ACRE Economics

An Analysis of the Potential Net Benefits of the Registration of RHDV2 as a Tactical Biocontrol Agent (Biocide) for the Control of Pest Rabbits in Australia

FINAL REPORT - REVISED

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Acronyms and Abbreviations

ABS	Australian Bureau of Statistics
APVMA	Australian Pesticides and Veterinary Medicines Authority
BCR	Benefit-Cost Ratio
Biocide	Tactical Biocontrol Agent
Biocontrol	Biological Control
CISS	Centre for Invasive Species Solutions
EMAI	Elizabeth Macarthur Agricultural Institute
EPBC Act	Environmental Protection & Biodiversity Conservation Act 1999
GDP	Gross Domestic Product
HRZ	High Rainfall Zone
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
MV	Myxoma Virus
NPV	Net Present Value
NSW DPI	New South Wales Department of Primary Industries
PaZ	Pastoral Zone
PVB	Present Value of Benefits
PVC	Present Value of Costs
RD&E	Research, Development, and Extension
RHD	Rabbit Haemorrhagic Disease
RHDV1	Rabbit Haemorrhagic Disease Virus
RHDV2	Rabbit Haemorrhagic Disease Virus 2
WSZ	Wheat Sheep Zone

Executive Summary

The Centre for Invasive Species Solutions (CISS) and its partners currently are considering whether to invest in the full registration and approval of rabbit haemorrhagic disease virus 2 (RHDV2) as a tactical biocontrol agent (biocide) for rabbit control in Australia. However, RHDV2 now is endemic in Australia so the potential additional benefits of a RHDV2 biocide are unknown. The current analysis was funded by CISS to assess and estimate the costs and potential expected net benefits associated with registration of RHDV2 as a biocide.

The results of the analysis indicated potential expected net benefits of investment to facilitate the registration, approval, and release of a RHDV2 biocide at approximately $0.69 million (present value terms, over 30 years using a 5% discount rate). However, the best-case cost scenario where no-additional non-target species testing is required, suggested total nominal investment costs of $3.2 million over a period of five years equivalent to $2.64 million in present value terms. The discounted benefit and cost cash flows gave a net present value of -$1.95 million and a benefit-cost ratio of 0.26. The estimated total expected net benefits of just $0.69 million and corresponding investment criteria estimated suggest that the additional investment required to achieve full registration and approval of a RHDV2 biocide is unlikely to generate a positive return on investment. Further, the analysis identified several issues associated with a RHDV2 biocide that support the quantitative findings. Such issues include that RHDV2 would need to be listed separately to 'rabbit calicivirus disease organisms' under the Biological Control Act 1984 which would necessitate a public consultation process, evidence from existing biocide use indicates that almost three quarters of reported biocide releases are misapplied by land managers, and early data has shown that RHDV1-K5 appears to be better able to overcome RHDV2 immunity.

A brief analysis of potential investment to increase and improve the use of the existing RHDV1-K5 biocide was undertaken to provide a point of comparison for the RHDV2 biocide. The RHDV1-K5 comparison analysis had an estimated total expected net benefit of $2.17 million (present value terms) against potential costs of $0.68 million (present value terms). This gave an estimated net present value of $1.49 million and a benefit-cost ratio of approximately 3.2 to 1 over 30 years using a 5% discount rate. Investment criteria were positive from 10 years from the first year of investment assumed. A further analysis that assessed the potential net benefits of investment in the registration and implementation of a RHDV2 biocide without a nationally coordinated release (with and without the need for additional non-target species RD&E) supported the main analysis findings. This additional analysis showed that, based on the assumptions used, the total investment required to register a legal RHDV2 biocide and the risks associated with the pathways to impact result in negative investment criteria out to 30 years from the first year of investment. This suggests that the proposed RHDV2 biocide investment is unlikely to generate significant benefits or a positive return on investment in the medium- to long-term.

Based on the results of the analysis, it is recommended that rabbit biocontrol and invasive species stakeholders continue to monitor and evaluate the wild rabbit population and changing environment with respect to existing biocontrol agents (RHDV1 strains and endemic RHDV2). Also, it is likely to be worthwhile to put some investment into increasing and improving the use of the existing RHDV1-K5 biocide. Existing and completed CISS research projects are likely to have produced information and data on RHDV2 that may be sufficient for future registration of a RHDV2 biocide. Therefore, if the rabbit biocontrol situation evolves such that it would be highly likely for a RHDV2 biocide to produce positive net benefits, the appropriate next steps toward registration could be undertaken using existing data as a platform.

1.0 Introduction

The Centre for Invasive Species Solutions (CISS) invests significant resources in research, development, and extension (RD&E) targeted at mitigating the negative impacts of invasive European rabbits (*Oryctolagus cuniculus*). Part of this investment includes world leading RD&E in biological control (biocontrol) of wild rabbit populations. Biocontrol RD&E typically involves long-term investment commitments and substantial regulatory hurdles. CISS and its partners currently are considering whether to invest in the full registration of rabbit haemorrhagic disease virus 2 (RHDV2) as a tactical biocontrol agent (biocide) to complement existing rabbit management practices in Australia. However, RHDV2 now is endemic in Australia having been detected in wild rabbit populations in 2015 so the potential additional benefits of tactical use of RHDV2 as a biocide are unknown. The current analysis was funded by CISS to assess and estimate the costs and potential net benefits associated with registration of RHDV2 as a biocide for pest rabbit control in Australia.

2.0 Rabbit Biocontrol in Australia: A Brief Overview

Rabbits were introduced in Australia in 1859 and spread rapidly and widely to become one of Australia's most destructive pests. Within 70 years rabbits had spread to 70 per cent of Australia's land mass, the fastest known invasion by a mammal anywhere in the world. Invasive wild rabbits compete with livestock and native animals for food, affect tree plantings, and reduce ground water absorption. Less than 0.5 rabbits per hectare are sufficient to prevent the regeneration of native vegetation. Competition and land degradation by rabbits is listed as a key threatening process under the Australian Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act), and a formal Threat Abatement Plan is in place (CSIRO, 2017).

A research program to control rabbits in Australia using biocontrol has been in place since the late 1940s. Through this research Australia has introduced four biocontrol agents for rabbits over the past 60 years: two viral diseases (myxoma virus – MV and rabbit haemorrhagic disease virus – RHDV1) and two flea vectors (*Spilopsyllus cuniculi* and *Xenophsylla cunicularis*) to aid their transmission. A third viral agent, RHDV2, was detected in Australia in 2014, but it is not known how the virus entered the country. A new strain of RHDV1, K5, was released nationally in 2017 (Peacock, et al., 2021).

Prior to the release of MV, the economic impacts of rabbits on agriculture alone were estimated at $2 billion per annum. Rabbit biocontrol based on the myxoma virus and RHDV1 Czech 351 strain reduced this impact to about 15% of the pre-release cost. The RHD viruses introduced (or naturalised) since 2014 (that is, RHDV2, RHDVa and RHDV1 K5) are expected to generate benefits of an additional $4 billion over the next 30 years. This is on top of the ongoing benefits derived from MV and the original RHDV1 Czech 351 strain (Peacock, et al., 2021).

Rabbit biocontrol also has had major benefits for native plant and animal species, and in arid inland Australia has been attributed as the single most important and cost-effective conservation action for small, threatened mammals and a range of ecosystems in recent decades. An associated benefit enabling their recovery has been a reduction in abundance of foxes and feral cats which is directly attributed to the removal of their primary prey, the rabbit (Peacock, et al., 2021).

Despite the success of the rabbit biocontrol program to date, and the application of complementary control methods such as warren ripping and fumigating, shooting, trapping, exclusion fencing, and other baiting, rabbits remain one of the top three costliest invasive species in Australia (Bradshaw, et al., 2021). Various estimates of the specific impact costs of rabbits have been published over the years, most recently McLeod (2016) estimated that European rabbits impose aggregate annual agricultural production losses of between $108.31 and $250.57 million (average of $216.63 million). In addition, it was estimated that around $20 million per annum is spent on rabbit control (McLeod, 2016).

To support ongoing management of invasive rabbits, CISS and its partners continue to invest in the rabbit biocontrol program and other rabbit control RD&E.

3.0 RHDV2 as a Potential Biocide: Background and Context

3.1 Background

RHDV2 was first reported in Canberra (Australia) in May 2015 (Hall, et al., 2017). However, serological studies indicated that this exotic RHDV variant had been in the country since as early as January 2014. It is not known how RHDV2 entered Australia. In the 15 months following the RHDV2 incursion, several additional outbreaks were reported in both domestic and wild rabbits and the virus had spread as far as Western Australia (Hardaker & Chudleigh, 2020).

Early research has shown that RHDV2 has the capacity to overcome immunity to other RHDV strains including rabbits vaccinated against RHDV (Peacock, et al., 2017). Further, RHDV2 appears to have other advantages over endemic RHDV1 strains in that RHDV2 can cause death in both young rabbit kittens (3-4 weeks) as well as adult rabbits (Strive, et al., 2020). By late 2018, RHDV2 was the dominant RHDV strain in the Australian landscape and reduced rabbit abundance by an average of 60%, with impacts most pronounced in southern and western Australia (Ramsey, et al., 2019).

Two strains of RHDV1 have previously been progressed through the significant RD&E investment and regulatory requirements and been fully registered as biocides for rabbit control in Australia. The two variants now available to land managers are:

- RHDV1 Czech-351 - the first RHDV1 variant released in Australia in the mid-1990s. The Czech-351 variant was able to spread naturally and is now endemic in Australia. RHDV1 Czech-351 was also registered as a biocide to initiate tactical outbreaks of RHD to complement other rabbit control methods.
- RHDV1-K5 – a novel variant imported from Korea selected for its apparent ability to better overcome partial protection from the benign endemic RHDVa (CSIRO, 2017). RHDV1-K5 was released nationally in March 2017. Recent data from the NSW Department of Primary NSW DPI) Industries Elizabeth Macarthur Agricultural Institute (EMAI) indicates that RHDV1-K5 has largely replaced/ been substituted for RHDV1 Czech-351 as the dominant biocide requested by land managers (Pat Taggart, pers. comm., 2022).

The current analysis estimates the potential expected net benefits of investing in the RD&E and regulatory approvals required to progress RHDV2 as a fully registered biocide. The analysis has been designed to provide input to CISS investment decision making processes and to support best practice resource allocation for invasive species RD&E. There are several key issues associated with the potential registration of RHDV2 as a biocide for rabbit biocontrol in Australia. The following sections describe the current context for the analysis in terms of the issues associated with registration of RHDV2.

3.2 RHDV2 Biocide: Potential Advantages

As noted previously, rabbits remain one of the top three costliest invasive species in Australia (Bradshaw, et al., 2021). If effective, an additional tactical biocontrol tool that may contribute to ongoing suppression of the wild rabbit population, could be beneficial. Some of the potential advantages of registering RHDV2 as a legal biocide are briefly summarised below.

- Research data from overseas and Australia indicates that RHDV2 shows some ability to overcome previous immunity to RHDV1 strains (such as Czech-351 and K5). Though not currently a specific advantage as RHDV2 is the dominant RHDV strain in Australia and RHDV1 circulates in the environment rarely and at low levels. However, this relationship may lead to beneficial synergies between RHDV2 outbreaks and outbreaks of RHDV1, or subsequent targeted RHDV releases.
- Registration of RHDV2 as a legal biocide would mean that there would be no time delay for invasive species managers/land managers between wanting to access the biocide and being able to obtain the biocide for release.
- Through the strategic national release of RHDV1-K5 in 2017 there has been increased community engagement associated with managing wild rabbit populations. Registration of a RHDV2 biocide product may provide similar opportunities to increase community knowledge and engagement thereby improving ongoing rabbit control practices.

3.3 RHDV2 Biocide: Potential Disadvantages

RHDV2 is still relatively new in the Australian environment and there are several areas of uncertainty that may negatively affect the effectiveness and efficiency of RHDV2 as a biocide. Some of these uncertainties are summaries below.

- The impact of the 2017 national release of a RHDV1-K5 for rabbit biocontrol was suppressed by the emergence of RHDV2. An evaluation of the impact of RHDV1-K5 completed in early 2020 estimated that the incursion and spread of RHDV2 in Australia had reduced the potential impact of RHDV1-K5 by approximately 37% (Hardaker & Chudleigh, 2020). Hence, the success of further releases of similar RHDV strains (e.g., RHDV2) for rabbit biocontrol is highly uncertain (Ramsey, et al., 2019).
- RHDV2 currently is the dominant RHDV strain in the Australian landscape and has reduced rabbit abundance by an average of 60%, with impacts most pronounced in southern and western Australia (Ramsey, et al., 2019). Consequently, additional releases of RHDV2 in the near future are unlikely to result in substantial reductions in rabbit numbers as the virus already naturally circulates widely and frequently.
- The endemic RHDV2 continues to spread and mutate in wild rabbit populations. Despite research and data produced to date, registration of a single variant of RHDV2 will take time. This means that any RHDV2 variant registered as a biocide is likely to be evolutionarily out-dated and potentially inferior relative to the prevailing strains of the wild virus.
- A project aspect of CISS Project B-001 experimentally investigated the protective effects of simulated maternal antibodies to RHDV2 in young rabbits. The study found that maternal antibodies to RHDV2 do not protect young rabbits from infection but can prevent death, with survivors mounting a strong immune response to RHDV2 (Hall et al., 2021b). This means that RHDV2 is not likely to be suitable to be released year-round but will have similar caveats around release timing as does RHDV (Czech & K5). Thus, inappropriate release of RHDV2 could lead to increased survival of young rabbits with maternal antibodies, leading to adverse outcomes such as more rapid increases in the overall wild rabbit population over time.

3.4 Other Issues

3.4.1 Complex Registration Process

Australia has strict regulatory requirements for the registration of biological control agents. Though a significant amount of the data required for potential registration of RHDV2 has been produced through existing CISS RD&E projects (P01-B-001 and P01-B-002), it is expected to take substantial additional investment and at least two to three years before a RHDV2 biocide product could be made available. Further, registration with the Australian Pesticides and Veterinary Medicines Authority (APVMA) may require additional information on the risks of RHDV2 to non-target species (additional species specificity testing) and RHDV2 would need to be listed separately to 'rabbit calicivirus disease organisms' under the Biological Control Act 1984 which would necessitate a public consultation process.

3.4.2 Potential Misapplication of RHDV Biocides

A recent analysis of the use of existing RHDV biocides (Czech-351 and K5) showed that approximately half of all RHDV supply (47%) and almost three quarters of reported releases (74%) Australia-wide occurred during the anticipated major rabbit breeding seasons when the risk of immunising young rabbits is greatest (Taggart, et al., 2022). Misuse/misapplication of registered biocides by well-intentioned land managers is likely to lead to adverse outcomes including reduced effectiveness of biocide products and, potentially, more rapid increases in the overall wild rabbit population over time. The addition of a new biocide seems unlikely to change these behaviours as data indicated that land managers tended to utilise biocide products during the breeding season because this is when they notice, and therefore want to control, pest rabbits.

3.4.3 Improved Effectiveness of RHDV1-K5

Early data from research investigating the interactions between RHDV2 and other RHDV variants has shown that RHDV1-K5 appears to be better able to overcome RHDV2 immunity. In laboratory trials, all rabbits that were vaccinated against RHDV2 were killed by RHDV1 infection. In field trials, 9-13% of RHDV2 positive rabbits were killed by RHDV1 infection. These findings suggest that endemic RHDV2 may improve the effectiveness of existing registered biocide products (Czech-351 and K5).

4.0 Analysis of the Potential Expected Net Benefits of a RHDV2 Biocide

The following sections describe the method and findings of the analysis of the potential expected net benefits of investing in the RD&E and regulatory approvals required to register RHDV2 as a legal biocide for rabbit control in Australia.

4.1 Baseline: Case without Further Investment

The first step in the analysis of the potential expected net benefits of RHDV2 was to estimate the current and expected future impact costs of rabbits without the additional investment required to register RHDV2 as a legal biocide. That is, the impact and control costs associated with pest rabbits given current controls including RHDV1 Czech-351 and RHDV1-K5. A degree of conservativism was used when developing the assumptions underpinning the analysis.

McLeod (2016) estimated that European rabbits impose aggregate annual agricultural production losses averaging $216.63 million in 2013/14-dollar terms. In addition, it was estimated that around $20 million per annum is spent on rabbit control (McLeod, 2016). The estimated for control costs was taken from the estimate reported in Bomford & Hart (2002) reported in 1999/2000-dollar terms. The rabbit impact and control costs were updated to 2021/22 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP) (Australian Bureau of Statistics (ABS), 2022) and allocated across the three major Australian agricultural zones (High Rainfall Zone (HRZ), Wheat Sheep Zone (WSZ), and Pastoral Zone (PaZ)) based on the distribution of rabbit impact costs reported in Agtrans (2011).

The impact and control costs in each agricultural zone last estimated for 2013/14 (McLeod, 2016) then were reduced by the expected impact of the incursion of RHDV2 in 2014/15 and the national release of RHDV1-K5 in 2016/17 as reported in Hardaker & Chudleigh (2020). Specific assumptions for the estimation of the baseline rabbit impact and control costs are described in Table 3.

4.2 Potential Net Benefits of Registering a RHDV2 Biocide

4.2.1 Investment Costs

Current RD&E Costs

Through projects P01-B-001 and P01-B-002, CISS and partners have investment approximately $7.6 million (nominal dollars) in RD&E aimed at better understanding RHDV2. These investments are likely to contribute most of the information and data required to register RHDV2 with the APVMA (Tanja Strive, pers. comm., 2022). As these project costs already have been incurred, the investment in the two CISS projects is treated as a sunk cost and not directly included in the following estimation of the net benefits. If RHDV2 is not progressed for registration as a biocide in the near term, the RD&E outputs from the two CISS projects would provide a useful platform for the registration of RHDV2 sometime in the future.

APVMA Registration

APVMA registration assessments may take up to 18 months and cost up to $100,000 for registration fees (APVMA, 2021). At this stage, it also is unknown whether the APVMA would require or request additional information and data on the risks of RHDV2 to non-target species. Therefore, two scenarios have been considered in the analysis:

1. Additional non-target species testing **not** required (Scenario R1):

In this scenario (Scenario R1), no additional research is required, and the only cost associated with registration would be the APVMA registration fees.

2. Additional non-target species testing required (Scenario R2):

Scenario R2 assumed that some limited additional non-target species testing would be required for APVMA registration of RHDV2. This would require additional RD&E funding of approximately $3.5 million over three years (Tanja Strive, pers. comm., 2022). The estimated additional RD&E costs were based on the additional non-target species research costs estimated in Peacock (2015) and consultation with current rabbit biocontrol experts.

Community Consultation and Regulatory Costs

RHDV2 would need to be listed separately to 'rabbit calicivirus disease organisms' under the Biological Control Act 1984. This would necessitate a public consultation process. Further, a new RHDV2 biocide would need to pass several government regulatory hurdles to be approved for use. Additional time and resources are expected to be incurred because of community consultation requirements and regulatory approval process. It was assumed that this process would take approximately three years at a total cost of $1.5 million ($500,000 per annum). This estimate was based on the investment costs estimated for the development of RHDV2 as a biocide as part of a business case to advance the selection of new rabbit biocontrol agents (Peacock D. , 2015).

National Release Costs

For both scenarios it was assumed that APVMA and regulatory approval would be followed by a nationally coordinated release of the RHDV2 biocide product similar to that undertaken for RHDV1-K5. This would increase adoption of the new biocide product and improve land managers' understanding of best practice for implementing the RHDV2 biocide. It was assumed that the cost of such a nationally coordinated initial release would occur in a single season/year at a value of approximately $1.6 million. This estimate was based on the estimated cost of the national coordinated release of RHDV1-K5 reported in Hardaker & Chudleigh (2020).

Ongoing Implementation Costs

Land managers wishing to use a RHDV2 biocide product will have to request and purpose vials of the new biocide for baiting applications, as is the case with existing biocide products (Czech-351 and RHDV1-K5). A vial of RHDV from the EMAI costs approximately $200 plus postage. Currently, between 121 and 142 RHDV requests are made each year and 480 and approximately 1,200 vials of RHDV are supplied annual (average of 833 vials per annum from 2018 to 2020; Pat Taggart, pers. comm., 2022). Based on evidence that RHDV1-K5 has largely replace/been substituted for the Czech-351 strain since its release in 2017, it was assumed that a new RHDV2 biocide would likely replace RHDV1 use by land managers.

The range of potential costs associated with the registration and regulatory approval of RHDV2 as a biocide is summarised in Table 1 below.

Table 1: Potential Additional Costs for the Registration and Regulatory Approval of RHDV2 as a Biocide for Rabbit Control in Australia

Cost Category	Estimated Cost
Sunk costs – RD&E associated with CISS project P01-B-001 and P01-B-002	$7.6 million (2018/19 to 2021/22)
APVMA registration with **no** additional non-target species testing required	$100,000 registration fee over 18 months
APVMA registration with additional non-target species testing required	$1.5 million per annum for three years for additional RD&E plus $100,00 registration fee over 18 months
Community consultation and government regulatory costs	$0.5 million per annum over three years
Nationally coordinated release of RHDV2 biocide	$1.6 million in one season/year
Ongoing implementation costs for land managers	$220 per vial including postage (note: RHDV2 likely to be substituted for RHDV1 biocides)

Based on the information presented in Table 1, excluding sunk costs and ongoing land manager costs, the maximum potential additional investment required to achieve successful registration and approval of a RHDV2 biocide could be $7.7 million over a period of up to eight years (including the release year).

4.2.2 Expected Impact

Research to date showed that, in field experiments, RHDV2 kill approximately 19.6% of experimentally inoculated rabbits irrespective of their immune status (95% confidence interval of 11.0% to 32.5%; P. Taggart and T. Strive, pers. comm., 2022). Given that the immune status of the Australian wild rabbit population is unknown, this mortality rate (19.6%) represents the average that could be expected from the intention release of a RHDV2 biocide. Specific assumptions for estimating the impact of the use of a RHDV2 biocide are described in Table 3.

4.2.3 Other Considerations

Relationship Between Rabbit Control and Rabbit Impacts

The relationship between rabbit control, reduced rabbit populations, and any reduction in rabbit impact and control costs is uncertain. For the purpose of the current analysis, it was assumed that a 1% reduction in rabbit population leads to a 1% reduction in rabbit impact and control costs. This assumption is consistent with previous analyses of rabbit biocontrol investments.

Counterfactual

To estimate the potential net benefits of the investment required for registration and regulatory approval of a RHDV2 biocide it was necessary to define the counterfactual, or without investment, scenario. It was assumed that, without additional investment, RHDV2 would not be registered as a legal biocide. However, the information and data produced by the sunk RD&E investment in CISS projects P01-B-001 and P01-B-002 would provide most, if not all, of the required data for APVMA registration in the future should decision makers move to progress RHDV2 at a later stage.

Risk Factors

The analysis of the potential net benefits of investment to develop a RHDV2 biocide was conducted in a risk-based framework. Risk factors along the expected pathways to impact were assessed and taken into account in the form of probabilities. It was considered highly likely that, given additional investment is funded to progress RHDV2 to full registration and release, registration and regulatory approval would be successful, a RHDV2 biocide product would be adopted by land managers, and the biocide would create localised knockdowns of rabbit populations. Specific assumptions regarding the relevant RHDV2 risk factors are shown in Table 3.

Attribution

The potential net benefits of a RHDV2 biocide are dependent on the suite of RD&E investments that would enable RHDV2 to be successfully registered with the APVMA and pass through the required community and government approval processes. This means that a portion of any future net benefits would be attributable to the original investment in CISS projects P01-B-001 and P01-B-002. Attribution of the potential benefits to the additional investment required was accommodated through the application of an attribution factor to the estimated expected net benefits. Specific assumptions regarding the attribution of net benefits are reported in Table 3.

4.3 Summary of Assumptions

The following sections summarise the specific assumptions used in the RHDV2 biocide analysis.

4.3.1 Baseline Assumptions: Current and Future Rabbit Impact Costs without RHDV2 Biocide

Table 2 below shows the baseline data and assumptions used to estimate the current and future impact and control costs of pest rabbits in Australia from 2014/15 onward. These assumptions establish the baseline rabbit impact and controls costs where no additional investment is made to release a registered and approved RHDV2 biocide.

Table 2: Assumptions Used to Estimate the Baseline Current and Future Impact Costs of Rabbits Without Additional Investment to Register and Release a RHDV2 Biocide

Variable	Assumption	Source/Notes
Baseline data on rabbit impact and control costs		
Estimated average annual impact costs of rabbits on agricultural production (livestock only: wool, sheep meat, and beef) - Prior to incursion of RHDV2 and release of RHDV1-K5	$216.63 million (2013/14-dollar terms)	McLeod (2016)
Estimated average annual control costs for rabbits	$20 million (1999/2000-dollar terms)	Bomford & Hart (2002) - also reported in Gonget al., (2009) and McLeod (2016)
Estimated distribution of impact and control costs by rainfall zone		
High Rainfall Zone (HRZ)	38.6%	Derived from impact cost distribution data in '*Prospective economic assessment of investment in importation of new Rabbit Haemorrhagic Disease Virus (RHDV) strains for rabbit biocontrol*' (Agtrans Research, 2011)
Wheat-Sheep Zone (WSZ)	29.1%	
Pastoral Zone (PaZ)	32.3%	
Average annual rabbit impact and control costs by rainfall zone updated to 2021/22-dollar terms - PRIOR to detection of RHDV2 and release of RHDV1-K5		
Impact Costs - agricultural production (livestock)		
HRZ	$98.55 million p.a.	Updated to 2021/22-dollar terms using relevant Australian Bureau of Statistics (ABS) Implicit Price Deflators for Gross Domestic Product (GDP)
WSZ	$74.30 million p.a.	
PaZ	$82.47 million p.a.	
Total impact costs (production)	$255.31 million p.a.	
Impact Costs - control costs		
HRZ	$14.50 million p.a.	
WSZ	$10.93 million p.a.	
PaZ	$12.13 million p.a.	
Total impact costs (control)	$37.57 million p.a.	
Estimated impact costs (production losses and control costs) given endemic RHDV2 variants and release of RHDV1-K5 by rainfall zone (2014/15 onwards)		
Impact Costs - agricultural production (livestock)		
HRZ	$39.37 million p.a.	Based on data and assumptions in Hardaker & Chudleigh (2020) with an average mortality of 60% for endemic RHDV2 and 13.9% for RHDV1-K5 biocide based on box trial. Note: there was not assumed to be any different in average mortality across the different agricultural zones.
WSZ	$29.68 million p.a.	
PaZ	$32.95 million p.a.	
Total impact costs (production)	$102.00 million p.a.	
Impact Costs - control costs		
HRZ	$5.79 million p.a.	
WSZ	$4.37 million p.a.	
PaZ	$4.85 million p.a.	
Total impact costs (control)	$15.01 million p.a.	

		Updated to 2021/22-dollar terms using relevant ABS Implicit Price Deflators for GDP. Assumes endemic RHDV2 and ongoing use of RHDV1-K5 as a localised biocide that does not spread naturally.
First year of combined maximum impact of new biocontrol (RHDV2 and RHDV1-K5)	2018/19	Based on detection and spread of RHDV2 in Australia in from approximately 2014/15 and release of RHDV1-K5 in 2016/17.
Period of stable impact with endemic RHDV2 and tactical use of RHDV1-K5	10 years from maximum spread of RHDV2 in 2017/18 (to 2026/27)	Analyst assumption - consistent with Hardaker & Chudleigh (2020)
Increase in rabbit populations and associated total impact costs after stable impact ends (because of increases resistance/immunity in wild rabbit populations)		
Average annual increase in rabbit populations and associated impact and control costs	46% p.a.	Dave Ramsey, pers. comm., 2022 (report in press)
Maximum potential annual rabbit impact costs with no additional new interventions	100% of 2013/14 levels	Analyst assumption after consultation with rabbit biocontrol experts – assumes rabbit numbers will never again reach pre-RHDV1 levels given ongoing management practices

4.3.2 Assumptions for Estimating the Potential Expected Net Benefits of a RHDV2 Biocide

Table 3 below shows the assumptions used to estimate the potential expected net benefits of the release and ongoing application of a registered RHDV2 biocide for rabbit control in Australia.

Table 3: Assumptions for Estimating the Potential Expected Net Benefits of a Registered RHDV2 Biocide for Rabbit Control in Australia

Variable	Assumption	Source/Notes
With RHDV2 biocide registration		
Area of Australia inhabited by pest rabbits	5.3 million square kilometres	https://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/rabbits/rabbit-biology
Area of land benefiting from release of RHDV2 biocide – first year – coordinated national release	Approximately 94,200 square kilometres	Analyst assumption – based on a nationally coordinated release of 1,600 vials of RHDV2 biocide, equivalent to approximately 1,200 releases, with a localised impact and 5km effective radius (based on the RHDV1-K5 national release where approximately ~600 additional vials were supplied leading to approximately double the rabbit affected area targeted by typical annual biocide use)

Proportion of rabbit impacted area potentially benefiting from the release of RHDV2 as a tactical biocide – first year – nationally coordinated release	1.78% in year one (initial release)	= 94,200 / 5,300,000
Area of land benefiting from release of RHDV2 biocide – subsequent years – ongoing use by land managers	Approximately 47,100 square kilometres	Analyst assumption - based on average annual supply of approximately 800 vials of RHDV2 biocide (replacing RHDV1-K5 use) equivalent to approximately 600 releases with a localised impact and 5km effective radius
Proportion of rabbit impacted area potentially benefiting from the release of RHDV2 as a tactical biocide – subsequent years – ongoing biocide use by land managers	0.89% per annum from year two	= 47,100 / 5,300,000
First year of impact (nationally coordinated release of new RHDV2 biocide and associated extension activities)	2026/27 (no additional non-target species testing) 2029/30 (with additional non-target species testing)	See Table 4 and Table 5 below
Reduction in rabbit impact costs due through application of a RHDV2 biocide	19.6%	Based on box trial data indicating an average mortality rate of 19.6% for RHDV2 regardless of underlying rabbit population RHDV immune status (P. Taggart and T. Strive, pers. comm., 2022). Note: there was not assumed to be any different in average mortality across the different agricultural zones.
Other Factors		
Probability of output (successful full registration of a RHDV2 biocide)	90%	Analyst assumption – allows for uncertainty and exogenous factors that may affect realisation of impact (e.g., global COVID-19 pandemic). Further, the probability of impact allows misuse of rabbit biocide products by land managers based on evidence that approximately half of all RHDV supply (47%) occur at the wrong time of year
Probability of outcome (adoption/use of RHDV2 biocide at levels assumed)	90%	
Probability of impact (given adoption at level assumed)	50%	
Attribution of benefits to additional investment (assumes nationally coordinated release)	29.6% (no additional non-target species testing) 50.3% (with additional non-target species testing)	Estimated based on the additional investment costs including national release relative to the total investment including sunk RD&E costs (see Table 1)

4.4 RHDV2 Investment Cost Scenarios

For the base analyses of the potential expected net benefits of investment to produce a fully registered and approved RHDV2 biocide two key investment scenarios were considered:

1) Full registration and approval costs with no additional non-target species testing required and including a nationally coordinated release (shown in Table 4), and
2) Full registration and approval costs with additional non-target species testing required by the APVMA and including a nationally coordinated release (shown in Table 5).

Table 4: Additional Investment Costs for Full Registration and Approval of a RHDV2 Biocide – No Additional Non-Target Species Testing

Year (ended 30 June)	**Additional Costs (nominal $s)**	**Cost Category**
2023	$50,000	APVMA registration fees (total of $100,00 over 18 months)
2024	$550,000	APVMA registration fees and first year of community consultation and government approval process
2025	$500,000	Community consultation and government approval process
2026	$500,000	Community consultation and government approval process
2027	$1,600,000	Nationally coordinated release of new RHDV2 biocide
Total additional costs to register and release a RHDV2 biocide	**$3,200,000**	
Other costs from 2028	$175,000 per annum	Costs incurred by land managers – based on an average annual supply of approximately 800 vials at $220 per vial including postage
Note: Based on evidence from the release of RHDV1-K5 it was assumed that a RHDV2 biocide would largely replace other RHDV biocides in use by land managers.		

Table 5: Additional Investment Costs for Full Registration and Approval of a RHDV2 Biocide – With Additional Non-Target Species Testing

Year (ended 30 June)	**Additional Costs (nominal $s)**	**Cost Category**
2023	$1,500,000	Additional non-target species testing RD&E
2024	$1,500,000	Additional non-target species testing RD&E
2025	$1,500,000	Additional non-target species testing RD&E
2026	$50,000	APVMA registration fees (total of $100,00 over 18 months)
2027	$550,000	APVMA registration fees and first year of community consultation and government approval process
2028	$500,000	Community consultation and government approval process
2029	$500,000	Community consultation and government approval process
2030	$1,600,000	Nationally coordinated release of new RHDV2 biocide
Total additional costs to register and release a RHDV2 biocide	**$7,700,000**	
Other costs from 2028	$175,000 per annum	Costs incurred by land managers – based on an average annual supply of approximately 800 vials at $220 per vial including postage
Note: Based on evidence from the release of RHDV1-K5 it was assumed that a RHDV2 biocide would largely replace other RHDV biocides in use by land managers.		

5.0 Results

All benefit and cost cash flows were expressed in 2021/22-dollar terms and were discounted to the year 2021/22 (year of evaluation) using a 5% discount rate. The discounted benefit and cost cash flows, termed the present value of benefits (PVB) and the present value of costs (PVC), then were used to estimate investment criteria including the net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR) and modified IRR (MIRR) for the additional investment required to achieve a fully registered, approved and nationally released RHDV2 biocide. The modified internal rate of return (MIRR) was estimated using a 5% reinvestment rate.

The base analysis used the best estimates of each variable, notwithstanding a high level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the first year of additional investment assumed (2022/23). The following sections report the results of the analysis. Investment criteria were estimated for two different RHDV2 investment cost scenarios:

1) Full registration and approval costs with no additional non-target species testing required and including a nationally coordinated release (Section 4.4, Table 4), and
2) Full registration and approval costs with additional non-target species testing required by the APVMA and including a nationally coordinated release (Section 4.4, Table 5).

5.1 Investment Criteria

Table 6 shows the investment criteria for the first scenario where no additional non-target species testing would be required by the APVMA.

Table 6: Investment Criteria for RHDV2 Biocide Investment
(No Additional Non-Target Species Testing, 5% Discount Rate)

Investment criteria	**Number of years from first year of investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.04	0.22	0.38	0.51	0.61	0.69
Present value of costs ($m)	0.00	2.64	2.64	2.64	2.64	2.64	2.64
Net present value ($m)	0.00	-2.61	-2.42	-2.26	-2.13	-2.03	-1.95
Benefit-cost ratio	n.c.	0.01	0.08	0.14	0.19	0.23	0.26
Internal rate of return (%)	n.c.	n.c.	n.c.	n.c.	neg.	neg.	neg.
MIRR (%)	n.c.	neg.	neg.	neg.	neg.	neg.	neg.

n.c.: not calculable; neg.: negative

Table 7 shows the investment criteria for the first scenario where additional non-target species testing is required by the APVMA.

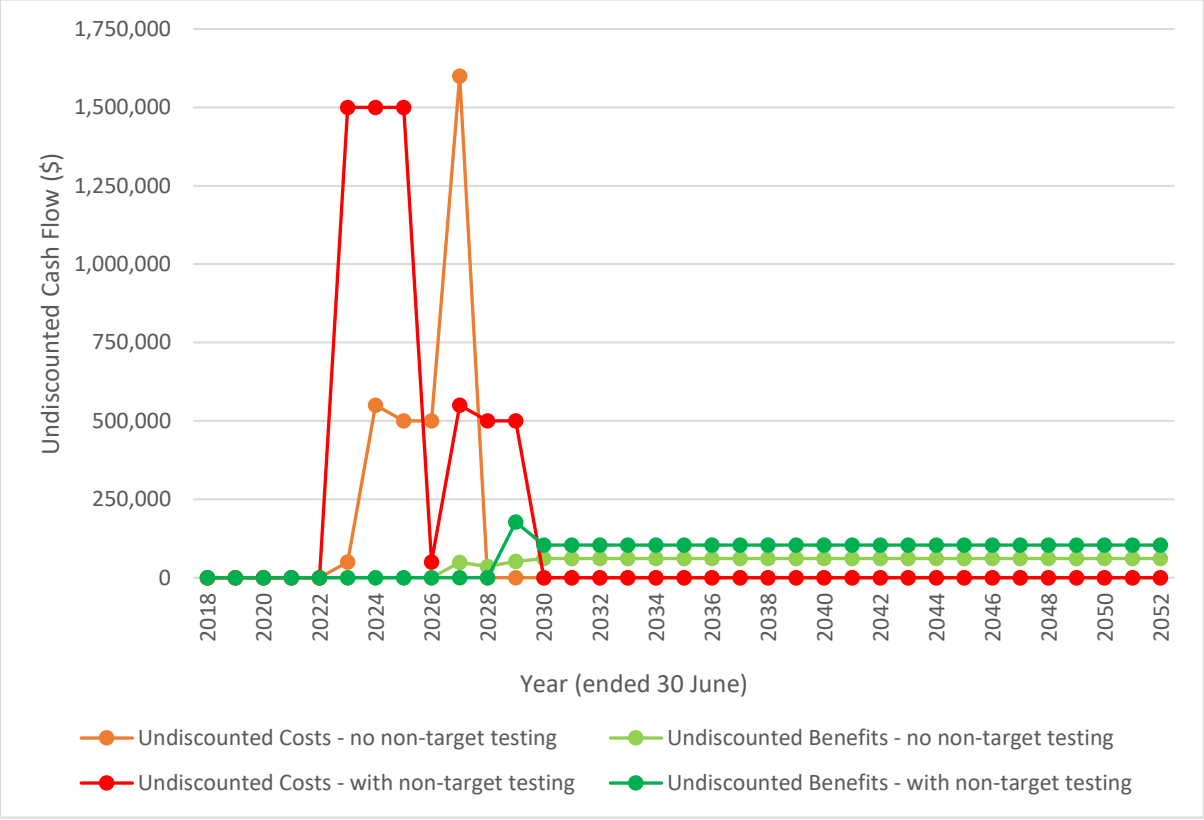
Table 7: Investment Criteria for RHDV2 Biocide Investment
(With Additional Non-Target Species Testing, 5% Discount Rate)

Investment criteria	Number of years from first year of investment						
	0	5	10	15	20	25	30
Present value of benefits ($m)	0.00	0.00	0.33	0.60	0.82	0.99	1.12
Present value of costs ($m)	0.00	4.56	5.29	5.29	5.29	5.29	5.29
Net present value ($m)	0.00	-4.56	-4.96	-4.68	-4.47	-4.30	-4.16
Benefit-cost ratio	n.c.	0.00	0.06	0.11	0.16	0.19	0.21
Internal rate of return (%)	n.c.	n.c.	neg.	n.c.	neg.	neg.	neg.
MIRR (%)	n.c.	neg.	neg.	neg.	neg.	neg.	neg.

n.c.: not calculable; neg.: negative

The annual undiscounted benefit and cost cash flows for both scenarios are shown in Figure 1.

Figure 1: Annual Undiscounted Total Benefit and Cost Cash Flows for RHDV2 Biocide Investment Scenarios



5.2 Sensitivity Analysis

Sensitivity analyses were undertaken for variables that were considered key drivers of the investment criteria and/or were the most uncertain. All other variables were kept at base values. Analyses were undertaken for the total investment assuming no additional non-target species testing (best case cost scenario) and for 30 years from the first year of additional investment assumed (2022/23).

A sensitivity analysis was conducted on the discount rate. The results, reported in Table 8, showed a moderate to low sensitivity to the discount rate. This was largely because the cost cash flows occur in the near future and therefore are subject to lesser discounting.

Table 8: Sensitivity of Investment Criteria to the Discount Rate
(Total Investment, No Non-Target Species Testing, 30 Years)

	Discount Rate		
Investment Criteria	**0%**	**5% (base)**	**10%**
PVB ($m)	1.54	0.69	0.36
PVC ($m)	3.20	2.64	2.21
NPV ($m)	-1.66	-1.95	-1.85
BCR	0.48	0.26	0.16

A sensitivity analysis then was conducted on the area benefiting from RHDV2 biocide releases from year 2 (ongoing use by land managers). The area benefiting from RHDV2 biocide use was a key variable for determining the potential expected net benefits of the investment. The results, reported in Table 9, showed a moderate to high sensitivity to the ongoing area benefiting assumed. This was largely because the ongoing benefit cash flows occur well into the future and therefore are subject to relatively higher discounting. Further, as time progresses, the underlying impact costs of rabbits increases which may increase the benefits of tactical use of an RHDV2 biocide.

A break-even analysis showed that the investment criteria became positive (BCR $\geq$ 1) when the ongoing area benefiting from the RHDV2 biocide was approximately 188,675 km2 (3.56% of the rabbit affected area), approximately four times higher than the base case. This indicates that significant extension activities may need to be undertaken to increase adoption and appropriate use of a RHDV2 biocide if positive benefits were to be achieved in the long-term.

Table 9: Sensitivity of Investment Criteria to the Area Benefiting from Ongoing Use of a New RHDV2 Biocide (Total Investment, No Non-Target Species Testing, 5% Discount Rate, 30 Years)

	Area Benefiting from Ongoing Use of New RHDV2 Biocide		
Investment Criteria	**47,100 km^2 (0.89%) (base)**	**2x base (94,200 km^2; 1.78%)**	**5x base (235,500 km^2; 4.44%)**
PVB ($m)	0.69	1.34	3.29
PVC ($m)	2.64	2.64	2.64
NPV ($m)	-1.95	-1.30	0.65
BCR	0.26	0.51	1.24

A final sensitivity analysis was conducted on the risk factors affecting the potential benefits. The investment criteria are reported in Table 10. The results show a moderate to high sensitivity to the risk factors assumed. This was likely because the benefit cash flows occur well into the future and are increase (in absolute terms) as the rabbit impact costs increase over time with rabbit population growth.

Further, the analysis suggests that, if all risk factors are eliminated (probabilities of 100%), meaning that the release, use and impact of a RHDV2 biocide occurs exactly as assumed based on the base case, the investment criteria remain negative (BCR < 1). This suggest that, based on the assumptions made, additional investment to register RHDV2 as a legal biocide is unlikely to produce positive net benefits in the current rabbit population and biocontrol environment.

Table 10: Sensitivity of Investment Criteria to the Assumed Risk Factors
(Total Investment, No Non-Target Species Testing, 5% Discount Rate, 30 Years)

	Risk Factors		
Investment Criteria	**Output 90% Outcome 75% Impact 25% (pessimistic)**	**Output 90% Outcome 90% Impact 50% (base)**	**Output 100% Outcome 100% Impact 100% (optimistic)**
PVB ($m)	0.29	0.69	1.70
PVC ($m)	2.64	2.64	2.64
NPV ($m)	-2.36	-1.95	-0.94
BCR	0.11	0.26	0.64

6.0 Discussion and Conclusions

The current analysis aimed to estimate the potential expected net benefits of additional investment to develop a registered and approved RHDV2 biocide. The results indicated potential expected net benefits of a RHDV2 biocide of approximately $0.69 million (present value terms). However, the best-case cost scenario where no-additional non-target species testing is required, suggested total nominal investment costs of $3.2 million over a period of five years equivalent to $2.64 million in present value terms. The discounted benefit and cost cash flows gave a net present value of -$1.95 million and a benefit-cost ratio of 0.26.

Sensitivity analyses were undertaken to investigate the key variables within the analysis. These analyses showed that, in a best-case scenario where a RHDV2 biocide is successfully registered with no additional non-target species testing required and then implemented appropriately by land managers, expected net benefits increased to approximately $1.7 million (present value terms). This was still less than the present value of costs of $2.64 million. An analysis of the likely adoption of a RHDV2 biocide, represented as the rabbit affected area benefiting from the new biocide, showed that adoption of a RHDV2 biocide would need to be at least four times higher than assumed to generate positive investment criteria.

The estimated total expected net benefits of a RHDV2 biocide of just $0.69 million (over 30 years at a 5% discount rate) and corresponding investment criteria estimated suggest that the additional investment required to achieve full registration and approval of a RHDV2 biocide is unlikely to generate a positive return on investment. Further, the analysis identified several issues associated with a RHDV2 biocide that support the quantitative findings. Such issues include that RHDV2 would need to be listed separately to 'rabbit calicivirus disease organisms' under the Biological Control Act 1984 which would necessitate a public consultation process, evidence from existing biocide use indicates that almost three quarters of reported biocide releases are misapplied by land managers, and early data has shown that RHDV1-K5 appears to be better able to overcome RHDV2 immunity.

A brief analysis of potential investment to increase and improve the use of the existing RHDV1-K5 biocide was undertaken to provide a point of comparison for the RHDV2 biocide analysis (see Appendix 1). The RHDV1-K5 comparison analysis had an estimated total expected net benefit of $2.17 million (present value terms) against potential costs of $0.68 million (present value terms). This gave an estimated net present value of $1.49 million and a benefit-cost ratio of approximately 3.2 to 1 over 30 years using a 5% discount rate. Investment criteria were positive from 10 years from the first year of investment assumed. This suggests that positive net benefits would be achieved as early as 2031/32 based on the assumptions made.

A further analysis that assessed the potential net benefits of investment in the registration and implementation of a RHDV2 biocide without a nationally coordinated release (with and without the need for additional non-target species RD&E) supported the main analysis findings. This additional analysis showed that, based on the assumptions used, the total investment required to register a legal RHDV2 biocide and the risks associated with the pathways to impact result in negative investment criteria out to 30 years from the first year of investment. This suggests that the proposed RHDV2 biocide investment is unlikely to generate significant benefits or a positive return on investment in the medium- to long-term.

CISS projects P01-B-001 and P01-B-002 are likely to have produced information and data on RHDV2 that may be sufficient for APVMA registration of a RHDV2 biocide. Registration with the APVMA can cost up to $100,000 and take up to 18 months. Based on the findings of the current analysis, it is recommended that rabbit biocontrol and invasive species stakeholders continue to monitor and evaluate the wild rabbit population and changing environment with respect to existing biocontrol agents (RHDV1 strains and endemic RHDV2). Also, it is likely to be worthwhile to put some investment into increasing and improving the use of the existing RHDV1-K5 biocide. Then, in the future, if the rabbit biocontrol situation evolves such that it would be highly likely for a RHDV2 biocide to produce positive net benefits, the appropriate next steps toward registration could be undertaken using the existing data as a platform.

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Appendix 1: Analysis of Improved Use of RHDV1-K5 Biocide

A brief analysis on the potential expected net benefits of increased and improved use of the existing RHDV1-K5 biocide was undertaken to provide a point of comparison with the RHDV2 analysis.

Summary of Assumptions

The following sections briefly summarise the specific assumptions used in the RHDV1-K5 comparison analysis.

Baseline Assumptions: Current and Future Rabbit Impact Costs

Table 11 below shows the baseline data and assumptions used to estimate the current and future impact and control costs of pest rabbits in Australia from 2014/15 onward.

Table 11: Assumptions Used to Estimate the Baseline Current and Future Impact Costs of Rabbits Without Additional Investment to Register and Release a RHDV2 Biocide

Variable	Assumption	Source/Notes
Baseline data on rabbit impact and control costs		
Estimated average annual impact costs of rabbits on agricultural production (livestock only: wool, sheep meat, and beef) - Prior to incursion of RHDV2 and release of RHDV1-K5	$216.63 million (2013/14-dollar terms)	McLeod (2016)
Estimated average annual control costs for rabbits	$20 million (1999/2000-dollar terms)	Bomford & Hart (2002) - also reported in Gonget al., (2009) and McLeod (2016)
Estimated distribution of impact and control costs by rainfall zone		
High Rainfall Zone (HRZ)	38.6%	Derived from impact cost distribution data in '*Prospective economic assessment of investment in importation of new Rabbit Haemorrhagic Disease Virus (RHDV) strains for rabbit biocontrol*' (Agtrans Research, 2011)
Wheat-Sheep Zone (WSZ)	29.1%	
Pastoral Zone (PaZ)	32.3%	
Average annual rabbit impact and control costs by rainfall zone updated to 2021/22-dollar terms - PRIOR to detection of RHDV2 and release of RHDV1-K5		
Impact Costs - agricultural production (livestock)		
HRZ	$98.55 million p.a.	Updated to 2021/22-dollar terms using relevant Australian Bureau of Statistics (ABS) Implicit Price Deflators for Gross Domestic Product (GDP)
WSZ	$74.30 million p.a.	
PaZ	$82.47 million p.a.	
Total impact costs (production)	$255.31 million p.a.	
Impact Costs - control costs		
HRZ	$14.50 million p.a.	
WSZ	$10.93 million p.a.	
PaZ	$12.13 million p.a.	
Total impact costs (control)	$37.57 million p.a.	

Estimated impact costs (production losses and control costs) given endemic RHDV2 variants and release of RHDV1-K5 by rainfall zone (2014/15 onwards)		
Impact Costs - agricultural production (livestock)		
HRZ	$39.37 million p.a.	Based on data and assumptions in Hardaker & Chudleigh (2020) with an average mortality of 60% for endemic RHDV2 and 13.9% for RHDV1-K5 biocide based on box trial. Note: there was not assumed to be any different in average mortality across the different agricultural zones. Updated to 2021/22-dollar terms using relevant ABS Implicit Price Deflators for GDP. Assumes endemic RHDV2 and ongoing use of RHDV1-K5 as a localised biocide that does not spread naturally.
WSZ	$29.68 million p.a.	
PaZ	$32.95 million p.a.	
Total impact costs (production)	$102.00 million p.a.	
Impact Costs - control costs		
HRZ	$5.79 million p.a.	
WSZ	$4.37 million p.a.	
PaZ	$4.85 million p.a.	
Total impact costs (control)	$15.01 million p.a.	
First year of combined maximum impact of new biocontrol (RHDV2 and RHDV1-K5)	2018/19	Based on detection and spread of RHDV2 in Australia in from approximately 2014/15 and release of RHDV1-K5 in 2016/17.
Period of stable impact with endemic RHDV2 and tactical use of RHDV1-K5	10 years from maximum spread of RHDV2 in 2017/18 (to 2026/27)	Analyst assumption - consistent with Hardaker & Chudleigh (2020)
Increase in rabbit populations and associated total impact costs after stable impact ends (because of increases resistance/immunity in wild rabbit populations)		
Average annual increase in rabbit populations and associated impact and control costs	46% p.a.	Dave Ramsey, pers. comm., 2022 (report in press)
Maximum potential annual rabbit impact costs with no additional new interventions	100% of 2013/14 levels	Analyst assumption after consultation with rabbit biocontrol experts – assumes rabbit numbers will never again reach pre-RHDV1 levels given ongoing management practices

Assumptions for Estimating the Potential Expected Net Benefits of Improved Use of Existing RHDV1-K5 Biocide

Table 12 shows the assumptions used to estimate the potential expected net benefits of improved use of RHDV1-K5 for rabbit control in Australia.

Table 12: Assumptions for the Estimation of the Potential Expected Net Benefits Improved Use of RHDV1-K5 Biocide for Rabbit Biocontrol

Variable	Assumption	Source/Notes
With Improved RHDV1-K5 Use		
Area of Australia inhabited by pest rabbits	5.3 million square kilometres	https://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/rabbits/rabbit-biology
Area of land currently benefiting from ongoing use of RHDV1-K5 biocide by land managers	Approximately 47,100 square kilometres	Analyst assumption - based on average annual supply of approximately 800 vials of RHDV2 biocide (replacing RHDV1-K5 use) equivalent to approximately 600 releases with a localised impact and 5km effective radius
Proportion of rabbit impacted area currently benefiting from use of RHDV1-K5 biocide	0.89% per annum from year two	= 47,100 / 5,300,000
Increase in the area benefiting through activities to improve the use of the RHDV1-K5 biocide	2x current area (94,200 square kilometres; 1.8%)	Analyst assumption
First year of impact (first year of activities aimed at increasing and improving use of RHDV1-K5 biocide)	2022/23	Analyst assumption
Year of maximum impact	2024/25	Based on three years after the first year of extension activities to improve RHDV1-K5 use
Reduction in rabbit impact costs through application of RHDV1-K5 biocide in additional area benefiting	13.9%	Based on box trial data indicating an average mortality rate of 13.9% for RHDV1-K5 with endemic RHDV2 (P. Taggart and T. Strive, pers. comm., 2022). Note: there was not assumed to be any different in average mortality across the different agricultural zones.
Other Factors		
Probability of output (successful full registration of a RHDV2 biocide)	100%	Analyst assumption – allows for uncertainty and exogenous factors that may affect realisation of impact (e.g., global COVID-19 pandemic). Further, the probability of impact allows misuse of rabbit biocide products by land managers based on evidence that approximately half of all RHDV supply (47%) occur at the wrong time of year
Probability of outcome (adoption/use of RHDV2 biocide at levels assumed)	90%	
Probability of impact (given adoption at level assumed)	50%	
Attribution of benefits to additional investment	100%	Analyst assumption

RHDV1-K5 Additional Investment Costs

It was assumed that some additional investment would be required to increase and improve the use of the existing RHDV1-K5 investment. Activities would likely include extension work such as land manager engagement, demonstrations/workshops, dissemination of digital communications products, and other education and communication. It was assumed that such activities would cost approximately $250,000 per annum for the three years from 2022/23 to 2024/25.

Results

All benefit and cost cash flows were expressed in 2021/22-dollar terms and were discounted to the year 2021/22 (year of evaluation) using a 5% discount rate. The discounted benefit and cost cash flows, termed the present value of benefits (PVB) and the present value of costs (PVC), then were used to estimate investment criteria including the net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR) and modified IRR (MIRR) for the additional investment required to achieve a fully registered, approved and nationally released RHDV2 biocide. The modified internal rate of return (MIRR) was estimated using a 5% reinvestment rate.

The base analysis used the best estimates of each variable, notwithstanding a high level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the first year of additional investment assumed (2022/23).

Investment Criteria

Table 13 shows the investment criteria for potential investment in increasing and improving the use of the existing RHDV1-K5 biocide.

Table 13: Investment Criteria for Improved Use of RHDV1-K5
(5% Discount Rate)

Investment criteria	**Number of years from first year of investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.25	0.78	1.26	1.64	1.94	2.17
Present value of costs ($m)	0.00	0.68	0.68	0.68	0.68	0.68	0.68
Net present value ($m)	0.00	-0.44	0.10	0.58	0.96	1.26	1.49
Benefit-cost ratio	n.c.	0.36	1.15	1.86	2.41	2.84	3.18
Internal rate of return (%)	n.c.	n.c.	3.1%	10.2%	12.1%	12.7%	13.0%
MIRR (%)	n.c.	neg.	4.0%	7.5%	7.9%	7.8%	7.5%

n.c.: not calculable; neg.: negative

Discussion and Conclusions

The brief comparison analysis of potential investment to increase and improve the use of the existing RHDV1-K5 biocide had an estimated total expected net benefit of $2.17 million (present value terms) against potential costs of $0.68 million (present value terms). This gave an estimated net present value of $1.48 million and a benefit-cost ratio of approximately 3.2 to 1 over 30 years using a 5% discount rate. Investment criteria were positive from 10 years from the first year of investment assumed. This suggests that positive net benefits would be achieved as early as 2031/32 based on the assumptions made.

Appendix 2: Additional Scenario – RHDV2 Biocide without Nationally Coordinated Release

An additional analysis on the potential expected net benefits of the registration and implementation of RHDV2 as a legal biocide was undertaken to provide a point of comparison with the original RHDV2 analysis scenarios described in Section 4.4.

RHDV2 Additional Investment Cost Scenarios

For the additional analyses of the potential expected net benefits of investment to produce a fully registered and approved RHDV2 biocide two key investment scenarios were considered, both without expenditure a nationally coordinated release:

1) Full registration and approval costs with no additional non-target species testing required (Table 14), and
2) Full registration and approval costs with additional non-target species testing required by the APVMA (Table 15).

Table 14: Additional Investment Costs for Full Registration and Approval of a RHDV2 Biocide – No Additional Non-Target Species Testing and No Nationally Coordinated Release

Year (ended 30 June)	**Additional Costs (nominal $s)**	**Cost Category**
2023	$50,000	APVMA registration fees (total of $100,00 over 18 months)
2024	$550,000	APVMA registration fees and first year of community consultation and government approval process
2025	$500,000	Community consultation and government approval process
2026	$500,000	Community consultation and government approval process
Total additional costs to register and release a RHDV2 biocide	**$1,600,000**	
Other costs from 2027	$175,000 per annum	Costs incurred by land managers – based on an average annual supply of approximately 800 vials at $220 per vial including postage
Note: Based on evidence from the release of RHDV1-K5 it was assumed that a RHDV2 biocide would largely replace other RHDV biocides in use by land managers.		

Table 15: Additional Investment Costs for Full Registration and Approval of a RHDV2 Biocide – With Additional Non-Target Species Testing, No Nationally Coordinated Release

Year (ended 30 June)	**Additional Costs (nominal $s)**	**Cost Category**
2023	$1,500,000	Additional non-target species testing RD&E
2024	$1,500,000	Additional non-target species testing RD&E
2025	$1,500,000	Additional non-target species testing RD&E
2026	$50,000	APVMA registration fees (total of $100,00 over 18 months)
2027	$550,000	APVMA registration fees and first year of community consultation and government approval process
2028	$500,000	Community consultation and government approval process
2029	$500,000	Community consultation and government approval process
Total additional costs to register and release a RHDV2 biocide	**$6,100,000**	
Other costs from 2030	$175,000 per annum	Costs incurred by land managers – based on an average annual supply of approximately 800 vials at $220 per vial including postage
Note: Based on evidence from the release of RHDV1-K5 it was assumed that a RHDV2 biocide would largely replace other RHDV biocides in use by land managers.		

Summary of Assumptions

The following sections briefly summarise the specific assumptions used in the RHDV2 no national release expenditure comparison analysis.

Baseline Assumptions: Current and Future Rabbit Impact Costs without RHDV2 Biocide

Table 16 below shows the baseline data and assumptions used to estimate the current and future impact and control costs of pest rabbits in Australia from 2014/15 onward. These assumptions establish the baseline rabbit impact and controls costs where no additional investment is made to release a registered and approved RHDV2 biocide.

Table 16: Assumptions Used to Estimate the Baseline Current and Future Impact Costs of Rabbits Without Additional Investment to Register and Release a RHDV2 Biocide

Variable	Assumption	Source/Notes
Baseline data on rabbit impact and control costs		
Estimated average annual impact costs of rabbits on agricultural production (livestock only: wool, sheep meat, and beef) - Prior to incursion of RHDV2 and release of RHDV1-K5	$216.63 million (2013/14-dollar terms)	McLeod (2016)
Estimated average annual control costs for rabbits	$20 million (1999/2000-dollar terms)	Bomford & Hart (2002) - also reported in Gonget al., (2009) and McLeod (2016)
Estimated distribution of impact and control costs by rainfall zone		
High Rainfall Zone (HRZ)	38.6%	Derived from impact cost distribution data in '*Prospective economic assessment of investment in importation of new Rabbit Haemorrhagic Disease Virus (RHDV) strains for rabbit biocontrol*' (Agtrans Research, 2011)
Wheat-Sheep Zone (WSZ)	29.1%	
Pastoral Zone (PaZ)	32.3%	
Average annual rabbit impact and control costs by rainfall zone updated to 2021/22-dollar terms - PRIOR to detection of RHDV2 and release of RHDV1-K5		
Impact Costs - agricultural production (livestock)		
HRZ	$98.55 million p.a.	Updated to 2021/22-dollar terms using relevant Australian Bureau of Statistics (ABS) Implicit Price Deflators for Gross Domestic Product (GDP)
WSZ	$74.30 million p.a.	
PaZ	$82.47 million p.a.	
Total impact costs (production)	$255.31 million p.a.	
Impact Costs - control costs		
HRZ	$14.50 million p.a.	
WSZ	$10.93 million p.a.	
PaZ	$12.13 million p.a.	
Total impact costs (control)	$37.57 million p.a.	
Estimated impact costs (production losses and control costs) given endemic RHDV2 variants and release of RHDV1-K5 by rainfall zone (2014/15 onwards)		
Impact Costs - agricultural production (livestock)		
HRZ	$39.37 million p.a.	Based on data and assumptions in Hardaker & Chudleigh (2020) with an average mortality of 60% for endemic RHDV2 and 13.9% for RHDV1-K5 biocide based on box trial. Note: there was not assumed to be any different in average mortality across the different agricultural zones.
WSZ	$29.68 million p.a.	
PaZ	$32.95 million p.a.	
Total impact costs (production)	$102.00 million p.a.	
Impact Costs - control costs		
HRZ	$5.79 million p.a.	
WSZ	$4.37 million p.a.	
PaZ	$4.85 million p.a.	
Total impact costs (control)	$15.01 million p.a.	

		Updated to 2021/22-dollar terms using relevant ABS Implicit Price Deflators for GDP. Assumes endemic RHDV2 and ongoing use of RHDV1-K5 as a localised biocide that does not spread naturally.
First year of combined maximum impact of new biocontrol (RHDV2 and RHDV1-K5)	2018/19	Based on detection and spread of RHDV2 in Australia in from approximately 2014/15 and release of RHDV1-K5 in 2016/17.
Period of stable impact with endemic RHDV2 and tactical use of RHDV1-K5	10 years from maximum spread of RHDV2 in 2017/18 (to 2026/27)	Analyst assumption - consistent with Hardaker & Chudleigh (2020)
Increase in rabbit populations and associated total impact costs after stable impact ends (because of increases resistance/immunity in wild rabbit populations)		
Average annual increase in rabbit populations and associated impact and control costs	46% p.a.	Dave Ramsey, pers. comm., 2022 (report in press)
Maximum potential annual rabbit impact costs with no additional new interventions	100% of 2013/14 levels	Analyst assumption after consultation with rabbit biocontrol experts – assumes rabbit numbers will never again reach pre-RHDV1 levels given ongoing management practices

Assumptions for Estimating the Potential Expected Net Benefits of a RHDV2 Biocide

Table 17 below shows the assumptions used to estimate the potential expected net benefits of the release and ongoing application of a registered RHDV2 biocide for rabbit control in Australia. These assumptions then were underpinned by the investment cost scenarios described in Table 14 and Table 15 for the analysis.

Table 17: Assumptions for Estimating the Potential Expected Net Benefits of a Registered RHDV2 Biocide for Rabbit Control in Australia

Variable	Assumption	Source/Notes
With RHDV2 biocide registration		
Area of Australia inhabited by pest rabbits	5.3 million square kilometres	https://www.dpi.nsw.gov.au/biosecurity/vertebrate-pests/pest-animals-in-nsw/rabbits/rabbit-biology
Area of land benefiting from release of RHDV2 biocide – first year – coordinated national release	Approximately 94,200 square kilometres	Analyst assumption – based on a nationally coordinated release of 1,600 vials of RHDV2 biocide, equivalent to approximately 1,200 releases, with a localised impact and 5km effective radius (based on the RHDV1-K5 national release where approximately ~600 additional vials were supplied leading to approximately double the rabbit affected area targeted by typical annual biocide use)
Proportion of rabbit impacted area potentially benefiting from the release of RHDV2 as a tactical biocide – first year – nationally coordinated release	1.78% in year one (initial release)	= 94,200 / 5,300,000
Area of land benefiting from release of RHDV2 biocide – subsequent years – ongoing use by land managers	Approximately 47,100 square kilometres	Analyst assumption - based on average annual supply of approximately 800 vials of RHDV2 biocide (replacing RHDV1-K5 use) equivalent to approximately 600 releases with a localised impact and 5km effective radius
Proportion of rabbit impacted area potentially benefiting from the release of RHDV2 as a tactical biocide – subsequent years – ongoing biocide use by land managers	0.89% per annum from year two	= 47,100 / 5,300,000
First year of impact – no nationally coordinated release	2026/27 (no additional non-target species testing) 2029/30 (with additional non-target species testing)	See Table 14 and Table 15
Reduction in rabbit impact costs due through application of a RHDV2 biocide	19.6%	Based on box trial data indicating an average mortality rate of 19.6% for RHDV2 regardless of underlying rabbit population RHDV immune status (P. Taggart and T. Strive, pers. comm., 2022). Note: there was not assumed to be any different in average mortality across the different agricultural zones.
Other Factors		

Probability of output (successful full registration of a RHDV2 biocide)	90%	Analyst assumption – allows for uncertainty and exogenous factors that may affect realisation of impact (e.g., global COVID-19 pandemic). Further, the probability of impact allows misuse of rabbit biocide products by land managers based on evidence that approximately half of all RHDV supply (47%) occur at the wrong time of year
Probability of outcome (adoption/use of RHDV2 biocide at levels assumed)	90%	
Probability of impact (given adoption at level assumed)	50%	
Attribution of benefits to additional investment (assumes no nationally coordinated release)	17.4% (no additional non-target species testing) 44.5% (with additional non-target species testing)	Estimated based on the additional investment costs relative to the total investment including sunk RD&E costs (see Table 1, Section 4.2.1)

Results

All benefit and cost cash flows were expressed in 2021/22-dollar terms and were discounted to the year 2021/22 (year of evaluation) using a 5% discount rate. The discounted benefit and cost cash flows, termed the PVB and the PVC, then were used to estimate investment criteria including the NPV, BCR, IRR and MIRR for the additional investment required to achieve a fully registered, approved and nationally released RHDV2 biocide. The MIRR was estimated using a 5% reinvestment rate.

The base analysis used the best estimates of each variable, notwithstanding a high level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the first year of additional investment assumed (2022/23).

Investment Criteria

Table 18 and Table 19 show the investment criteria for potential investment in development and implementation of a fully registered RHDV2 biocide without a nationally coordinated release for the 'no additional non-target species RD&E' and 'with additional non-target species RD&E' respectively.

Table 18: Investment Criteria for Development and Implementation of an RHDV2 Biocide with No Nationally Coordinated Release and No Requirement for Additional Non-Target Species RD&E (Total Investment, 5% Discount Rate)

Investment criteria	**Number of years from first year of investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.04	0.22	0.38	0.51	0.61	0.69
Present value of costs ($m)	0.00	1.39	1.39	1.39	1.39	1.39	1.39
Net present value ($m)	0.00	-1.35	-1.17	-1.01	-0.88	-0.78	-0.70
Benefit-cost ratio	0.00	0.03	0.16	0.28	0.37	0.44	0.50
Internal rate of return (%)	n.c.	n.c.	neg.	neg.	neg.	neg.	neg.
MIRR (%)	n.c.	neg.	neg.	neg.	neg.	neg.	0.7%

n.c.: not calculable; neg.: negative

Table 19: Investment Criteria for Development and Implementation of an RHDV2 Biocide with No Nationally Coordinated Release and With Additional Non-Target Species RD&E (Total Investment, 5% Discount Rate)

Investment criteria	**Number of years from first year of investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.00	0.33	0.60	0.82	0.99	1.12
Present value of costs ($m)	0.00	4.56	5.29	5.29	5.29	5.29	5.29
Net present value ($m)	0.00	-4.56	-4.96	-4.68	-4.47	-4.30	-4.16
Benefit-cost ratio	0.00	0.00	0.06	0.11	0.16	0.19	0.21
Internal rate of return (%)	n.c.	n.c.	neg.	neg.	neg.	neg.	neg.
MIRR (%)	n.c.	neg.	neg.	neg.	neg.	neg.	neg.

n.c.: not calculable; neg.: negative

Discussion and Conclusions

The additional scenario analysis of the investment to develop, register and implement an RHDV2 biocide without expenditure on a nationally coordinated showed that, in the best case scenario of no additional non-target species RD&E required, had negative investment criteria at 30 years from the first year of investment.

In the 'no additional non-target species testing' scenario, the total expected net benefits were estimated at $0.69 million (present value terms) with a present value of investment costs estimated at $1.39 million. This gave a NPV of -$0.7 million and a BCR of 0.50 to 1. Alternatively, in the 'with additional non-target species testing' scenario, the total expected net benefits were estimated at $1.12 million (present value terms) with a present value of investment costs estimated at $5.29 million. This scenario had a NPV of -$4.16 million and a BCR of 0.21 to 1.

The results of the additional scenario analyses that assessed the potential net benefits of investment in the registration and implementation of a RHDV2 biocide without a nationally coordinated release support the main analysis findings. Based on the assumptions used, the total investment required to register a legal RHDV2 biocide and the risks associated with the pathways to impact result in negative investment criteria and are unlikely to generate significant benefits or a positive return on investment in the medium- to long-term.