_13" *MJME/fortnight*
F_14 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_14+Lambs_b_14+Lambs_c_14+"10mo_cull_a_14"+"10mo_cull_b_14" *MJME/fortnight*
F_15 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_15+Lambs_b_15+Lambs_c_15+"10mo_cull_a_15"+"10mo_cull_b_15" *MJME/fortnight*
F_16 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_16+Lambs_b_16+Lambs_c_16+"10mo_cull_a_16"+"10mo_cull_b_16" *MJME/fortnight*
F_17 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_17+Lambs_b_17+Lambs_c_17+"10mo_cull_a_17"+"10mo_cull_b_17" *MJME/fortnight*
F_18 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_18+Lambs_b_18+Lambs_c_18+"10mo_cull_a_18"+"10mo_cull_b_18" *MJME/fortnight*
F_19 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_19+Lambs_b_19+Lambs_c_19+"10mo_cull_a_19"+"10mo_cull_b_19" *MJME/fortnight*
F_2 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+"2nd_X_ME_req".ME_Lactation*0.1304+MAE_Lactation_maintenance/6+"2nd_X_ME_req".ME_Gestation*0.016+"10mo_cull_a_2"+"10mo_cull_b_2" *MJME/fortnight*
F_20 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-

"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_20+Lambs_b_20+Lambs_c_20+"10mo_cull_a_20"+"10mo_cull_b_20" *MJME/fortnight*
F_21 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_21+Lambs_b_21+Lambs_c_21+"10mo_cull_a_21"+"10mo_cull_b_21" *MJME/fortnight*
F_22 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_22+Lambs_b_22+Lambs_c_22+"10mo_cull_a_22"+"10mo_cull_b_22" *MJME/fortnight*
F_23 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+"2nd_X_ME_req".ME_Gestation*0.098+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_23+Lambs_b_23+Lambs_c_23+"10mo_cull_a_23"+"10mo_cull_b_23" *MJME/fortnight*
F_24 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+"2nd_X_ME_req".ME_Gestation*0.1778+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_24+Lambs_b_24+Lambs_c_24+"10mo_cull_a_24"+"10mo_cull_b_24" *MJME/fortnight*
F_25 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_25+Lambs_b_25+Lambs_c_25+"10mo_cull_a_25"+"10mo_cull_b_25"+"2nd_X_ME_req".ME_Gestation*0.2486 *MJME/fortnight*
F_26 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN("2nd_X"."2X_barren_rate"_1))+"2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_26+Lambs_b_26+Lambs_c_26+"10mo_cull_a_26"+"10mo_cull_b_26"+"2nd_X_ME_req".ME_Gestation*0.3609 *MJME/fortnight*
F_3 =
"10mo_cull_b_3"+"10mo_cull_a_3"+"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+"2nd_X_ME_req".ME_Lactation*0.1546+MAE_Lactation_maintenance/6 *MJME/fortnight*
F_4 =
"10mo_cull_a_4"+"10mo_cull_b_4"+"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+"2nd_X_ME_req".ME_Lactation*0.172+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing") *MJME/fortnight*
F_5 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+IF("2nd_X_ME_req".MAE_weaning_age=8)OR("2nd_X_ME_req".MAE_weaning_age<8)THEN("2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_5+Lambs_b_5+Lambs_c_5+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"))ELSE("2nd_X_ME_req".ME_Lactation*0.195+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing"))+"10mo_cull_a_5"+"10mo_cull_b_5" *MJME/fortnight*
F_6 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+IF("2nd_X_ME_req".MAE_weaning_age=10)OR("2nd_X_ME_req".MAE_weaning_age<10)THEN("2nd_X_ME_req".Replacements_ME_r

eq/(52-
"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_6+Lambs_b_6+Lambs_c_6+MAE_Lactation_maintenance/6*(1-
"Cull_rate_exclu._barren"))ELSE("2nd_X_ME_req".ME_Lactation*0.2082+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing"))+"10mo_cull_a_6"+"10mo_cull_b_6"
MJME/fortnight
F_7 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+IF("2nd_X_ME_req".MAE_weaning_age=12)OR("2nd_X_ME_req".MAE_weaning_age<12)THEN("2nd_X_ME_req".Replacements_ME_req/(52-"2nd_X_ME_req".MAE_weaning_age)*2+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren")+Lambs_a_7+Lambs_b_7+Lambs_c_7)ELSE("2nd_X_ME_req".ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren"*"%_Culled_tailing"))+"10mo_cull_a_7"+"10mo_cull_b_7" *MJME/fortnight*
F_8 =
IF("2nd_X_ME_req".MAE_weaning_age=14)OR("2nd_X_ME_req".MAE_weaning_age<14)THEN("2nd_X_ME_req".Replacements_ME_req/(52-
"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_8+Lambs_b_8+Lambs_c_8+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren")+"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26)ELSE("2nd_X_ME_req".ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-
"Cull_rate_exclu._barren"*"%_Culled_tailing")+"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26)+"10mo_cull_a_8"+"10mo_cull_b_8" *MJME/fortnight*
F_9 =
"2nd_X_ME_req"."1yo_ME_req"/26+"2nd_X_ME_req".Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+"2nd_X_ME_req".Replacements_ME_req/(52-
"2nd_X_ME_req".MAE_weaning_age)*2+Lambs_a_9+Lambs_b_9+Lambs_c_9+"10mo_cull_a_9"+"10mo_cull_b_9" *MJME/fortnight*
Lambs_a_10 =
IF("2nd_X_ME_req".Lambs_a_Leave>18)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_11 =
IF("2nd_X_ME_req".Lambs_a_Leave>20)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_12 =
IF("2nd_X_ME_req".Lambs_a_Leave>22)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_13 =
IF("2nd_X_ME_req".Lambs_a_Leave>24)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_14 =
IF("2nd_X_ME_req".Lambs_a_Leave>26)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_15 =
IF("2nd_X_ME_req".Lambs_a_Leave>28)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_16 =
IF("2nd_X_ME_req".Lambs_a_Leave>30)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_17 =
IF("2nd_X_ME_req".Lambs_a_Leave>32)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_18 =
IF("2nd_X_ME_req".Lambs_a_Leave>34)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_19 =
IF("2nd_X_ME_req".Lambs_a_Leave>36)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight

Lambs_a_20 =
IF("2nd_X_ME_req".Lambs_a_Leave>38)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_21 =
IF("2nd_X_ME_req".Lambs_a_Leave>40)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_22 =
IF("2nd_X_ME_req".Lambs_a_Leave>42)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_23 =
IF("2nd_X_ME_req".Lambs_a_Leave>44)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_24 =
IF("2nd_X_ME_req".Lambs_a_Leave>46)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_25 =
IF("2nd_X_ME_req".Lambs_a_Leave>48)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_26 =
IF("2nd_X_ME_req".Lambs_a_Leave>50)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_5 = IF("2nd_X_ME_req".Lambs_a_Leave>8)THEN ("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_6 = IF("2nd_X_ME_req".Lambs_a_Leave>10)THEN ("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_7 = IF("2nd_X_ME_req".Lambs_a_Leave>11)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_8 = IF("2nd_X_ME_req".Lambs_a_Leave>14)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_9 = IF("2nd_X_ME_req".Lambs_a_Leave>16)THEN("2nd_X_ME_req".Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_10 =
IF("2nd_X_ME_req".Lambs_b_Leave>18)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_11 =
IF("2nd_X_ME_req".Lambs_b_Leave>20)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_12 =
IF("2nd_X_ME_req".Lambs_b_Leave>22)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_13 =
IF("2nd_X_ME_req".Lambs_b_Leave>24)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_14 =
IF("2nd_X_ME_req".Lambs_b_Leave>26)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_15 =
IF("2nd_X_ME_req".Lambs_b_Leave>28)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_16 =
IF("2nd_X_ME_req".Lambs_b_Leave>30)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_17 =
IF("2nd_X_ME_req".Lambs_b_Leave>32)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_18 =
IF("2nd_X_ME_req".Lambs_b_Leave>34)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_19 =
IF("2nd_X_ME_req".Lambs_b_Leave>36)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_20 =
IF("2nd_X_ME_req".Lambs_b_Leave>38)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_21 =
IF("2nd_X_ME_req".Lambs_b_Leave>40)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_22 =
IF("2nd_X_ME_req".Lambs_b_Leave>42)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_23 =
IF("2nd_X_ME_req".Lambs_b_Leave>44)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_24 =
IF("2nd_X_ME_req".Lambs_b_Leave>46)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_25 =
IF("2nd_X_ME_req".Lambs_b_Leave>48)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_26 =
IF("2nd_X_ME_req".Lambs_b_Leave>50)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_5 = IF("2nd_X_ME_req".Lambs_b_Leave>8)THEN ("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_6 = IF("2nd_X_ME_req".Lambs_b_Leave>10)THEN ("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_7 = IF("2nd_X_ME_req".Lambs_b_Leave>11)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_8 = IF("2nd_X_ME_req".Lambs_b_Leave>11)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_9 = IF("2nd_X_ME_req".Lambs_b_Leave>16)THEN("2nd_X_ME_req".lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_10 = IF("2nd_X_ME_req".Lambs_c_Leave>18)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_11 = IF("2nd_X_ME_req".Lambs_c_Leave>20)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_12 = IF("2nd_X_ME_req".Lambs_c_Leave>22)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_13 = IF("2nd_X_ME_req".Lambs_c_Leave>24)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_14 = IF("2nd_X_ME_req".Lambs_c_Leave>26)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_15 = IF("2nd_X_ME_req".Lambs_c_Leave>28)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_16 = IF("2nd_X_ME_req".Lambs_c_Leave>30)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_17 = IF("2nd_X_ME_req".Lambs_c_Leave>32)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_18 = IF("2nd_X_ME_req".Lambs_c_Leave>34)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_19 = IF("2nd_X_ME_req".Lambs_c_Leave>36)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_20 = IF("2nd_X_ME_req".Lambs_c_Leave>38)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_21 = IF("2nd_X_ME_req".Lambs_c_Leave>40)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_22 = IF("2nd_X_ME_req".Lambs_c_Leave>42)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_23 = IF("2nd_X_ME_req".Lambs_c_Leave>44)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_24 = IF("2nd_X_ME_req".Lambs_c_Leave>46)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_25 = IF("2nd_X_ME_req".Lambs_c_Leave>48)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_26 = IF("2nd_X_ME_req".Lambs_c_Leave>50)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_5 = IF("2nd_X_ME_req".Lambs_c_Leave>8)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_6 = IF("2nd_X_ME_req".Lambs_c_Leave>10)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_7 = IF("2nd_X_ME_req".Lambs_c_Leave>12)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_8 = IF("2nd_X_ME_req".Lambs_c_Leave>14)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_9 = IF("2nd_X_ME_req".Lambs_c_Leave>16)THEN ("2nd_X_ME_req".lambs_c_MEreq)ELSE(0) *MJME/fortnight*
LWC_Flushing = 2 *kg*
LWC_Gestation = 0 *kg*
LWC_Lactation = -2 *kg*
LWC_Summer = 0 *kg*
MAE_Flushing_maintenance = (((0.28*(MAE_LW_Flushing^0.75)*EXP(-0.03*"2nd_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*42+(IF(LWC_Flushing>0)THEN(LWC_Flushing*55)ELSE(LWC_Flushing*(-35)))+"2nd_X_ME_req".MAE_ME_Wool*42)*"Y2-7" *MJME*
MAE_Gestation_maintenance = (((0.28*("2nd_X_ME_req".MAE_LW_Gestation^0.75)*EXP(-0.03*"2nd_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*155+(IF(LWC_Gestation>0)THEN(LWC_Gestation*55)ELSE(LWC_Gestation*(-35)))+"2nd_X_ME_req".MAE_ME_Wool*155)*"Y2-7" *MJME*
MAE_Lactation_maintenance = (((0.28*(MAE_LW_Lactation^0.75)*EXP(-0.03*"2nd_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Lactation>0)THEN(LWC_Lactation*55)ELSE(LWC_Lactation*(-35)))+"2nd_X_ME_req".MAE_ME_Wool*84)*"Y2-7" *MJME*
MAE_LW_Flushing = 58 *kg*
MAE_LW_Lactation = 56 *kg*
MAE_LW_Summer = 56 *kg*
MAE_Summer_maintenance = (((0.28*(MAE_LW_Summer^0.75)*EXP(-0.03*"2nd_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Summer>0)THEN(LWC_Summer*55)ELSE(LWC_Summer*(-35)))+"2nd_X_ME_req".MAE_ME_Wool*84)*"Y2-7" *MJME*
Total_ME_req = F_1+F_2+F_3+F_4+F_5+F_6+F_7+F_8+F_9+F_10+F_11+F_12+F_13+F_14+F_15+F_16+F_17+F_18+F_19+F_20+F_21+F_22+F_23+F_24+F_25+F_26 *MJME*
"Y2-7" = "2nd_X".Ewe_flock-"2nd_X"."1yo" *sheep*

"2nd_X_ME_req":
maternal_lambs_finished = "2nd_X"."2X_Female_multiples_finished"+"2nd_X"."2X_Female_singles_finished"+"2nd_X"."2X_male_singles_weaned"+"2nd_X"."2X_male_multiples_weaned" {UNIFLOW} *sheep/year*
"10mo_cull_a_%" = 1 *%*

"10mo_cull_ME_req" = (("1yo_LW"-
Maternal_single_Weaning_wt)*55+(((0.28*(MEAN(Maternal_single_Weaning_wt,
"1yo_LW")^0.75)*EXP(-
0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))))*(365-
MAE_weaning_age*7)+(0.13*((Wool_2nd_X.MAE_GFW-1.86)*1000/(365-MAE_weaning_age*7)-
6)))*"2nd_X".Culled_10mo *MJME*
"10mo_cull_ME_req_a" = "10mo_cull_ME_req"*"10mo_cull_a_%" *MJME*
"10mo_cull_ME_req_b" = "10mo_cull_ME_req"*(1-"10mo_cull_a_%") *MJME*
"1y_wool_GFW" = 3.2 *kg*
"1yo_LW" = MAE_LW_Gestation*0.70 *kg*
"1yo_ME_LWG" = 55*(MAE_LW_Gestation-"1yo_LW") *MJME*
"1yo_ME_Maintenance" = ((0.28*(MEAN("1yo_LW", MAE_LW_Gestation)^0.75)*EXP(-
0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))) *MJME*
"1yo_ME_req" = ("1yo_wool_ME"+"1yo_ME_Maintenance"*365+"1yo_ME_LWG")*"2nd_X"."1yo"
MJME
"1yo_wool_ME" = 0.13*("1y_wool_GFW"*1000/365-6)+0.13*("6m_wool_GFW"*1000/365-6) *MJME*
"6m_wool_GFW" = 1.5 *kg*
a_Dressing% = .41 *%*
Cold = 0
Lambs_a_CW = 17.87 *kg*
Lambs_a_Leave = 25 *weeks after weaning*
Lambs_a_MEreq = (0.13*((Wool_2nd_X.MAE_GFW+(1.87*(Lambs_a_Leave/52)-
3.74))*1000/(Lambs_a_Leave*7)-6)*"2nd_X"."2X_Female_singles_finished"*((Lambs_a_Leave-
MAE_weaning_age)*7)+(Lambs_a_CW/a_Dressing%-
Maternal_single_Weaning_wt)*55*"2nd_X"."2X_Female_singles_finished"+(0.28*(MEAN(Maternal_sin
gle_Weaning_wt, (Lambs_a_CW/a_Dressing%))^0.75)*EXP(-
0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((Lambs_
a_Leave-MAE_weaning_age)*7)*"2nd_X"."2X_Female_singles_finished")/((Lambs_a_Leave-
MAE_weaning_age)/2) *MJME*
Lambs_b_CW = 17.87 *kg*
Lambs_b_Dressing% = .41 *%*
Lambs_b_Leave = 36 *weeks after weaning*
lambs_b_MEreq = (0.13*((Wool_2nd_X.MAE_GFW+(1.87*(Lambs_b_Leave/52)-
3.74))*1000/(Lambs_b_Leave*7)-6)*"2nd_X"."2X_Female_multiples_finished"*((Lambs_b_Leave-
MAE_weaning_age)*7)+(Lambs_b_CW/Lambs_b_Dressing%-
Maternal_multiple_Weaning_wt)*55*"2nd_X"."2X_Female_multiples_finished"+(0.28*(MEAN(Maternal
_multiple_Weaning_wt, (Lambs_b_CW/Lambs_b_Dressing%))^0.75)*EXP(-
0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((Lambs_
b_Leave-MAE_weaning_age)*7)*"2nd_X"."2X_Female_multiples_finished")/((Lambs_b_Leave-
MAE_weaning_age)/2) *MJME*
Lambs_c_CW = 17.87 *kg*
Lambs_c_Dressing% = .41 *%*
Lambs_c_Leave = 25 *weeks after weaning*
lambs_c_MEreq = (0.13*((Wool_2nd_X.MAE_GFW+(1.87*(Lambs_c_Leave/52)-
3.74))*1000/(Lambs_c_Leave*7)-6)*"2nd_X"."2X_male_singles_weaned"*((Lambs_c_Leave-
MAE_weaning_age)*7)+(Lambs_c_CW/Lambs_c_Dressing%-
Maternal_single_Weaning_wt)*55*"2nd_X"."2X_male_singles_weaned"+(0.28*(MEAN(Maternal_single
_Weaning_wt, (Lambs_c_CW/Lambs_c_Dressing%))^0.75)*EXP(-
0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((Lambs_
c_Leave-MAE_weaning_age)*7)*"2nd_X"."2X_male_singles_weaned")/((Lambs_c_Leave-
MAE_weaning_age)/2) *MJME*
Lambs_d_CW = 17.87 *kg*
Lambs_d_Dressing% = .41 *%*
Lambs_d_Leave = 36 *weeks after weaning*
lambs_d_MEreq = (0.13*((Wool_2nd_X.MAE_GFW+(1.87*(Lambs_d_Leave/52)-
3.74))*1000/(Lambs_d_Leave*7)-6)*"2nd_X"."2X_male_multiples_weaned"*((Lambs_d_Leave-
MAE_weaning_age)*7)+(Lambs_d_CW/Lambs_d_Dressing%-

Maternal_multiple_Weaning_wt)*55*"2nd_X"."2X_male_multiples_weaned"+(0.28*(MEAN(Maternal_multiple_Weaning_wt, (Lambs_d_CW/Lambs_d_Dressing%))^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*((Lambs_d_Leave-MAE_weaning_age)*7)*"2nd_X"."2X_male_multiples_weaned")/((Lambs_d_Leave-MAE_weaning_age)/2) *MJME*
Length_of_cold = 0
MAE_LW_Gestation = 58 *kg*
MAE_ME_Maintenance = ((0.28*(MAE_LW_Gestation^0.75)*EXP(-0.03*"2nd_X".Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))
MAE_ME_req = (MAE_ME_Maintenance*365+MAE_ME_Maintenance*(IF(Cold=1)THEN(0.2*Length_of_cold)ELSE(0))+MAE_ME_Wool*365)*"2nd_X".Ewe_flock *MJME*
MAE_ME_Wool = 0.13*(Wool_2nd_X.MAE_GFW*1000/365-6) *MJME*
MAE_weaning_age = 12 *weeks after start of lambing*
Maternal_Multiple_birth_weight = 4.5 *kg*
Maternal_multiple_Weaning_wt = 22.62 *kg*
Maternal_Single_Birth_weight = 5.5 *kg*
Maternal_single_Weaning_wt = 24.36 *kg*
ME_Gestation = ((("2nd_X"."2X_male_singles_weaned"+"2nd_X"."2X_Female_singles_weaned")/(1-"2nd_X"."2X_singles_loss_rate"))*Single_ME_req_gestation+(("2nd_X"."2X_Female_Multiples_weaned"+"2nd_X"."2X_male_multiples_weaned")/(1-"2nd_X"."2X_multiples_loss_rate"))*Multiple_ME_req_gestation) *MJME*
ME_Lactation = (("2nd_X"."2X_male_singles_weaned"+"2nd_X"."2X_Female_singles_weaned")/(1-"2nd_X"."2X_singles_loss_rate"))*Single_ME_req_lactation+(Multiple_ME_req_lactation/2*1.35)*+("2nd_X"."2X_Female_Multiples_weaned"+"2nd_X"."2X_male_multiples_weaned")/(1-"2nd_X"."2X_multiples_loss_rate") *MJME*
Multiple_ME_req_gestation = GRAPH(Maternal_Multiple_birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*
Multiple_ME_req_lactation = -1808+51.4*Maternal_multiple_Weaning_wt+134.7*MAE_weaning_age *MJME*
Ram_Age = 4 *years*
Ram_LW = 70 *kg*
Ram_ME_Maintenance = (((0.28*(Ram_LW^0.75)*EXP(-0.03*Ram_Age))/(0.02*Romney_ME_req."M/D"+0.5))*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))*1.15) *MJME*
Ram_ME_req = (Ram_ME_Maintenance*365+Ram_wool_ME*365+IF(Cold=1)THEN(Ram_ME_Maintenance*0.2*Length_of_cold)ELSE(0))*"2nd_X".Rams *MJME*
Ram_wool_ME = 0.13*(Wool_2nd_X.MAE_GFW*1000/365-6) *MJME*
Replacements_ME_req = (("1yo_LW"-Maternal_single_Weaning_wt)*55+(((0.28*(MEAN(Maternal_single_Weaning_wt, "1yo_LW")^0.75)*EXP(-0.03))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1))))*(365-MAE_weaning_age*7)+(0.13*((Wool_2nd_X.MAE_GFW-1.86)*1000/(365-MAE_weaning_age*7)-6)))*"2nd_X".Replacements *MJME*
Single_ME_req_gestation = GRAPH(Maternal_Single_Birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*
Single_ME_req_lactation = -1808+51.4*Maternal_single_Weaning_ wt+134.7*MAE_weaning_age *MJME*

Feed_Supply:
"%_sheep" = Total_me_req/Total_ME_from_pasture *%*
Apr_GR = GRAPH(GR)
(1.00, 10.000), (2.00, 41.000), (3.00, 29.000), (4.00, 29.000), (5.00, 28.000), (6.00, 25.000), (7.00, 26.000), (8.00, 21.000), (9.00, 14.000), (10.00, 20.000), (11.00, 13.000), (12.00, 5.000), (13.00, 0.000),

(14.00, 16.000), (15.00, 21.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Apr_ME = 30*Apr_GR*Apr_qual*"%_sheep"*Effective_ha*Feed_adjustment *MJME*
Apr_qual = 8.3 *MJME/kgDM*
Effective_ha = 530 *ha*
Aug_GR = GRAPH(GR)
(1.00, 20.000), (2.00, 0.000), (3.00, 33.000), (4.00, 14.000), (5.00, 18.000), (6.00, 15.000), (7.00, 32.000), (8.00, 7.000), (9.00, 9.000), (10.00, 11.000), (11.00, 0.000), (12.00, 0.000), (13.00, 0.000), (14.00, 9.000), (15.00, 16.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Aug_ME = 31*Aug_GR*Aug_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Aug_qual = 11.5 *MJME/kgDM*
Dec_GR = GRAPH(GR)
(1.00, 35.000), (2.00, 73.000), (3.00, 37.000), (4.00, 52.000), (5.00, 44.000), (6.00, 60.000), (7.00, 30.000), (8.00, 34.000), (9.00, 19.000), (10.00, 48.000), (11.00, 52.000), (12.00, 12.000), (13.00, 16.000), (14.00, 44.000), (15.00, 29.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Dec_ME = 31*Dec_GR*Dec_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Dec_qual = 8.5 *MJME/kgDM*
Feb_GR = GRAPH(GR)
(1.00, 15.000), (2.00, 61.000), (3.00, 30.000), (4.00, 38.000), (5.00, 26.000), (6.00, 35.000), (7.00, 12.000), (8.00, 35.000), (9.00, 14.000), (10.00, 43.000), (11.00, 35.000), (12.00, 7.000), (13.00, 8.000), (14.00, 28.000), (15.00, 32.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Feb_ME = 28*Feb_GR*Feb_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Feb_qual = 7.2 *MJME/kgDM*
Feed_adjustment = 0.77 *%*
GR = 15
Jan_GR = GRAPH(GR)
(1.00, 25.000), (2.00, 59.000), (3.00, 29.000), (4.00, 52.000), (5.00, 38.000), (6.00, 45.000), (7.00, 15.000), (8.00, 36.000), (9.00, 13.000), (10.00, 48.000), (11.00, 42.000), (12.00, 12.000), (13.00, 14.000), (14.00, 36.000), (15.00, 28.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Jan_ME = 31*Jan_GR*Jan_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Jan_qual = 8.2 *MJME/kgDM*
Jul_GR = GRAPH(GR)
(1.00, 10.000), (2.00, 24.000), (3.00, 19.000), (4.00, 8.000), (5.00, 12.000), (6.00, 5.000), (7.00, 16.000), (8.00, 3.000), (9.00, 5.000), (10.00, 5.000), (11.00, 0.000), (12.00, 0.000), (13.00, 0.000), (14.00, 5.000), (15.00, 12.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Jul_ME = 31*Jul_GR*Jul_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Jul_qual = 9.7 *MJME/kgDM*
Jun_GR = GRAPH(GR)
(1.00, 10.000), (2.00, 25.000), (3.00, 18.000), (4.00, 10.000), (5.00, 11.000), (6.00, 5.000), (7.00, 16.000), (8.00, 5.000), (9.00, 5.000), (10.00, 5.000), (11.00, 0.000), (12.00, 0.000), (13.00, 0.000), (14.00, 5.000), (15.00, 12.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Jun_ME = 30*Effective_ha*Feed_adjustment*"%_sheep"*Jun_qual*Jun_GR *MJME*
Jun_qual = 10 *MJME/kgDM*
Mar_GR = GRAPH(GR)
(1.00, 10.000), (2.00, 50.000), (3.00, 32.000), (4.00, 39.000), (5.00, 30.000), (6.00, 35.000), (7.00, 21.000), (8.00, 34.000), (9.00, 16.000), (10.00, 31.000), (11.00, 27.000), (12.00, 7.000), (13.00, 7.000), (14.00, 24.000), (15.00, 25.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Mar_ME = 31*Mar_GR*Mar_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Mar_qual = 8.5 *MJME/kgDM*
May_GR = GRAPH(GR)

(1.00, 15.000), (2.00, 32.000), (3.00, 24.000), (4.00, 15.000), (5.00, 20.000), (6.00, 15.000), (7.00, 25.000), (8.00, 8.000), (9.00, 8.000), (10.00, 10.000), (11.00, 3.000), (12.00, 1.000), (13.00, 0.000), (14.00, 9.000), (15.00, 15.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
May_ME = 31*May_GR*May_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
May_qual = 9.5 *MJME/kgDM*
Nov_GR = GRAPH(GR)
(1.00, 40.000), (2.00, 63.000), (3.00, 38.000), (4.00, 52.000), (5.00, 46.000), (6.00, 50.000), (7.00, 51.000), (8.00, 51.000), (9.00, 27.000), (10.00, 41.000), (11.00, 48.000), (12.00, 17.000), (13.00, 20.000), (14.00, 47.000), (15.00, 29.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Nov_ME = 30*Nov_GR*Nov_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Nov_qual = 9.8 *MJME/kgDM*
Oct_GR = GRAPH(GR)
(1.00, 45.000), (2.00, 58.000), (3.00, 47.000), (4.00, 46.000), (5.00, 46.000), (6.00, 55.000), (7.00, 70.000), (8.00, 51.000), (9.00, 37.000), (10.00, 40.000), (11.00, 39.000), (12.00, 24.000), (13.00, 18.000), (14.00, 46.000), (15.00, 25.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Oct_ME = 31*Oct_GR*Oct_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Oct_qual = 10 *MJME/kgDM*
Sep_GR = GRAPH(GR)
(1.00, 30.000), (2.00, 50.000), (3.00, 47.000), (4.00, 25.000), (5.00, 36.000), (6.00, 40.000), (7.00, 56.000), (8.00, 32.000), (9.00, 30.000), (10.00, 31.000), (11.00, 16.000), (12.00, 15.000), (13.00, 1.000), (14.00, 25.000), (15.00, 21.000), (16.00, 0.000), (17.00, 0.000), (18.00, 0.000), (19.00, 0.000), (20.00, 0.000) *kgDM/ha/day*
Sep_ME = 30*Sep_GR*Sep_qual*"%_sheep"*Feed_adjustment*Effective_ha *MJME*
Sep_qual = 9.9 *MJME/kgDM*
Total_ME_from_pasture =
June_ME_total+July_ME_total+August_ME_total+September_ME_total+October_ME_total+November_ME_total+December_ME_total+January_ME_total+February_ME_total+March_ME_total+April_ME_total+May_ME_total *MJME*
Total_me_req =
Romney_ME_req.F_1+"1st_X_ME_req".F_1+"2nd_X_ME_req".F_1+Romney_ME_req.F_2+"1st_X_ME_req".F_2+"2nd_X_ME_req".F_2+Romney_ME_req.F_3+"1st_X_ME_req".F_3+"2nd_X_ME_req".F_3+Romney_ME_req.F_4+"1st_X_ME_req".F_4+"2nd_X_ME_req".F_4+Romney_ME_req.F_5+"1st_X_ME_req".F_5+"2nd_X_ME_req".F_5+Romney_ME_req.F_6+
"1st_X_ME_req".F_6+"2nd_X_ME_req".F_6+Romney_ME_req.F_7+"1st_X_ME_req".F_7+"2nd_X_ME_req".F_7+Romney_ME_req.F_8+"1st_X_ME_req".F_8+"2nd_X_ME_req".F_8+Romney_ME_req.F_9+"1st_X_ME_req".F_9+"2nd_X_ME_req".F_9+Romney_ME_req.F_10+"1st_X_ME_req".F_10+"2nd_X_ME_req".F_10+Romney_ME_req.F_11+"1st_X_ME_req".F_11+"2nd_X_ME_req".F_11+Romney_ME_req.F_12+"1st_X_ME_req".F_12+"2nd_X_ME_req".F_12+Romney_ME_req.F_13+"1st_X_ME_req".F_13+"2nd_X_ME_req".F_13+"2nd_X_ME_req".F_14+"1st_X_ME_req".F_14+Romney_ME_req.F_14+"1st_X_ME_req".F_15+"2nd_X_ME_req".F_15+Romney_ME_req.F_15+"2nd_X_ME_req".F_16+"1st_X_ME_req".F_16+Romney_ME_req.F_16+"2nd_X_ME_req".F_17+"1st_X_ME_req".F_17+Romney_ME_req.F_17+"2nd_X_ME_req".F_18+"1st_X_ME_req".F_18+Romney_ME_req.F_18+"2nd_X_ME_req".F_19+"1st_X_ME_req".F_19+Romney_ME_req.F_19+"2nd_X_ME_req".F_20+"1st_X_ME_req".F_20+Romney_ME_req.F_20+"2nd_X_ME_req".F_21+"1st_X_ME_req".F_21+Romney_ME_req.F_21+"2nd_X_ME_req".F_22+"1st_X_ME_req".F_22+Romney_ME_req.F_22+"2nd_X_ME_req".F_23+"1st_X_ME_req".F_23+Romney_ME_req.F_23+"2nd_X_ME_req".F_24+"1st_X_ME_req".F_24+Romney_ME_req.F_24+"2nd_X_ME_req".F_25+"1st_X_ME_req".F_25+Romney_ME_req.F_25+"2nd_X_ME_req".F_26+"1st_X_ME_req".F_26+Romney_ME_req.F_26 *MJME*

Romney:
"1yo"(t) = "1yo"(t - dt) + (Replacements - "1yo_culls" - become_2yo - "1yo_deaths") * dt {NON-NEGATIVE} *sheep*
INIT "1yo" = 418 *sheep*
INFLOWS:

Replacements = (Maternal_female_singles_kept+Maternal_female_multiples_kept)*(1-Replacement_Buffer) {UNIFLOW} *sheep/year*
OUTFLOWS:
"1yo_culls" = "1yo_cull_rate"*"1yo" {UNIFLOW} *sheep/year*
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
"1yo_deaths" = "1yo_Death_rate"*"1yo" {UNIFLOW} *sheep/year*
"2yo"(t) = "2yo"(t - dt) + (become_2yo - become_3yo - "2yo_deaths" - "2yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "2yo" = 423 *sheep*
INFLOWS:
become_2yo = "1yo"-"1yo_culls"-"1yo_deaths" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
"2yo_deaths" = "2yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"2yo_culls" = "2yo"*(MAE_cull_rate+Cull_all) {UNIFLOW} *sheep/year*
"3_yo"(t) = "3_yo"(t - dt) + (become_3yo - become_4yo - "3yo_deaths" - "3yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "3_yo" = 389 *sheep*
INFLOWS:
become_3yo = "2yo"-"2yo_deaths"-"2yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
"3yo_deaths" = "3_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"3yo_culls" = "3_yo"*(MAE_cull_rate+Cull_all) {UNIFLOW} *sheep/year*
"4_yo"(t) = "4_yo"(t - dt) + (become_4yo - become_5yo - "4yo_deaths" - "4yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "4_yo" = 357 *sheep*
INFLOWS:
become_4yo = "3_yo"-"3yo_deaths"-"3yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
"4yo_deaths" = "4_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"4yo_culls" = "4_yo"*(MAE_cull_rate+Cull_all) {UNIFLOW} *sheep/year*
"5_yo"(t) = "5_yo"(t - dt) + (become_5yo - become_6yo - "5yo_deaths" - "5yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "5_yo" = 328 *sheep*
INFLOWS:
become_5yo = "4_yo"-"4yo_deaths"-"4yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
"5yo_deaths" = "5_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"5yo_culls" = (MAE_cull_rate+Cull_all)*"5_yo" {UNIFLOW} *sheep/year*
"6_yo"(t) = "6_yo"(t - dt) + (become_6yo - become_7yo - "6yo_deaths" - "6yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "6_yo" = 301 *sheep*
INFLOWS:
become_6yo = "5_yo"-"5yo_deaths"-"5yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
"6yo_deaths" = "6_yo"*Death_rate_MAE {UNIFLOW} *sheep/year*
"6yo_culls" = (MAE_cull_rate+Cull_all)*"6_yo" {UNIFLOW} *sheep/year*
"7_yo"(t) = "7_yo"(t - dt) + (become_7yo - "7yo_deaths" - "7yo_culls") * dt {NON-NEGATIVE} *sheep*
INIT "7_yo" = 278 *sheep*
INFLOWS:
become_7yo = "6_yo"-"6yo_deaths"-"6yo_culls" {UNIFLOW} *sheep/year*
OUTFLOWS:
"7yo_deaths" = "7_yo"*(Death_rate_MAE+0.02) {UNIFLOW} *sheep/year*

"7yo_culls" = "7_yo"-"7yo_deaths" {UNIFLOW} *sheep/year*
maternal_female(t) = maternal_female(t - dt) + (Maternal_Female_multiples_weaned - Maternal_female_multiples_kept - Maternal_female_multiples_sold) * dt {NON-NEGATIVE} *sheep*
INIT maternal_female = 0 *sheep*
INFLOWS:
Maternal_Female_multiples_weaned = IF((IF(Maternal_multiple_scan>0)THEN(Maternal_multiple_scan*(1-Maternal_multiples_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_multiples*0.5))<10)THEN(0)ELSE(IF(Maternal_multiple_scan>0)THEN(Maternal_multiple_scan*(1-Maternal_multiples_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_multiples*0.5)) {UNIFLOW} *sheep/year*
OUTFLOWS:
Maternal_female_multiples_kept = IF(Maternal_female_singles<Replacement_req)THEN(Replacement_req-Maternal_female_singles_kept)ELSE(0) {UNIFLOW} *sheep/year*
Maternal_female_multiples_sold = maternal_female-Maternal_female_multiples_kept {UNIFLOW} *sheep/year*
Maternal_female_singles(t) = Maternal_female_singles(t - dt) + (Maternal_Female_singles_weaned - Maternal_female_singles_sold - Maternal_female_singles_kept) * dt {NON-NEGATIVE} *sheep*
INIT Maternal_female_singles = 0 *sheep*
INFLOWS:
Maternal_Female_singles_weaned = IF((IF(Maternal_single_scan>0)THEN(Maternal_single_scan*(1-Maternal_singles_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_singles*0.5))<10)THEN(0)ELSE(IF(Maternal_single_scan>0)THEN(Maternal_single_scan*(1-Maternal_singles_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_singles*0.5)) {UNIFLOW} *sheep/year*
OUTFLOWS:
Maternal_female_singles_sold = Maternal_female_singles-Maternal_female_singles_kept {UNIFLOW} *sheep/year*
Maternal_female_singles_kept = IF(Maternal_female_singles>Replacement_req)OR(Maternal_female_singles=Replacement_req)THEN(Replacement_req)ELSE(Maternal_female_singles) {UNIFLOW} *sheep/year*
maternal_male_multiples(t) = maternal_male_multiples(t - dt) + (Maternal_male_multiples_weaned - Male_Multiples_multiples_sold) * dt {NON-NEGATIVE} *sheep*
INIT maternal_male_multiples = 0 *sheep*
INFLOWS:
Maternal_male_multiples_weaned = IF((IF(Maternal_multiple_scan>0)THEN(Maternal_multiple_scan*(1-Maternal_multiples_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_multiples*0.5))<10)THEN(0)ELSE(IF(Maternal_multiple_scan>0)THEN(Maternal_multiple_scan*(1-Maternal_multiples_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_multiples*0.5)) {UNIFLOW} *sheep/year*
OUTFLOWS:
Male_Multiples_multiples_sold = maternal_male_multiples {UNIFLOW} *sheep/year*
Maternal_male_singles(t) = Maternal_male_singles(t - dt) + (Maternal_male_singles_weaned - Male_Multiples_singles_sold) * dt {NON-NEGATIVE} *sheep*
INIT Maternal_male_singles = 0 *sheep*
INFLOWS:
Maternal_male_singles_weaned = IF((IF(Maternal_single_scan>0)THEN(Maternal_single_scan*(1-Maternal_singles_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_singles*0.5))<10)THEN(0)ELSE(IF(Maternal_single_scan>0)THEN(Maternal_single_scan*(1-Maternal_singles_loss_rate)*0.5)ELSE(Maternal_lambs_weaned*Maternal_singles*0.5)) {UNIFLOW} *sheep/year*
OUTFLOWS:
Male_Multiples_singles_sold = Maternal_male_singles {UNIFLOW} *sheep/year*
"1X_singles_weaned" = IF((IF("1X_single_scan">0)THEN("1X_single_scan"*(1-"1X_singles_loss_rate"))ELSE("1X_lambs_weaned"*"1X_singles"))<10)THEN(0)ELSE(IF("1X_single_scan">

0)THEN("1X_single_scan"*(1-"1X_singles_loss_rate"))ELSE("1X_lambs_weaned"*"1X_singles"))
{UNIFLOW} *sheep/year*
"1Xmultiples_weaned" = IF((IF("1X_multiple_scan">0)THEN("1X_multiple_scan"*(1-
"1X_multiples_loss_rate"))ELSE("1X_lambs_weaned"*"1X_multiples"))<10)THEN(0)ELSE(IF("1X_multiple
_scan">0)THEN("1X_multiple_scan"*(1-
"1X_multiples_loss_rate"))ELSE("1X_lambs_weaned"*"1X_multiples")) {UNIFLOW} *sheep/year*
Rams = ROUND(Ewe_flock/Ram_ratio) {UNIFLOW} *sheep/year*
"%_Lambs_from_1yo" = ("1yo"*"1yo_lambing_rate")/Maternal_lambs_weaned *sheep*
"%_MAE_to_Merino" = 1 *%*
"1X_barren_rate" = .03 *%*
"1X_lambing_rate" = 1.316 *%*
"1X_lambs_born/_ewe_lambing" = "1X_lambs_weaned"*(1+MEAN("1X_multiples_loss_rate",
"1X_singles_loss_rate"))/(Ewe_flock*(1-"1X_barren_rate")*("%_MAE_to_Merino"+0.00001)+0.00001)
%
"1X_lambs_weaned" =
"%_MAE_to_Merino"*"1X_lambing_rate"*("1yo"*"1yo_lambing_rate"+"2yo"*0.85+"3_yo"*0.97+"4_yo
"*1.04+"5_yo"*1.09+"6_yo"*1.06+"7_yo"*0.99) *sheep*
"1X_multiple_scan" = 0 *sheep*
"1X_multiples" = GRAPH("1X_lambs_born/_ewe_lambing")
(1.000, 0.000), (1.100, 0.050), (1.200, 0.200), (1.300, 0.300), (1.400, 0.400), (1.500, 0.480), (1.600,
0.600), (1.700, 0.680), (1.800, 0.720), (1.900, 0.780), (2.000, 0.800), (2.100, 0.820), (2.200, 0.830),
(2.300, 0.860), (2.400, 0.880), (2.500, 0.880) *sheep*
"1X_multiples_loss_rate" = .16 *%*
"1X_single_scan" = 0 *sheep*
"1X_singles" = GRAPH("1X_lambs_born/_ewe_lambing")
(1.000, 1.000), (1.100, 0.950), (1.200, 0.800), (1.300, 0.700), (1.400, 0.600), (1.500, 0.500), (1.600,
0.400), (1.700, 0.320), (1.800, 0.280), (1.900, 0.220), (2.000, 0.200), (2.100, 0.180), (2.200, 0.170),
(2.300, 0.140), (2.400, 0.120), (2.500, 0.120) *sheep*
"1X_singles_loss_rate" = .16 *%*
"1yo_cull_rate" = 0 *%*
"1yo_Death_rate" = 0.02 *%*
"1yo_lambing_rate" = 0.55 *%*
Age_MAE =
("2yo"*2+"3_yo"*3+"4_yo"*4+"5_yo"*5+("6_yo"+"7_yo")*6)/("2yo"+"3_yo"+"4_yo"+"5_yo"+"6_yo"+"7
_yo"+0.00001) *years*
Cull_all = IF(Ewe_flock<Eradicate)AND(Eradicate>0)THEN(1)ELSE(0) *sheep*
Death_rate_MAE = 0.052 *%*
Deaths = Wastage+"7yo_culls"-Ewe_culls-"1yo_deaths" *sheep*
Desired_ewe_flock = 2483 *sheep*
Eradicate = 1500 *sheep*
Ewe_culls = "2yo_culls"+"3yo_culls"+"4yo_culls"+"5yo_culls"+"6yo_culls"+"7yo_culls"+"1yo_culls"
sheep
Ewe_flock =
IF(("7_yo"+"6_yo"+"5_yo"+"4_yo"+"3_yo"+"2yo"+"1yo")<10)THEN(0)ELSE("7_yo"+"6_yo"+"5_yo"+"4_y
o"+"3_yo"+"2yo"+"1yo") *sheep*
MAE_cull_rate = 0.03 *%*
Maternal_barren_rate = .03 *%*
Maternal_lambing_rate = 1.316
"Maternal_lambs_born/_ewe_lambing" =
Maternal_lambs_weaned*(1+MEAN(Maternal_multiples_loss_rate,
Maternal_singles_loss_rate))/(Ewe_flock*(1-Maternal_barren_rate-"%_MAE_to_Merino")+0.00001) *%*
Maternal_lambs_weaned = (1-"%_MAE_to_Terminal"-
"%_MAE_to_Merino")*Maternal_lambing_rate*("1yo"*"1yo_lambing_rate"+"2yo"*0.85+"3_yo"*0.97+
"4_yo"*1.04+"5_yo"*1.09+"6_yo"*1.06+"7_yo"*0.99) *sheep*
Maternal_multiple_scan = 0 *sheep*
Maternal_multiples = GRAPH("Maternal_lambs_born/_ewe_lambing")

(1.000, 0.000), (1.100, 0.050), (1.200, 0.200), (1.300, 0.300), (1.400, 0.400), (1.500, 0.480), (1.600, 0.600), (1.700, 0.680), (1.800, 0.720), (1.900, 0.780), (2.000, 0.800), (2.100, 0.820), (2.200, 0.830), (2.300, 0.860), (2.400, 0.880), (2.500, 0.880) *sheep*
Maternal_multiples_loss_rate = .16 *%*
Maternal_single_scan = 0 *sheep*
Maternal_singles = GRAPH("Maternal_lambs_born/_ewe_lambing")
(1.000, 1.000), (1.100, 0.950), (1.200, 0.800), (1.300, 0.700), (1.400, 0.600), (1.500, 0.500), (1.600, 0.400), (1.700, 0.320), (1.800, 0.280), (1.900, 0.220), (2.000, 0.200), (2.100, 0.180), (2.200, 0.170), (2.300, 0.140), (2.400, 0.120), (2.500, 0.120) *sheep*
Maternal_singles_loss_rate = .16 *%*
Ram_ratio = 100
Replacement_Buffer = 0.3 *%*
Replacement_req = (IF((Ewe_flock+Wastage+"7yo_culls")<Desired_ewe_flock)THEN(Desired_ewe_flock-Ewe_flock+Wastage+"7yo_culls")ELSE(Wastage+"7yo_culls"))/(1-Replacement_Buffer) *sheep*
Wastage =
"2yo_deaths"+"3yo_deaths"+"4yo_deaths"+"5yo_deaths"+"1yo_deaths"+"6yo_deaths"+"7yo_deaths"+Ewe_culls-"7yo_culls" *sheep*

Romney_fortnightly_feed_demand:
"Cull_rate_exclu._barren" = (Romney.Ewe_culls-Romney.Ewe_flock*MEAN(Romney.Maternal_barren_rate))/(Romney.Ewe_flock-Romney.Ewe_flock*MEAN(Romney.Maternal_barren_rate)+0.00001) *%*
"%_Culled_tailing" = .1 *%*
Breed_hoggets_1or2_months_later? = 2
F_1 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+Romney_ME_req.ME_Lactation*0.084+MAE_Lactation_maintenance/6+IF(Breed_hoggets_1or2_months_later?=0)THEN(Romney_ME_req.ME_Gestation*0.1188)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney_ME_req.ME_Gestation*0.1188*(1-Romney."%_Lambs_from_1yo")+Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.2486)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney_ME_req.ME_Gestation*0.1188*(1-Romney."%_Lambs_from_1yo")+Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.098)ELSE(0) *MJME/fortnight*
F_10 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_10+Lambs_b_10+Lambs_c_10+Lambs_from_1yo_10 *MJME/fortnight*
F_11 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_11+Lambs_b_11+Lambs_c_11+Lambs_from_1yo_11 *MJME/fortnight*
F_12 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26++MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_12+Lambs_b_12+Lambs_c_12+Lambs_from_1yo_12 *MJME/fortnight*
F_13 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_13+Lambs_b_13+Lambs_c_13+Lambs_from_1yo_13 *MJME/fortnight*
F_14 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-

Romney_ME_req.MAE_weaning_age)*2+Lambs_a_14+Lambs_b_14+Lambs_c_14+Lambs_from_1yo_14 *MJME/fortnight*
F_15 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Flushing_maintenance/3*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_15+Lambs_b_15+Lambs_c_15+Lambs_from_1yo_15 *MJME/fortnight*
F_16 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_16+Lambs_b_16+Lambs_c_16+Lambs_from_1yo_16 *MJME/fortnight*
F_17 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_17+Lambs_b_17+Lambs_c_17+Lambs_from_1yo_17 *MJME/fortnight*
F_18 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_18+Lambs_b_18+Lambs_c_18+Lambs_from_1yo_18 *MJME/fortnight*
F_19 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_19+Lambs_b_19+Lambs_c_19+Lambs_from_1yo_19 *MJME/fortnight*
F_2 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+Romney_ME_req.ME_Lactation*0.1304+MAE_Lactation_maintenance/6+IF(Breed_hoggets_1or2_months_later?=0)THEN(Romney_ME_req.ME_Gestation*0.016)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney_ME_req.ME_Gestation*0.016*(1-Romney."%_Lambs_from_1yo")+Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.3609)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney_ME_req.ME_Gestation*0.016*(1-Romney."%_Lambs_from_1yo")+Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.1778)ELSE(0) *MJME/fortnight*
F_20 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_20+Lambs_b_20+Lambs_c_20+Lambs_from_1yo_20 *MJME/fortnight*
F_21 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_21+Lambs_b_21+Lambs_c_21+Lambs_from_1yo_21 *MJME/fortnight*
F_22 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_22+Lambs_b_22+Lambs_c_22+Lambs_from_1yo_22 *MJME/fortnight*

F_23 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+Romney_ME_req.ME_Gestation*0.098+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_23+Lambs_b_23+Lambs_c_23+Lambs_from_1yo_23 *MJME/fortnight*
F_24 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+Romney_ME_req.ME_Gestation*0.1778+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_24+Lambs_b_24+Lambs_c_24+Lambs_from_1yo_24 *MJME/fortnight*
F_25 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_25+Lambs_b_25+Lambs_c_25+Lambs_from_1yo_25 *MJME/fortnight*
F_26 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Gestation_maintenance/11*(1-"Cull_rate_exclu._barren"-MEAN(Romney.Maternal_barren_rate))+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_26+Lambs_b_26+Lambs_c_26+Lambs_from_1yo_26 *MJME/fortnight*
F_3 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+Romney_ME_req.ME_Lactation*0.1546+MAE_Lactation_maintenance/6+IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.1188+Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.084)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.2486)ELSE(0) *MJME/fortnight*
F_4 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+Romney_ME_req.ME_Lactation*0.172+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing")+IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.016+Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.1304)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.3609)ELSE(0) *MJME/fortnight*
F_5 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+IF(Romney_ME_req.MAE_weaning_age=8)OR(Romney_ME_req.MAE_weaning_age<8)THEN(Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_5+Lambs_b_5+Lambs_c_5+
+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"))ELSE(Romney_ME_req.ME_Lactation*0.195+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing")+IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.1546)ELSE(0))+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.1188+Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.084)ELSE(0) *MJME/fortnight*
F_6 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+IF(Romney_ME_req.MAE_weaning_age=10)OR(Romney_ME_req.MAE_weaning_age<10)THEN(Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_6+Lambs_b_6+Lambs_c_6+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"))ELSE(Romney_ME_req.ME_Lactation*0.2082+MAE_Lactation_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing"))+Lambs_from_1yo_6 *MJME/fortnight*

F_7 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+Lambs_from_1yo_7+IF(Romney_ME_req.MAE_weaning_age=12)OR(Romney_ME_req.MAE_weaning_age<12)THEN(Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+Lambs_a_7+Lambs_b_7+Lambs_c_7)ELSE(Romney_ME_req.ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing"))
MJME/fortnight
F_8 =
IF(Romney_ME_req.MAE_weaning_age=14)OR(Romney_ME_req.MAE_weaning_age<14)THEN(Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_8+Lambs_b_8+Lambs_c_8+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+Lambs_from_1yo_8+Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26)ELSE(Romney_ME_req.ME_Lactation*0.2187+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren"*"%_Culled_tailing")+Lambs_from_1yo_8+Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26) *MJME/fortnight*
F_9 =
Romney_ME_req."1yo_ME_req"/26+Romney_ME_req.Ram_ME_req/26+MAE_Summer_maintenance/6*(1-"Cull_rate_exclu._barren")+Romney_ME_req.Replacements_ME_req/(52-Romney_ME_req.MAE_weaning_age)*2+Lambs_a_9+Lambs_b_9+Lambs_c_9+Lambs_from_1yo_9
MJME/fortnight
Lambs_a_10 =
IF(Romney_ME_req.Lambs_a_Leave>18)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_11 =
IF(Romney_ME_req.Lambs_a_Leave>20)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_12 =
IF(Romney_ME_req.Lambs_a_Leave>22)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_13 =
IF(Romney_ME_req.Lambs_a_Leave>24)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_14 =
IF(Romney_ME_req.Lambs_a_Leave>26)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_15 =
IF(Romney_ME_req.Lambs_a_Leave>28)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_16 =
IF(Romney_ME_req.Lambs_a_Leave>30)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_17 =
IF(Romney_ME_req.Lambs_a_Leave>32)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_18 =
IF(Romney_ME_req.Lambs_a_Leave>34)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_19 =
IF(Romney_ME_req.Lambs_a_Leave>36)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_20 =
IF(Romney_ME_req.Lambs_a_Leave>38)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight

Lambs_a_21 =
IF(Romney_ME_req.Lambs_a_Leave>40)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_22 =
IF(Romney_ME_req.Lambs_a_Leave>42)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_23 =
IF(Romney_ME_req.Lambs_a_Leave>44)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_24 =
IF(Romney_ME_req.Lambs_a_Leave>46)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_25 =
IF(Romney_ME_req.Lambs_a_Leave>48)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_26 =
IF(Romney_ME_req.Lambs_a_Leave>50)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_5 = IF(Romney_ME_req.Lambs_a_Leave>8)THEN (Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_6 = IF(Romney_ME_req.Lambs_a_Leave>10)THEN (Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_7 = IF(Romney_ME_req.Lambs_a_Leave>11)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_8 = IF(Romney_ME_req.Lambs_a_Leave>14)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_a_9 = IF(Romney_ME_req.Lambs_a_Leave>16)THEN(Romney_ME_req.Lambs_a_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_10 = IF(Romney_ME_req.Lambs_b_Leave>18)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_11 = IF(Romney_ME_req.Lambs_b_Leave>20)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_12 = IF(Romney_ME_req.Lambs_b_Leave>22)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_13 = IF(Romney_ME_req.Lambs_b_Leave>24)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_14 = IF(Romney_ME_req.Lambs_b_Leave>26)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_15 = IF(Romney_ME_req.Lambs_b_Leave>28)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_16 = IF(Romney_ME_req.Lambs_b_Leave>30)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_17 = IF(Romney_ME_req.Lambs_b_Leave>32)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_18 = IF(Romney_ME_req.Lambs_b_Leave>34)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_19 = IF(Romney_ME_req.Lambs_b_Leave>36)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_20 = IF(Romney_ME_req.Lambs_b_Leave>38)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_21 = IF(Romney_ME_req.Lambs_b_Leave>40)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_22 = IF(Romney_ME_req.Lambs_b_Leave>42)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_23 = IF(Romney_ME_req.Lambs_b_Leave>44)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight

Lambs_b_24 = IF(Romney_ME_req.Lambs_b_Leave>46)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_25 = IF(Romney_ME_req.Lambs_b_Leave>48)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_26 = IF(Romney_ME_req.Lambs_b_Leave>50)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_5 = IF(Romney_ME_req.Lambs_b_Leave>8)THEN (Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_6 = IF(Romney_ME_req.Lambs_b_Leave>10)THEN (Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_7 = IF(Romney_ME_req.Lambs_b_Leave>11)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_8 = IF(Romney_ME_req.Lambs_b_Leave>11)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_b_9 = IF(Romney_ME_req.Lambs_b_Leave>16)THEN(Romney_ME_req.lambs_b_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_10 = IF(Romney_ME_req.Lambs_c_Leave>18)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_11 = IF(Romney_ME_req.Lambs_c_Leave>20)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_12 = IF(Romney_ME_req.Lambs_c_Leave>22)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_13 = IF(Romney_ME_req.Lambs_c_Leave>24)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_14 = IF(Romney_ME_req.Lambs_c_Leave>26)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_15 = IF(Romney_ME_req.Lambs_c_Leave>28)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_16 = IF(Romney_ME_req.Lambs_c_Leave>30)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_17 = IF(Romney_ME_req.Lambs_c_Leave>32)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_18 = IF(Romney_ME_req.Lambs_c_Leave>34)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_19 = IF(Romney_ME_req.Lambs_c_Leave>36)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_20 = IF(Romney_ME_req.Lambs_c_Leave>38)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_21 = IF(Romney_ME_req.Lambs_c_Leave>40)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_22 = IF(Romney_ME_req.Lambs_c_Leave>42)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_23 = IF(Romney_ME_req.Lambs_c_Leave>44)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_24 = IF(Romney_ME_req.Lambs_c_Leave>46)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_25 = IF(Romney_ME_req.Lambs_c_Leave>48)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_26 = IF(Romney_ME_req.Lambs_c_Leave>50)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_5 = IF(Romney_ME_req.Lambs_c_Leave>8)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_6 = IF(Romney_ME_req.Lambs_c_Leave>10)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight
Lambs_c_7 = IF(Romney_ME_req.Lambs_c_Leave>12)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0)
MJME/fortnight

Lambs_c_8 = IF(Romney_ME_req.Lambs_c_Leave>14)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_c_9 = IF(Romney_ME_req.Lambs_c_Leave>16)THEN (Romney_ME_req.lambs_c_MEreq)ELSE(0) *MJME/fortnight*
Lambs_from_1yo_10 = +IF(Breed_hoggets_1or2_months_later?=1)AND(Romney_ME_req.Lambs_from_1yo_leave>14)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)AND(Romney_ME_req.Lambs_from_1yo_weaning_age>9)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.2082)ELSE(IF(Romney_ME_req.Lambs_from_1yo_leave<10)THEN(0)ELSE(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))) *MJME/fortnight*
Lambs_from_1yo_11 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_12 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_13 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_14 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_15 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_16 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_17 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_18 = Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2) *MJME/fortnight*
Lambs_from_1yo_19 = IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>32)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>28)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_20 = IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>34)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>30)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_21 = IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>36)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>32)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*

Lambs_from_1yo_22 =
IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>38)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>34)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_23 =
IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>40)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>36)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_24 =
IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>42)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>38)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_25 =
IF(Breed_hoggets_1or2_months_later?=0)THEN(Romney_ME_req.ME_Gestation*0.2486)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney_ME_req.ME_Gestation*0.2486*(1-Romney."%_Lambs_from_1yo")+Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.098)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney_ME_req.ME_Gestation*0.2486*(1-Romney."%_Lambs_from_1yo"))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>44)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>40)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_26 =
IF(Breed_hoggets_1or2_months_later?=0)THEN(Romney_ME_req.ME_Gestation*0.3609)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney_ME_req.ME_Gestation*0.3609*(1-Romney."%_Lambs_from_1yo")+Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.1778)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney_ME_req.ME_Gestation*0.3609*(1-Romney."%_Lambs_from_1yo"))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=1)AND(Romney_ME_req.Lambs_from_1yo_leave>46)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0)+IF(Romney_ME_req.ME_Lactation_Lambs_from_1yo=2)AND(Romney_ME_req.Lambs_from_1yo_leave>42)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
Lambs_from_1yo_6 =
IF(Breed_hoggets_1or2_months_later?=1)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.172)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney."%_Lambs_from_1yo"*Romney_ME_req.ME_Gestation*0.016+Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.1304)ELSE(0)
MJME/fortnight
Lambs_from_1yo_7 =
IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.1546)ELSE(0)+IF(Breed_hoggets_1or2_months_later?=1)AND(Romney_ME_req.Lambs_from_1yo_weaning_age>7)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.195)ELSE(IF(Romney_ME_req.Lambs_from_1yo_leave<10)AND(Breed_hoggets_1or2_months_later?=1)THEN(0)ELSE(Romney_ME_req.L

ambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))) *MJME/fortnight*
Lambs_from_1yo_8 =
IF(Breed_hoggets_1or2_months_later?=1)AND(Romney_ME_req.Lambs_from_1yo_weaning_age>9)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.2082)ELSE(IF(Romney_ME_req.Lambs_from_1yo_leave<12)THEN(0)ELSE(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2)))+IF(Breed_hoggets_1or2_months_later?=2)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.172)ELSE(0) *MJME/fortnight*
Lambs_from_1yo_9 =
IF(Breed_hoggets_1or2_months_later?=2)AND(Romney_ME_req.Lambs_from_1yo_weaning_age>7)THEN(Romney_ME_req.ME_Lactation_Lambs_from_1yo*0.195)ELSE(IF(Romney_ME_req.Lambs_from_1yo_leave<8)THEN(0)ELSE(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2)))+IF(Breed_hoggets_1or2_months_later?=1)AND(Romney_ME_req.Lambs_from_1yo_leave>12)THEN(Romney_ME_req.Lambs_from_1yo_MEreq/((Romney_ME_req.Lambs_from_1yo_leave-Romney_ME_req.Lambs_from_1yo_weaning_age)/2))ELSE(0) *MJME/fortnight*
LWC_Flushing = 2 *kg*
LWC_Gestation = 0 *kg*
LWC_Lactation = -2 *kg*
LWC_Summer = 0 *kg*
MAE_Flushing_maintenance = (((0.28*(MAE_LW_Flushing^0.75)*EXP(-0.03*Romney.Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*42+(IF(LWC_Flushing>0)THEN(LWC_Flushing*55)ELSE(LWC_Flushing*(-35)))+Romney_ME_req.MAE_ME_Wool*42)*"Y2-7" *MJME*
MAE_Gestation_maintenance = (((0.28*(Romney_ME_req.MAE_LW_Gestation^0.75)*EXP(-0.03*Romney.Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*155+(IF(LWC_Gestation>0)THEN(LWC_Gestation*55)ELSE(LWC_Gestation*(-35)))+Romney_ME_req.MAE_ME_Wool*155)*"Y2-7" *MJME*
MAE_Lactation_maintenance = (((0.28*(MAE_LW_Lactation^0.75)*EXP(-0.03*Romney.Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Lactation>0)THEN(LWC_Lactation*55)ELSE(LWC_Lactation*(-35)))+Romney_ME_req.MAE_ME_Wool*84)*"Y2-7" *MJME*
MAE_LW_Flushing = 66 *kg*
MAE_LW_Lactation = 66 *kg*
MAE_LW_Summer = 65 *kg*
MAE_Summer_maintenance = (((0.28*(MAE_LW_Summer^0.75)*EXP(-0.03*Romney.Age_MAE))/(0.02*Romney_ME_req."M/D"+0.5)*(IF(Romney_ME_req.Activity=1)THEN(1.1)ELSE(1)))*84+(IF(LWC_Summer>0)THEN(LWC_Summer*55)ELSE(LWC_Summer*(-35)))+Romney_ME_req.MAE_ME_Wool*84)*"Y2-7" *MJME*
"Y2-7" = Romney.Ewe_flock-Romney."1yo" *sheep*

Romney_ME_req:
Maternal_lambs_finished(t) = Maternal_lambs_finished(t - dt) + (Maternal_finished - Sold_lambs_a - Sold_lambs_d - Sold_lambs_b - Sold_lambs_c) * dt {NON-NEGATIVE} *sheep/year*
INIT Maternal_lambs_finished = 0 *Sheep*
INFLOWS:
Maternal_finished =
Romney.Maternal_female_multiples_sold+Romney.Maternal_female_singles_sold+Romney.Male_Multiples_multiples_sold+Romney.Male_Multiples_singles_sold-Romney."%_Lambs_from_1yo"*All_lambs {UNIFLOW} *sheep/year*
OUTFLOWS:
Sold_lambs_a =
IF(Maternal_lambs_finished>Sold_maternal_lambs_a)OR(Maternal_lambs_finished=Sold_maternal_lambs_a)THEN(Sold_maternal_lambs_a)ELSE(Maternal_lambs_finished) {UNIFLOW} *sheep/year*

Sold_lambs_d = Maternal_lambs_finished-Sold_lambs_a-Sold_lambs_b-Sold_lambs_c {UNIFLOW} *sheep/year*
Sold_lambs_b =
IF(Maternal_lambs_finished>(Sold_maternal_lambs_a+Sold_maternal_lambs_b))OR(Maternal_lambs_finished=(Sold_maternal_lambs_a+Sold_maternal_lambs_b))THEN(Sold_maternal_lambs_b)ELSE(Maternal_lambs_finished-Sold_maternal_lambs_a) {UNIFLOW} *sheep/year*
Sold_lambs_c =
IF(Maternal_lambs_finished>(Sold_maternal_lambs_a+Sold_maternal_lambs_b+Sold_maternal_lambs_c))OR(Maternal_lambs_finished=(Sold_maternal_lambs_a+Sold_maternal_lambs_b+Sold_maternal_lambs_c))THEN(Sold_maternal_lambs_c)ELSE(Maternal_lambs_finished-Sold_maternal_lambs_a-Sold_maternal_lambs_b) {UNIFLOW} *sheep/year*
Lambs_from_1yo = Romney."%_Lambs_from_1yo"*All_lambs {UNIFLOW} *sheep/year*
"1y_wool_GFW" = 3.2 *kg*
"1yo_LW" = MAE_LW_Gestation*0.70 *kg*
"1yo_ME_LWG" = 55*(MAE_LW_Gestation-"1yo_LW") *MJME*
"1yo_ME_Maintenance" = ((0.28*(MEAN("1yo_LW", MAE_LW_Gestation)^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))) *MJME*
"1yo_ME_req" = ("1yo_wool_ME"+"1yo_ME_Maintenance"*365+"1yo_ME_LWG")*Romney."1yo" *MJME*
"1yo_wool_ME" = 0.13*("1y_wool_GFW"*1000/365-6)+0.13*("6m_wool_GFW"*1000/365-6) *MJME*
"6m_wool_GFW" = 1.5 *kg*
Activity = 1
All_lambs =
Romney.Maternal_Female_singles_weaned+Romney.Maternal_Female_multiples_weaned+Romney.Maternal_male_singles_weaned+Romney.Maternal_male_multiples_weaned *sheep*
Cold = 0
Lambs_a_CW = 17.87 *kg*
Lambs_a_Dressing% = .41 *%*
Lambs_a_Leave = 17 *weeks after weaning*
Lambs_a_MEreq = (0.13*((Wool_Romney.Ave_GFW_MAE+(1.87*(Lambs_a_Leave/52)-3.74))*1000/(Lambs_a_Leave*7)-6)*Sold_lambs_a*((Lambs_a_Leave-MAE_weaning_age)*7)+(Lambs_a_CW/Lambs_a_Dressing%-Maternal_single_Weaning_wt)*55*Sold_lambs_a+(0.28*(MEAN(Maternal_single_Weaning_wt,(Lambs_a_CW/Lambs_a_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Lambs_a_Leave-MAE_weaning_age)*7)*Sold_lambs_a)/((Lambs_a_Leave-MAE_weaning_age)/2) *MJME*
Lambs_b_CW = 17.87 *kg*
Lambs_b_Dressing% = .41 *%*
Lambs_b_Leave = 25 *weeks after weaning*
lambs_b_MEreq = (0.13*((Wool_Romney.Ave_GFW_MAE+(1.87*(Lambs_b_Leave/52)-3.74))*1000/(Lambs_b_Leave*7)-6)*Sold_lambs_b*((Lambs_b_Leave-MAE_weaning_age)*7)+(Lambs_b_CW/Lambs_b_Dressing%-Maternal_multiple_Weaning_wt)*55*Sold_lambs_b+(0.28*(MEAN(Maternal_multiple_Weaning_wt,(Lambs_b_CW/Lambs_b_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Lambs_b_Leave-MAE_weaning_age)*7)*Sold_lambs_b)/((Lambs_b_Leave-MAE_weaning_age)/2) *MJME*
Lambs_c_CW = 32 *kg*
Lambs_c_Dressing% = 1 *%*
Lambs_c_Leave = 36 *weeks after weaning*
lambs_c_MEreq = (0.13*((Wool_Romney.Ave_GFW_MAE+(1.87*(Lambs_c_Leave/52)-3.74))*1000/(Lambs_c_Leave*7)-6)*Sold_lambs_c*((Lambs_c_Leave-MAE_weaning_age)*7)+(Lambs_c_CW/Lambs_c_Dressing%-Maternal_multiple_Weaning_wt)*55*Sold_lambs_c+(0.28*(MEAN(Maternal_multiple_Weaning_wt,(Lambs_c_CW/Lambs_c_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Lambs_c_Leave-MAE_weaning_age)*7)*Sold_lambs_c)/((Lambs_c_Leave-MAE_weaning_age)/2) *MJME*
Lambs_d_CW = 18 *kg*

Lambs_d_Dressing% = .5 *%*
Lambs_d_Leave = 16 *weeks after weaning*
lambs_d_MEreq = (0.13*((Wool_Romney.Ave_GFW_MAE+(1.87*(Lambs_d_Leave/52)-3.74))*1000/(Lambs_d_Leave*7)-6)*Sold_lambs_d*((Lambs_d_Leave-MAE_weaning_age)*7)+(Lambs_d_CW/Lambs_d_Dressing%-Maternal_single_Weaning_wt)*55*Sold_lambs_d+(0.28*(MEAN(Maternal_single_Weaning_wt, (Lambs_d_CW/Lambs_d_Dressing%))^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Lambs_d_Leave-MAE_weaning_age)*7)*Sold_lambs_d)/((Lambs_d_Leave-MAE_weaning_age)/2) *MJME*
Lambs_from_1yo_leave = 28 *weeks after weaning*
Lambs_from_1yo_MEreq = (Lambs_from_1yo_sold_LW-Lambs_from_1yosingle_Weaning_wt)*55*Lambs_from_1yo+(0.28*(MEAN(Lambs_from_1yosingle_Weaning_wt, Lambs_from_1yo_sold_LW)^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))*((Lambs_from_1yo_leave-Lambs_from_1yo_weaning_age)*7)*Lambs_from_1yo *MJME*
Lambs_from_1yo_Single_ME_req_lactation = -1808+51.4*Lambs_from_1yosingle_Weaning_wt+134.7*Lambs_from_1yo_weaning_age *MJME*
Lambs_from_1yo_sold_LW = 32 *kg*
Lambs_from_1yo_weaning_age = 10 *weeks after start of lambing*
Lambs_from_1yosingle_Weaning_wt = 23 *kg*
Length_of_cold = 0
"M/D" = 10 *MJME/kgDM*
MAE_LW_Gestation = 67 *kg*
MAE_ME_Maintenance = ((0.28*(MAE_LW_Gestation^0.75)*EXP(-0.03*Romney.Age_MAE))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))) *MJME*
MAE_ME_req = (MAE_ME_Maintenance*365+MAE_ME_Maintenance*(IF(Cold=1)THEN(0.2*Length_of_cold)ELSE(0))+MAE_ME_Wool*365)*Romney.Ewe_flock *MJME*
MAE_ME_Wool = 0.13*(Wool_Romney.Ave_GFW_MAE*1000/365-6) *MJME*
MAE_weaning_age = 12 *weeks after start of lambing*
Maternal_Multiple_birth_weight = 4.5 *kg*
Maternal_multiple_Weaning_wt = 26 *kg*
Maternal_Single_Birth_weight = 5.5 *kg*
Maternal_single_Weaning_wt = 28 *kg*
ME_Gestation = (((Romney.Maternal_Female_singles_weaned+Romney.Maternal_male_singles_weaned)/(1-Romney.Maternal_singles_loss_rate))*Single_ME_req_gestation+((Romney.Maternal_Female_multiples_weaned+Romney.Maternal_male_multiples_weaned)/(1-Romney.Maternal_multiples_loss_rate)))*Multiple_ME_req_gestation *MJME*
ME_Lactation = ((Romney.Maternal_Female_singles_weaned+Romney.Maternal_male_singles_weaned)/(1-Romney.Maternal_singles_loss_rate)*(1-Romney."%_Lambs_from_1yo"))*Single_ME_req_lactation+(Multiple_ME_req_lactation/2*1.35)+(Romney.Maternal_Female_multiples_weaned+Romney.Maternal_male_multiples_weaned)/(1-Romney.Maternal_multiples_loss_rate)*(1-Romney."%_Lambs_from_1yo") *MJME*
ME_Lactation_Lambs_from_1yo = Lambs_from_1yo_Single_ME_req_lactation*Romney."%_Lambs_from_1yo"*All_lambs *MJME*
Multiple_ME_req_gestation = GRAPH(Maternal_Multiple_birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*
Multiple_ME_req_lactation = -1808+51.4*Maternal_multiple_Weaning_wt+134.7*MAE_weaning_age *MJME*
Ram_Age = 4 *years*
Ram_LW = 70 *kg*
Ram_ME_Maintenance = (((0.28*(Ram_LW^0.75)*EXP(-0.03*Ram_Age))/(0.02*"M/D"+0.5))*(IF(Activity=1)THEN(1.1)ELSE(1))*1.15) *MJME*

Ram_ME_req =
(Ram_ME_Maintenance*365+Ram_wool_ME*365+IF(Cold=1)THEN(Ram_ME_Maintenance*0.2*Length_of_cold)ELSE(0))*(Romney."%_MAE_to_Merino"*Romney.Rams) *MJME*
Ram_wool_ME = 0.13*(Wool_Romney.Ave_GFW_MAE*1000/365-6) *MJME*
Replacements_ME_req = (("1yo_LW"-Maternal_single_Weaning_wt)*55+(((0.28*(MEAN(Maternal_single_Weaning_wt, "1yo_LW")^0.75)*EXP(-0.03))/(0.02*"M/D"+0.5)*(IF(Activity=1)THEN(1.1)ELSE(1))))*(365-MAE_weaning_age*7)+(0.13*((Wool_Romney.Ave_GFW_MAE-1.86)*1000/(365-MAE_weaning_age*7)-6)))*Romney.Replacements *MJME*
Single_ME_req_gestation = GRAPH(Maternal_Single_Birth_weight)
(3.000, 155.0), (4.000, 200.0), (5.000, 255.0), (6.000, 300.0) *MJME*
Single_ME_req_lactation = -1808+51.4*Maternal_single_Weaning_wt+134.7*MAE_weaning_age *MJME*
Sold_maternal_lambs_a = 1137 *sheep*
Sold_maternal_lambs_b = 460 *sheep*
Sold_maternal_lambs_c = 1000 *sheep*

Wool_1st_X:
"+/-_2_micron" = GRAPH(2/Std_dev_1X_lamb_FD)
(0.000, 0.0987), (0.250, 0.1915), (0.500, 0.3413), (1.000, 0.4332), (1.500, 0.500) *%*
"+/-_4_micron" = GRAPH(4/Std_dev_1X_lamb_FD)
(0.000, 0.0987), (0.250, 0.1915), (0.500, 0.3413), (1.000, 0.4332), (1.500, 0.500) *%*
"+/-_6_micron" = GRAPH(6/Std_dev_1X_lamb_FD)
(0.000, 0.0987), (0.250, 0.1915), (0.500, 0.3413), (1.000, 0.4332), (1.500, 0.500) *%*
Ave_1X_lamb_FD = MEAN(Ram_FD, Ewe_FD) *µm*
Ave_adult_FD = ("1st_X"."2yo"*(MAE_GFW-0.09)*(Ave_FD_Post_10mo_Cull*1.1)+"1st_X"."3_yo"*(MAE_GFW+0.42)*(Ave_FD_Post_10mo_Cull*1.12)+"1st_X"."4_yo"*(MAE_GFW+0.28)*(Ave_FD_Post_10mo_Cull*1.13)+"1st_X"."5_yo"*(MAE_GFW+0.05)*(Ave_FD_Post_10mo_Cull*1.12)+"1st_X"."6_yo"*(MAE_GFW-0.14)*(Ave_FD_Post_10mo_Cull*1.14)+"1st_X"."7_yo"*(MAE_GFW-0.5)*(Ave_FD_Post_10mo_Cull*1.1))/(MAE_GFW*("1st_X".Ewe_flock-"1st_X"."1yo")+0.0001)
Ave_FD_Post_10mo_Cull = Z_score_new_ave_FD*Std_dev_1X_lamb_FD+Ave_1X_lamb_FD *µm*
Ewe_FD = 36 *µm*
FD_1yo = Ave_FD_Post_10mo_Cull*1.02 *µm*
FD_2yo = Ave_FD_Post_10mo_Cull*1.1 *µm*
FD_3yo = Ave_FD_Post_10mo_Cull*1.12 *µm*
FD_4yo = Ave_FD_Post_10mo_Cull*1.13 *µm*
FD_5yo = Ave_FD_Post_10mo_Cull*1.12 *µm*
FD_6yo = Ave_FD_Post_10mo_Cull*1.11 *µm*
FD_7yo = Ave_FD_Post_10mo_Cull*1.1 *µm*
Income_10mo_wool = ("Wool_price_+2"*"kg_wool_+/-_2_micron"+"Wool_price_-_2"*"kg_wool_+/-_2_micron"+"Wool_price_+_4"*"kg_wool_+/-_4_micron"+"Wool_price_-_4"*"kg_wool_+/-_4_micron"+"Wool_price_+_6"*"kg_wool_+/-_6_micron"+"Wool_price_-_6"*"kg_wool_+/-_6_micron"+"Wool_price_+_8"*"kg_wool_+/-_8_micron"+"Wool_price_-_6"*"kg_wool_+/-_8_micron")/100
"kg_wool_+/-_2_micron" = Wool_production_at_10mo*"+/-_2_micron"
"kg_wool_+/-_4_micron" = Wool_production_at_10mo*"+/-_4_micron"-"kg_wool_+/-_2_micron"
"kg_wool_+/-_6_micron" = Wool_production_at_10mo*"+/-_6_micron"-"kg_wool_+/-_2_micron"-"kg_wool_+/-_4_micron"
"kg_wool_+/-_8_micron" = Wool_production_at_10mo*0.5-"kg_wool_+/-_2_micron"-"kg_wool_+/-_4_micron"-"kg_wool_+/-_6_micron" *$*
MAE_GFW = 4.44 *kg*
Ram_FD = 21 *µm*
Std_dev_1X_lamb_FD = 6.86 *µm*
Total_wool_income =
Wool_income_1yo+Wool_income_2yo+Wool_income_3yo+Wool_income_4yo+Wool_income_5yo+Wool_income_6yo+Wool_income_7yo+Income_10mo_wool+"1st_X".Rams*MAE_GFW*12.26
Wool_income_1yo = "1st_X"."1yo"*(MAE_GFW-0.23)*Wool_price_curve_1/100

Wool_income_2yo = "1st_X"."2yo"*(MAE_GFW-0.23)*Wool_price_curve_2/100
Wool_income_3yo = "1st_X"."3_yo"*(MAE_GFW-0.23)*Wool_price_curve_3/100
Wool_income_4yo = "1st_X"."4_yo"*(MAE_GFW-0.23)*Wool_price_curve_4/100
Wool_income_5yo = "1st_X"."5_yo"*(MAE_GFW-0.23)*Wool_price_curve_5/100
Wool_income_6yo = "1st_X"."6_yo"*(MAE_GFW-0.23)*Wool_price_curve_6/100
Wool_income_7yo = "1st_X"."7_yo"*(MAE_GFW-0.23)*Wool_price_curve_7/100 *$*
"Wool_price_+_4" = GRAPH(Ave_1X_lamb_FD+3)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_+_6" = GRAPH(Ave_1X_lamb_FD+5)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_+_8" = GRAPH(Ave_1X_lamb_FD+8)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_+2" = GRAPH(Ave_1X_lamb_FD+1)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_2" = GRAPH(Ave_1X_lamb_FD-1)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_4" = GRAPH(Ave_1X_lamb_FD-3)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_6" = GRAPH(Ave_1X_lamb_FD-5)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_8" = GRAPH(Ave_1X_lamb_FD-8)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_1 = GRAPH(FD_1yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_2 = GRAPH(FD_2yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_3 = GRAPH(FD_3yo)

(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_4 = GRAPH(FD_4yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_5 = GRAPH(FD_5yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_6 = GRAPH(FD_6yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_7 = GRAPH(FD_7yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_production_1X = "1st_X".Ewe_flock*MAE_GFW+Wool_production_at_10mo *kg*
Wool_production_at_10mo = (MAE_GFW-2.18)*("1st_X"."10mo_culls"+"1st_X".replacements) *kg*
Z_score_new_ave_FD = GRAPH("1st_X".Sort10mo_cull_rate)
(0.0500, -0.07), (0.1000, -0.12), (0.1500, -0.2), (0.2000, -0.25), (0.2500, -0.33), (0.3000, -0.38), (0.3500, -0.46), (0.4000, -0.52), (0.4500, -0.61), (0.5000, -0.67), (0.5500, -0.77), (0.6000, -0.84), (0.6500, -0.95), (0.7000, -1.03), (0.7500, -1.17), (0.8000, -1.28), (0.8500, -1.47), (0.9000, -1.64), (0.9500, -2.05)

Wool_2nd_X:
"+/-_2_micron" = GRAPH(2/Std_dev_2X_lamb_FD)
(0.000, 0.0987), (0.250, 0.1915), (0.500, 0.3413), (1.000, 0.4332), (1.500, 0.500) *%*
"+/-_4_micron" = GRAPH(4/Std_dev_2X_lamb_FD)
(0.000, 0.0987), (0.250, 0.1915), (0.500, 0.3413), (1.000, 0.4332), (1.500, 0.500) *%*
"+/-_6_micron" = GRAPH(6/Std_dev_2X_lamb_FD)
(0.000, 0.0987), (0.250, 0.1915), (0.500, 0.3413), (1.000, 0.4332), (1.500, 0.500) *%*
Ave_2X_lamb_FD = MEAN(Ram_FD, Ewe_FD) *µm*
Ave_FD_Post_10mo_Cull = Z_score_new_ave_FD*Std_dev_2X_lamb_FD+Ave_2X_lamb_FD *µm*
Ave_MAE_FD = ("2nd_X"."2yo"*(MAE_GFW-0.09)*(Ave_FD_Post_10mo_Cull*1.1)+"2nd_X"."3_yo"*(MAE_GFW+0.42)*(Ave_FD_Post_10mo_Cull*1.12)+"2nd_X"."4_yo"*(MAE_GFW+0.28)*(Ave_FD_Post_10mo_Cull*1.13)+"2nd_X"."5_yo"*(MAE_GFW+0.05)*(Ave_FD_Post_10mo_Cull*1.12)+"2nd_X"."6_yo"*(MAE_GFW-0.14)*(Ave_FD_Post_10mo_Cull*1.14)+"2nd_X"."7_yo"*(MAE_GFW-0.5)*(Ave_FD_Post_10mo_Cull*1.1))/(MAE_GFW*("2nd_X".Ewe_flock-"2nd_X"."1yo")+0.0001) *µm*
Ewe_FD = 29 *µm*
FD_1yo = Ave_FD_Post_10mo_Cull*1.02 *µm*
FD_2yo = Ave_FD_Post_10mo_Cull*1.1 *µm*
FD_3yo = Ave_FD_Post_10mo_Cull*1.12 *µm*
FD_4yo = Ave_FD_Post_10mo_Cull*1.13 *µm*
FD_5yo = Ave_FD_Post_10mo_Cull*1.12 *µm*
FD_6yo = Ave_FD_Post_10mo_Cull*1.11 *µm*
FD_7yo = Ave_FD_Post_10mo_Cull*1.1 *µm*
Income_10mo_wool = ("Wool_price_+2"*"kg_wool_+/-_2_micron"+"Wool_price_-_2"*"kg_wool_+/-_2_micron"+"Wool_price_+_4"*"kg_wool_+/-_4_micron"+"Wool_price_-_4"*"kg_wool_+/-_4_micron"+"Wool_price_+_6"*"kg_wool_+/-_6_micron"+"Wool_price_-_6"*"kg_wool_+/-

_6_micron"+"Wool_price_+_8"*"kg_wool_+/-_8_micron"+"Wool_price_-_6"*"kg_wool_+/-_8_micron")/100
"kg_wool_+/-_2_micron" = Wool_at_10mo*"+/-_2_micron"
"kg_wool_+/-_4_micron" = Wool_at_10mo*"+/-_4_micron"-"kg_wool_+/-_2_micron"
"kg_wool_+/-_6_micron" = Wool_at_10mo*"+/-_6_micron"-"kg_wool_+/-_2_micron"-"kg_wool_+/-_4_micron"
"kg_wool_+/-_8_micron" = Wool_at_10mo*0.5-"kg_wool_+/-_2_micron"-"kg_wool_+/-_4_micron"-"kg_wool_+/-_6_micron" *$*
MAE_GFW = 3.75 *kg*
Ram_FD = 21 *µm*
Std_dev_2X_lamb_FD = Ave_2X_lamb_FD*0.25 *µm*
Total_wool_income =
Wool_income_1yo+Wool_income_2yo+Wool_income_3yo+Wool_income_4yo+Wool_income_5yo+Wool_income_6yo+Wool_income_7yo+Income_10mo_wool+"2nd_X".Rams*MAE_GFW*Wool_price_curve_4*0.01 *$*
Wool_at_10mo = (MAE_GFW-2.18)*("2nd_X".Culled_10mo+"2nd_X".Replacements) *kg*
Wool_income_1yo = "2nd_X"."1yo"*(MAE_GFW-0.23)*Wool_price_curve_1/100 *$*
Wool_income_2yo = "2nd_X"."2yo"*(MAE_GFW-0.23)*Wool_price_curve_2/100 *$*
Wool_income_3yo = "2nd_X"."3_yo"*(MAE_GFW-0.23)*Wool_price_curve_3/100 *$*
Wool_income_4yo = "2nd_X"."4_yo"*(MAE_GFW-0.23)*Wool_price_curve_4/100 *$*
Wool_income_5yo = "2nd_X"."5_yo"*(MAE_GFW-0.23)*Wool_price_curve_5/100 *$*
Wool_income_6yo = "2nd_X"."6_yo"*(MAE_GFW-0.23)*Wool_price_curve_6/100 *$*
Wool_income_7yo = "2nd_X"."7_yo"*(MAE_GFW-0.23)*Wool_price_curve_7/100 *$*
"Wool_price_+_4" = GRAPH(Ave_2X_lamb_FD+3)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_+_6" = GRAPH(Ave_2X_lamb_FD+5)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_+_8" = GRAPH(Ave_2X_lamb_FD+8)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_+2" = GRAPH(Ave_2X_lamb_FD+1)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_2" = GRAPH(Ave_2X_lamb_FD-1)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_4" = GRAPH(Ave_2X_lamb_FD-3)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_6" = GRAPH(Ave_2X_lamb_FD-5)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00,

763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
"Wool_price_-_8" = GRAPH(Ave_2X_lamb_FD-8)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_1 = GRAPH(FD_1yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_2 = GRAPH(FD_2yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_3 = GRAPH(FD_3yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_4 = GRAPH(FD_4yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_5 = GRAPH(FD_5yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_6 = GRAPH(FD_6yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_price_curve_7 = GRAPH(FD_7yo)
(15.00, 1698.0), (16.00, 1619.0), (17.00, 1541.0), (18.00, 1462.0), (19.00, 1384.0), (20.00, 1305.0), (21.00, 1226.0), (22.00, 1173.0), (23.00, 1120.0), (24.00, 1031.0), (25.00, 942.0), (26.00, 852.0), (27.00, 763.0), (28.00, 668.0), (29.00, 615.0), (30.00, 561.0), (31.00, 508.0), (32.00, 454.0), (33.00, 348.0), (34.00, 348.0), (35.00, 348.0), (36.00, 348.0), (37.00, 348.0), (38.00, 348.0) *$/kg greasy*
Wool_prod_2X_kg = Wool_at_10mo+MAE_GFW*"2nd_X".Ewe_flock *kg*
Z_score_new_ave_FD = GRAPH("2nd_X".Sort10mo_cull_rate)
(0.0500, -0.07), (0.1000, -0.12), (0.1500, -0.2), (0.2000, -0.25), (0.2500, -0.33), (0.3000, -0.38), (0.3500, -0.46), (0.4000, -0.52), (0.4500, -0.61), (0.5000, -0.67), (0.5500, -0.77), (0.6000, -0.84), (0.6500, -0.95), (0.7000, -1.03), (0.7500, -1.17), (0.8000, -1.28), (0.8500, -1.47), (0.9000, -1.64), (0.9500, -2.05)

Wool_Romney:
age = 0.5 *years*
Ave_GFW_MAE = 4.57 *kg*
"GFW_<1yo_1_a" = IF(age<0.2)THEN(0)ELSE(Ave_GFW_MAE+(1.8743*age-3.7371))*(IF(Shearing_date<Romney_ME_req.Lambs_a_Leave)THEN(Romney_ME_req.Sold_lambs_a)ELSE(0)) *kg*
"GFW_<1yo_1_b" = IF(age<0.2)THEN(0)ELSE(Ave_GFW_MAE+(1.8743*age-3.7371))*(IF(Shearing_date<Romney_ME_req.Lambs_b_Leave)THEN(Romney_ME_req.Sold_lambs_b)ELSE(0)) *kg*

"GFW_<1yo_1_c" = IF(age<0.2)THEN(0)ELSE(Ave_GFW_MAE+(1.8743*age-3.7371))*(IF(Shearing_date<Romney_ME_req.Lambs_c_Leave)THEN(Romney_ME_req.Sold_lambs_c)ELSE(0)) *kg*
"GFW_<1yo_1_store" = IF(age<0.2)THEN(0)ELSE(Ave_GFW_MAE+(1.8743*age-3.7371))*(IF(Shearing_date<Romney_ME_req.Lambs_from_1yo_leave)THEN(Romney_ME_req.Lambs_from_1yo)ELSE(0)) *kg*
MAE_wool_income = (Romney."1yo"*(Ave_GFW_MAE-0.23)+Romney."2yo"*(Ave_GFW_MAE-0.09)+Romney."3_yo"*(Ave_GFW_MAE+0.42)+Romney."4_yo"*(Ave_GFW_MAE+0.28)+Romney."5_yo"*(Ave_GFW_MAE+0.05)+Romney."6_yo"*(Ave_GFW_MAE-0.14)+Romney."7_yo"*(Ave_GFW_MAE-0.5))*Strong_wool_price *$*
Ram_wool_income = Romney.Rams*Strong_wool_price*Ave_GFW_MAE*(1-Romney."%_MAE_to_Merino")+Romney.Rams*Ave_GFW_MAE*Romney."%_MAE_to_Merino"*12.26 *$*
Shearing_date = 15 *weeks after start of lambing*
Strong_wool_price = 2.149 *$/kg greasy*
Total_wool_income = "Wool_income_<2yo"+MAE_wool_income+Ram_wool_income *$*
"Wool_income_<2yo" = ("GFW_<1yo_1_a"+"GFW_<1yo_1_b"+"GFW_<1yo_1_c"+"GFW_<1yo_1_store"+Romney.Replacements*(Ave_GFW_MAE-2.93795))*Strong_wool_price *$*
Wool_production = (Romney."1yo"+Romney."2yo"+Romney."3_yo"+Romney."4_yo"+Romney."5_yo"+Romney."6_yo"+Romney."7_yo")*Strong_wool_price *kg*

Economics:
"1&2yo_cull_price_1X" = 125.22 *$/head*
"1&2yo_cull_price_2X" = 116.45 *$/head*
"1&2yo_cull_price_R" = 134.64 *$/head*
"1X_expenses" = (expenses_per_Stock_Units_1X*Sheep_stock_units_1X)+Wool_testing_price*("1st_X"."10mo_culls"+"1st_X".replacements) *$*
"1X_Income" = Wool_1st_X.Total_wool_income+Stock_income_1X *$*
"2X_expenses" = (Expenses_per_Stock_Units_2X*Sheep_stock_units_2X)+Wool_testing_price*("2nd_X".Culled_10mo+"2nd_X".Replacements) *$*
"2X_Income" = Wool_2nd_X.Total_wool_income+Stock_income_2X *$*
Animal_health_1X = 6 *$/SU*
Animal_health_2X = 6 *$/SU*
Animal_health_R = 6 *$/SU*
"Beef_COS/ha" = 280 *$/ha*
Cash_Operating_surplus = "Beef_COS/ha"*(1-Feed_Supply."%_sheep")*Feed_Supply.Effective_ha+COS_per_ha*Feed_Supply.Effective_ha*Feed_Supply."%_sheep" *$/ha*
COS_per_ha = (Total_income-Total_expenses)/(Feed_Supply.Effective_ha*"Feed_Supply."%_sheep") *$/ha*
expenses_per_Stock_unit_R = Animal_health_R+FWE_R+Shearing_R *$/SU*
expenses_per_Stock_Units_1X = Animal_health_1X+FWE_1X+Shearing_1X *$/SU*
Expenses_per_Stock_Units_2X = Animal_health_2X+FWE_2X+Shearing_2X *$/SU*
"Expenses/ha" = Total_expenses/Feed_Supply.Effective_ha *$/ha*
FWE_1X = 47.79 *$/SU*
FWE_2X = 47.79 *$/SU*
FWE_R = 47.79 *$/SU*
Lamb_income_1X = Lambs_price_a_1X*"1st_X".Maternal_Female_singles_sold+Lambs_price_b_1X*"1st_X".Maternal_Female_multiples_sold+Lambs_price_c_1X*"1st_X".Multiples_Male_singles_finished+Lambs_price_d_1X*"1st_X".Maternal_Male_multiples_finished *$*
Lamb_income_2X = Lambs_price_a_2X*"2nd_X"."2X_Female_singles_finished"+Lambs_price_b_2X*"2nd_X"."2X_Female_m

ultiples_finished"+Lambs_price_c_2X*"2nd_X"."2X_male_singles_weaned"+Lambs_price_d_2X*"2nd_X"."2X_male_multiples_weaned" *$*
Lamb_income_R =
Romney_ME_req.Sold_lambs_a*Maternal_lambs_price_a_R+Romney_ME_req.Sold_lambs_c*Maternal_lambs_price_c_R+Romney_ME_req.Sold_lambs_d*Maternal_lambs_price_4_R+Romney_ME_req.Sold_lambs_b*Maternal_lambs_price_b_R+Lambs_from_1yo_price_R*Romney_ME_req.Lambs_from_1yo *$*
Lambs_from_1yo_price_R = 99.44 *$/head*
Lambs_price_a_1X = 106.13 *$/head*
Lambs_price_a_2X = 107.18 *$/head*
Lambs_price_b_1X = 107.22 *$/head*
Lambs_price_b_2X = 110.47 *$/head*
Lambs_price_c_1X = 106.13 *$/head*
Lambs_price_c_2X = 107.18 *$/head*
Lambs_price_d_1X = 107.22 *$/head*
Lambs_price_d_2X = 110.47 *$/head*
MAE_Stock_Units_1X =
0.12679+0.011357*"1st_X_ME_req".MAE_LW_Gestation+0.002179*(Prolificacy_1X*100) *SU*
MAE_Stock_Units_2X =
0.12679+0.011357*"2nd_X_ME_req".MAE_LW_Gestation+0.002179*(Prolificacy_2X*100) *SU*
MAE_stock_Units_R =
0.12679+0.011357*Romney_fortnightly_feed_demand.MAE_LW_Summer+0.002179*(Prolificacy_R*100) *SU*
Maternal_lambs_price_4_R = 0 *$/head*
Maternal_lambs_price_a_R = 101.86 *$/head*
Maternal_lambs_price_b_R = 107.27 *$/head*
Maternal_lambs_price_c_R = 99.44 *$/head*
Mutton_price_1X = 105.77 *$/head*
Mutton_price_2X = 98.37 *$/head*
Mutton_price_R = 113.73 *$/head*
Prolificacy_1X =
(Romney."1X_singles_weaned"+Romney."1Xmultiples_weaned")/("1st_X".Ewe_flock+0.00001) *%*
Prolificacy_2X =
("2nd_X"."2X_lambs_weaned"+"1st_X"."2X_singles_weaned"+"1st_X"."2X_multiples_weaned")/("2nd_X".Ewe_flock+0.00001) *%*
Prolificacy_R =
(Romney.Maternal_Female_multiples_weaned+Romney.Maternal_Female_singles_weaned)/(Romney.Ewe_flock+0.00001) *%*
Romney_expenses = (expenses_per_Stock_unit_R*Sheep_stock_units_R) *$*
Romney_Income = Wool_Romney.Total_wool_income+Stock_income_R *$*
Shearing_1X = 9 *$/SU*
Shearing_2X = 9 *$/SU*
Shearing_R = 9 *$/SU*
Sheep_stock_units_1X =
"1st_X".Ewe_flock*MAE_Stock_Units_1X+"1st_X"."10mo_culls"+"1st_X".Rams+"1st_X".replacements *SU*
Sheep_stock_units_2X =
"2nd_X".Ewe_flock*MAE_Stock_Units_2X+"2nd_X".Culled_10mo+"2nd_X".Rams+"2nd_X".Replacements *SU*
Sheep_stock_units_R = Romney.Ewe_flock*MAE_stock_Units_R+Romney.Rams+Romney.Replacements *SU*
Stock_income_1X = ("1st_X".Ewe_culls-"1st_X"."1yo_culls"-"1st_X"."2yo_culls")*Mutton_price_1X+("1st_X"."10mo_culls"+"1st_X"."1yo_culls"+"1st_X"."2yo_culls")*"1&2yo_cull_price_1X"+Lamb_income_1X *$*
Stock_income_2X = ("2nd_X".Ewe_culls-"2nd_X"."1yo_culls"-"2nd_X"."2yo_culls")*Mutton_price_2X+("2nd_X".Culled_10mo+"2nd_X"."1yo_culls"+"2nd_X"."2yo_culls")*"1&2yo_cull_price_2X"+Lamb_income_2X *$*

Stock_income_R = (Romney.Ewe_culls-Romney."1yo_culls"-Romney."2yo_culls")*Mutton_price_R+(Romney."2yo_culls"+Romney."1yo_culls")*"1&2yo_cull_price_R"+Lamb_income_R *$*
Total_expenses = Romney_expenses+"1X_expenses"+"2X_expenses" *$*
Total_income = Romney_Income+"1X_Income"+"2X_Income" *$*
Wool_testing_price = 2.25 *$/head*

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STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Lydia Farrell
Name/title of Primary Supervisor:	Peter Tozer
Name of Research Output and full reference:	
Farrell, L., Tozer, P., Kenyon, P., Ramilan, T. & Cranston, L. 2019. The effect of ewe wastage in New Zealand sheep and beef farms on flock productivity and farm profitability. Agricultural Systems, 174, 125-132. 10.1016/j.agsy.2019.04.013	
In which Chapter is the Manuscript /Published work:	Three
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Developed model, found input data, ran scenarios, analysed output, wrote manuscript	
For manuscripts intended for publication please indicate target journal:	
Candidate's Signature:	Farrell
Date:	24-02-2020
Primary Supervisor's Signature:	
Date:	24-02-2020

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Name of candidate:	Lydia Farrell
Name/title of Primary Supervisor:	Peter Tozer
Name of Research Output and full reference:	
Quantifying sheep enterprise profitability with varying flock replacement rates, lambing rates, and breeding strategies in New Zealand.	
In which Chapter is the Manuscript /Published work:	Four
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Extended model, found input data, ran scenarios, analysed output, wrote manuscript	
For manuscripts intended for publication please indicate target journal:	
Agricultural Systems - Under review	
Candidate's Signature:	LFarrell
Date:	24-02-2020
Primary Supervisor's Signature:	
Date:	24-02-2020

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Name of candidate:	Lydia Farrell
Name/title of Primary Supervisor:	Peter Tozer
Name of Research Output and full reference:	
The transition from Romney to Merino cross: A New Zealand study	
In which Chapter is the Manuscript /Published work:	Five
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Extended model, found input data, ran scenarios, analysed output, wrote manuscript	
For manuscripts intended for publication please indicate target journal:	
Animals or Small Ruminant Research	
Candidate's Signature:	
Date:	24-02-2020
Primary Supervisor's Signature:	
Date:	24-02-2020

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