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Evaluation of Eradication Strategies for Ovine Johne's Disease.

Abstract

Johne's disease, caused by *Mycobacterium avium* subspecies *paratuberculosis* (Mptb), is spreading through domestic and non-domestic populations of ruminants worldwide. Ovine Johne's Disease (OJD) is considered to be a relatively new disease in Australia (25 – 50 years) that at present has infected less than 10% of sheep flocks nationally. The great majority of infected flocks are concentrated around a number of foci of infection in the southern mainland and adjacent islands. OJD is highly infectious but difficult to detect early in the cycle of infection because of a lengthy incubation period (2 – 3 years) and insensitive tests for sub-clinically infected sheep. Currently there is international debate among gastroenterologists and microbiologists regarding Mptb's involvement in the aetiology of Crohne's disease in humans. In 1998 steering committees representing the sheep industries and state and federal governments agreed on a national program of regulation, education and research to contain and improve our understanding of the epidemiology and pathology of OJD under Australian conditions. Whole of flock destocking and restocking was considered to be one potential strategy to prevent further spread of the disease and underpin systematic regional eradication campaigns. This report presents the results of a field evaluation of the biological efficacy and economic viability of destocking and restocking strategies to eradicate OJD from farms in south eastern Australia. Of 41 flocks that were monitored for three years after restocking decontaminated farms, 28 (68%) presented with evidence of OJD. Among these (re)infected farms there was a substantial reduction in mean apparent prevalence between destocking and three years after restocking. Although equivocal, eradication failures appear to have been primarily of local origin (ie reinfection from neighbouring flocks and/or incomplete decontamination). Because of low efficacy, 20 year simulations of net farm income revealed that destocking and restocking was less profitable than vaccination as an OJD management option.

Executive summary

Ovine Johne's disease (OJD) is caused by a host specific strain of *Mycobacterium avium* subspecies *paratuberculosis* (Mptb). This and the cattle strain of Mptb are spreading through domestic and non-domestic populations of ruminants around the world. OJD is considered to be a relatively new disease in Australia (25 – 50 years) that at present has infected less than 10% of sheep flocks nationally. The great majority of infected flocks are concentrated around a number of foci of infection in the southern mainland and adjacent islands. OJD is highly infectious but difficult to detect early in the cycle of infection because of a lengthy incubation period (2 – 3 years) and insensitive tests for subclinically infected sheep. It impacts on sheep enterprises primarily through increased mortality rather than subclinical production losses. Currently there is international debate among gastroenterologists and microbiologists regarding Mptb's involvement in the aetiology of Crohne's disease in humans. In 1998 steering committees representing the sheep industries and state and federal governments agreed on a national program of regulation, education and research to contain and improve our understanding of the epidemiology and pathology of OJD under Australian conditions. This report presents the results of a field evaluation of the biological efficacy and economic viability of destocking and restocking strategies to eradicate OJD from farms in south eastern Australia.

A total of 44 farms managing 45 monitor flocks were contracted to participate in the field evaluation. To facilitate decontamination, these farms were destocked of all susceptible species (primarily sheep and goats) for 15 to 21 months including two summer periods. The farms were restocked with at least 700 monitor sheep that were purchased from flocks complying with ovine Johne's disease Market Assurance Program disease risk assurance standards. The flocks were monitored for evidence of OJD for the next three years via clinical investigations of ill-thrift and culture of samples of faeces collected from at least 500 monitor sheep two and three years after restocking. Mptb positive cultures were typed to distinguish between sheep and cattle strains of the bacteria.

The results in summary

- 28 of 41 flocks (68%) that were monitored to the completion of the project, presented with evidence of OJD following three years of exposure to decontaminated sites.

- 39 of 40 Mptb positive faecal cultures collected from these flocks were identified as sheep strain.

- There was a 20 fold reduction in the mean apparent prevalence between destocking (18%) and three years after restocking (0.9%) the 28 (re)infected sites.

- Eradication failures appear to have been primarily of local origin (ie reinfection from neighbouring flocks and/or incomplete decontamination)

- Efforts to identify infectious refugia in the summer prior to restocking yielded only one Mptb positive culture from 279 samples of topsoil, dam water and dam sediment

- 20 year simulations of net farm income based on data derived from farms participating in the field evaluation revealed that destocking and restocking was less profitable than vaccination as an OJD management option.

Contents

Page

1 Background and context for the Australian sheep industries

Ovine Johne's disease (OJD) results from infection of the intestine of sheep (and goats) by a host specific strain of *Mycobacterium avium* subspecies *paratuberculosis* (Mptb). The disease's primary economic impact on sheep enterprises is through increased mortality rather than sub-clinical production losses. Mortalities due to the disease are commonly under 5% per annum but can exceed 10% in chronically infected flocks (Eppleston et al 2000).

OJD was first diagnosed in Australia in 1980 in a flock of sheep near Blayney in the Central Tablelands of NSW (Seaman et al 1981). Through routine investigations of illthrift, 36 flocks had been found to be infected by the early 1990's, all within the same locale (Denholm et al 1997). By 1994 the disease had been identified elsewhere in NSW and by the end of 1998 a total of 578 infected flocks had been detected primarily in NSW (n = 440) but also in Victoria, Tasmania, South Australia and the Australian Capital Territory (Allworth and Kennedy 1999).

Recognition by the sheep industries and state and federal governments that the disease was more widespread than initially suspected and was continuing to spread, ultimately led in 1998 to the development of a national strategy (National Ovine Johne's Disease Control and Evaluation Program) to contain and understand this relatively new disease and determine if its eradication from Australia was feasible. An important objective within the national initiative was to evaluate the efficacy of destocking and restocking strategies to decontaminate previously infected farms as a basis for systematic regional eradication campaigns.

Why contemplate systematic eradication of a disease that had been spreading within Australia for at least 20 years?

The incentives for attempting OJD eradication in Australia stem from the need

- to protect flocks and regions that were considered to be free of the disease
- to avoid the additional mortality and future husbandry costs to be incurred in managing the disease indefinitely
- to maintain the competitive advantage enjoyed by Australia via the health status of Australia's sheep and goat meat products generally but particularly in relation to the international debate regarding Mptb's equivocal association with Crohne's disease in humans (Harris and Lammerding 2001, Greenstein 2003).

The rationale for evaluating destock – restock strategies relied on the generally accepted knowledge that

- at that time the great majority (>90%) of Australian flocks were thought to be free of OJD (Ausvet Animal Health Services 2001) and with adequate disease risk assurance, provided the prerequisite source of disease free replacement sheep to restock decontaminated farms

- Mptb is a highly host specific obligate pathogen that does not form spores when exposed to the elements

- Mptb, although relatively resistant, cannot live indefinitely outside of the host animal and

- Mptb is transmitted primarily through the ingestion of infected faecal material and/or pasture contaminated by it.

This report documents the results of an evaluation of the efficacy of OJD eradication on commercial sheep farms in south eastern Australia by destocking infected flocks for a prescribed interval to decontaminate pasture of Mptb and restocking with sheep that comply with prescribed disease risk assurance standards.

2 Objectives

The objectives as stated in the funding agreement between Meat and Livestock Australia and NSW Agriculture for OJD.001 were as follow

"The trial has been designed to answer the question:

- Can destocking and decontamination over a 15 month period eradicate OJD from infected properties which are undergoing an approved PDEP and, under what conditions is it an economically viable option?

- To determine the net financial costs and benefits to individual producers of eradicating OJD from their properties through destocking. "

As the project progressed new objectives emerged and the emphasis for economic analyses shifted. The restated objectives were

1. Determine the efficacy of eradicating Ovine Johne's disease from individual farms by implementing a 15 month Property Disease Eradication Plan (PDEP) and restocking with sheep complying with Market Assurance Program (MAP) disease risk assurance standards on 50 farms in south eastern Australia.

2. Determine if possible the reasons for (re)infection of sheep subsequently exposed to these farms.

3. Evaluate the potential to identify infectious refugia for Mptb in the second summer following destocking.

4. Evaluate the financial returns of destocking and restocking to eradicate OJD relative to other control strategies.

3 Methods

3.1 Site selection.

Sites were selected in NSW, Victoria and South Australia on the basis of having

- a formal Property Disease Eradication Plan (PDEP) under the supervision of an accredited veterinarian.
- objective evidence of OJD infection in the year of destocking
- site owners and managers, considered to be committed to the objective of OJD eradication, as signatories to a legal binding contract with NSW Agriculture to comply with the conditions of the project.

Infected farms in Victoria and South Australia were nominated by the relevant State departments of agriculture and enrolled. Infected farms in NSW were selected from 118 expressions of interest to participate in the field evaluation on the basis of apparent severity of infection. NSW sites determined to have greater disease prevalence were given priority. Disease prevalence scores were allocated according to the following criteria:

1 = 1/450 serologically positive, zero mortality
2 = 1/300 serologically positive, zero mortality
3 = clinical cases confirmed by post-mortem or 1/50 serologically positive and 0 - 2% mortality
4 = 2/50 serologically positive, 3-5% mortality, clinical cases
5 = 5% mortality, long standing infection, > 4/50 serologically positive
6 = 5 -10% mortality, clinical cases, long standing infection, advanced lesions on post-mortem.

The selected sites were at various stages of destocking at the initiation of the project such that destocking of all sites was phased over three years. Table 1 shows the number of sites selected for the project by state and year of destocking.

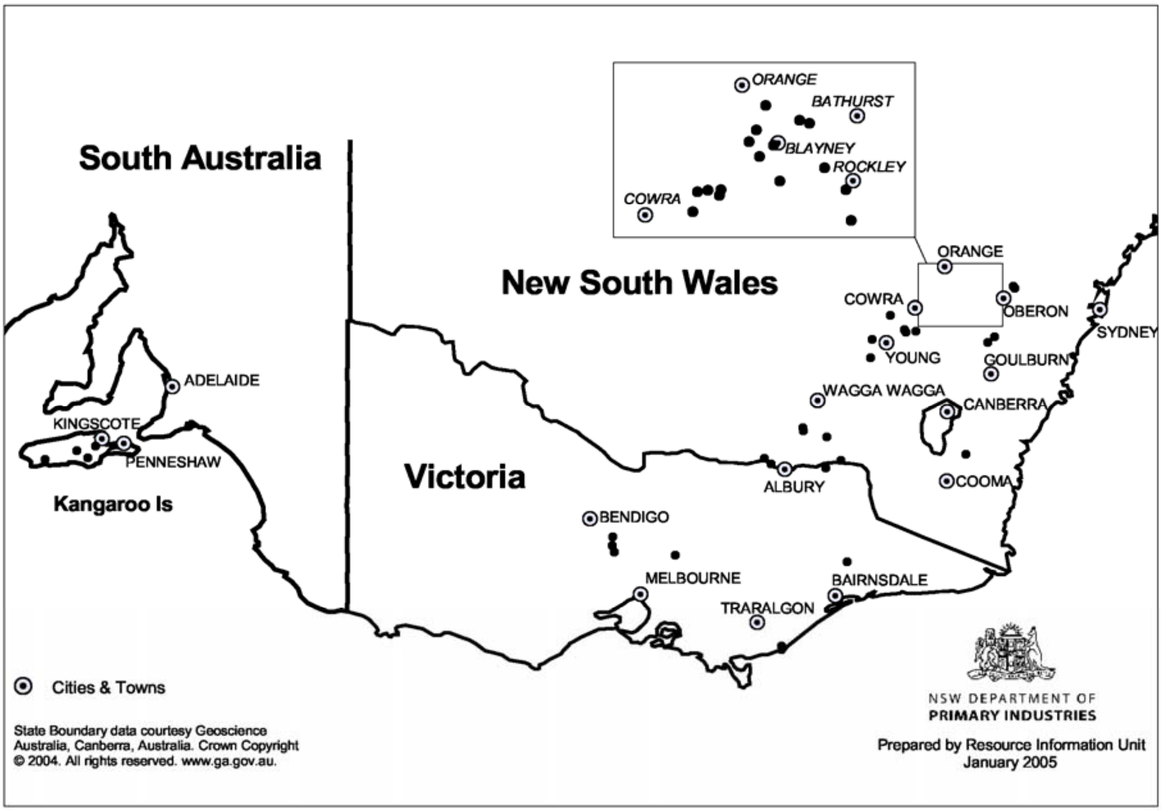
Table 1 Selected evaluation sites by state and year of destock.

State	1997	1998	1999	Total
NSW	5	16	12*	33
Victoria	2	0	5	7
South Aust	0	3	1	4

* one NSW site was contracted to restock with 2 independent monitor flocks.

A total of 44 sites (managing 45 monitor flocks) were enrolled to participate in the project which included 33 in NSW, seven in Victoria and four in South Australia. Figure 1 shows the location of all sites that participated in the field evaluation. The geographic distribution of sites enrolled in the project is generally representative of the range of locations and environments known to carry infected flocks at the time of initiating the project in 1999.

Figure 1 Location of all participating eradication evaluation sites



3.2 Requirement to destock and operate during the destocked phase

A written agreement between the farm owner/manager and the relevant State authority (PDEP) was required for each participating site. PDEPs stipulate a minimum 15 month interval between destocking all infected flocks and restocking the property. This period had to include two summers such that sites were destocked in late spring and not restocked until the second following autumn. Flocks and herds of susceptible species (primarily sheep and goats) were to be destocked from each site by November 30 in the year of destocking. In a number of cases young lambs were allowed to be retained but had to be destocked by no later than six months of age to preclude any further contamination of these sites. PDEPs also detail planned interim grazing enterprises and any actions required to mitigate against reintroducing the disease via interim livestock and/or neighbouring properties (eg double boundary fencing, restrictions on sheep grazing around the perimeter). Site managers were allowed to pursue their chosen interim enterprises during the destocked phase provided they were managed in accordance with the requirements of their PDEP.

3.3 Restocking requirements

Participants were required to restock with at least 700 low-risk sheep within six months of completing their approved 15 month PDEP. Lambs born to purchased ewes were also eligible provided they were born within the six month restocking interval. Sheep could be purchased from Market Assurance Program (MAP) flocks or flocks tested to the MAP standard (98% assurance of detecting a 2% or greater disease prevalence). Initially this required blood samples from 450 or faecal samples from 350 sheep of at least two years of age. Later the prescribed number of blood samples increased to 875 as the sensitivity of serology was better defined. These risk-assured sheep were referred to as the Monitor Flock and were fitted with customised numerical ear tags identifying them to the project on entry to each participating site.

3.4 Measuring the results of the eradication process

The restocked sheep and/or lambs born within the six month restocking interval (monitor sheep) were monitored for evidence of OJD for the next three years. The efficacy of the eradication process was ultimately determined by culturing faecal samples from at least 500 monitor sheep in pools of 50 (ie 99.7% assurance of detecting $\geq$2% prevalence) at 24 months and if negative for OJD again at 36 months after restocking. All *Mycobacterium avium* subspecies *paratuberculosis* (Mptb) positive cultures were strain typed using IS1311 to distinguish between Sheep (S) and Cattle (C) strains.

3.5 Investigation of eradication failures

Initially sites with evidence of (re)infection were sampled for whole of flock prevalence testing via faecal culture and strain typing of positive cultures. Changes to the MAP status of Market Assured vendors of purchased sheep were verified and, where possible, flocks of non-MAP vendors were retested. The advice of local veterinarians was also sought on the OJD status of neighbours(hoods) of vendors to all failed trial sites. By September 2003 further attempts to identify reasons for failure were abandoned

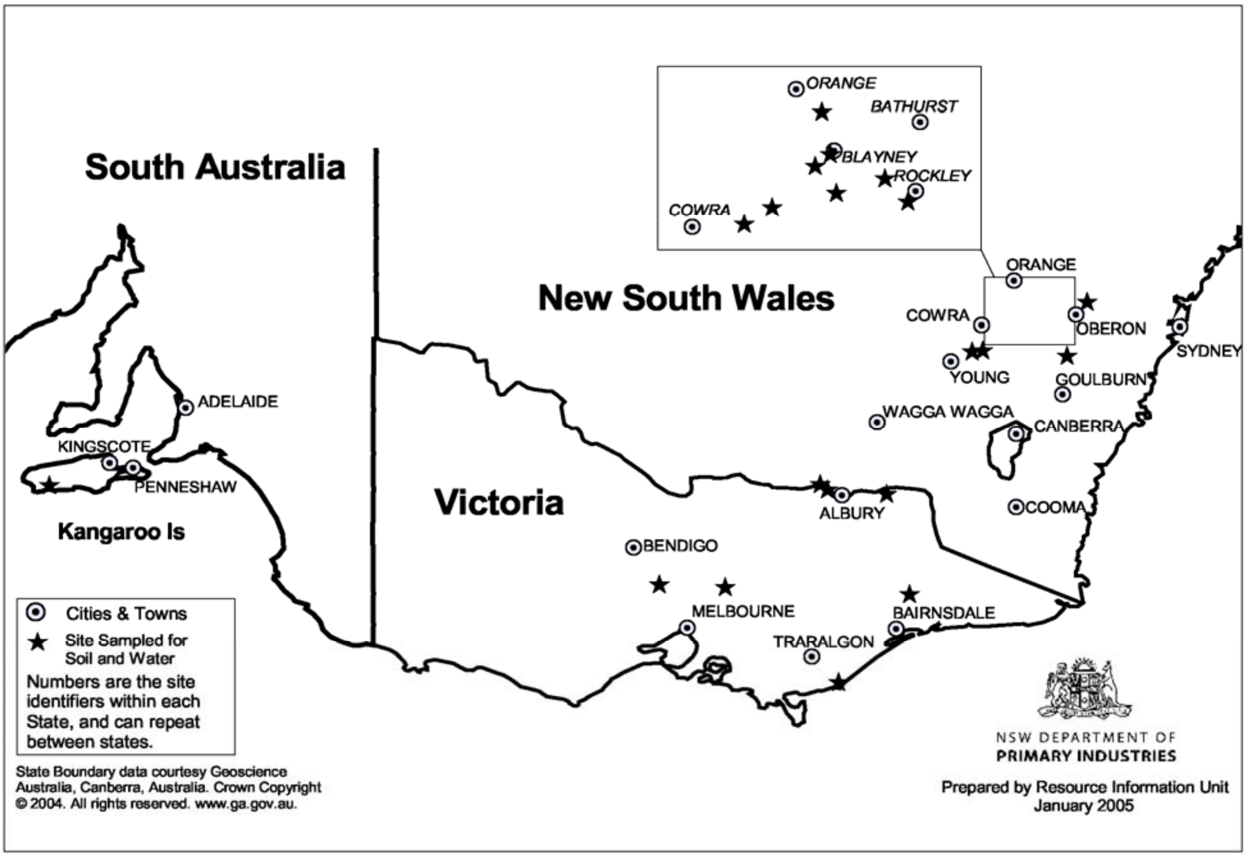
3.6 Audits of sheep camps and watering points

An investigation of the infective status of 20 participating farms was undertaken between December 2000 and February 2001. This sampling period coincided with the second summer following destocking of 18 farms which had been destocked of all sheep for between 11 and 15 months. For the remaining two farms, sections of which had been restocked with MAP assured sheep, samples were collected from sites that had not been exposed to sheep for 24 months. The location of farms selected ranged from the Central (n = 9) and Southern (3) Tablelands and Eastern Riverina (3) of New South Wales to the Gippsland (2) and Central Districts (2) of Victoria to Kangaroo Island (1) in South Australia. Figure 2 shows the location of the 20 farms sampled. The farms sampled generally cover the range of environments represented by all farms participating in the Trial (cf. Figure 1).

Within these farms, sites considered to have been either heavily contaminated by and/or conducive to the accumulation and survival of *Mptb* were selected on each property. They included sheep camps (n = 93), farm dams (89), creeks (2) and persistently damp low-lying areas (5). Shaded sites were selected where possible. Samples of surface water and sediment were collected from dams, creeks and damp low-lying areas. One litre of surface water was collected adjacent to stock access points. Care was taken to avoid disturbing sediment and contaminating surface water samples. 80 millilitres of sediment was collected from directly below the surface water sampling point.

Samples of soil, including surface litter, were collected from sheep camps by the following procedure. The approximate centre of the camp was identified using a marker peg. Soil core samples to 2cm depth were collected adjacent to the marker peg and at 2 and 4 meters north and south and east and west of the central marker peg. The nine soil cores were pooled for each camp yielding a total sample of ~ 40cc of material. Standing vegetation was removed prior to collecting each core sample but decaying organic matter, where present, was included in each core. Intact pellets of sheep faeces were not present on any of the sheep camps sampled. See Whittington et al (2003) for sample preparation and culturing methodology.

Figure 2 Location of 20 farms sampled for soil and water prior to restocking



4 Results and discussion

4.1 Eradication efficacy

Although 44 sites (including 45 monitor flocks) were enrolled in the project, during the course of the field evaluation four sites either withdrew or were terminated prematurely. A Victorian site withdrew from the project in 2001 prior to any testing. In 2003, two sites were found to be negligent of their responsibilities under the requirements of the project and were either not tested or omitted from the results. In 2004 a site, which had tested negative for OJD at year two, was forced to destock the monitor flock prior to a three year test because of increasing mortalities to wild dogs. The results of testing the remaining 41 monitor flocks are given in Table 2. Appended is a site reference map (Figure A1) together with a table of selected details for each site (Table A1).

Table 2 Results of testing Trial 1.1 monitor flocks two and three years after restocking (number positive/number tested)

Result	Test year				Total (re)infected	
	2001	2002	2003	2004		
Evidence of OJD after 2 years	4/6 (1w)	6/19	6/17 (2w)	-	16/42(3w)	38.1%
Evidence of OJD after 3 years	-	1/2	7/13	4/10(1w)	12/25(1w)	48.0%
Eradication failure by year of restock	5/6 83.3%	13/19 68.4%	10/16 62.5%	-	28/41(4w)	68.3%

w = withdrew or terminated from the project

Overall the efficacy of the destocking and restocking protocol imposed by the project to eradicate OJD was low at 31.7%, with only 13 of 41 monitor flocks testing OJD negative three years after restocking. Evidence of OJD was detected in 16 of 42 monitor flocks (38.1%) by the end of the second year following restocking and 12 of the 25 monitor flocks (48%) that went on to retest at year three. Although the failure rate was high regardless of the year of restocking, the results suggest that efficacy improved from the first to the last year of restocking with monitor flock failure rates of 83.3%, 68.4% and 62.5% for sites that restocked in 1999, 2000 and 2001 respectively. These differences are not statistically significant. (P = 0.37).

Although the high failure rate is disappointing it is perhaps not surprising. For any given site to successfully eradicate OJD:

- the decontamination interval must be sufficient for residual Mptb to die
- the site must be protected from contamination from neighbouring flocks and
- the replacement sheep must be free of the disease.

There are uncertainties associated with each of these conditions. Firstly, although overseas research on the cattle strain of Mptb would suggest that 15 months should be an adequate decontamination interval, Whittington (2001) successfully cultured the sheep strain up to 55 weeks after *in vitro* contamination and indicated that his estimates may underestimate actual survival time by several months. Secondly, because we have little relevant data on the mobility of Mptb in contaminated neighbourhoods, for the purposes of PDEPs it was assumed that it is only transported by sheep and goats and that double fencing would contain it. Finally there are no guarantees of freedom from OJD for sheep purchased from MAP flocks or flocks tested to MAP equivalent assurance. In relation to the first two conditions at least, it could be argued that within this field evaluation, eradication efficacy was estimated under worse case scenarios. The majority of sites enrolled were selected because they were heavily contaminated by high prevalence, chronically infected flocks. Logically, this not only had the potential to increase the time required for decontamination but almost guaranteed that neighbouring sheep flocks were also infected. Whether detected or not these infected neighbouring flocks pose a substantial risk of reinfection after restocking.

4.2 Reasons for eradication failure

In total we identified OJD-infected source flocks for four monitor flocks that failed in 2001 and 2002. In one of those cases because of the timing of detection, the source sheep were considered to be the only possible reason for the failure. In the other three we could not exclude the possibility of incomplete decontamination nor reinfection from neighbours. Based on the risk-assurance attained for purchased sheep and on subjective risk assessment of their place of origin, another 14 failures are considered to be of local origin (ie infected neighbours and/or incomplete decontamination). Only two of these local failures were not exposed to neighbouring flocks at some stage during the course of the project. The remaining 10 failures are indeterminate.

In all cases of eradication failure all Mptb positive cultures that were strain typed (n = 39) were identified as S strain. Throughout the course of the project, only one C strain positive culture was recorded from monitor sheep faecal samples from a site with a history of bovine Johne's disease. This monitor flock was found to be OJD negative after three years of testing.

Because the project was initiated with the primary purpose of estimating eradication efficacy under commercial conditions in a range of environments, there was nothing in the design to enable failures to be attributed to decontamination or reintroduction or neighbouring flocks with any certainty. Along with the various site management practices approved within PDEP guidelines, the presence or absence of an OJD infected neighbour for example was left to chance. In spite of this, for the failures that occurred in 2001 and 2002 we attempted to identify a cause.

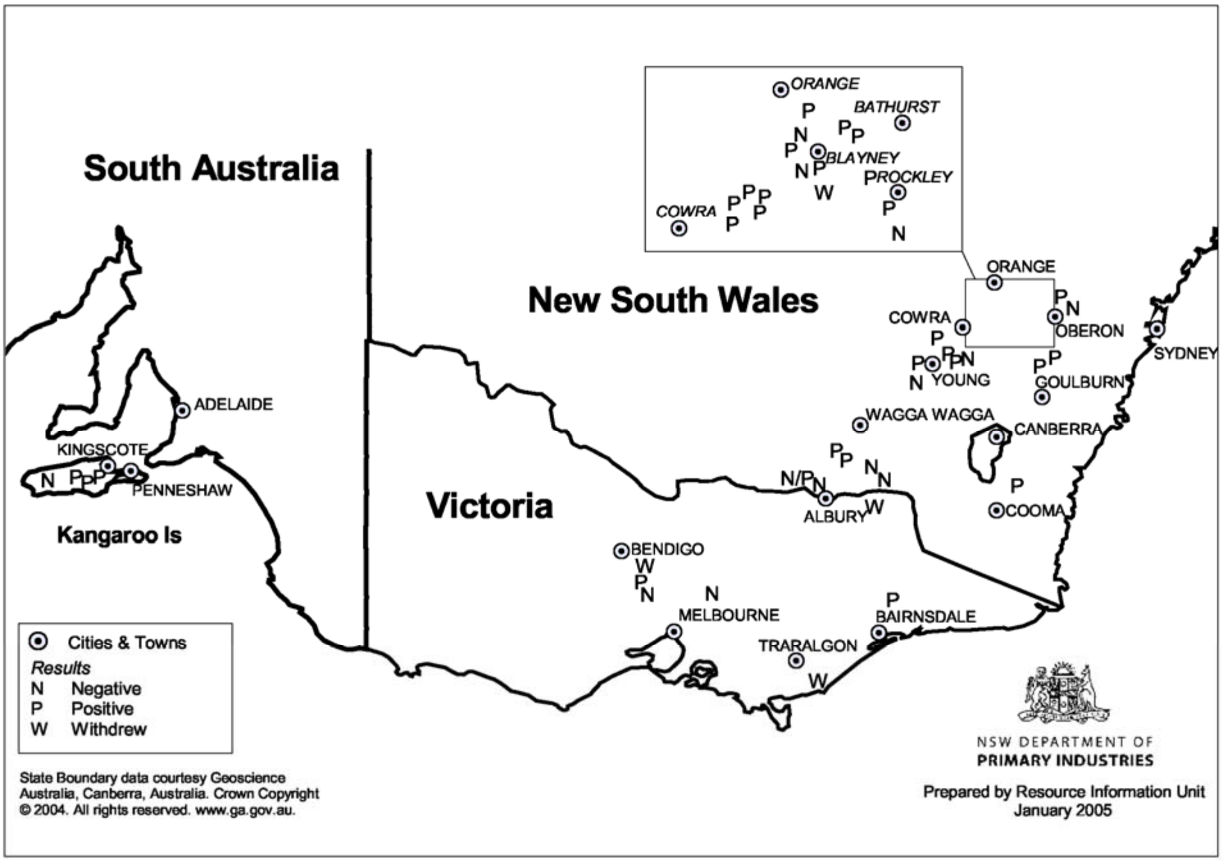
Early failure investigations entailed whole of flock sampling and faecal culture to identify potential sources of reinfection. Subsequent requests to retest potential sources of infected monitor sheep that may have been undetected by the MAP or by testing at restocking or both were all refused by vendors of these sheep. Given the disease history of these failed sites, there was doubtful regulatory jurisdiction to force retesting nor the political will to do so. Over time a number were identified through independent tracings or upon retesting to progress through the MAP. Generally the failure investigations were expensive and inconclusive. As the number of failures increased they were abandoned.

Although the project has not delivered definitive explanations for eradication failures it is reasonable to assume that local issues are responsible for the majority. Based on our best estimates of regional flock prevalence (Ausvet Animal Health Services 2001) at the time that these farms were restocking, the probability of purchasing from an infected flock selected at random without the benefit of MAP assurance ranged from 6.5% in the then Control Zone of NSW (for example) to a maximum of 39% in the endemic Residual Zone. The failure rate of 68% recorded in this trial and the fact that very few sheep were purchased from the Residual Zone indicates that the failures resulted primarily from infected neighbours and/or incomplete decontamination. Unfortunately the design of the trial makes it impossible to determine the relative contribution of each local pathway to failure.

4.3 Factors affecting eradication efficacy

An issue that was considered in the planning of the project was the possibility of regional differences in eradication efficacy. At the time, it was considered in relation to OJD prevalence zones and the prospect of more stringent PDEP requirements within the high prevalence residual zones. The location and test status of all monitor flocks three years after restocking is depicted in Figure 3.

Figure 3 Location and final test status of all monitor flocks.



Eradication failures were recorded across the range of locations represented by monitor flocks. Depending on how the sites are grouped (which is somewhat arbitrary), regional differences in estimates of eradication efficacy are evident. Within NSW there are three reasonably distinct clusters of sites. The first group lies within the inset representing the Central Tablelands (n = 15) together with the adjacent sites to the east (2) and southeast (2). The second group of six sites is scattered around the township of Young. The third group of six sites (including seven monitor flocks) lies between Wagga and Albury in southern NSW. Estimates of efficacy ranged from 21% in the Central Tablelands to 33.3% around Young to 57.1% in the southern group of flocks. Because the number of monitor flocks in groups two and three are small these regional differences are not statistically significant but may represent real geographic variation in the risk of reinfection from neighbours and/or the duration of survival of Mptb during the decontamination interval. The low efficacy on Kangaroo Island (25%), which had a high flock-prevalence (20 – 30%) during the trial period, supports this observation. Monitor flocks in Victoria were too few and too scattered to draw conclusions regarding regional differences in efficacy within that State.

Participants in the trial were required to provide detailed information on disease history, pasture conditions and land management practices during the PDEP and monitor phases of the project. These were collated for potential retrospective analyses to identify risk factors that may have influenced eradication efficacy. The results of preliminary analyses of a short list of candidate risk factors are presented in Table 3.

Table 3 Risk factors presumed to influence efficacy

Monitor flock category	Pre-destock prevalence score(2 - 6×)*	Staged destock (% of sites)	Cultivation during PDEP (% of sites)	Decontamination interval (months)	Infected neighbouring flock (% of sites)
OJD +ve	4.0	30	52	17.7	80
OJD -ve	3.4	23	36	16.8	90
Relative risk	1.18	1.30	1.44	1.05	0.89

* see section 4.1 for score criteria

None of the differences between OJD positive and OJD negative monitor flocks presented in Table 3 are statistically significant. This is due in part to the small number of sites participating in the project, the suboptimal proportion of OJD negative monitor flocks and the relatively small differences between OJD positive and OJD negative sites. The fact that no single risk factor has emerged from the data to date may also indicate that there are other unidentified factors that have predisposed some sites to failure. That said, the results in Table 3 are of interest and may have legitimate implications for decontamination strategies. Compared to monitor flocks that were OJD negative at year three, failed monitor flocks were exposed to sites that tended to have higher disease prevalence histories, were more often destocked in stages and were more likely to have been ploughed during the decontamination period. They also had slightly longer decontamination intervals and marginally less exposure to infected neighbouring flocks.

It could be argued that differences in the first three variables are consistent with increasing risk of incomplete decontamination. Whittington (2001) has indicated that the greater the initial burden of Mptb the longer the decontamination interval required. Staged destocking increases the risk of exposing stage 1 replacement sheep to Mptb carried from stage 2 paddocks within only four months of destocking stage 2 sheep. Intuitively, ploughing during the decontamination period will bury Mptb and protect it from an important decontaminant, sunlight. Rather than identify definitive risks for eradication failure, the results suggest a number of hypotheses to be tested experimentally.

Differences between the two groups of monitor flocks in the decontamination interval and exposure to infected neighbouring flocks are counterintuitive but too small to provide insight to the reasons for failure. Although we strongly suspect that infected neighbouring flocks present a real risk of reinfection, the fact that 90% of OJD negative monitor flocks had infected neighbouring flocks indicates that there may be spatial and topographic features that moderate that risk. Because some of these variables and a number of other risk factors including pasture parameters are confounded, more appropriate step-wise logistic regression analyses are required and will be conducted prior to scientific publication of the results of this trial. Although the factors in Table 3 are unlikely to be statistically significant as main effects under logistic regression, the analyses may identify other variables and interactions between variables that are.

4.4 Pre-destock and post-restock prevalence on failed sites

Although complete eradication was not achieved on 68% of sites, we have consistently observed a dramatic reduction in prevalence between destocking and detecting OJD in the monitor flocks two and three years after restocking. The apparent prevalence of OJD in the year of destocking and following detection of (re)infection in the monitor flocks that failed two and three year tests are given in Table 4.

Table 4 Apparent OJD prevalence before destocking and after restocking

	Estimated prevalence in year of destocking (%)#	Estimated prevalence after restocking * (%)
Detected at year 2	18.9 (range 2 – 40)	0.9 (range 0.3 – 1.75)
Detected at year 3	17.7 (range 4 – 48)	0.8 (range 0.5 – 3.5)

*Based on PFC sensitivity of 40%. # observed OJD mortality x 4,

The low prevalences observed in these failed monitor flocks indicates that the decontamination process is working. They have resulted from almost complete decontamination and/or almost complete quarantine of neighbouring flocks and/or almost complete freedom of OJD in the monitor sheep. The results have important implications for OJD management strategies particularly for heavily infected flocks and farms. They indicate that destocking and cautious restocking will be a viable strategy to rapidly reduce OJD related mortality and dramatically reduce the degree of pasture contamination on these farms. If used in conjunction with vaccination of restocked sheep it is likely that the decontamination interval could be reduced to four summer months with similar response in prevalence.

4.5 Audits of potential refuge environments for Mptb prior to restocking

It is reasonable to assume that there will be variation among farms in the time required to completely decontaminate Mptb. It is also reasonable to assume that there will be even greater variation among microenvironments within farms in the necessary decontamination interval. In an attempt to quantify this variation we cultured 279 samples from 93 sheep camps, 89 farm dams, two creeks and five damp low-lying areas on 20 participating farms covering the range of locations represented by the eradication evaluation. The sampling sites were considered to be conducive to the concentration and survival of Mptb. The intention was to resample any Mptb positive sites at regular intervals until cultures were no longer positive. Samples were collected between 11 and 24 months after infected flocks had been destocked. From 96 water, 90 dam sediment and 93 soil samples we recorded only one Mptb positive culture. This was a sediment sample collected between sedges growing three metres away from a permanent flowing spring on a property in central Victoria (Vic 1). The site had been destocked for 12 months. The growth characteristics of the culture indicated low numbers of viable bacilli (Whittington et al 2003) and one subsequent sample was culture negative. This farm was found to be OJD negative three years after restocking. Seventeen of the farms sampled proceeded to a final monitor flock test. Of these, 10 were found to be OJD positive two (5) and three (5) years after restocking.

The simplest interpretation of these results is that the decontamination interval was sufficient on all farms but 10 monitor flocks were either already infected but not detected and/or exposed to Mptb from neighbouring flocks (8/10) during the period after restocking. The fact that equivalent samples of soil and water collected from other farms stocked with infected flocks at the time of sampling yielded only 20% OJD positive cultures (Whittington et al 2003), places that interpretation in some doubt. Uncertainty regarding the sensitivity of the sampling and culture techniques used raises the possibility that decontamination on some of these farms may have been incomplete as well.

5 Background to financial analyses

The 'economic studies' component of the project was undertaken to determine the financial costs and benefits to individual producers from eradicating OJD from their properties through the destocking process. While there has been considerable work into the "economic" effects of OJD (see ABARE 1997, Topp et al 2001, Hassall & Associates 2000, Holmes and Sackett P/L 1996, Australian Animal Health Council 1997, NSW Farmers' Association 1997, and Patterson 1998), this work tends to rely on simplified, steady state, enterprise budgets which do not adequately track enterprise mix changes over time. Many also use simplistic assumptions in regard to the epidemiology of the disease and some go on to multiply their inherent errors by extrapolating individual producer estimates to represent the effect of OJD on the state or national sheep industry without any attempt to model industry supply responses to the changing economic environment.

The usefulness of previous investigations into the estimated financial position of an OJD affected producer is further compromised by the invariable comparison between infected and uninfected flocks. As McInerney et al (1992) points out, it is not the total cost of a particular disease that is useful, but the avoidable component of that cost. In the case of OJD, it is therefore more appropriate to compare the infected status quo with realistic alternative scenarios, such as a vaccination program or an attempt to decontaminate the property.

This section of the report describes the method by which participating farms were used to obtain estimates of the on-farm financial consequences of the three main options available to producers running OJD infected flocks and the subsequent results of this work. It is based on a paper describing the study's preliminary results (Webster 2002), although the model has been re-run with updated commodity prices. Most importantly, the model's output has been weighted by the probable consequence of each option, based on trial observations, to enable the results to be expressed in expected value terms – a more realistic basis on which individual producers can base their production decisions.

6 Financial analyses

6.1 The model

The inherently biased selection technique employed to select project participants meant that statistical methods for interrogating Trial data could not be used. It was therefore decided to conduct detailed case-studies of three or four co-operators in each of the three major locations – the Central Tablelands of NSW, South Gippsland in Victoria and Kangaroo Island in South Australia – to produce a spreadsheet-based simulation model for a representative farm in each location. All three areas are dominated by grazing enterprises, particularly sheep, have relatively high carrying capacities and few cropping opportunities.

For each location, the model calculates a stream of monthly net farm income over a 20 year period for each of three OJD management options: the status quo, vaccination and decontamination. The first two options do not involve any change to the enterprise mix, but decontamination requires the disbandment of all existing sheep enterprises and their replacement with various interim enterprises until the expiry of the destocked period, when the previous sheep enterprises are reinstated.

The model is largely deterministic in that all future prices and costs are exogenously determined and held constant over time. This allows the effect of the various OJD options to be separated from the "noise" that would inevitably result from the inclusion of observed prices and costs. The annual carrying capacity of each representative farm also remains static over time.

The model produces a number of outputs to assist in evaluating the outcomes of each management option. The effect of each management option on individual enterprise gross margins is reported, as is the net present value (NPV) of monthly net income over time periods up to twenty years. The level of equity held in the business over time is also estimated.

6.2 Assumptions

Farm area, enterprise mix, overhead costs, land value and level of debt for each location were determined using data from project participants, the NSW Agriculture OJD database, real estate agents, rural financial counsellors and a special data extraction from ABARE's farm survey database. Further information, particularly with regard to the calender of operations, was obtained through detailed interviews with the case study co-operators in each location.

The primary physical and financial characteristics of each representative farm are detailed in Table 5. While these characteristics were derived to represent the farming system in each location, the area and carrying capacities of all three representative farm models were found to be similar.

Table 5 Representative farm physical characteristics by location

Characteristic	Central Tablelands	Kangaroo Island	South Gippsland
Property size (ha)	700	650	635
Carrying capacity (DSE per ha)[1]	7.5	10	8.5

Information about the assumed initial enterprise mix and proportion of carrying capacity attributed to each enterprise in each location is contained in Table 6. The initial enterprise mix of all three representative farms is dominated by Merino wool enterprises, although the type and quantity of wool varies considerably, with the Central Tablelands, Kangaroo Island and South Gippsland farms

[1] Nutrition requirements for the various categories of livestock modelled were estimated in dry sheep equivalents (DSEs). Due to interstate variations in the definition of a DSE, all nutrition requirements in the model have been standardised to DSEs defined as the average energy requirements of a 50kg wether, equalling 9.7 megajoules per day.

assumed to be running 18, 23 and 19.5 micron ewes and wethers, respectively. First cross ewes producing export weight second cross lambs and a significant beef cattle breeding herd are also assumed to be run in the Central Tablelands, whereas trade weight first cross lambs are produced on Kangaroo Island by joining sound cast-for-age Merino ewes to terminal sires.

Table 6 Initial enterprise mix and proportion of carrying capacity by location

	Central Tablelands		Kangaroo Island		South Gippsland	
Enterprise	# head	% DSEs	# head	% DSEs	# head	% DSEs
Merino ewes	929	46.0%	1250	60.0%	1267	70.0%
Merino wethers	776	20.0%	1233	30.0%	1098	30.0%
1st cross lambs	n/a	n/a	246	10.0%	n/a	n/a
2nd cross lambs	227	10.0%	n/a	n/a	n/a	n/a
Beef cows	52	14.0%	n/a	n/a	n/a	n/a
Beef yearlings	66	10.0%	n/a	n/a	n/a	n/a

The assumed interim enterprises for each location are described in Table 7. After consultation with producers in each location, it has been assumed within the Central Tablelands representative farm that a beef breeding herd is maintained, a yearling steer operation is expanded and a Merino wether lamb trading enterprise is introduced during the destocked period. Seasonal factors enable two intakes of Merino wether lambs to occur while the representative farm is destocked. For the Kangaroo Island representative farm it is assumed that both a yearling steer enterprise and a Merino wether lamb enterprise is introduced. Only one intake of Merino wether lambs is included due to the seasonal pattern of Kangaroo Island. The proximity of South Gippsland to the Victorian dairy industry has enabled many OJD affected producers in that location to undertake a range of dairy related enterprises, including a permanent switch to dairying where irrigation is available. With respect to the South Gippsland representative farm, it is assumed that two consecutive September 100-head intakes of pedigreed dairy heifer calves are included as an interim enterprise. These are sold, in calf, at around 15 months. Pregnant dairy cows are also assumed to be agisted during the destocked winter in order to maintain pasture condition and provide cash flow.

Table 7: Interim (destocked) enterprise mix and proportion of carrying capacity by location

	Central Tablelands		Kangaroo Island		South Gippsland	
Enterprise	# head	% DSEs	# head	% DSEs	# head	% DSEs
Merinowether lambs	1,881	43%	2,462	50%	n/a	n/a
Beef cows	52	14%	n/a	n/a	n/a	n/a
Beef yearlings	282	43%	406	50%	n/a	n/a
Dairy heifers	n/a	n/a	n/a	n/a	200	3.4%
Dairy agistment	n/a	n/a	n/a	n/a	200	24.6%

While both the Central Tablelands and Kangaroo Island representative farms are assumed to be fully stocked during the destocked period, the South Gippsland farm is not. This is because the dairy heifer raising enterprise assumed to be run in the latter location is highly labour intensive, particularly in the early stages, and it was deemed unrealistic for any further calves or other enterprises to be run during the destocked period. Similarly, it has been assumed that all representative farms have access to adequate cattle handling facilities, although this may mean sharing a neighbour's cattle yards, and that the South Gippsland farm has suitable shed space for the initial stages of the dairy heifer raising enterprise. As the above assumptions applied to most case study properties interviewed, no capital expenditure has been allowed in any location for the switch to cattle enterprises during the decontamination option.

The use of realistic mortality rates and distribution within the simulated flock is important as it directly affects some of the most basic determinants of enterprise profit, such as the number of sheep joined, shorn and to lamb, as well as the number of surplus sheep sold. Table 8 contains information about the flock mortality assumptions incorporated in the base run simulations. The "background" mortality regime represents deaths unrelated to OJD, such as lambing complications, flystrike etc, and applies to all management options including post-decontamination enterprises. The model adds the relevant mortality regimes to derive the total flock mortality for each management option. For instance, total mortality under the status quo scenario is represented by the sum of the background and infected mortality regimes. The mortality rates for beef cows, yearlings steers and dairy heifers are assumed to be two per cent, one per cent and one per cent (post weaning), respectively, in all locations.

Table 8: Base run annual flock mortality assumptions by age group

Sheep Age Cohort or Enterprise	Infected Mortality	Vaccinated Mortality	Background Mortality	Comment
0.25 -1.5	0.5%	0.00%	2.5%	Weaning to joining age
1.5 - 2.5	5.9%	0.00%	2.5%	Applied to all ewe enterprises in all locations. Wether enterprises assumed to have adult average uninfected mortality of 1.5% due to no lambing risk
2.5 - 3.5	9.8%	0.24%	2.5%	
3.5 - 4.5	5.0%	0.50%	2.5%	
4.5 - 5.5	2.6%	0.39%	2.5%	
5.5 - 6.5	1.3%	0.13%	2.5%	
Adult average	**5.0%**	**0.25%**	**2.5%**	**1.5 to 6.5 years old**
>6.5	1.3%	0.13%	3.0%	Older KI ewes for 1^{st} X lambs

OJD related mortality, either as the direct consequence of wasting or from the systematic culling of clinically affected animals, is the most obvious biological impact of the disease. Annual losses of up to 20% have been reported, although mortality rates above 10% are uncommon (Eppleston et al 1999). An initial OJD attributable whole-flock mortality rate of 5 per cent per annum was assumed for all locations. While this mortality rate is perhaps double the typical rate (Eppleston et al, 2003), it is well within reported ranges and it was assumed that OJD mortality had to be significant for an individual producer to consider an option as drastic as decontamination. The rate of OJD attributable mortality was also assumed to vary between different age cohorts within an infected flock, with OJD mortalities usually peaking at around three years of age (Eppleston et al, 2003).

OJD vaccines are widely reported as being at least 90 per cent effective in reducing mortalities and bacterial shedding (Denholm 1999, Brett 1998), with Eppleston et al (2004) reporting a mortality rate of around 0.23 per cent in experimental animals. OJD-related mortalities were therefore assumed to be 0.25 per cent for vaccinates under the vaccination management option.

The infected mortalities detailed in Table 8 represent the initial mortality regime for all three management options. Epidemiological studies have shown that middle-aged cohorts are most likely to suffer the highest mortalities, and that the overall rate of OJD mortality for an unvaccinated flock generally rises over time, although climate and soil types may also have a role (Eppleston et al 1999, Denholm et al 1994, Sigurdsson 1960). The proportion of OJD related mortalities for each age cohort are therefore made to conform to an assumed distribution for any given level of OJD mortality, where OJD related mortality peaks at 40 per cent of all OJD related mortalities within the 2.5 to 3.5 year old age cohort. OJD related flock mortality for the status quo management option is also assumed to increase by 10 per cent each year.

Thus, as each vaccinated cohort moves through the various age categories, the OJD related mortality applied to that age group switches from the infected to the vaccinated mortality regimes in Table 8. It therefore takes six simulated years before OJD related mortalities are minimised under the vaccination management option. OJD related mortality has been shown to be delayed by vaccination (Eppleston et al, 2003). Consequently, the proportion of OJD related mortalities for each age cohort is assumed to peak within the 3.5 to 4.5 year old age cohort under the vaccination management option.

While anecdotal evidence also suggests that OJD adversely affects productivity through reduced lambing percentages, reduced wool production, and possibly decreased fibre quality, recent field work has not substantiated these claims (Eppleston et al, 2003). Therefore, other than the loss of wool from sheep that have died before shearing and the loss of lambs whose mothers have died prior to weaning, these effects have not been included in the model.

The model runs conducted in 2002 (and reported in Webster, 2002) incorporated two major effects of OJD on farm businesses; additional flock mortality and price discounts on surplus sheep sales. The latter effect was based on reported experiences in New Zealand and the opinion of various industry participants. However, recent industry experience and formal abattoir data collection has indicated that sale discounts for vaccinated sheep do not appear to have eventuated in Australia. Sale discounts for vaccinated sheep have therefore been removed from the model.

Wool quantity and quality is an important factor influencing the profitability of Merino enterprises. Both production characteristics depend to a large extent on animal age. In tracking each age cohort separately, the model is able to apply different wool cuts and prices to hoggets, 1.5 to 6.5 year old adults and ewes older than 6.5 years. This provides a more accurate estimation of the effect of age related OJD mortalities under the three management options examined than has been attempted in past studies. The main wool and livestock prices assumed to be received by the enterprises run in each location are detailed in Table 9. The earlier model runs were also conducted at a time when there existed significant regulatory restrictions under the National OJD Program (NOJDP), particularly on the movement of stock. For example, the trading restrictions that applied to infected properties imposed significant financial costs on sheep producers that specialise in the production of store lambs and replacement ewes or wethers, as such stock had to be sold for slaughter, thereby imposing a considerable discount on the prices received relative to the price that would be obtained for replacement sheep. It would have been desirable to update all livestock prices to post-NOJDP levels so that the distortionary effects of the NOJDP restrictions were not incorporated in the model. However, as there was less than a year of post-NOJDP price data available, it was decided to use three-year (2002-2004) average stock prices (from ABARE and NLIS) in the model. For consistency, average 2001-02 to 2003-04 wool prices were also used (from the Pricemaker website).

Table 9: Main assumed wool and livestock prices by location

	Central Tablelands		Kangaroo Island		South Gippsland	
Enterprise	Price*	description	Price*	description	Price*	description
Merino adult wool	814	18 micron	567	23 micron	627	19.5 micron
Merino lambs wool[2]	743	19 micron	567	20 micron	n/a	n/a
Crossbred wool	235	28 micron	n/a	n/a	n/a	n/a
Prime lambs	259	22-25kg	275	18-22kg	n/a	n/a
Beef weaners	131	steers	n/a	n/a	n/a	n/a
Beef yearlings	141	steers	146	steers	n/a	n/a
Dairy heifers	n/a	n/a	n/a	n/a	$900/h	in calf
Dairy agistment	n/a	n/a	n/a	n/a	$5/h	per week

* prices expressed as cents per kilo (clean for wool, dressed for lambs and liveweight for cattle), unless otherwise specified.

The assumed livestock sale prices are listed in Table 10. It has been assumed that there are no premiums or discounts associated with vaccinated Merino replacement sheep relative to uninfected sheep. However, large discounts have been applied to infected replacement sheep as vendors still must provide information on their stock's health status to prospective purchasers. Consequently, vendors are assumed to either sell them to specialist finishers at a substantial discount or attempt to finish stock and sell them to slaughter – a strategy not without cost. It was felt that the assumed prices in Table 10 adequately approximate either strategy.

Table 10: Assumed base-run sale prices for surplus Merino weaners and hoggets by location

Sheep type	Central Tablelands	Kangaroo Island	South Gippsland
Uninfected wether weaner	$40.00	$40.00	$40.00
Vaccinated wether weaner	$40.00	$40.00	$40.00
Infected wether weaner	$20.00	$20.00	$20.00
Uninfected ewe hogget	$53.00	$46.50	$46.50
Vaccinated ewe hogget	$53.00	$46.50	$46.50

[2] Specifically, the wool produced by interim Merino wether lambs.

Infected ewe hogget	$26.50	$33.00	$33.00

The assumed financial parameters used in the base run simulations for all three locations are listed in Table 11. Initial equity was set at 80 per cent of land value in all three locations. The uninfected total gross margin of the initial enterprise mix indicates that the level of returns in each location are similar, as are annual fixed costs.

Table 11: Base-run financial parameters by location

Parameter	Central Tablelands	Kangaroo Island	South Gippsland
Initial equity[3]	80%	80%	80%
Land value per hectare	$2,000	$855	$2,200
Uninfected total gross margin	$81,465	$98,143	$95,588
Fixed costs per annum	$61,500	$56,700	$54,000

6.3 Risk

OJD affected producers who are deciding on their management strategy face significant price and production risks that are additional to the usual price and seasonal risk faced by all sheep producers. Producers attempting an eradication strategy face the following three major risks:

1. decontamination is unsuccessful, in that Mptb persists on the pasture or in watercourses, thereby infecting restocked sheep;
2. decontamination is successful, but Mptb is reintroduced to the property from an infected neighbour via either straying sheep or other vectors; and
3. decontamination is successful but infected sheep are unwittingly purchased to restock and recontaminate the property.

The realisation of any of these risks may place the producer in question in a worse financial position than when they started the process, as they have effectively invested thousands of dollars in destocking without receiving the full benefit associated with an uninfected flock. It should, however, be recognised that some benefit will be derived from an unsuccessful attempt at decontamination in the form of much lower disease prevalence and consequent mortality.

To take the risk of unsuccessful eradication into account, the eradication scenario incorporated into the model is reported in expected value terms – that is, the results are a hybrid of two scenarios – successful eradication and eradication failure, weighted by the probability of each outcome. The level of eradication failure from all causes during the trial is estimated to be 68 per cent of all participants, and so this weighting has been used in the model. It is assumed that producers who

[3] Equity has been calculated using the method recognised by financial institutions: (total land value – total debt)/total land value. This differs from the accounting approach, which uses total assets rather than land value, and thereby affects a producer's ability finance decontamination.

have experienced eradication failure begin a vaccination program in year three of the simulation and that OJD mortality at that time is 0.1 per cent.

A report into the epidemiology of OJD in New South Wales (Sergeant, 2001) suggests that proximity to known infected flocks was the major risk factor for presently uninfected flocks and that the regulatory regime of the time was having little impact on inter-neighbour spread of OJD. The high eradication failure rate observed among participating farms is therefore not surprising.

With respect to other risks, the major price risk is that associated with stock prices. Should a producer attempt to decontaminate their property, they will need to sell all of their sheep, buy into or expand an existing interim enterprise, and then purchase replacement sheep at the end of the destocked period. Similarly, where a producer ties up most of their available capital in an interim enterprise based on store cattle, as is assumed in all three representative farm models, the producer faces the risk of major losses should cattle prices decline significantly during the destocked period. Of course, interim enterprises may also rise during the destocked period, resulting in a windfall gain to the producer. No attempt to take this type of price risk into account has been made, with the model assuming that all stock prices remain constant throughout the simulation period.

“Opportunity cost” can also affect the OJD management decisions of producers. For instance, fluctuations in wool or prime lamb prices can represent a risk over and above the consequent affect on replacement sheep prices. The opportunity cost of not having sheep, albeit infected sheep, during the destocked period would increase if wool or prime lamb prices increased. Eradication is therefore less likely to be attempted if producers feel that wool or prime lamb prices are going to rise, and vice versa.

A further opportunity cost which may affect the willingness of producers to digress from the status quo is regulatory risk. At any given time, there is always the possibility that government policy affecting the profitability of OJD infected sheep enterprises might change. The switch in national emphasis from eradication to vaccination, and particularly the end of the NOJDP, is a case in point. An OJD affected producer four years ago effectively had two options – the status quo or eradication. The availability of vaccine has provided many New South Wales producers with a third, less risky, option that is no doubt reducing the number of producers presently attempting eradication.

7 Financial results and discussion

Charts 1 to 3 display the simulated annual net farm incomes of the representative farms in each location over twenty years. Of the locations, only the Central Tablelands consistently returns negative annual net farm income for all three management options (infected status quo, vaccination and eradication). The relatively low profitability of the Central Tablelands representative farm model is primarily a function of the assumed commodity price and debt levels and the land values used in the model. As these fluctuate over time, it is not the actual estimates that are important but rather the relative performances of the three management options examined.

Chart 1 Estimated Annual Net Farm Incomes for the Central Tablelands Representative Farm

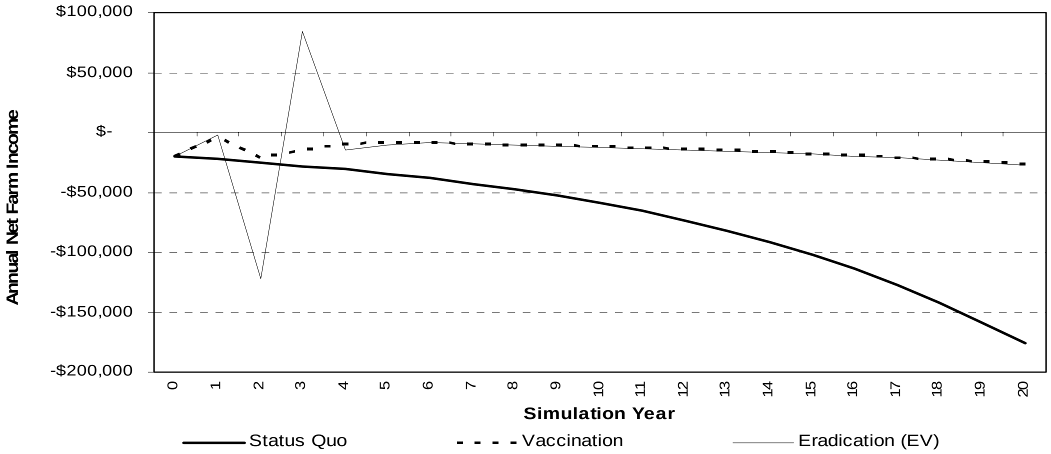


Chart 2 Estimated Annual Net Farm Incomes for the Kangaroo Island Representative Farm

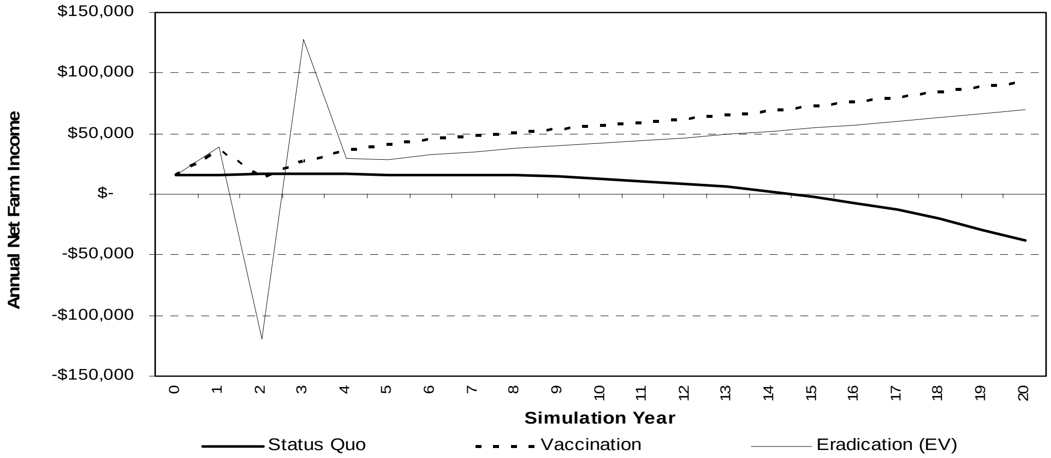
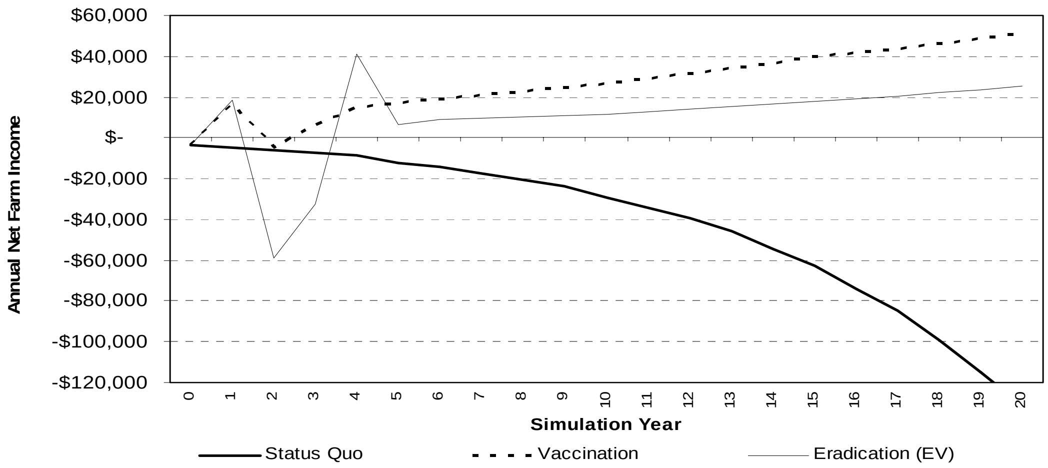


Chart 3: Estimated Annual Net Farm Incomes for the South Gippsland Representative Farm



While the estimated annual net farm incomes presented above indicate that vaccination is likely to yield the highest annual income over time, these results must be manipulated into net present values (NPV) before accurate comparisons can be made. Consequently, the difference in monthly net farm income between the vaccinated and status quo options and the eradication (expected value) and status quo options were calculated over twenty years. The NPV of these differences, which are detailed in Table 12, were then calculated using a real discount rate of 4 percent per annum to allow comparison of the three management options in each location.

Table 12 must be interpreted as providing a means of comparison between the vaccination and eradication options over a fixed planning horizon. There is no definitive method for choosing a planning horizon – it varies according to personal circumstance. For instance, a producer ten years away from retirement may choose to compare alternative courses of action over ten years. The two most salient points to be made about Table 12 are, however, that vaccination yields positive returns from year two in all locations and that vaccination is the preferred option over all planning horizons and locations.

This latter result differs from those presented in Webster 2002, where eradication was preferred to vaccination in all locations, although the time horizon for this to occur varied from two years on Kangaroo Island, seven years in the Central Tablelands and thirteen years in South Gippsland. The introduction of a high probability of decontamination failure has essentially reversed these results[4], as decontamination failure causes the farm to revert to a vaccination program where a reduction in OJD prevalence and mortality has in effect been brought forward by a large initial outlay when compared to the modelled vaccination scenario. It is therefore not surprising that the vaccination scenario NPV is consistently higher than that for the expected value decontamination scenario.

Eradication requires a much larger initial investment than a vaccination program, but results in higher annual gross margin relative to infected enterprises once the initial enterprise mix is reinstated – even if eradication was unsuccessful (because disease prevalence is much lower than previously). However, subsequent net farm income, which is gross margin less fixed costs and

[4] Although the updating of commodity prices has also had an effect. For instance, if decontamination is taken to be 100 per cent successful, decontamination now takes a planning horizon of thirteen years, compared to seven years in the previous analysis, to become the preferred option in the Central Tablelands.

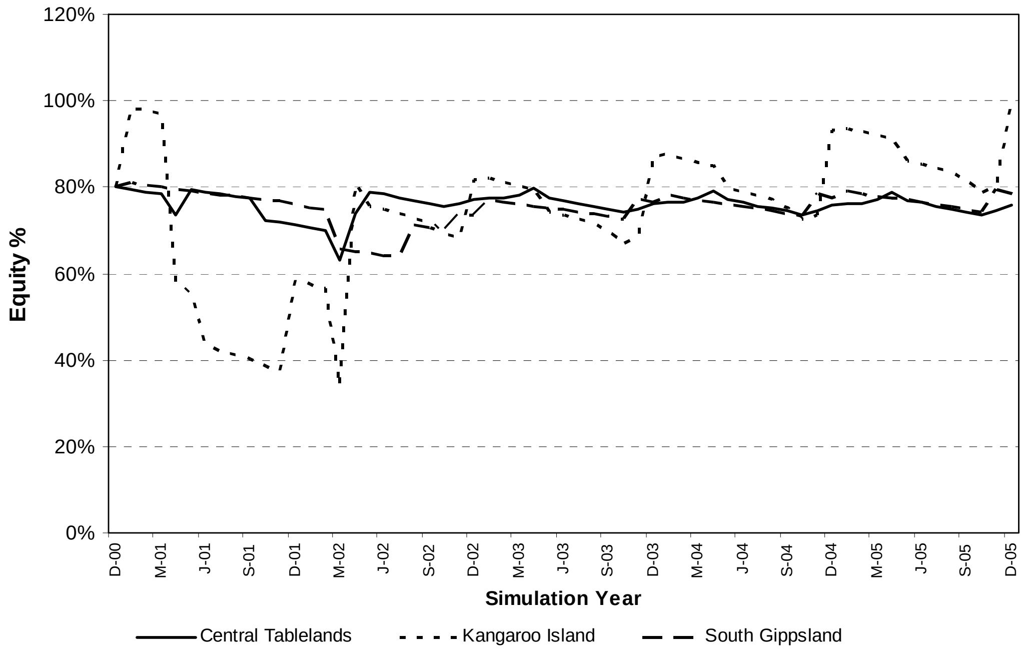
interest on debt, may be higher or lower following attempted eradication depending on the extent to which debt levels have changed. For instance, if eradication was successful but caused a large increase in total farm debt, then a producer could end up having a post eradication higher gross margin but a lower net farm income relative to that experienced before eradication was attempted. These effects explain the differences across locations in Table 12, where eradication is only marginally less attractive than vaccination in the Central Tablelands, whereas this difference between the two options in both South Gippsland and Kangaroo Island is much larger.

Table 12: NPV of vaccination and eradication options over the status quo by location

Horizon (years)	Central Tablelands		Kangaroo Island		South Gippsland	
	Vaccination	Eradication	Vaccination	Eradication	Vaccination	Eradication
1	-1,558	-99,753	-1,627	-131,628	-1,391	-53,027
2	6,332	798	9,170	-25,232	9,282	-81,411
5	56,612	43,678	71,428	9,726	72,656	-11,213
10	175,205	160,529	211,862	98,974	229,969	94,980
15	349,830	333,025	395,473	230,620	464,255	267,733
20	607,310	587,909	649,214	429,728	799,764	541,590

In addition to the NPV comparisons presented in Table 12, an OJD affected producer that is contemplating eradication as a management option would need to consider the financial constraints that may thwart such a decision. Financial institutions lend on the basis of business equity expressed as a proportion of the property's land value, with few willing to lend beyond 50 per cent equity. It is therefore possible that a switch to a finance-intensive interim enterprise, such as yearling steers, could not be funded through short-term debt. For example, Chart 4 tracks the equity level for each location under the eradication management option.

Chart 4: Base run eradication equity to year 5



The short-term fall in equity shortly after commencing eradication may mean that a producer may not be able to fully stock their property, and hence maximise their income, during the destocked period, thereby further increasing the relative cost of the option. While the base runs ignore these financial constraints, it is worth noting that, at an initial equity of 80 per cent, the financial constraint is likely to be binding only for Kangaroo Island producers, who have relatively low land values. At initial equity levels lower than 70 per cent, however, such finance constraints also affect the Central Tablelands and South Gippsland.

8 Concluding remarks

At the time that this field evaluation was conceived, there was an urgent need to quantify the efficacy of OJD eradication under the commercial conditions emulated by the protocol implemented within this trial. It was one potential pathway for the Australian sheep industries to manage this relatively new disease. To that end OJD.001 has been successful. It is unfortunate that more thought was not given during the planning stages to design an evaluation that shed light on the reasons for potential eradication failures. One important concern is that of infected neighbouring flocks. With the benefit of hindsight the results would have been more informative if a proportion of sites had been deliberately selected that had no neighbouring sheep flocks.

The poor efficacy of the OJD eradication protocol implemented on these farms is disappointing and is clearly not a viable option for systematic eradication of the disease. As far as we can tell it is unlikely to have resulted from human error on the part of the farmers involved. With the exception of one farm that inadvertently restocked with sheep found to be infected soon after arrival, all participants successfully restocked with sheep that complied with the MAP risk assurance standard. During the course of the project two other sites were found to be negligent of their responsibilities to follow trial protocol and were terminated from the project. Their results are not included in this estimate of efficacy. The remainder were committed to the objective of eradication and are to be congratulated on their efforts to achieve that goal.

The financial analyses have shown that under a wide range of mortality assumptions, vaccination is a substantially more profitable OJD management strategy than either the infected status quo or eradication in the Central Tablelands, on Kangaroo Island and in South Gippsland. Vaccination also has the advantage of being far less costly to implement than eradication and is a much less risky management strategy

If in future there is renewed interest in identifying more efficacious strategies to eradicate OJD from farms and regions, before embarking on any field evaluations, it would be prudent to conduct carefully designed and controlled experiments to

- re-evaluate effective decontamination intervals for a range of land use practices using flocks of young sheep to monitor decay rates of Mptb

  and

- elucidate the movement and modes of transport of Mptb in infected neighbourhoods

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11 Appendix

Table A1 Site and monitor flock details.

Map Identifier	Nearest Town	Restock year	Pre-destock Enterprise. Code	Predestoc kMortality	Predestock prevalence index	Monitor flock risk assurance	No. bloods	No. PFC's	Restock test	2 year test	3 year test
NSW 1	Young	1999	SRM	1-5%	2	Blood, PFC	458	1	✓	×	
NSW 2	Henty	2000	SRM	0.5%	2	MN1	Nil	Nil	Nil	×	
NSW 3	Caloola	2001	SRM/XB	10%	6	PFC x2	Nil	14	✓	✓	×
NSW 4	Millthorpe	2000	SRM	8%	5	Blood, PFC	450	9	✓	✓	✓
NSW 5	Rockley	1999	SRM	10%	6	PFC	Nil	8	✓	✓	✓
NSW 6	Grenfell	2000	MS	1.5%	3	MN1, MN2	Nil	Nil	Nil	✓	×
NSW 7	Rydal	2001	SRM/XB	6.5%	4	PFC	Nil	7	✓	×	
NSW 8	Vittoria	1999	SRM	5%	5	Blood, PFC	450	7	✓	×	
NSW 9	Crowther	2001	SRM	2-4%	2	MN1	Nil	Nil	Nil	×	
NSW 10	Millthorpe	2001	M/XB	1%	3	MN1, MN2	Nil	Nil	Nil	✓	×
NSW 11	Vittoria	1999	SRM	8%	6	PFC	Nil	21	✓	×	
NSW 12	Brown's Creek	2000	SRM	4 -20%	5	PFC	Nil	7	✓	✓	×
NSW 13	Golspie	2000	SRM/XB	5%	6	PFC	Nil	13	✓	×	
NSW 14	Lyndhurst	2000	D/M/ XB	1-3%	4	Blood, PFC	442	5	✓	✓	×
NSW 15	Woodstock	2000	SRM	4 -5%	4	MN2, PFC	Nil	14	✓	×	
NSW 16	Wallendbeen	2000	M/XB	7%	2	MN1	Nil	Nil	Nil	✓	✓
NSW 17	Blayney	2001	C/M	1%	3	PFC	Nil	7	✓	✓	×
NSW 18	Lyndhurst	2001	SRM/XB/D	8%	3	Blood	450	Nil	✓	×	
NSW 19	Rydal	2000	SRM/XB	18%	4	Blood, MN1	286	Nil	✓	✓	✓
NSW 20	Taralga	2001	SRM/XB	10%	5	PFC	Nil	13	✓	×	
NSW 21	Woodstock	2001	SRM/XB	2%	4	MN1, MN2	Nil	Nil	Nil	×	
NSW 22a	Howlong	2001	SRM	1%	4	PFC	Nil	14	✓	✓	×
NSW 22b	Howlong	2001	SRM	1%	4	PFC	Nil	14	✓	✓	✓
NSW 23	Crowther	1999	SRM	6%	6	MN1	Nil	Nil	Nil	✓	×
NSW 24	Woodstock	2000	SRM/XB	4%	3	Blood, PFC	450	6	✓	✓	×
NSW 25	Jerangle	2000	SRM	4%	3	Blood	450	Nil	✓	×	
NSW 26	Carcoar	2000	SRM/G	6%	4	MN1	Nil	Nil	Nil	✓	✓
NSW 27	Henty	2000	SRM	5%	2	PFC	Nil	7	✓	×	
NSW 28	Barry	2001	SRM	5%	5	PFC	Nil	7	✓	w	
NSW 29	Howlong	2001	M/XB	2 - 4%	2	MN1, MN2	Nil	Nil	Nil	✓	✓
NSW 30	Jingelic	2000	M	5%	2	Blood	450	Nil	✓	✓	✓
NSW 31	Holbrook	2000	M/XB	0.5%	2	MN1	Nil	Nil	Nil	✓	✓
NSW 32	Boorowa	2001	M/XB	2%	4	MN2	Nil	Nil	Nil	✓	✓
NSW 33	Rockley	2000	SRM/XB	8%	6	MN1	Nil	Nil	Nil	✓	×
SA 1	Parndana	2000	SRM/XB	5%	5	MN1, PFC	Nil	7	✓	×	
SA 2	Parndana	2000	SRM	3.5%	5	MN1	Nil	Nil	Nil	✓	×
SA 3	Karatta	2001	SRM	3.5%	3	MN1	Nil	Nil	Nil	✓	✓
SA 4	Cygnet River	2000	SRM/Suffolk	1-2%	3	MN1, Blood, PFC	454	7	✓	✓	×
Vic 1	Kyneton	2001	SRM/XB	0%	2	PFC	Nil	7	✓	✓	✓
Vic 2	Mia Mia	1999	SRM	0%	3	Blood, PFC	499	10	✓	w	
Vic 3	Kyneton	1999	SRM	5%	3	MN1, PFC	Nil	7	✓	×	
Vic 4	Ensay	2001	SRM/Dorset	0.5%	3	Assumed MN1	Nil	10	×		
Vic 5	Woodside	2001	SRM/XB	0.1%	3	PFC	Nil	7	✓	w	
Vic 6	Yea	2001	SRM/Dorset	1-10%	4	PFC	375	4	✓	✓	✓
Vic 7	Wodonga	2001	SRM/XB	0.1%	3	MN2	Nil	Nil	Nil	✓	w

Figure A1 OJD eradication evaluation site reference map