Modelling the impact of BVDV in Australian dairy farms

Using *BVD Farm Model V 1.0*

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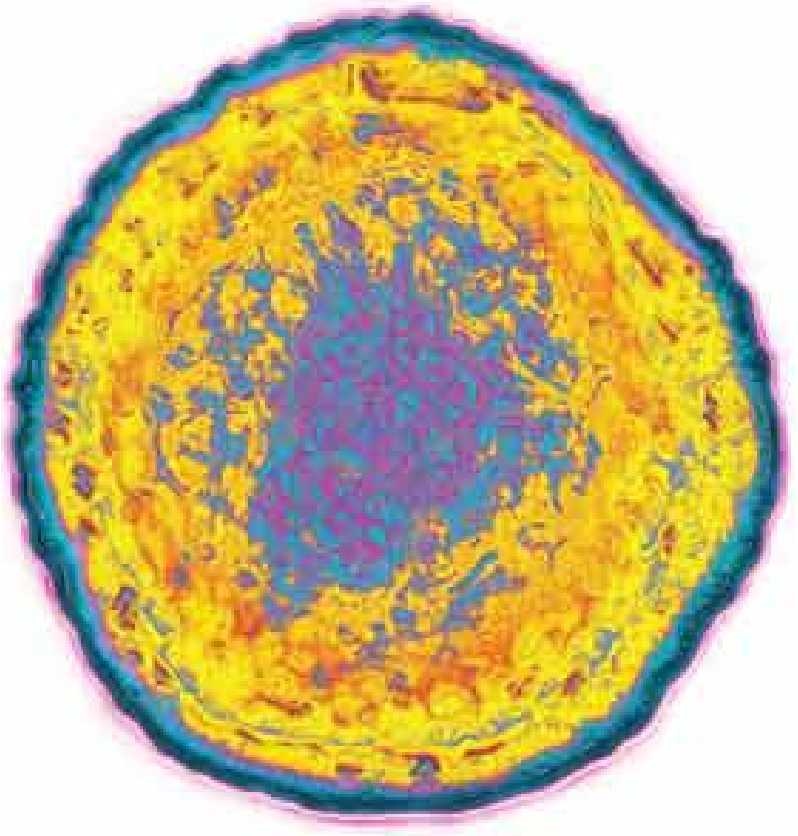

Dairy Australia

HERD HEALTH

Contents

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1 Executive Summary

This document describes the construction and operation of a Bovine Viral Diarrhoea Virus (BVDV) computer simulation model developed to examine the impact of BVDV (also called 'pestivirus') on the physical and financial performance of Australian dairy herds. The herd examines the behaviour and impact of virus in seasonal, split and year-round calving systems and explores the cost-benefit of various controls for BVDV. We use the terminology BVDV to refer to the pestivirus and the term BVD to refer to the impact of virus and/or its control on herd performance and function. The model was developed by Richard Shephard in the R Environment (The R Foundation for Statistical Computing; R version 3.0.1 onwards).

The construction of the model, the underlying module logic and the integration of the modules into a working system is described with sufficient detail for an expert in dairy management / reproduction to understand the model and for an expert in the behaviour of BVDV to examine virus and host interactions and impacts. The herd component is a detailed working model of dairy herd management and performance that has been used and validated in other areas (eg Johne's disease management, genetics). The combination of a BVDV module into the working dairy herd management model provides an effective way of examining the behaviour of virus in typical Australian dairy herds.

A total of 15 control scenarios were modelled. These included BVDV-free and no-control (unmanaged BVDV) along with various combinations of testing, culling, vaccination and biosecurity controls currently in use in the industry. The same start-up herd was used within each scenario of each calving system and 100 replicates of each combination were performed to determine the range of outcomes. The herd size studied was between 285–300 milking cows.

Comparison of BVDV-free scenarios to unmanaged BVDV scenarios revealed no meaningful difference in herd annual conception rates —both AI and overall, herd pregnancy rates, embryonic loss rates or farm milk production. The average financial impact of BVDV in endemically infected herds is small. Low-cost control of BVDV is supported — but the return on investment is not great over the long term. For many detailed and higher cost controls the long-term return from investment in BVDV management is negative.

Control of BVDV in year-round herds where virus is more able to persist and impact on näive pregnant animals is greater than for seasonal and split calving systems.

Control of BVDV changes the background risk of the herd to large-scale outbreaks of disease. The impact of control is difficult to predict because effective control both reduces the risk of introduction of virus but also increases the risk profile of the herd (more animals are näive. In general, modelling indicates the importance of biosecurity to prevent (re)introduction of virus in preventing large scale outbreaks.

The following observations are made:

1. Most dairy herds have evidence of current or recent infection (as indicated by seroprevalence).

2. BVDV infection in most animals produces no clinical disease or only limited sub-clinical disease. Typically there is no financial loss as a result of infection.

3. Endemically infected dairying regions typically do not experience noticeable physical or financial losses due to BVDV. This is because most endemically infected herds have few näive females at the vulnerable stage of their reproductive cycle.

4. Endemically infected herds experience natural cycling of virus. The number and proportion of susceptible and näive animals change due to infection and from natural herd turnover.

5. Endemically infected herds can spontaneously eradicate virus when reservoirs (PIs) are lost and not replaced (i.e. no Trojans) and as herd immunity builds thereby preventing ongoing virus transmission. There is a high background risk of re-infection in herds that spontaneously eradicate BVDV and take no controls against reintroduction of virus. A ten-year virus eradication and re-introduction cycle for dairy herds in endemic regions appears evident from herd serological profile studies.

6. Permanently-infected (PI) animals are the main reservoir of infection in herds. Transiently infected (TI) animals do not persist with circulating virus for more than a few days. Removal of PIs from a herd (and all Trojan pregnancies) typically results in rapid loss of virus from the herd — persistence of virus in the absence of a PI beyond one month is not common.

7. Controls to identify and eradicate BVDV from infected herds are effective. Individual-animal tests for exposure (antibody) and for circulating virus (primarily used to detect PIs) are highly sensitive and specific.

8. Long-term control of BVDV in endemically-infected dairy herds is a break-even economic proposition for most herds. Any extra return from controlling BVDV circulation is generally offset by the extra cost of running the control program.

9. Whilst the long-term endemic loss from BVDV in dairy herds is small, BVDV can produce large-scale outbreaks in näive herds. This can result in business-threatening economic losses — depending on the number and class of stock infected and the timing of the outbreak relative to the reproductive cycle of the herd. Farmers and advisors need to understand the risks and impacts of larger-scale outbreaks in their herds when selecting a BVDV control strategy — knowing the long-term average cost-benefit of control is insufficient information on which to base a control decision.

10. All BVDV control strategies — including choosing not to control BVDV — will change the future herd outbreak risk profile.

11. Knowing herd and group infection and immunity status can be useful information. However, the timing of testing to ascertain the status of classes of stock is important for the information to be used effectively. Timing is not the same for all classes

of stock or for all calving systems. Implementing strategic testing strategies is problematic in year-round calving herds where there is a continual cycle of mating, calving and of animals changing groups.

2 Objective of modelling

The primary objective of modelling was to estimate the cost-benefit of (various) BVDV controls and to identify the impact of various control strategies on the risk of large-scale future outbreaks of disease. The choice of controls for BVDV is a function of both the cost-benefit from controlling disease and the change to the risk profile of the herd for a large-scale (catastrophic) outbreak of disease. The cost-benefit of controlling endemic disease is determined by the level of reduction of endemic disease losses arising as a result of improved control of infection that are offset against the (extra) costs from implementing the specific BVDV controls. This component is analogous to decisions made to control disease — such as for mastitis in the herd where extra intervention/control is justified if the returns from the extra control exceed the extra cost of implementing; understanding that eradication of mastitis from a herd is impossible and infeasible. The risk profile component explores the change to future susceptibility of the herd and likelihood of a large-scale outbreak. This aspect is comparable to evaluation of insurance policies against rare events such as house fire. The cost of the premium and the magnitude of the potential loss in the absence of insurance determines actions. Individuals vary in their attitude to risk therefore it can be expected that farmers with similar herds, levels of BVDV, impacts of endemic disease and access to controls may choose different approaches to the management of BVDV in their herd. This project is designed to assist farmers and their advisers make an appropriate control choice for their herd.

3 How the model works

An individual-animal, event-based, discrete stochastic simulation model of a dairy herd was combined with a Reed-Frost BVDV infection dynamics model to examine the magnitude and range of impacts of BVDV and its control on farm physical and financial performance.

An individual-cow model of Australian dairy farms was developed for other uses (Johne's disease modelling, genetics etc.) and was adapted to include a BVDV component. The herd model combined known dairy herd management rules with individual animal (typically probabilistic) events to simulate a working herd. Basic animal events such as the return to cycling activity after calving, the risk of conception after service, the morbidity and mortality of animals and the milk production performance was simulated and sampled from distributions derived from industry data. These have been described elsewhere (see *BVD Model Construction*). All functions were mathematically defined from existing data and subject to extensive verification and validation of performance. Management was coded using fixed values or logical (Boolean) rules. Examples include the: farm stocking rate, number of paddocks, grazing rotation length, range of allowable herd sizes (milking cows), start and end of mating for seasonally-calving herds, length of the voluntary wait period and the maximum number of AIs for year-round herds, maximum age of cows before culling, bull power etc. For example, the period of mating (in

seasonal and split calving systems) was defined and a simple rule applied to determine if a cow experiencing a heat would be submitted for detection and subsequent service. The model reproductive performance was validated against the 2011 InCalf project data by matching the 6-week and total in-calf rate for cohorts of cows based on their week of calving (seasonal calving system) against observed industry data.

The model tracks individual animals for life. Each animal is uniquely identified and daily and lifetime performance monitored and updated. The current status of the animal (age, lactation, production, pregnancy etc.) is updated daily along with lifetime counts/sums of items such as matings, pregnancies, production. Animal start time (i.e. birth, purchase etc.) is recorded and current time is updated each day the animal remains alive and in the herd. The end time (i.e. death or sale) of each animal is recorded and final status and lifetime summary of the animal updated and maintained within the inventory. Animals are subject to a number of management controls and exposed to a range of (typically probabilistic) events such as mating, mastitis, giving birth to a heifer etc. as they travel through life. All mating events are recorded — all calves born during the simulation have full parentage recorded. Some cow-level characteristics/statuses are set for life (such as sex, cow follicular wave type, inter-heat interval etc.). These are generated and recorded at cow establishment (i.e. birth or purchase). Other variables that change over time (e.g. day of next heat, lactation production variance, mastitis status) are updated as required. Both permanent and temporary variable values are stored against the cow ID in the inventory. It should be noted that many stored characteristics or status levels are 'hidden'; that is, impossible to observe in real life.

Individual events were separately coded using functions that mathematically describe the (known) relationships. Examples include the: risk of oestrus by time after calving, risk of abortion, lactation performance, daily energy requirement, risk of (other) disease. Where mathematical relationships were not available from literature expert opinion was used. All key event functions were extensively tested by verifying logic and validated by comparing output to real data (where available). Event functions are called sequentially and as required each day for each individual animal and the animal variables are updated accordingly. These include variables describing physiological status, production, infection and immunity, reproductive and productive history for each animal. Not all functions are called for all animals. For example, the pregnancy function is not required for bulls or for young stock. A series of logical vectors (T/F) indicating which functions are required for each individual animal are updated each day. Required functions are called daily and as required — many output values from one function provide input to another event function. The sequential and logical calling of functions ensures that the appropriate inputs are made available to each function as required. This daily updating of individual animal status and performance variables provides the effective linkage between individual functions. For example, if a cow that was pregnant experienced an abortion then the time of the abortion was recorded. This information is then used by the oestrus function to determine the next heat date (in this example, an abortion would result in a delayed return to cycling activity).

Daily herd-level summaries were collated and written to file. This includes information such as the number of animals of each class, amount of milk produced, number of matings and number of calvings for the day. Individual animal daily physiological status is not written to external file but overwritten each day as required.

A Reed-Frost infection dynamics model was used for BVDV transmission and survival in infected herds. The movement of virus was defined by the proportion of animals within susceptible (S), infected/infective (I), recovered/removed (R) classes. A separate subset of infected/infective was used for BVD. The permanently infected (PI) class included animals that were continually infective to others and represent the PI animal that was infected in utero. Transmission functions that defined the risk of virus transfer (probability) after an effective contact were defined along with functions that described the number of effective contacts between herd mates within the same animal group and for non-herd mates that were in adjoining paddocks ('over-the-fence' contacts). Infection probability distributions were validated using field observational data. External risk of (re-)introducing disease was modelled via the over-the-fence contact function and by a probability function for vector-based introductions. Stochasticity provided randomness to the introduction, spread, persistence and elimination of virus from herds. Various controls for BVDV were modelled by variously changing the level, persistence, spread and introduction of virus into a herd.

The economics of disease was assessed using gross margins of herd performance. The income for the farm was calculated as the combined returns from milk sales and livestock sales as well as changes in the value of inventory — livestock and conserved feed. The variable costs for the farm included herd, shed and supplementary feed costs. The distribution of discounted ten-year gross margins of scenario replicates were compared between scenarios to determine the impact of BVD on herd financial performance and the effectiveness of control.

A burn-in period was used to generate start-up herds. Here virus was artificially inserted into herds (except for the BVDV-free scenario) and the (uncontrolled BVDV) simulation run for five years to allow virus to distribute through the herd, to allow herd members to seroconvert and to provide opportunity for pregnancies to be infected with virus. The composition of the herd at the end of the five-year burn-in period was used to populate the start-up herds. This provided for variation in the count and distribution of infected (PIs and TIs), immune and näive within and between animal groups in the herd.

3.1 Herd-level parameters

A brief summary of model components follows:

3.1.1 Herd size and calving pattern

The milking herd size is set by choosing the desired number of replacement heifers required each year. Actual milking herd size is determined by age cohort survival and was set at 4.4 times (i.e. a herd replacement rate of 22%) the desired number of replacement

heifers. Herd size was maintained by counting and managing the number of calvings expected for the year (or period) ahead. A tolerance of 1% was used to provide the allowable range of herd sizes. The number of pregnant cows (and heifers) to calve are actively monitored at set times (depending on the calving system) and corrective actions taken to ensure the correct number of calvings will occur in the upcoming period. In the event of a surplus, the voluntary culling function is called to sell sufficient late-lactation lowly-ranked cows to return number of calvings to within the desired range. Point-of-calving heifers are purchased if insufficient calvings are predicted for the upcoming period. If surplus heifers were available then sufficient under-performing cows were sold (voluntary culls) to maintain herd size. If insufficient heifers were available to maintain herd size extra were bought to keep the milking herd size within the desired size range.

Herd size was kept constant to control for differences in farm financial performance due solely to differences in number of animals. Most farms will respond to inadequate or excessive number of animals by buying or selling so farm herd size was maintained at constant levels for this analysis.

Three calving patterns were modelled: seasonal, split and year-round calving. Seasonal calving mated for 15 weeks with 42 days of AI to start the mating period. Split calving systems included a second mating of 6-weeks duration with 21 days of AI to start. Year-round herds applied a 50-day voluntary withhold period and a maximum of 5 matings per cow before marking for culling if not pregnant. All herds used AI on yearling heifers with two rounds of AI followed by bull mating for 4 weeks.

In split-calving herds up to 10% of non-pregnant cows at the end of either mating period may be carried over to the next mating period. Cows may only be carried over once and carryover cows must meet minimum milk production performance to be eligible. The total number of pregnant and carryover cows provide the predicted future herd size. Surplus cows (carryovers) were sold if herd size was predicted to be above the upper limit. Point-of-calving heifers were purchased if predicted herd size was below the lower limit. Each calving period was set to have 50% of cows calving in modelled split herds.

3.1.2 Reproduction

The probability estimates for risk of submission and for conception of individual animals based upon the interval from calving were derived from the 2010 InCalf Fertility Data Project [1]. Subbmodel output was validated against this data. Baseline event probabilities obtained from these curves are subject to further adjustments according to the number of ovulations post calving,age, genetic merit of the individual animal, health of the cow and herd heat detection efficiency. matings were controlled in the sense that the sire was recorded. This has implications for vertical transmission of virus from infected dams. A background risk of abortion for the gestations was set at 3%. The mating function uses individual animal physiological status to modify outcome risk for the stochastic process.

[1] Dairy Australia (2011). *InCalf Fertility Data Project 2011*, Southbank, Melbourne, 3000

3.1.3 Nutrition

Herd feeding uses a base of home-grown pasture supplemented with purchased grain. Pasture growth rates from the Macalister Irrigation District were used. Daily herd energy demand was calculated using ARC growth equations. Daily differences between herd total energy demand and herd total daily pasture energy supply were summed and used to calculate the amount of supplementary grain required or surplus pasture that was conserved across each month.

3.1.4 Morbidity and Mortality

Probability functions were used to assign individual animals for premature removal from the herd (sale as culls) due to illness and for on-farm death of individuals. The morbidity and mortality probabilities and the distribution of times after calving were obtained from analysis of HiCo MISTRO data. Functions included variable risk per month of lactation with the majority of illness and death occurring in the first months of lactation

3.1.5 Culling

Two types of culling events were coded — involuntary and voluntary. Involuntary culling was primarily reproductive-driven whereby empty cows that are not producing sufficient milk were forcibly removed from the herd at the end of lactation. Involuntary culling also followed repeated clinical mastitis events and by age (cows older than 12 years were culled). Voluntary culling also occurred under certain circumstances. The voluntary culling module is only called when a surplus of calving cows was identified. A 'demerit' system that scores cows for age, production, state of pregnancy was used to rank all adult herd members and sufficient numbers of the highest cull ranked cows were sold at the end of their current lactation. This effectively maintained herd size by controlling the maximum number of calving to occur in the upcoming period. It should be noted that this mechanism provides a way for underperforming PIs to be removed from the herd without knowing their infection status.

3.2 Cow-level parameters

3.2.1 Generating new individuals

Individual animals are generated either at birth, on initiation of the simulation, or on a purchase signal (if the number of milking cows was expected to be less than the minimum number). All animals have a unique identity. The status of the animal (alive, dead, sold) is recorded and updated daily. Dead or removed animals are maintained in the herd inventory (but recorded as removed). If the cow is born from an existing herd cow (i.e. not generated at the start of the simulation), the identity of the dam and sire is recorded and parentage details are stored). Each new animal is assigned individual lifetime lactation constants (using a random sample from a normal curve of production — derived from the HiCO MISTRO herd recording data). Daily milk production is calculated using Woods curve functions to determine milk, fat and protein production

for the individual by stage of lactation. Individual parameter constants such as whether the animal is a 2-wave or 3-wave cow and the inter-ovulation interval are generated at inception and recorded (for life). All events are recorded and updated daily including pregnancy status, mating events (AI and natural), mastitis events (clinical and sub-clinical and by pathogen) and BVD status. Production and reproductive histories for the animal (for the current lactation and over the lifetime of the animal) are updated. The SCC is updated daily and determined by stage of lactation, mastitis status and BVD status. Pregnancy information is also updated daily. A counter updates the number of days that the animal remains in the herd and an exit time is recorded in the event of death or sale of the animal.

3.3 Subroutines

3.3.1 New-born heifer function

The function is called whenever a cow carrying an AI heifer calf reaches term. The newborn calf is added to the herd inventory and sire and dam information is recorded. The in-utero infection status of the calf is determined during the gestation period. If the dam is a PI the calf will be a PI (if it survives). If the cow is transiently infected during pregnancy the risk of infection is determined probabilistically. Foetuses of sufficient age (>100 days) mount an immune response with 50% of infected foetuses clearing infection. The remaining infected foetuses from TIs either die and are resorbed, become PIs or are born with congenital abnormalities. The abortion/embryonic loss rate for an infected foetus is double the background of loss in unaffected foetuses — $1/3^{rd}$ of infected foetuses die in-utero. Most of the foetuses that survive become a PI. Foetuses between 100–150 days that become infected are at increased risk of developing congenital abnormalities. Foetuses older than 150 days that become infected mostly eliminate infection and become immune in-utero.

3.3.2 Buy bull function

This function is called if the number of bulls required to naturally mate the herd is insufficient (bull power is set by the operator with a minimum of two bulls as standard). New bulls are generated (sex is set to 1; a male). Bulls are forcibly culled after 3 seasons. The BVD status of the purchased bulls is determined from the background prevalence of infection with 2% of animals being PIs and 0.5% TIs. However, scenarios that undertake bull testing do not permit the purchase of any virus-positive bulls.

3.3.3 Buy extra heifers function

In the event that there is insufficient home-bred replacements to maintain herd size and herd size will fall below the lower limit extra replacement point-of-calving heifers will be purchased. This incurs a risk of introducing BVD. The risk is determined by the background prevalence of PIs (2%) and TIs (0.5%) modified by the farm biosecurity and testing management policies. Similarly, the risk of introducing previously infected and

now immune animals is determined by the background seroprevalence (80% of farms infected with a within-herd seroprevalence of 70%) and farm management policies.

3.3.4 Move groups vector function

This function is also called once every 365 days. Their are five groups on the farm: calves/yearling (group 1); heifers (group 2); lactating cows (group 3); dry cows (group 4) and bulls (group 5). Heifers that calve for the first time automatically move to the lactating cow group as do dry cows that calve. Lactating cows that are dried off automatically move to the dry cow group. Calves over the age of 300 days are moved into the heifer group on a set day. Uncalved (non-pregnant) heifers remain as heifers until forcibly culled (or subsequently pregnant and they calve).

3.3.5 Pregnancy update function

All live females are passed to the pregnancy update function irrespective of current pregnancy status. This is because empty cows must meet a culling decision point at some stage based on the number of days not pregnant and the mating history of the cow. The pregnancy function therefore identifies empty cows for involuntary culling. Pregnant cows are updated daily and there is a daily background abortion risk applied. Cows that do not abort have their stage of pregnancy updated each day until term is reached (282 days). At term, the cow is coded to begin lactation and has mating variables reset to allow the reproductive function to be called appropriately. Non-pregnant cows are also updated and long-term empty cows are earmarked for culling.

3.3.6 Lactation update function

This function updates the daily lactation output from lactating cows. The productive ability of the cow is assigned at generation or purchase (randomly). These are modified at calving to adjust for the herd productive capacity (herd-year effect), the age effect of the cow, BVD status and some random perturbation. Disease — such as being a PI — can induce lower milk production. The impact of disease on milk production is determined probabilistically.

3.3.7 Mastitis update function

A mastitis function was included because mastitis represents a major cause of involuntary culling. Baseline new infection risks for *S. aureus* and *S. uberis* were obtained from published data and used to determine daily risk of new infection. Baseline risk was modified by the herd prevalence of infection using simple prevalence-based scaling of risks. The somatic cell count (SCC) estimates for a cow were determined by the stage of lactation, the mastitis infection status (uninfected versus infected), the clinical status (clinical versus sub-clinical) and the pathogen involved (*S. aureus* or *S. uberis*). Again these equations were obtained from published data. A lactating cow and a dry cow treatment function was applied that modelled cure rates to both modalitied. These were used to determine (modify) the fate of infection in cows.

3.3.8 Mating update function

Eligible mature cycling animals are assigned a date for their next heat and a baseline probability of being detected and of conceiving (if detected and served). This is primarily affected by the number of days calved but also by the BVD status of the animal. These baseline probabilities are updated after each relevant event (e.g. calving). Mating is then determined by herd mating periods, the heat detection efficiency for the farm and the maximum number of matings and AIs (year round) already undertaken. AI events are assigned to an AI sire and bull matings to a herd bull at random and the identify of the sire is recorded. This is important for spread of virus (from bull to cow and to foetus and from cow to bull). A proportion of animals were randomly selected to become infertile after calving. Matings proceed for individual cows until the cow becomes pregnant, the mating period ends (seasonal and split) or the number of unsuccessful matings has been exceeded (year round). For AI pregnancies a binomial draw is performed to determine the sex of the foetus.

3.3.9 BVDV transmission function — Reed-Frost mob-level

BVDV transmission was simulated using a variation of Reed-Frost infection dynamics. This approach models four groups of animals within each mob. These are **S** (Susceptible), **I** (Infected and Infective), **R** (Removed or Resistant) and in this case **PI** (Permanently Infected). The basic course of individual-animal disease and the sequence and timing following infection (of infectivity, immunity, removal etc.) was modelled across a population comprised of various numbers of animals within each category using assumptions about transmission contacts between animals. Uniform within-mob mixing is assumed with all animals have equal probabilities of making an 'effective contact' each day. An effective contact between two individuals is one in which virus transmission can occur (i.e. 'nose-to-nose' touching between two cows). The number of effective contacts between an individual and the rest of the mob mates was modelled using a Poisson distribution. The number of effective contacts was estimated from observed rates and times of seroconversions of mobs of näive heifers who had one or more PIs introduced to the mob.

The model tracks the progress of infection and infectivity in each individual such that on any one day the viraemic (infective) animals and their relative infectivity as well as the identity of the näive animals and the immune animals in the mob are know. This information determines what happens when two individuals make effective contact. The number of effective contacts that each individual makes is randomly determined by sampling from the appropriate Poisson distribution. The individual contacts are also randomly sampled from the mob. The status of the source and target contact animals are therefore both known and recorded. Where the host is infected and infective and the target animal(s) näive these were each sent forward to a random binomial sample draw to determine if virus transmission occurred. In the event of contact with neighbouring cattle (or in the event of purchase of replacement animals) the background prevalence of infected herds and of TIs and PIs within the regional population was used to generate a temporary population of external cattle for the purpose of determining virus transmission

into the herd from an external source.

The relative infectivity of virus-positive animals was also set. For a PI this was constant (0.95). An equation defined the period of infectivity and the relative infectivity of TIs. Immune animals — from previous infection or from vaccination — are prevented from becoming infected whilst their ELISA S/P ratio remains above 0.25. Functions defining the response and decay of immunity were developed from vaccination and natural infection data and were therefore modelled using this combined with expert opinion.

Effective contacts and transmission risks were calculated daily for each animal in the herd. This system effectively modelled the transmission of virus within and between mobs over time. The natural management of the herd — movement of animals between mobs (e.g. from the dry cow herd to the milking herd on calving) and the culling and natural mortality of the herd combined with the virus spread dynamics to determine the transmission and persistence of virus in the mob and herd. Where appropriate, the presence of virus impacted on animal performance — notably reproductive efficiency, milk production and mastitis — and this consequently changed the survival of animals within the herd (through altering death and culling risks).

Virus was not modelled to survive outside a cow host for any length of time. The removal of the last PI and TI from a herd represents the clearance of virus from the herd. Reinfection was modelled through purchases, agistment and over-the-fence contact with neighbouring stock.

3.3.10 ELISA function

Andrew Weir provided the individual cow milk BVD ELISA titre function that includes a variable immunity component. The equation is:

$BVDELISA = exp(-0.007*Days+0.2*Ln(Days))+1.5–[1.25/(365*BVDAbDecline)]*Days*exp(-0.007*Days+0.2*log(Days))+1.5-(1.25/(365*abwane))*d)$

Where Days = days since infection for naturally infected animals. For vaccinated animals Days = days since vaccination + 1450 —- to control for the lesser immunity induced by vaccination. In the event an animal is vaccinated but has previously been naturally infected, the maximum of the natural infection and vaccinated BVD ELISA titres are assigned. Animals become susceptible to reinfection when the S/P ratio falls to 0.25 or below. The model calculates and updates cow ELISA titres on a daily basis and will change cow susceptibility from -1 (immune from natural infection) or -2 (immune from vaccination) to 0 (susceptible to reinfection) when the ELISA falls below this ratio.

3.3.11 AGID function

The function to determine the BVD AGID result for an animal was derived from longitudinal Australian data:

$AGID = round(6*[1/(sqrt(2*pi))]*[exp(-(log(days)-log(35))^2/(2*(max(3,log(BVDAbDec-1))^$

Where days = days since natural infection or days since vaccination + 250. For vaccination the days since vaccination + 1450 is used to model the AGID decline over time.

3.3.12 Modelling impact of disease on performance

Virus has varying impacts on reproduction, mastitis, production and survival. For TIs the modelled effects were small, transient and deterministically assigned. Effects were typically large, life-long but also stochastically assigned for PIs. Stochastic processes were used for PIs in order to mimic the variability in impact between PIs. This process allows for apparently 'normal' PIs to be mingled into the mob but ensuring that on average most PIs under perform compared to non-PI herd mates. Impacts were modelled by adjusting base rates using constants (for TIs) and sampling from distributions (for PIs) — no specific function was used.

Viraemia defined the period of reduced performance in milk production, risk of mastitis and recovery from infection and in the risk of culling due to morbidity (secondary infection) in TIs — except for recently resolved infections in the 42 days before mating on subsequent conception rates. Recovered animals experienced a slight reduction in conception rate due to damage inflicted on the forming follicle during the preceding viraemic phase. Effects were transient and resolved after 42 days. This approach allowed a small and transient impact of infection on involuntary culling in TIs

No group immunosuppresive effects were specifically modelled — besides the effect of transient increases in risk of other disease. The model did not increase the risk of secondary diseases such as salmonella outbreak in the calf pen or a mastitis outbreak when virus was present in the herd and mob. This was considered to add a 'black box' component to the disease model as it could not be effectively defined or parameterised from the literature or expert opinion. This was consistent with other economic modelling approaches[2].

3.3.13 BVDV transmissibility function — animal-level

This was derived using expert opinion. The function determines the BVD infectivity of a transiently infected animal. Infectivity depends upon the number of days since infection. There are a number of user defined parameters. These and their default values are: the upper limit for infectivity is set to 0.95 (the default infectivity for a PI); the pre patent period is set to 3 days; the maximum infectivity day is set to 5; and the infectivity decay constant is set to 0.3. The equation is:

$$Infectivity = BVD.TI.max.contact.transmission.rate * 100 * exp(-BVD.TI.infectivity.decay.constant * (days - BVD.TI.max.infectivity.day)$$

Once infectivity returns to zero the BVDStatus is updated to -1 (immune).

3.3.14 BVDV susceptibility

Animal susceptibility is related to ELISA immunity. Each individual animal on birth is assigned a constant that determines the rate of decline of Ab after infection or vaccination. This hidden variable *BVDAbDecline* for natural infections is given by: $BVDAbDecline = max(1, rnorm(mean = 5, sd = 0.75)$

[2] e.g. Houe, (2003) Economic impact of BVDV infection in dairies. *Biologicals*, 31; 137-143

For vaccinated animals the decline is effectively equivalent to:
$BVDAbDecline = max(1, rnorm(mean = 1, sd = 0.75)$

3.3.15 Economics

The economics module calculates the gross margin for each scenario — including cash and non-cash income and costs. The marginal cost of pasture production was set at $125 per tonne. Grain was costed at $350 per tonne. Profit from home-conserved hay was imputed at $125 per tonne (after removing conservation costs). Average herd and shed costs were obtained from recent industry data (Dairy Farm Monitor Project) and costed out daily ($175 per animal per year). No difference between young stock and lactating stock in costs were assumed. This is then used to calculate then yearly percentage difference in performance (as $100 * (Without - With)/Without$) and overall for the scenario. It is this figure that is of most interest in assessing the real economic impact of disease within Australian dairy farms.

4 BVDV Model Input Values

Relevant BVD model parameters values are provided below:

BVD.birthdefect.cutpoint The maximum foetal age at infection that can result in birth defects in TI dams. Birth defects were set to occur between 100 – 150 days of gestation.

BVD.CR.redn Absolute reduction in conception rate due to BVD in TIs. This number is multiplied by BVD Infectivity to give the reduction in daily probability of conception following service. Set at 0.33

BVD.EEL.day.cutpoint The maximum foetal age at infection that can result in infection and death of the embryo. Embryos infected up to day 30 of gestation are lost.

BVD.in.utero.infection.risk The proportion of foetuses in a viraemic TI dam that will become infected. Set at 0.95 (note that 100% of foetuses of PIs become infected)

BVD.in.utero.immune.response.rate The proportion of foetuses between 100–150 days that mount an immune response in utero. Set at 0.5

BVD.infection.abortion.risk.ratio The increased relative risk of abortion in an infected foetus. Set at 1.0 (this makes the relative risk of abortion 1 + 1 = 2 — i.e. a doubling of risk)

BVD.mastitis.cure.decreased.risk The reduction in cure rate for mastitis in TIs. Multiplied by the BVD Infectivity to give the decreased daily cure rate for mastitis. Set at 0.33

BVD.PI.day.cutpoint The maximum foetal age at infection that can result in a PI foetus in TI dams. PIs occur in foetuses infected between up to 100 days of gestation

BVD.PI.effective.contact.transmission.rate A numerical variable describing the probability of infection transmission between a PI and a näive animal after effective contact. Set at 0.95

BVD.PI.reduction.mean The mean relative reduction in performance of PIs for mating, mastitis and cure. Set at 0.33. This implies an average reduction in risk of service and of conception, increased daily risk of mastitis, reduced cure rate and decreased milk production of 33% in PIs.

BVD.PI.reduction.sd The standard deviation of the relative reduction in performance of PIs for mating, mastitis and cure. Set at 0.15. This implies a 95% range in reduction in risk of service and of conception, increased daily risk of mastitis, reduced cure rate and decreased milk production of between 0% and 66% — at the mean PI reduction of 33%.

BVD.SR.redn Absolute reduction in submission rate due to BVD in TIs. This number is multiplied by BVD Infectivity to give the reduction in daily probability of submission for service. Set at 0.33

BVD.TI. mastitis.inceased.risk The increase in daily risk of mastitis in TIs due to infection with BVD. Multiplied by the BVD Infectivity to give the increase in daily probability of mastitis. Set at 0.15

BVD.TI.max.contact.transmission.rate A numerical variable describing the peak probability of infection transmission between a TI and a näive animal after effective contact. Set at 0.10

BVD.TI.days.premating.1 The maximum number of days before mating that conception rates are reduced for the 1st tier pre-mating period. Set at 14 days

BVD.TI.premating.1.CR.RR The relative risk multiplier for conception risk in TIs infected before mating and within the 1st tier pre-mating period. Set at 0.55

BVD.TI.days.premating.2 The maximum number of days before mating that conception rates are reduced for the 2nd tier pre-mating period. Set at 28 days

BVD.TI.premating.2.CR.RR The relative risk multiplier for conception risk in TIs infected before mating and within the 2nd tier pre-mating period. Set at 0.76

BVD.TI.days.premating.3 The maximum number of days before mating that conception rates are reduced for the 3rd tier pre-mating period. Set at 42 days

BVD.TI.max.infectivity.day A numerical variable describing the day after first infection that a TI sheds peak amounts of virus. Set at 3.0

BVD.TI.infectivity.decay.constant The daily proportional rate of decline in infectivity after peak infectivity in TIs. Set at 0.3

BVD.TI.premating.3.CR.RR The relative risk multiplier for conception risk in TIs infected before mating and within the 3rd tier pre-mating period. Set at 0.89

BVD.TI.prepatent.period.days A numerical variable describing the number of days folliwing first infection that a TI does not shed virus. Set at 2.0 days

external.herd.contact.rate The daily probability that a mob of cattle will graze a paddock with a shared boundary fence to a paddock containing stock on a neighbouring farm. Set at 0.02

external.herd.contact.mob.size The number of cattle in over-the-fence contacts (neighbouring farms). This determines the number of TIs and PIs in the neighbour's mob and important for the number of effective contacts. Set at 100 animals.

heifers.off.farm A T/F variable determining if the heifers are carried off farm. This determines the contact rate with home mobs and external mobs.

heifers.off.farm.OTF.contact.prob A numerical variable determining the daily probability of over-the-fence contact on agistment block. Set at 0.10.

internal.herd.contact.rate The daily probability that a mob of cattle will graze a paddock with a shared internal fence to a paddock containing another class of stock on the home farm. Set at 0.25

mean.daily.contacts.within.mob The average number of effective contacts (contacts capable of transmitting virus) between each animal and other herd mates in the same mob. Set at 20.

mean.daily.contacts.OTF The average number of effective contacts (contacts capable of transmitting virus) between each animal and neighbouring cattle over the fence (OTF). Set at 2

propn.BVD.birthdefects The proportion of eligible infected foetuses that mount an immune response that develop birth defects.

propn.BVD.EELs The proportion of eligible infected foetuses that are lost. Set at 0.50

propn.PI.window.embryos.escape The proportion of eligible infected foetuses in TI dams that do not become PIs

TI milk production depression 20% (whilst viraemic).

BVD vaccine foetal protection 80%.

Bulk milk ELISA cutpoint for vaccination 0.75 — if less than this the herd may be vaccinated. If above this then the herd is considered sufficiently immune and not vaccinated.

Young stock seroprevalence for vaccination 0.65 — if less than this then the young-stock may be sent for vaccination. If above this then the young stock are considered sufficiently immune and not vaccinated.

Cohort ear-notch test proportion 0.05 — this is the proportion of animals that are individually tested for being PIs. Used to determine how many cows in the milking herd will be tested to find the PI.

Calf value $250 (at birth).

Yearling heifer value $1,500.

Cull cow value $1,000.

BVD vaccine cost $5.00 (dose).

BVD serology test cost $10.00 (per test).

BVD crush-side test cost $20.00 (per test).

BVD PCR test cost $15.00 (per test).

Veterinary labour charge $200.00 per hour.

The following parameters were used to define the BVD-management control components within each scenario. These parameter descriptions are also repeated in the Section **??** (*Input Parameters*). Refer to this section for specific virus-transmission and impact related variables.

screen.cows.to.decide.vaccinate A T/F variable that determines if a bulk milk sample is to be taken at a regular interval in order to estimate the BVDV seroprevalence of the herd. This information can guide decisions to vaccination or otherwise (depending on the scenario).

cow.bmelisa.vax.screen.cutpoint A numeric variable that sets the bulk-milk ELISA test value below which the herd is considered sufficiently näive to vaccinate — if bulk milk screening is undertaken on the farm and if vaccination can be strategically used.

screen.youngstock.to.decide.vaccinate A T/F variable that determines if a sample of yearlings will be routinely tested to determine the seroprevalence of the mob of young stock. This information can guide decisions to vaccination or otherwise.

youngstock.seroprev.vax.screen.cutpoint A numeric variable that sets the upper limit for the proportion of näive young stock in a sample for the group to be considered näive. Such mobs may be eligible for vaccination — if vaccination is available as a control option. An individual is considered näive if it returns an ELISA S/D ratio < 0.25.

young.stock.vaccinate.BVD A T/F variable that determines if vaccination of young stock before first mating is used.

cows.vaccinate.BVD A T/F variable that determines if adult cows are able to be vaccinated (boosted) against BVDV. If True the actual adult vaccination program depends upon other variable settings.

cows.booster.vaccinate A T/F variable that determines if cows are routinely boosted as adults — if vaccination is used as a control.

bulls.vaccinated.BVD A T/F variable determining if bulls are routinely vaccinated before each use.

bulls.tested.BVD A T/F variable that determines if all purchased bulls are routinely tested for virus before entry to the farm and first use. If true, no positive bulls is allowed entry to the farm or herd (including young stock).

new.heifer.vaccinated A T/F variable determining if any purchased heifer is routinely vaccinated against BVDV before introduction to the farm and herd.

new.heifer.PI.test A T/F variable that determines if purchased heifers are to be routinely tested for the presence of virus before introduction to the farm and herd. Virus-positive heifers are prevented from entering the farm or herd.

BVD.trojan.test.exposed.calves A T/F variable that determines if all calves that are born to potentially exposed dams are routinely tested for presence of virus shortly after birth. If true, any PI is removed on testing.

BVD.PI.hunt A T/F variable determining that the milking herd be tested and any PI removed when it is suspected that one or more PIs may exist. If triggered, any PI in the milking herd is found and immediately removed. The evidence to evoke a PI hunt depends on the suite of evidence available and the chosen cut-point for suspecting a PI may exist in the milkers (see other variables).

BVD.Bulk.Milk.ELISA.test a T/F variable determining if regular bulk milk ELISA testing is conducted in order to estimate the seroprevalence of the herd and/or the likelihood of a PI in the milking herd.

BVD.Bulk.Milk.PCR.test A T/F variable determining is a bulk milk PCR test is to be conducted when the bulk milk ELISA test is above the threshold value for suspicion of the presence of a PI. All PIs will be found if testing is induced.

BVD.calf.PI.test A T/F variable to determine if all keeper calves are tested for being PIs within 30 days of birth.

external.herd.contact.rate A numeric variable defining the daily probability that cows or calves have over-the-fence contact with neighbouring cattle. For the disease-free scenario this is set to 0. For other scenarios this value is set under the assumption that animals exist in 5 separate mobs (calves, yearlings, milkers, dry cows and bulls), half the 30 paddocks are boundary paddocks with two sides of the property adjoining other cattle producers and cattle rotate around both the study farm and the neighbouring farm.

BVD.seropositive.farms A numeric variable that sets the background prevalence of virus-positive dairy farms in the district. This is used to determine the probability of a purchased animal having virus and the probability that neighbouring properties harbour virus.

BVD.within.herd.seroprevalence A numeric variable that sets the background mean seroprevalence (of immunity) in the herd (and neighbouring herds)

BVD.TI.prevalence A numeric variable that sets the background prevalence of TIs (virus positive) in the regional cattle population. This is important for determining risk of introduction of virus from purchased animals and from over-the-fence contact with neighbouring stock or agistment contacts.

BVD.PI.prevalence A numeric variable that sets the background prevalence of PIs in the regional cattle population. This is important for determining risk of introduction of virus from purchased animals and from over-the-fence contact with neighbouring stock or agistment contacts.

5 BVDV Modelled Scenarios

A total of 15 BVDV control scenarios were modelled within each calving system type. The features of each scenario are dexcribed below.

5.1 No BVD

This scenario models herd performance in the absence of virus. No virus is allowed to enter the herd and no controls are employed or surveillance undertaken. This is achieved by setting the background prevalence of disease to zero (PI, TI and seroprevalence set to 0). The external herd contact rate is also set to 0. This effectively prevents any over-the-fence contact with neighbouring cattle from occurring. No animals have immunity to disease (within-herd seroprevalence is 0) but no animal is exposed to virus. This scenario defines the upper limit of herd performance in a disease-free world and provides the baseline for comparison of other scenario performance against. It should be noted that there would be very few herds in Australia that meet these criteria given the high prevalence of infected herds and the range of controls that may be employed by farmers to protect their herd and/or to minimise risk.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	F
cows.vaccinate.BVD	F
cows.booster.vaccinate	F
bulls.vaccinated.BVD	F
bulls.tested.BVD	F
BVD.test.yearlings	F
new.heifer.vaccinated	F
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	F
BVD.Bulk.Milk.PCR.test	F
BVD.calf.PI.test	F
external.herd.contact.rate	0
seroprevalence.at.start	0
BVD.seropositive.farms	0.0
BVD.within.herd.seroprevalence	0
BVD.TI.prevalence	0
BVD.PI.prevalence	0

Table 1: *No BVD* parameter settings

5.2 No control

This scenario models herd performance in the presence of uncontrolled virus. No activity to detect or eradicate or prevent virus entry occurs. Virus may spontaneously enter and leave the herd according to external contacts. The background prevalence of disease (PI, TI and seroprevalence) drives the exposure of the herd to disease and the response to virus once it enters the herd. There is a daily 5% chance that a mob of cattle will occupy a boundary fence that is occupied (on then other side) by cattle. The external herd risk of BVD exposure is 80% and the within-herd seroprevalence of disease in exposed herds was st to 70% with 5% of animals being TIs and 1% of animals PIs. These population prevalences were also used to determine the risk of introduction of disease via purchases (in the absence of testing). This scenario defines another baseline — that being of unmanaged (unaware) herds in endemic regions. A large number of herds in Australia would meet these criteria given the high prevalence of infected herds and the general absence of awareness or use of specific controls by farmers to protect the herd.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	F
cows.vaccinate.BVD	F
cows.booster.vaccinate	F
females.max.no.booster.vaxs	0
bulls.vaccinated.BVD	F
bulls.tested.BVD	F
BVD.test.yearlings	F
new.heifer.vaccinated	F
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	F
BVD.Bulk.Milk.PCR.test	F
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 2: *No BVD control* parameter settings

5.3 Full control

This scenario models herd performance in the presence of complete control against virus. The background prevalence of disease (PI, TI and seroprevalence) drives the exposure of the herd to disease and the response to virus once it enters the herd. There is a daily 5% chance that a mob of cattle will occupy a boundary fence that is occupied (on then other side) by cattle. The external herd risk of BVD exposure is 80% and the within-herd seroprevalence of disease in exposed herds was st to 70% with 5% of animals being TIs and 1% of animals PIs. However in full control all introductions are tested for the presence of virus and this effectively prevents purchasing virus. Trojan exposure is controlled by testing at risk calves with removal of PI calves from the herd if any are found. Calf crops are regularly tested for seroconversion and virus and a PI hunt is undertaken with PIs removed on detection. Bulk milk is regularly monitored using ELISA and followed-up with PCR if virus incursion is suspected. If virus is found in bulk milk, a PI hunt involving serological testing of milking cows is undertaken to identify and remove PIs. Vaccination is used for all animals with annual boosters. All herd bulls are tested for virus before introduction and any PIs removed. All virus-negative bulls are vaccinated before introduction to the herd.

Parameter	Value
screen.cows.to.decide.vaccinate	T
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	T
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	T
females.max.no.booster.vaxs	20
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	T
new.heifer.vaccinated	T
new.heifer.PI.test	T
BVD.trojan.test.exposed.calves	T
BVD.PI.hunt	T
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	T
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 3: *Full BVD control* parameter settings

5.4 Full control — no PI hunts

This scenario is the same as *Full Control* except that there are no PI hunts in the event of a breach.

Parameter	Value
screen.cows.to.decide.vaccinate	T
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	T
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	T
females.max.no.booster.vaxs	20
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	T
new.heifer.vaccinated	T
new.heifer.PI.test	T
BVD.trojan.test.exposed.calves	T
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 4: *Full BVD control — no PI hunt* parameter settings

5.5 Full control — no PI hunts in adult cows

This scenario is the same as *Full Control* except that there are no PI hunts in adults (milking herd) in the event of a breach.

Parameter	Value
screen.cows.to.decide.vaccinate	T
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	T
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	T
females.max.no.booster.vaxs	20
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	T
new.heifer.vaccinated	T
new.heifer.PI.test	T
BVD.trojan.test.exposed.calves	T
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	T
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 5: *Full BVD control — no PI hunt cows* parameter settings

5.6 Full control — no female vaccination

This scenario is the same as *Full Control* except that there is no female vaccination. Control is based on exclusion of virus.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	F
cows.vaccinate.BVD	F
cows.booster.vaccinate	F
females.max.no.booster.vaxs	0
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	T
new.heifer.vaccinated	T
new.heifer.PI.test	T
BVD.trojan.test.exposed.calves	T
BVD.PI.hunt	T
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	T
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 6: *Full BVD control — no female vaccination* parameter settings

5.7 Full control — no females 3YO+ vaccination

This scenario is the same as *Full Control* except that there is no booster vaccination of females aged 3 years or older. Control is based on exclusion of virus and managing immunity of young stock and heifers.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	T
youngstock.seroprev.vax.screen.cutpoint	0.65
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	F
cows.booster.vaccinate	T
females.max.no.booster.vaxs	0
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	T
new.heifer.vaccinated	T
new.heifer.PI.test	T
BVD.trojan.test.exposed.calves	T
BVD.PI.hunt	T
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	T
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 7: *Full BVD control — no 3YO+ female vaccination* parameter settings

5.8 Full control — no females 4YO+ vaccination

This scenario is the same as *Full Control* except that there is no booster vaccination of females aged 4 years or older (first-calved heifers are boostered). Control is based on exclusion of virus and managing immunity of young stock and heifers.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	T
youngstock.seroprev.vax.screen.cutpoint	0.65
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	F
cows.booster.vaccinate	T
females.max.no.booster.vaxs	1
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	T
new.heifer.vaccinated	T
new.heifer.PI.test	T
BVD.trojan.test.exposed.calves	T
BVD.PI.hunt	T
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	T
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 8: *Full BVD control — no 4YO+ female vaccination* parameter settings

5.9 Full control — no trojan testing introductions

This scenario is the same as *Full Control* except that there is no testing of possible trojan-carrying pregnancy dams.

Parameter	Value
screen.cows.to.decide.vaccinate	T
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	T
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	T
females.max.no.booster.vaxs	20
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	T
new.heifer.vaccinated	T
new.heifer.PI.test	T
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	T
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	T
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 9: *Full BVD control — no trojan testing* parameter settings

5.10 Simplest control

This scenario models basic and easily-applied BVD controls. These are vaccination with boosters for bulls and all females and testing of all herd bulls for virus with exclusion of all PI bulls from the herd. No regular screening testing is undertaken and therefore no PI hunts occur.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	T
females.max.no.booster.vaxs	20
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	F
new.heifer.vaccinated	T
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	F
BVD.Bulk.Milk.PCR.test	F
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 10: *Simplest BVD control* parameter settings

5.11 Simplest control — no females 3YO+ vaccination

This scenario is the same as *Simplest* except there is no booster vaccination of adult females.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	F
females.max.no.booster.vaxs	0
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	F
new.heifer.vaccinated	T
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	F
BVD.Bulk.Milk.PCR.test	F
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 11: *Simplest BVD control — no 3YO+ female vaccination* parameter settings

5.12 Simplest control — no females 4YO+ vaccination

This scenario is the same as *Simplest* except there is no booster vaccination of females over 4 years of age (First calved heifers are booster vaccinated).

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	F
females.max.no.booster.vaxs	1
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	F
new.heifer.vaccinated	T
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	F
BVD.Bulk.Milk.PCR.test	F
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 12: *Simplest BVD control — no 4YO+ female vaccination* parameter settings

5.13 Low cash cost control

This scenario uses controls that have lowest cash outlay.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	T
females.max.no.booster.vaxs	20
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	F
new.heifer.vaccinated	F
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 13: *Low cash cost BVD control* parameter settings

5.14 Low cash cost control — no females 3YO+ vaccination

This scenario is the same as *Low cash cost* control but does not booster vaccinate adult females.

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	F
females.max.no.booster.vaxs	0
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	F
new.heifer.vaccinated	F
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 14: *Low cash cost — no 3YO+ female vaccination BVD control* parameter settings

5.15 Low cash cost control — no females 4YO+ vaccination

This scenario is the same as *Low cash cost* control but does not booster females aged 4 years or older (first calved heifers are booster vaccinated).

Parameter	Value
screen.cows.to.decide.vaccinate	F
cow.bmelisa.vax.screen.cutpoint	N/A
screen.youngstock.to.decide.vaccinate	F
youngstock.seroprev.vax.screen.cutpoint	N/A
young.stock.vaccinate.BVD	T
cows.vaccinate.BVD	T
cows.booster.vaccinate	T
females.max.no.booster.vaxs	1
bulls.vaccinated.BVD	T
bulls.tested.BVD	T
BVD.test.yearlings	F
new.heifer.vaccinated	F
new.heifer.PI.test	F
BVD.trojan.test.exposed.calves	F
BVD.PI.hunt	F
BVD.Bulk.Milk.ELISA.test	T
BVD.Bulk.Milk.PCR.test	T
BVD.calf.PI.test	F
external.herd.contact.rate	0.05
seroprevalence.at.start	0.70
BVD.seropositive.farms	0.80
BVD.within.herd.seroprevalence	0.70
BVD.TI.prevalence	0.05
BVD.PI.prevalence	0.01

Table 15: *Low cash cost — no 4YO+ female vaccination BVD control* parameter settings

6 Results

Results are presented as annualised single-herd performance results. Differences between scenarios represent the expected annual difference attributable to BVDV and/or its control.

6.1 Physical

The presence of unmanaged BVD did not result in meaningful difference between yearly herd conception rates or between the number of yearly embryonic losses experienced by the herd for any scenario compared to BVD-free herds in any calving pattern. This includes both AI conception rates and overall (total) farm conception rates. The natural yearly variation in conception rate and in the number of embryonic losses was greater than the loss that attributable to the presence of BVDV in an endemically infected but unmanaged herd. The difference in annual conception rate between unmanaged-BVD and BVD-free herds is presented in Figure 1 and for the number of embryonic losses experienced each year in Figure 2. This implies that for most endemically infected herds there are no clear indicators of presence of (endemic) BVDV in herd mating and calving performance statistics — mating analysis will rarely show evidence indicating the presence of BVDV in endemically infected herds.

Figure 1: Difference in annual conception rate between unmanaged BVD scenario and BVD-free scenario

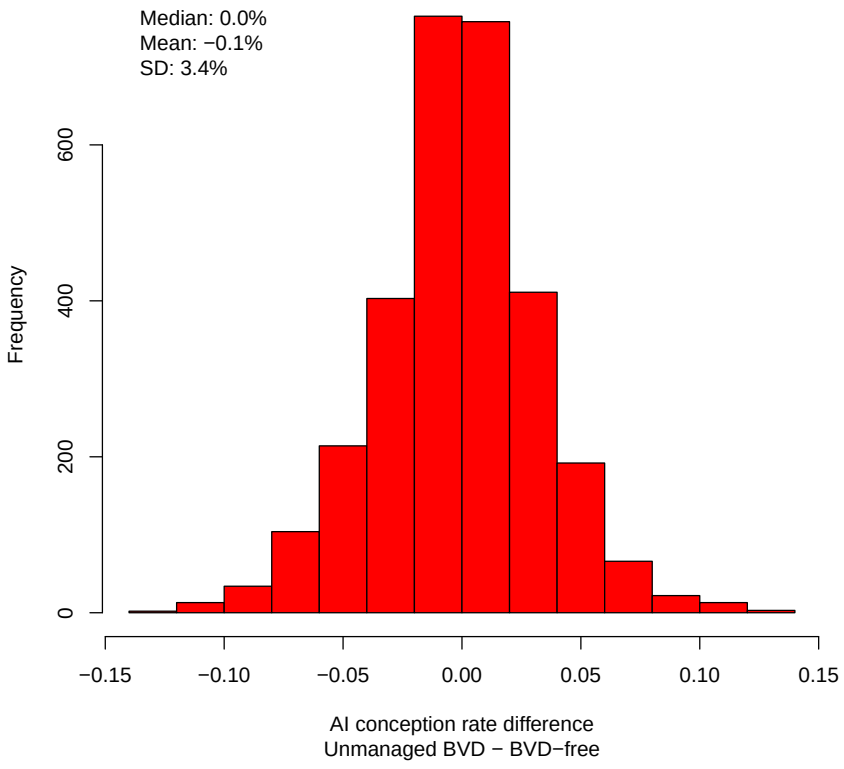
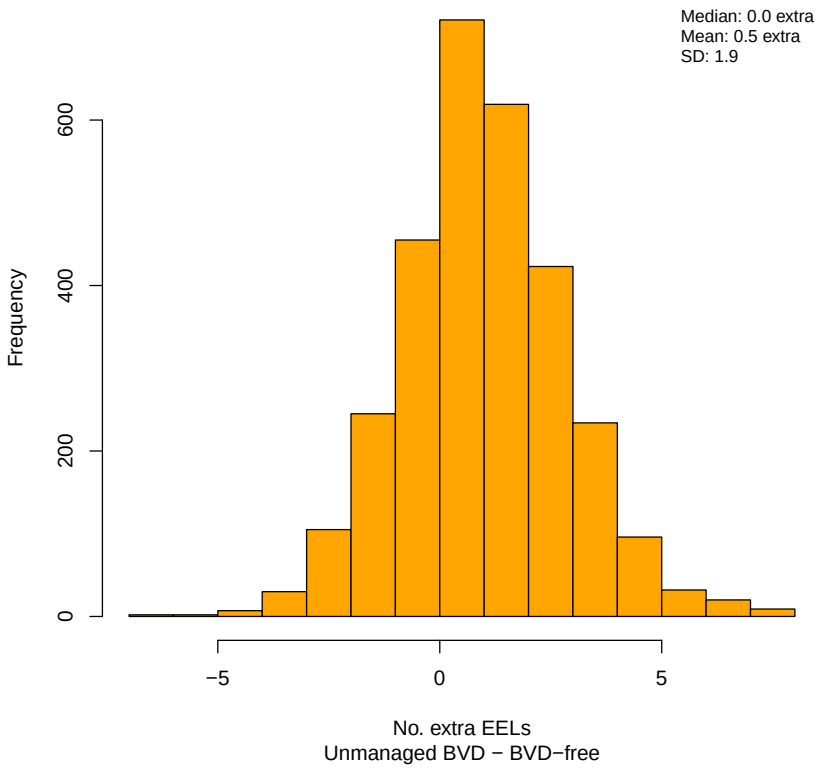


Figure 2: Difference in number of embryonic losses between unmanaged BVD scenarios and BVD-free scenario



6.2 Economics

Partial budgeting and an economic risk assessment of future gross margins were used to compare scenarios. This dual approach was used because different people have different attitudes towards long-run investment returns and appetites for future risk of serious failure. For some, the average return on investment in a control program may dominate thinking when choosing one BVDV control strategy over another whereas others may be more influenced by the threat of serious impact. These individuals may prefer a control strategy that minimises the future risk of a serious outbreak.

A partial budget using annual gross margins was used to compare each scenario against the performance of the unmanaged BVD scenario. The annual gross margin profit was calculated as the total income (milk, livestock trading, inventory changes) less costs (herd, feed, and BVD control costs) for each scenario. Scenario gross margins were compared against the gross margin of the unmanaged BVD scenario with the difference between the two gross margins (scenario minus unmanaged BVD) providing the

partial budget estimate for the control scenario (against not actively managing virus). Differences between the two gross margins implies that more profit will be generated on average per year through choosing to manage BVDV according to the stipulated scenario controls than would occur by choosing to leave BVDV unmanaged in an endemically infected herd. A negative difference between the two gross margins indicates that on average the extra costs of the scenario controls are not offset by any extra income generated such that leaving BVDV unmanaged will on average generate more profit over the long term.

Partial budgeting compares the long-term (annual) averages — any individual year can and will differ from this average — therefore it can only provide part of the information necessary for selecting an appropriate control strategy. BVDV can induce endemic losses in a chronically-infected herd but also (sporadic) epidemic losses in a näive herd. Some control strategies may reduce the circulation of virus within and between herds and this may increase the susceptibility of animals within the herd over time. Paradoxically, this may increase the future risk of a large scale (epidemic) outbreak and losses — should virus re-enter the herd. Therefore the impact of the control strategy on the future likelihood of a large-scale (epidemic) loss is essential to fully inform the control strategy selection process.

The estimated average annual loss per milking cow attributable to BVDV was estimated by subtracting average gross margin for *No Control* from the average gross margin for *No BVD* scenarios and dividing by the average number of milking cows per day for seasonal, split and year-round calving herds. These values represent the maximum returns achievable (per cow) from the elimination of BVDV. Given BVDV control programs incur cost, the maximum investment per cow in controlling BVDV will be a fraction of these amounts. The average annual losses due to the presence to BVDV is estimated at \$4.77, \$5.44, and \$13.77 per milking cow per year for seasonal, split and year-round calving herds respectively.

6.2.1 Long-term average losses — partial budgets.

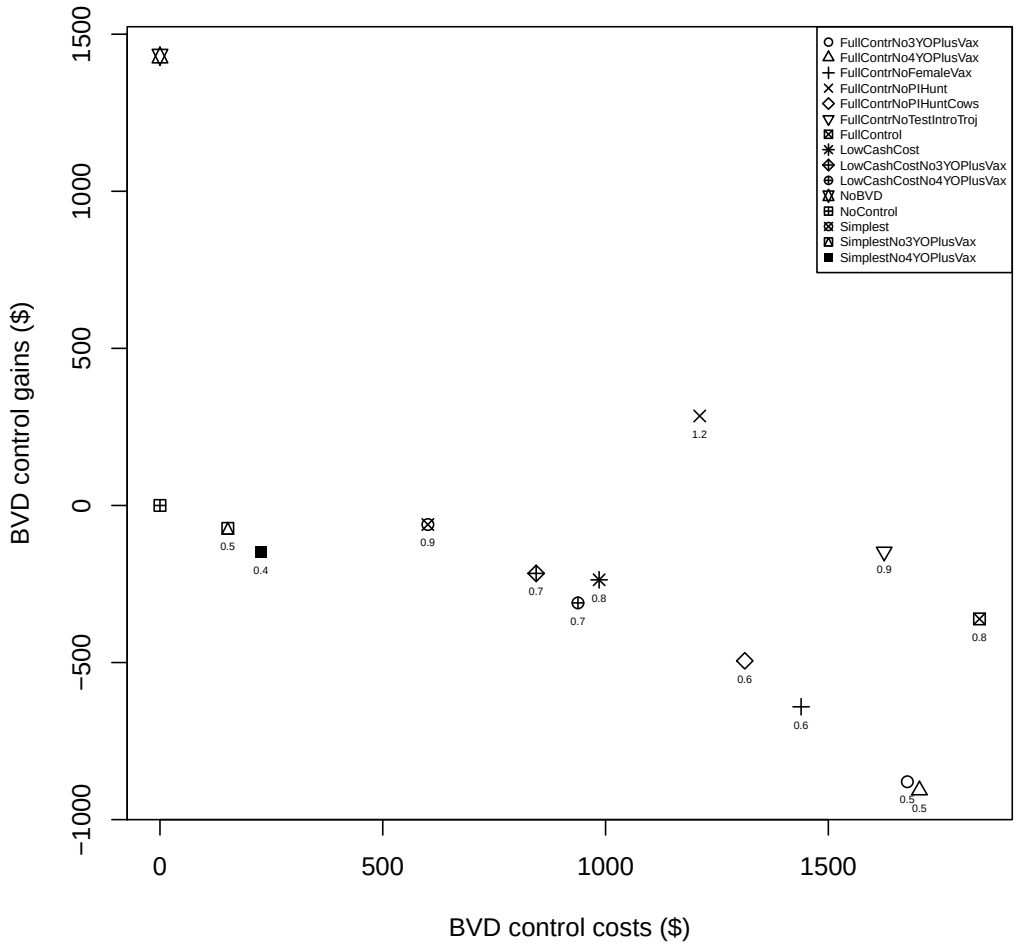
The partial budget comparisons for each scenario against unmanaged BVD ('No Control') were presented as *gain-expenditure frontier* plots. This is a visual representation of the net gain (partial budget benefit) against the specific BVD control costs for the control scenario of each competing option. Gain-expenditure frontier plots for each calving system are presented in Figures 3 to 5. The gain for the scenario is the increase in gross margin over that achieved with the unmanaged BVD scenario ('No Control') representing the change in income less the change in variable costs for the scenario[3] The expenditure is the total amount spent on the various control components of the scenario. Cheaper controls scenarios are located to the left hand side of the plot than more expensive control scenario. An ideal control program is cost-effective — returning a larger increase in gross margin — and does this for a small investment in control. These

[3]For example an increase in gross income of \$1,000 arising as a result of controls that cost \$400 to implement will provide an increase in gross margin of \$600. This example has a benefit-cost ratio of 1.5 (\$600/\$400)

scenarios are located in the top left quadrant of the plot (i.e maximum increase in gross margin for minimal additional cost).

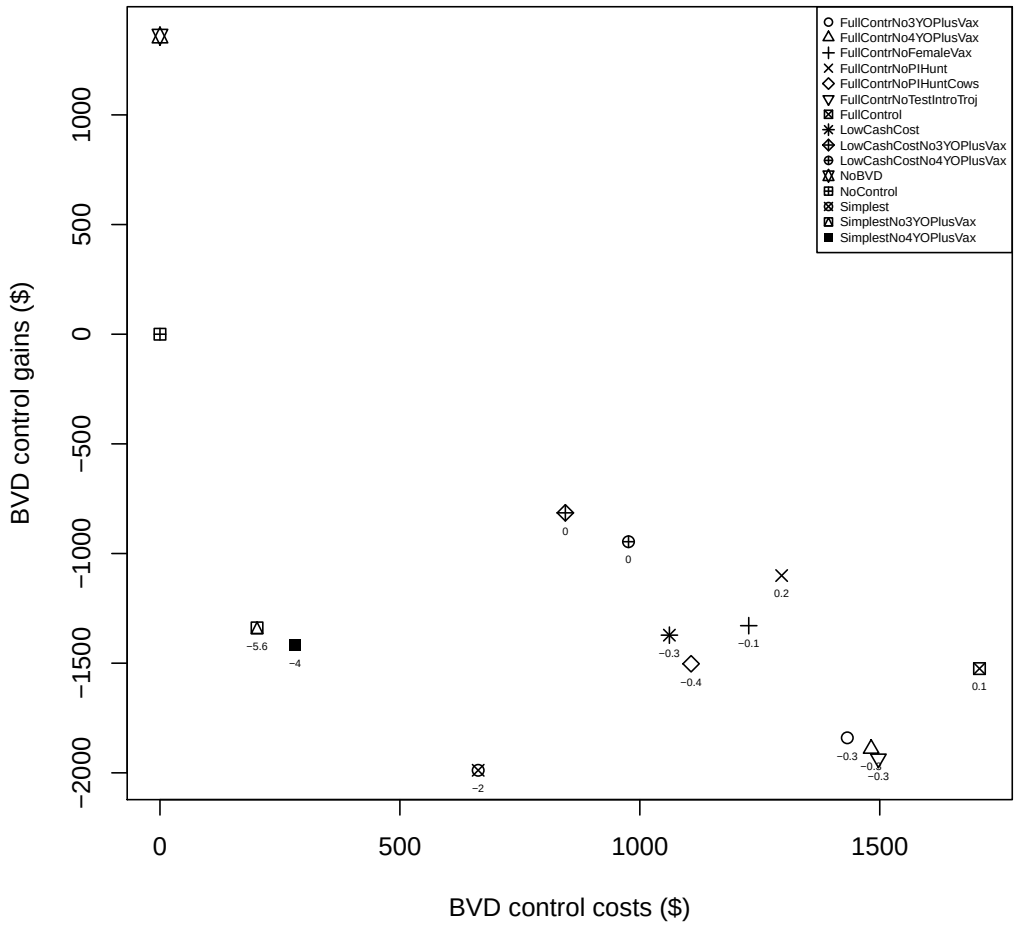
Control programs that generate more profit then they cost to implement are feasible options. However, they should be compared against alternative investments of capital, labour and resources directed against other farm problems (non-BVDV) before deciding to undertake the control as other investments may generate more profit and/or have a larger benefit-cost ratios than some of the profitable BVDV control scenarios. The magnitude of any economic benefit and the benefit-cost ratio from BVDV control should be considered along with the complexity of the control program and the likelihood of success and this suite of information compared to a similar assessment of investment into addressing other farm problems to inform any commitment to control. The gain-expenditure frontier and benefit-cost of various BVDV control programs provides some of this information.

Figure 3: Long-term average annual scenario gain-expenditure frontier and benefit-cost — seasonal herds



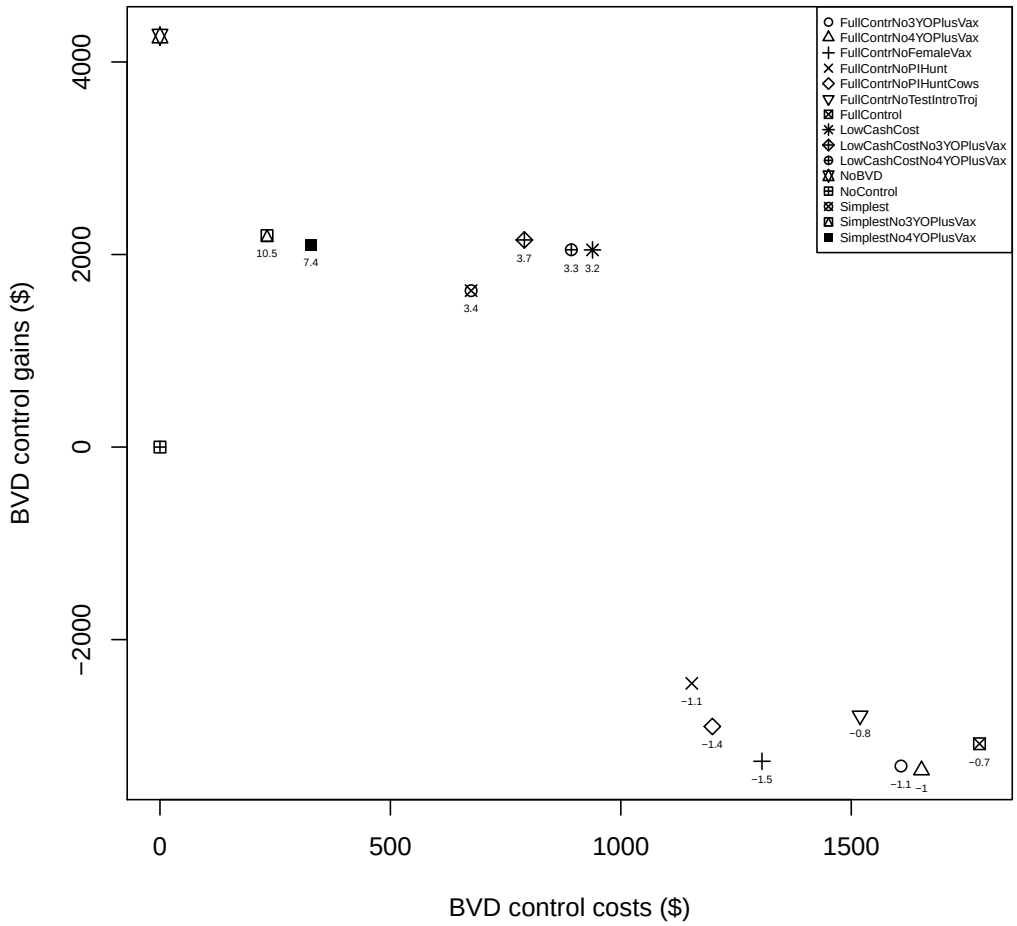
(The standard deviation of control gains against the median annual performance of unmanaged BVD averaged $3,900 across all scenario)

Figure 4: Long-term average annual scenario gain-expenditure frontier and benefit-cost — split herds



(The standard deviation of BVD control gains was an average of $3,400)(The standard deviation of control gains against the median annual performance of unmanaged BVD averaged $3,400 across all scenario)

Figure 5: Long-term average annual scenario gain-expenditure frontier and benefit-cost — year-round herds



(The standard deviation of BVD control gains was an average of $3,200(The standard deviation of control gains against the median annual performance of unmanaged BVD averaged $3,200 across all scenario)

The annual gross margin mean and standard deviation (SD) and annual BVD control cost mean and standard deviation for control scenarios within calving system are presented in Tables 16 (seasonal calving), 17 (split calving) and 18 (year round calving) herds.

Table 16: Annual gross margin and standard deviation and BVD control expensiture and standard deviation by control scenario for seasonally calving herds

Scenario	GM (Mean)	GM (SD)	BVD (Mean)	BVD (SD)
FullContrNo3YOPlusVax	872,498	91,386	1,677	788
FullContrNo4YOPlusVax	872,471	91,387	1,704	790
FullContrNoFemaleVax	872,736	91,358	1,439	814
FullContrNoPIHunt	873,662	91,367	1,211	636
FullContrNoPIHuntCows	872,883	91,338	1,312	751
FullContrNoTestIntroTroj	873,230	91,383	1,625	765
FullControl	873,016	91,390	1,839	832
LowCashCost	873,141	91,633	986	590
LowCashCostNo3YOPlusVax	873,161	91,966	844	573
LowCashCostNo4YOPlusVax	873,067	91,973	938	603
NoBVD	874,808	91,952	0	0
NoControl	873,377	91,727	0	0
Simplest	873,317	92,164	601	375
SimplestNo3YOPlusVax	873,304	91,557	152	105
SimplestNo4YOPlusVax	873,230	91,563	227	149

Table 17: Annual gross margin and standard deviation and BVD control expensiture and standard deviation by control scenario for split calving herds

Scenario	GM (Mean)	GM (SD)	BVD (Mean)	BVD (SD)
FullContrNo3YOPlusVax	771,090	90,375	1,432	602
FullContrNo4YOPlusVax	771,040	90,386	1,482	582
FullContrNoFemaleVax	771,601	90,165	1,227	683
FullContrNoPIHunt	771,830	90,571	1,296	621
FullContrNoPIHuntCows	771,427	90,310	1,107	608
FullContrNoTestIntroTroj	770,995	90,449	1,497	665
FullControl	771,405	90,515	1,708	633
LowCashCost	771,558	89,658	1,062	658
LowCashCostNo3YOPlusVax	772,116	89,780	845	638
LowCashCostNo4YOPlusVax	771,984	89,799	976	682
NoBVD	774,289	88,999	0	0
NoControl	772,930	88,948	0	0
Simplest	770,942	87,932	663	323
SimplestNo3YOPlusVax	771,591	88,202	202	133
SimplestNo4YOPlusVax	771,512	88,221	282	159

Table 18: Annual gross margin and standard deviation and BVD control expenditure and standard deviation by control scenario for year round calving herds

Scenario	GM (Mean)	GM (SD)	BVD (Mean)	BVD (SD)
FullContrNo3YOPlusVax	808,600	109,601	1,608	678
FullContrNo4YOPlusVax	808,556	109,583	1,652	668
FullContrNoFemaleVax	808,649	109,791	1,306	622
FullContrNoPIHunt	809,458	109,787	1,154	590
FullContrNoPIHuntCows	809,011	109,578	1,199	568
FullContrNoTestIntroTroj	809,123	109,654	1,519	637
FullControl	808,831	109,677	1,778	686
LowCashCost	813,961	109,900	939	563
LowCashCostNo3YOPlusVax	814,065	109,739	791	555
LowCashCostNo4YOPlusVax	813,963	109,741	893	580
NoBVD	816,182	109,262	0	0
NoControl	811,913	110,673	0	0
Simplest	813,538	109,174	675	339
SimplestNo3YOPlusVax	814,110	108,745	232	116
SimplestNo4YOPlusVax	814,015	108,742	327	162

The relationship between change in gross margin excluding BVD control costs and annual BVD control cost for the control scenarios within calving system are presented in Tables 19 (seasonal calving), 20 (split calving) and 21 (year round calving) herds.

Table 19: Annual gross margin (plus BVD control costs), BVD control cost and gross margin change (percentage of uncontrolled BVD gross margin) by control scenario for seasonally calving herds

Scenario	GM Difference	BVD Control Cost	GM Difference (%)
FullContrNo3YOPlusVax	-879	1,677	-0.10
FullContrNo4YOPlusVax	-906	1,704	-0.10
FullContrNoFemaleVax	-641	1,439	-0.07
FullContrNoPIHunt	285	1,211	0.03
FullContrNoPIHuntCows	-494	1,312	-0.06
FullContrNoTestIntroTroj	-147	1,625	-0.02
FullControl	-361	1,839	-0.04
LowCashCost	-236	986	-0.03
LowCashCostNo3YOPlusVax	-216	844	-0.02
LowCashCostNo4YOPlusVax	-310	938	-0.04
NoBVD	1,431	0	0.16
NoControl	0	0	0.00
Simplest	-60	601	-0.01
SimplestNo3YOPlusVax	-73	152	-0.01
SimplestNo4YOPlusVax	-147	227	-0.02

Table 20: Annual gross margin (plus BVD control costs),BVD control cost and gross margin change (percentage of uncontrolled BVD gross margin) by control scenario for split calving herds

Scenario	GM Difference	BVD Control Cost	GM Difference (%)
FullContrNo3YOPlusVax	-1,840	1,432	-0.24
FullContrNo4YOPlusVax	-1,890	1,482	-0.24
FullContrNoFemaleVax	-1,329	1,227	-0.17
FullContrNoPIHunt	-1,100	1,296	-0.14
FullContrNoPIHuntCows	-1,503	1,107	-0.19
FullContrNoTestIntroTroj	-1,935	1,497	-0.25
FullControl	-1,525	1,708	-0.20
LowCashCost	-1,372	1,062	-0.18
LowCashCostNo3YOPlusVax	-814	845	-0.11
LowCashCostNo4YOPlusVax	-946	976	-0.12
NoBVD	1,359	0	0.18
NoControl	0	0	0.00
Simplest	-1,988	663	-0.26
SimplestNo3YOPlusVax	-1,339	202	-0.17
SimplestNo4YOPlusVax	-1,418	282	-0.18

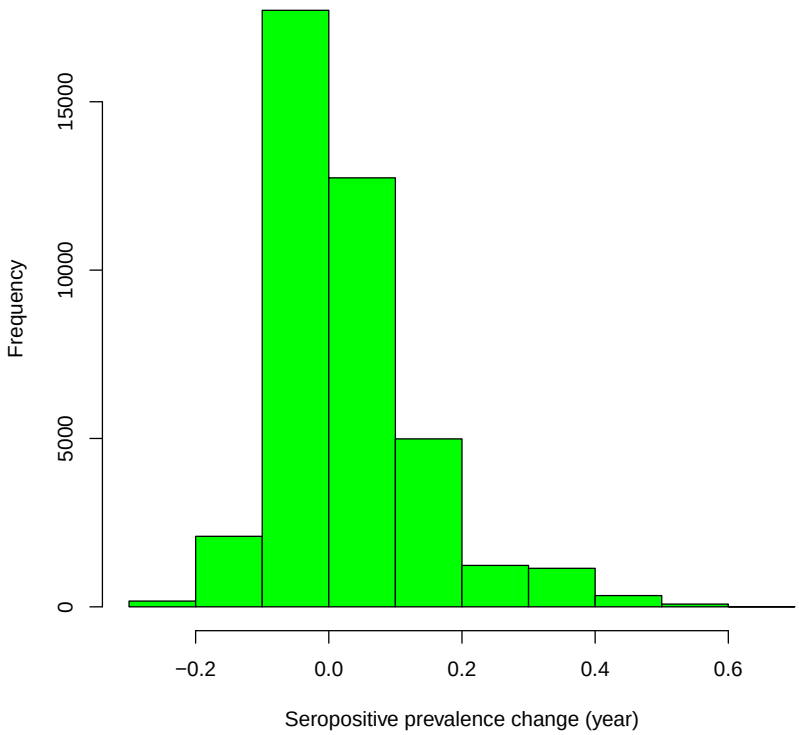
Table 21: Annual gross margin (plus BVD control costs), BVD control cost and gross margin change (percentage of uncontrolled BVD gross margin)by control scenario for year-round calving herds

Scenario	GM Difference	BVD Control Cost	GM Difference (%)
FullContrNo3YOPlusVax	-3,313	1,608	-0.41
FullContrNo4YOPlusVax	-3,357	1,652	-0.41
FullContrNoFemaleVax	-3,264	1,306	-0.40
FullContrNoPIHunt	-2,455	1,154	-0.30
FullContrNoPIHuntCows	-2,902	1,199	-0.36
FullContrNoTestIntroTroj	-2,790	1,519	-0.34
FullControl	-3,082	1,778	-0.38
LowCashCost	2,048	939	0.25
LowCashCostNo3YOPlusVax	2,152	791	0.27
LowCashCostNo4YOPlusVax	2,050	893	0.25
NoBVD	4,269	0	0.53
NoControl	0	0	0.00
Simplest	1,625	675	0.20
SimplestNo3YOPlusVax	2,197	232	0.27
SimplestNo4YOPlusVax	2,102	327	0.26

6.2.2 Impact of control strategy on likelihood of an outbreak

Simulation output was examined to quantify outbreak risk. Because economically important outbreaks are rare, physical rather than economic measures of outbreaks were used. Under the assumption that an outbreak results in the mass infection and subsequent seroconversion of previously näive animals we used an (arbitrary) short-term seroconversion rate of 40% to indicate that a surge of infection had spread rapidly through the herd. Such an event in groups of susceptible female timed to occur at the most vulnerable stage of their reproductive cycle would potentially result in production of many PIs and subsequent outbreak losses. We estimated the annual risk of virus introduction/spread events where 40% or more of the herd subsequently seroconverted. Note, that for this to occur, at least 40% of the herd must be näive and for many herds seroprevalence remained above 60% for prolonged periods of time. The risk of 40% or more of the herd seroconverting in any year is presented in Figure 6. This suggests that 1–2% of herds each year experience a large-scale seroconversion event ($\geq$ 40%) each year.

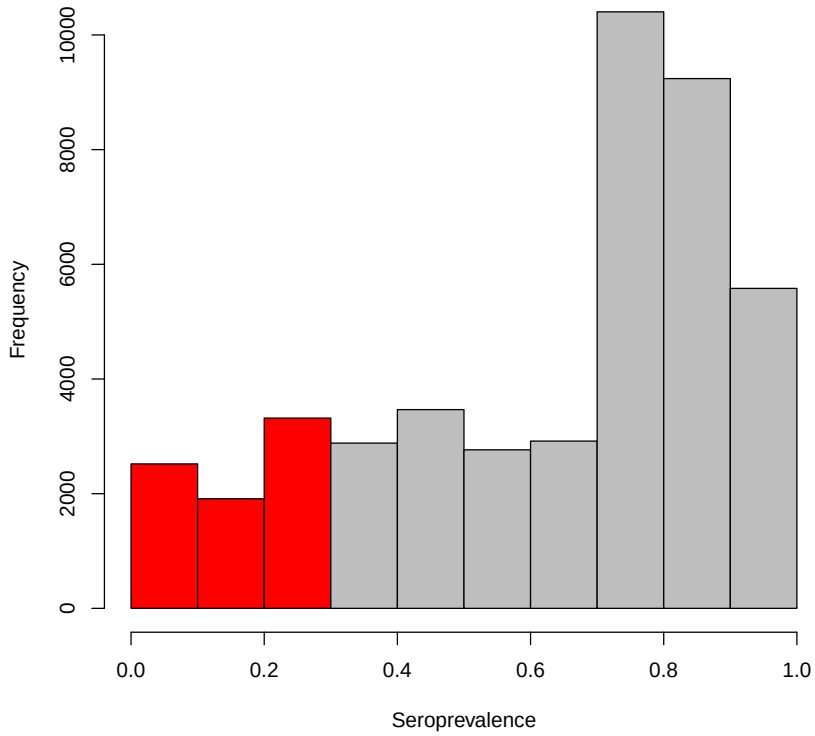
Figure 6: Distribution of herd seroprevalence change per year



Large-scale seroconversion can only occur in herds that are essentially näive. A

herd with a seroprevalence of 25% or less is essentially näive. The distribution of herd prevalence each year is presented in Figure 7. This suggests that approximately one quarter of herds at any given time will have a within-herd seroprevalence $\leq 25\%$. The relative rarity of large-scale seroconversions (see Figure 6) suggests that näive herds can persist for a number of years before virus re-enters the herd.

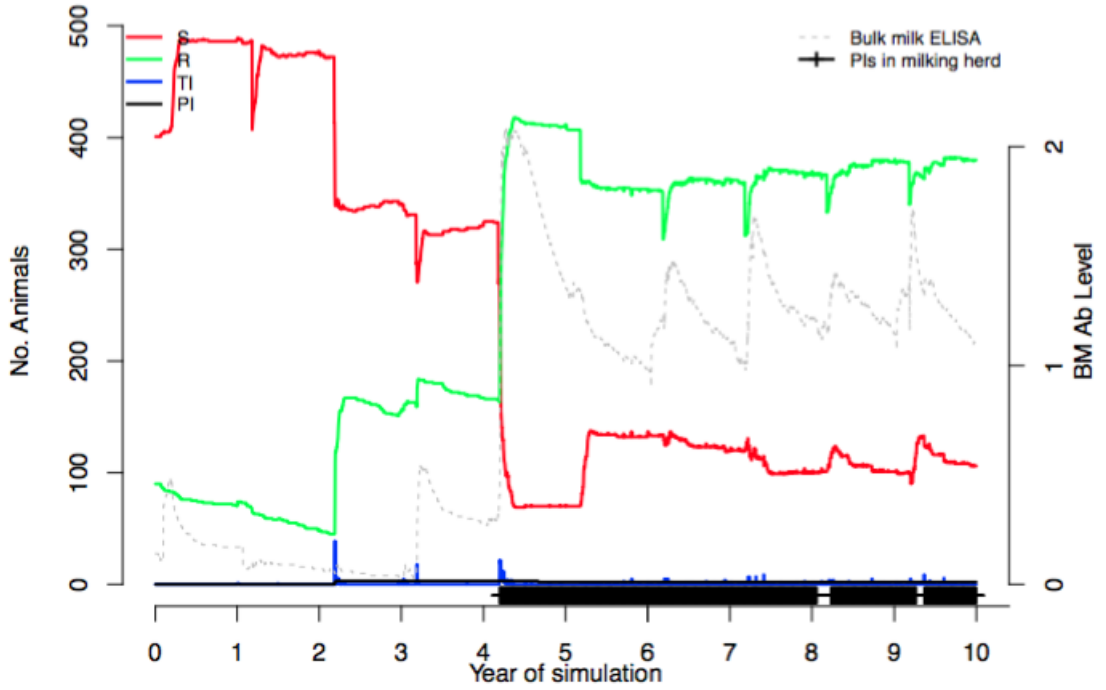
Figure 7: Distribution of herd seroprevalence per year



6.3 Example affected herd

An example simulation herd with an annual gross margin in the bottom 1% of years is presented in Figure 8.

Figure 8: Example seasonal calving herd with a bottom 1% economic performance (year 5)



This herd was seasonally (Autumn) calving and did not have any BVDV control program. Virus entered the herd early in year 3 — most likely as a PI calf born from a trojan pregnancy. Mini epidemics followed the survival of the PI calf resulting in outbreaks in susceptible groups in years 3 (calves), 4 (yearlings) and 5 (milking cows) as indicated by the blue TI spikes. A PI heifer calved and entered the mostly näive milking herd early in the 5th year. This resulted in spread of virus through the milkers over the following months and into the mating period There were 319 pregnancies in the year that virus entered the milking herd — approximately 11 fewer than for preceding years. The fewer pregnancies arose from the combination of an approximately 1.9% reduction in herd conception rate (reducing from 44.4% to 42.5%) and from around 7 more embryonic losses.

Virus stabilised in the milking herd around the middle of the 5th year. Once endemic and stable, the rate of new infection decreased. The high rate of new infections during the 5th year produced most of the economic loss as this was when virus accessed the mostly näive milking herd. But it should be noted that most new infections of milking cows did not produce economic loss because many of these cows had fully recovered (and seroconverted) before the start of the seasonal mating period.

The reduction in the number of pregnancies in the 5th year resulted in extra empty cow sales in that year (thereby maintaining herd gross margin) but resulted in reduced livestock income in the following year when there were fewer surplus cows. There was

a slight reduction in milk income during the following year. Milking herd size in year 6 was maintained because sufficient yearling heifers were available to meet the increased demand for replacements. There was a reduction in milk production as a result of the slightly younger milking herd age structure in year 6. The resultant farm gross margin in year 6 — the year after virus first entered the milking herd — was $24,405 less than the median performance of preceding years. This represents an approximately 3.4% reduction in farm gross margin.

7 Conclusions from modelling

The following conclusions are drawn from analysis of model output:

1. Endemically infected dairy herds within endemic regions typically do not experience noticeable physical or financial losses due to BVDV. This is because most endemically infected herds experience few infections in susceptible animals whilst at the vulnerable stage of their reproductive cycle and because most herds are similarly impacted — resulting in similar average performance of herds across the region. However, all endemically infected herds experience some physical and financial loss from circulating BVDV over time.

2. Endemically infected herds within endemic regions experience natural cycling of virus. The number and proportion of susceptible and näive animals change due to infection and from natural herd turnover. These cyclical changes in herd immunity alter the amount and frequency of virus circulation in the herd. The calving pattern, herd size and herd group management structure influences the compartmentalisation of the herd and this influences the BVDV infection cycle.

3. Endemically infected herds within endemic regions can spontaneously eradicate virus when reservoirs (PIs) are lost and not replaced (i.e. no Trojans) and as herd immunity builds thereby preventing ongoing virus transmission. There is a high background risk of re-infection in herds that spontaneously eradicate BVDV and take no controls against reintroduction of virus. A ten-year virus eradication and re-introduction cycle for dairy herds in endemic regions appears evident from herd serological profile studies.

4. Permanently-infected (PI) animals are the main reservoir of infection in herds. Transiently infected (TI) animals do not persist with circulating virus for more than a few days. Removal of PIs from a herd (and all Trojan pregnancies) typically results in rapid loss of virus from the herd — persistence of virus in the absence of a PI beyond one month is not common.

5. Controls to identify and eradicate BVDV from infected herds are effective. Individual-animal tests for exposure (antibody) and for circulating virus (primarily used to detect PIs) are highly sensitive and specific. Bulk milk testing for virus has modest

correlation between bulk milk ELISA level and herd seroprevalence — infrequent bulk milk testing does may not accurately represent the current or recent infection/exposure status of the milking herd. Most herds that embark on a test-and-cull program identify all virus-carrying PIs and are typically virus free well inside of one year.

6. Long-term control of BVDV in endemically-infected dairy herds within endemic regions is a break-even economic proposition for most herds. Any extra return from controlling BVDV circulation is generally offset by the extra cost of running the control program. This means that most farmers can make more profitable investments on their dairy farms elsewhere rather than from investing in BVDV control. The long-term economics of controlling BVDV in endemically-infected year-round herds is more compelling than for split calving or seasonally calving herds. This is because the average annual endemic losses are greater in year-round calving herds than for split- or seasonally-calving herds — however, the benefit-cost ratio and absolute return from control are modest.

7. Whilst the long-term endemic loss from BVDV in dairy herds is small, BVDV can produce large-scale outbreaks in näive herds. This can result in business-threatening economic losses — depending on the number and class of stock infected and the timing of the outbreak relative to the reproductive cycle of the herd. Farmers and advisors need to understand the risks and impacts of larger-scale outbreaks in their herds when selecting a BVDV control strategy — knowing the long-term average cost-benefit of control is insufficient information on which to base a control decision.

8. All BVDV control strategies — including choosing not to control BVDV — will change the future herd outbreak risk profile. Some strategies focus on managing the susceptibility of the herd to infection (e.g. vaccination) whilst other control strategies focus on reducing the risk of virus introduction (e.g. bull testing). Some strategies will increase the susceptibility of the herd (by making the herd näive) but offset this by reducing the risk of virus re-introduction. These controls are very sensitive to program breakdown. Strategies that manage (decrease) herd susceptibility to infection tend to be more resistant to intermittent and partial program failure.

9. Control of BVDV is economical over the long-term in typical infected year-round dairy herds. However, control is more likely to be a break-even investment for most infected split and seasonally-calving dairy herds. Deciding to leave BVDV unmanaged may be a rational strategy for some split- and seasonal-calving herd managers.

10. Effective control of BVDV will reduce the circulation of virus in herds. This will result in increasing näivety and susceptibility of the herd over time as natural immunity wanes. Maintaining virus freedom in free herds with a control program

depends upon the combined effectiveness of biosecurity to preventing virus re-introduction and use of timely biosurveillance to detect and cull any PIs that have gained entry to the herd before mating.

11. Bulk milk ELISA monitoring is poorly predictive of herd seroprevalence and therefore immunity. Annual bulk milk ELISA testing is not an effective way to monitor herd infection and immunity status.

12. More comprehensive control strategies — programs that combine high-level biosecurity and biosurveillance (including PI hunts where required) — do not provide sufficient extra return or a sufficient reduction in risk of low financial performance to recommend their use. The long term cost of the program outweighs the extra benefit obtained over simpler and cheaper control programs

8 BVDV — draft key messages

1. Never knowingly introduce BVDV into a herd — irrespective of the herd's status. Whilst testing of all introductions for the presence of virus may not be economical in all circumstances all herd bull introductions should be tested to ensure they are not PIs. Never admit a bull of unknown status to a dairy herd. The magnitude of impact of a viraemic herd bull during mating is great and this outweighs the small cost of vaccination for herd bulls. All identified PI bulls should be removed before they are used or exposed to the female herd.

2. Consider your attitude to risk, capacity to implement effective biosecurity and biosurveillance and the background virus challenge of your farm when selecting a control strategy. Consider including vaccination into your control program if you are risk averse or their are obstacles to implementing effective biosecurity and biosurveillance and/or there is likely to be significant external viral challenge for your herd if you decide to actively control BVDV.

3. If you choose to eradicate BVDV from your herd, once it is eradicated, routinely monitor immunity in yearling and cows or commence routine vaccination. Discuss options with your veterinarian. Bulk milk ELISA is poorly correlated with cow-level seroprevalence making once-off bulk milk testing only moderately effective for assessing the level of immunity in the herd.

4. Always test all introduced bulls to ensure none are persistently infected with BVDV.

    - Talk to your vet about testing bulls for persistent infection.
    - Only one test in each bull's life is necessary as cattle cannot become persistently infected after birth. Initially test all bulls then test each newly introduced bull well before it is required for use.

- Expect most bulls to test negative. Persistently infected bulls are uncommon but can have devastating effects. The aim of bull testing is to ensure no persistently infected bulls cause problems in your herd.
- Cull persistently infected bulls. Never allow contact between persistently infected bulls and female cattle.

5. If you wish to assess the proportion of animals in a mob or a milking herd that are immunologically naïve to help decide whether to vaccinate, test 30–40 representative animals.

    - When assessing milking herds, only a very low bulk milk ELISA result is informative, generally indicating that most milking cows are immunologically näive.
    - A moderate to high bulk milk ELISA result provides little information about the proportion of milking cows that are immunologically näive and subsequent testing of 20–30 representative animals is required.
    - Because very low bulk milk ELISA results are uncommon, proceeding directly to testing representative animals may be more efficient than first testing bulk milk.

6. If you choose to undertake additional BVDV control options, consider simpler and cheaper options over more complex and expensive options. Discuss options with your veterinarian.

    - Even in typical year-round calving herds, only the simpler and cheaper BVDV control options result in modest increases in herd profitability and reduction in risk of low profit years.
    - Over the long term, more complex and expensive options reduce herd profitability.

7. If your herd calves year-round, consider discussing additional BVDV control options with your veterinarian. If your herd uses seasonal or split calving and there are ongoing health problems in young stock or cows, discuss with your veterinarian whether BVDV may be contributing to these.

    - In typical year-round calving herds, over the long term ongoing BVDV control can result in modest increases in herd profitability and some reduction in risk of low profit years.
    - In typical seasonal and split calving herds, over the long term, BVDV control has a net cost and increases the risk of low profit years.