Benefit Cost Analysis of Wine Australia R&D Investments 2020-21

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Prepared by:

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Executive Summary

Economic analyses of three research and development (R&D) projects funded by Wine Australia has been undertaken. The main purpose was to demonstrate the outcomes and benefits that have emerged or are likely to emerge from investment. This forms part of the process for the Council of Rural Research & Development Corporations (CRRDC) that aims to demonstrate the impact, effectiveness and return on investment from the Rural Research and Development Corporations. Wine Australia is funded by statutory levies paid by industry participants, with matching funding provided by the Australian Government up to 0.5 per cent of the industry's gross value of production.

Each of the three analyses provides a description of the constituent projects including objectives, outputs, activities, costs, outcomes, and benefits. Benefits are described qualitatively according to their contribution to the triple bottom line of economic, environmental, and social benefits. While a range of potential benefits of each project are identified, the analysis focused on the most likely and most significant benefit stream. A number of potential benefits therefore remained unquantified and hence the estimated net benefits of some projects may be considered conservative. The analyses were undertaken for total benefits and Wine Australia benefits, including those expected in the future as a result of the investment.

Investment in all three projects yielded positive results at a 5% discount rate and a 30 year analysis period.

Table ES1: Benefit Cost Analyses Three Wine Australia R&D Investments 2020-21 (discount rate 5%)

<table>
<tr><th rowspan="2">Investment Criteria</th><th colspan="3">Investment Project</th></tr>
<tr><th>New techniques for yield, crop condition, and quality estimation (CSA 1602</th><th>Managing the impact of vintage advancement and compression (AWR 1701-4.1.1)</th><th>Integrated management of established grapevine phylloxera (DED 1701)</th></tr>
<tr><td>Benefit–cost ratio</td><td>4.83</td><td>5.80</td><td>5.46</td></tr>
<tr><td>Benefit-cost ratio range - core assumption sensitivity</td><td>1.21 to 13.21</td><td>2.84 to 13.87</td><td>3.29 to 9.54</td></tr>
<tr><td rowspan="2">Quantified benefits</td><td>Grape grower profit increase with accurate yield, condition, and quality forecasts.</td><td>Avoided loss of quality and revenue from wine made with grapes containing elevated sugars.</td><td rowspan="2">Reduction in the rate of spread and cost of phylloxera management in the Phylloxera Infestation Zones and the Phylloxera Risk Zones (avoided replant and production loss costs).</td></tr>
<tr><td>Wine maker profit increase with accurate yield, condition, and quality forecasts.</td><td>Avoided loss of grape grower revenue from grapes with elevated sugars.</td></tr>
<tr><td rowspan="4">Unquantified benefits</td><td rowspan="2">Supply chain efficiencies with winery customers assured of the quality and quantity of wine available for sale.</td><td rowspan="2">Avoided increase in chemical inputs for the treatment of low acid ferments associated with high-sugar grapes. With less chemical use there is both a cost saving and less risk of damage to the winery environment.</td><td>Movement towards more environmentally benign phylloxera disinfestation (Dettol rather than bleach).</td></tr>
<tr><td>Improved workplace OHS and a reduction in uncertainty/anxiety associated with phylloxera infestation, in all grape growing regions.</td></tr>
<tr><td>Increased transport efficiency and coordination with wineries enabling space and energy to be saved.</td><td>New scientific knowledge in relation to wine making and new wine maker skills in dealing with high sugar fruit.</td><td rowspan="2">A more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).</td></tr>
<tr><td>Additional sensor, imaging, radar, ‘big data’ analysis and algorithm development skills</td><td>Health – increased availability and consumption of flavoursome, moderate alcohol wines.</td></tr>
</table>

	for use in the Australian wine industry and other Australian industries.		
	A dataset available for future wine industry research.		
	When accurate yield, composition, and condition forecasts are available there should be less anxiety due to earlier and better certainty of pricing and income.		
	A more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).		

Comparisons between project results should be made with caution due to uncertainties involved with assumptions and differing frameworks for each of the analyses.

Technical Summary

This report presents the results of economic analyses of investments within the R&D Program of Wine Australia. The Program is funded by statutory levies paid by industry participants, with matching funding provided by the Australian Government up to 0.5 per cent of the industry's gross value of production.

The main purpose of undertaking the analyses was to demonstrate the outcomes and benefits that have emerged or are likely to emerge from investments. This forms part of the process for the Council of Rural Research & Development Corporations (CRRDC) that aims to demonstrate the impact, effectiveness and return on investment of the Rural Research and Development Corporations.

Wine Australia provided AgEconPlus with a list of the completed projects which the analyst numbered 1 to 8. An online random number generator was used to select projects. The results of random project selection is shown in Table 1.

Table 1 Projects Randomly Selected for Benefit Cost Analysis 2020-21

No.	Code	Project Title	Investment
1	CSA 1602	New non-destructive technologies for simultaneous yield, crop condition and quality estimation	$1,317,585#
4	AWR 1701-4.1.1	Managing the impact of vintage advancement and compression	$275,080
5	DED 1701	Integrated management of established grapevine phylloxera	$895,493
		Investment in projects for analysis	$2,488,158
		Total of Wine Australia investment in completed projects	$4,816,432
		Analysis projects share of total investment	52%

includes RRND4P funds managed by Wine Australia

Documentation for each of these projects was assembled with assistance from Wine Australia personnel and included project applications, contract schedules and final reports. Each of the analyses provides a description of the constituent projects including objectives, outputs, activities, costs, outcomes, and benefits. Benefits are described qualitatively according to their contribution to the triple bottom line of economic, environmental, and social benefits. While a range of potential benefits of each project are identified, the analysis focused on the most likely and most significant benefit stream. A number of potential benefits therefore remained unquantified and hence the estimated net benefit of some projects may be considered conservative.

Benefit cost analysis was conducted on the three projects to generate investment criteria. The Present Value of Benefits (PVB) and Present Value of Costs (PVC) were used to estimate investment criteria of Net Present Value and Benefit-Cost Ratio (BCR) at a discount rate of 5%. The Internal Rate of Return and Modified Internal Rate of Return were also estimated from the annual net cash flows. The PVB and PVC are the sums of the discounted streams of benefits and costs. All dollar costs and benefits were expressed in 2021 dollar terms. Future costs and benefits were discounted to the 2021 year while past costs were inflated to 2021 using the Gross Domestic Product deflator. A 30-year benefit time frame was used in all analyses, with benefits estimated for 30 years from the year of last investment in each project. Costs for the R&D projects included cash contributions (includes both Wine Australia and industry investment), as well as any other resources contributed by third parties (e.g., researchers or additional industry funds). Investment criteria were reported for 5 year intervals of benefits from zero to 30 years.

The analyses were undertaken for total benefits, including benefits expected in the future as a result of the investment. A degree of conservatism was used when finalising assumptions.

Sensitivity analysis was undertaken for several assumptions that had the greatest degree of uncertainty or for those that were seen to be key drivers of the investment criteria.

Table 2 presents the investment criteria for each of the projects analysed at a 5% discount rate and expressed in 2021 dollar terms. Given the assumptions made for each evaluation, all three investments are expected to produce positive net benefits over 30 years from the last year of investment.

Table 2: Benefit Cost Analyses for Three Wine Australia R&D Investments 2020-21 (discount rate 5%)

<table>
<tr><th rowspan="2">Investment Criteria</th><th colspan="3">Investment Project</th></tr>
<tr><th>New techniques for yield, crop condition, and quality estimation (CSA 1602)</th><th>Managing the impact of vintage advancement and compression (AWR 1701-4.1.1)</th><th>Integrated management of established grapevine phylloxera (DED 1701)</th></tr>
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	A more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).		

1. Introduction

This report presents the results of economic analyses of investments within the R&D Program of Wine Australia. The Program is funded by statutory levies paid by industry participants, with matching funding provided by the Australian Government up to 0.5 per cent of the industry's gross value of production.

The main purpose of undertaking the analyses was to demonstrate the outcomes and benefits that have emerged or are likely to emerge from investments made in the program. This forms part of the process for the Council of Rural Research & Development Corporations (CRRDC) that aims to demonstrate the impact, effectiveness and return on investment from the Rural Research and Development Corporations.

Three R&D projects were randomly selected by AgEconPlus for evaluation.

Ascertaining the extent of benefits that have accrued as a result of the program investment can demonstrate to stakeholders such as levy payers, the impact of research investment. In addition, it can inform Wine Australia management regarding program performance from past investment decisions as well as for future allocation of program resources.

A summary of methods used in the analysis, is provided in Section 2, including the process of project selection and the steps involved with individual benefit evaluation. Section 3 reports a summary of the benefits and of the investment criteria estimated for the three projects. A brief conclusion is provided in Section 4. Appendices 1 to 3 provide the detailed analyses for each of the projects.

2. Materials and Methods

2.1 Projects for Evaluation

Wine Australia provided AgEconPlus with a list of the completed projects which the analyst numbered 1 to 8. An online random number generator was used to select three projects. The results of random project selection are shown in Table 2.1.

Table 2.1 Projects Randomly Selected for Benefit Cost Analysis 2020-21

No.	Code	Project Title	Investment
1	CSA 1602	New non-destructive technologies for simultaneous yield, crop condition and quality estimation	$1,317,585#
4	AWR 1701-4.1.1	Managing the impact of vintage advancement and compression	$275,080
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		Investment in projects for analysis	$2,488,158
		Total of Wine Australia investment in completed projects	$4,816,432
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includes RRND4P funds managed by Wine Australia

2.2 Individual Analyses

Each investment was evaluated through the following steps:

1. Information from the original project application, revised schedule and final report or other relevant reports and material was assembled with assistance from Wine Australia.
2. An initial description of the project background, rationale, objectives, activities, outputs and expected outcomes and impacts was drafted.
3. Initial drafts were forwarded to project principal investigators, members of any project steering committees, industry representatives, and Wine Australia personnel for comment.
4. Initial drafts were modified in light of stakeholder feedback.
5. Further information was assembled where appropriate, including from contact with industry representatives, and the quantitative analysis undertaken.
6. Some analyses proceeded through several drafts, both internally within the project team as well as externally via Wine Australia personnel and others.
7. Final drafts were passed to Wine Australia personnel for comment.

The potential benefits from each investment were identified and described in a triple bottom line context. The value of some of these benefits was then quantified.

The factors that drive the investment criteria for R&D include:

- The cost of the R&D.
- The magnitude of the net benefit per unit of production affected; this net benefit per unit also takes into account the costs of implementation.
- The quantity of production affected by the R&D, in turn a function of the size of the target audience or area, and the level of initial and maximum adoption ultimately expected, and level of adoption in the intervening years.
- The discount rate.
- The time elapsed between the R&D investment and commencement of the accrual of benefits.
- The time taken from first adoption to maximum adoption.
- An attribution factor can apply when the specific project or investment being considered is only one of several pieces of research or activity that has contributed to the outcome being evaluated.

It is also necessary when quantifying benefits to define a 'without R&D' scenario, referred to as the 'counterfactual'. The counterfactual usually lies somewhere between the status quo or business as usual case and the more extreme positions that the research would have happened anyway but at a later time; or the benefit would have been delivered anyway through another mechanism. The important issue is that the definition of the counterfactual scenario is made as consistently as possible between analyses.

Benefit cost analysis was conducted on all projects to generate investment criteria. The Present Value of Benefits (PVB) and Present Value of Costs (PVC) were used to estimate investment criteria of Net Present Value and Benefit-Cost Ratio (BCR) at a discount rate of 5%. The Internal Rate of Return and Modified Internal Rate of Return were also estimated from the annual net cash flows. The PVB and PVC are the sums of the discounted streams of benefits and costs. All dollar costs and benefits were expressed in 2021 dollar terms. Future costs and benefits were discounted to the 2021 year while past costs were inflated to 2021 using the Gross Domestic Product deflator. A 30-year benefit time frame was used in all analyses, with benefits estimated for 30 years from the year of last capital investment in each project. Costs for the R&D projects included the cash contributions of the Project (includes both Wine Australia and industry

investment), as well as any other resources contributed by third parties (e.g., researchers or additional industry funds). Investment criteria were reported for 5 year intervals of benefits from zero to 30 years.

The analyses were undertaken for total benefits, including benefits expected in the future as a result of the investment. A degree of conservatism was used when finalising assumptions.

Sensitivity analysis was undertaken for several assumptions that had the greatest degree of uncertainty or for those that were seen to be key drivers of the investment criteria.

Some identified benefits were not quantified mainly due to:

- A suspected, weak, or uncertain scientific or causal relationship between the research investment and the actual R&D outcomes and associated benefits; and/or
- The magnitude of the value of the benefit was thought to be only minor.

3. Summary of Results

3.1 Qualitative Results

Table 3.1 identifies the benefits from investment in each of the projects. Each benefit is categorised as economic, environmental, or social.

Table 3.1: Summary of Benefits for the Three Projects

Project	Benefits
New non-destructive techniques for simultaneous yield, crop condition, and quality estimation (CSA 1602)	Economic • Grape grower additional profit with accurate yield, composition, and condition forecasts. • Wine maker efficiencies with accurate yield, composition, and condition forecasts which in turn result in improved profit. • Supply chain efficiencies with winery customers assured of the quality and quantity of wine available for sale, Environmental • Increased transport efficiency and coordination with wineries enabling fermentation space to be optimised and energy to be saved. Social • Capacity – additional research skills including sensors, imaging, radar, 'big data' analysis and algorithm development. • Capacity – a dataset available for future wine industry research. • When accurate yield, composition, and condition forecasts are available there should be less anxiety due to earlier and better certainty of pricing and income. • A more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).
Managing the impact of vintage advancement and compression (AWR 1701-4.1.1)	Economic • Avoided loss of wine quality and revenue from wine made with grapes containing elevated sugars. • Avoided loss of grape grower revenue from grapes with elevated sugars. Environmental • Avoided increase in chemical inputs for the treatment of low acid ferments associated with high-sugar grapes. With less chemical use there is both a cost saving and less risk of damage to the winery environment. Social • Capacity – new scientific knowledge in relation to wine making and new wine maker skills in dealing with high sugar fruit.

	• Health – increased availability and consumption of flavoursome, moderate alcohol wines. • A more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).
Integrated management of established grapevine phylloxera (DED 1701)	<u>Economic</u> • Reduction in the rate of spread and cost of phylloxera in the Phylloxera Infestation and Phylloxera Risk Zones (avoided replant and production loss costs). <u>Environmental</u> • Movement towards more environmentally benign phylloxera disinfestation (Dettol rather than bleach). <u>Social</u> • Capacity – growers, researchers, and regulators with new phylloxera detection and management skills. • Health – improved workplace OHS and a reduction in uncertainty/anxiety associated with phylloxera infestation, in all grape growing regions. • A more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).

3.2 Quantitative Results

The investment criteria calculated for each research area were the Net Present Value (NPV), the Benefit Cost Ratio (B/C Ratio), the Internal Rate of Return (IRR) and the Modified IRR (MIRR). The NPV is the difference between the Present Value of Benefits (PVB) and the Present Value of Costs (PVC). Present values are the sum of discounted streams of benefits and/or costs. The B/C Ratio is the ratio of the PVB to the PVC. The IRR is the discount rate that would equate the PVB and the PVC, thus making the NPV zero and the B/C Ratio 1:1. The MIRR is the same as the IRR but assumes that the reinvestment rate is the same as the assumed discount rate i.e. 5%, rather than the level of the estimated IRR.

Table 3.2 presents the investment criteria for each of the project investments analysed at a 5% discount rate.

Further details on each of these investments and the associated results are provided in the individual project reports (Appendices 1 to 3).

Table 3.2: Investment Criteria for Three Wine Australia Investments (discount rate 5%, 30 years from last year of investment)

Investment Criteria	Investment Project		
	New techniques for yield, crop condition, and quality estimation (CSA 1602	**Managing the impact of vintage advancement and compression (AWR 1701-4.1.1)**	**Integrated management of established grapevine phylloxera (DED 1701)**
Present value of benefits ($m)	14.35	2.19	9.33
Present value of costs ($m)	2.97	0.38	1.71
Net present value ($m)	11.38	1.81	7.62
Benefit–cost ratio	4.83	5.80	5.46
Benefit-cost ratio range - core assumption sensitivity	1.21 to 13.21	2.84 to 13.87	3.29 to 9.54
Internal rate of return (%)	14.4	19.6	23.8
Modified internal rate of return (%)	10.0	10.6	10.2

4. Conclusion

All three investment analyses yielded positive results at the 5% discount rate, with B/C Ratios of 4.83, 5.80 and 5.46.

The results from the analyses are dependent on the assumptions made, which in places are uncertain. Assumptions and frameworks could be refined in the future as research outputs are realised, to improve the overall analysis. Comparisons between project results should be made with caution due to uncertainties involved in assumptions and differing frameworks for each of the three analyses.

Appendix 1: Economic Analysis Wine Australia's Investment in New Non-destructive Techniques for Simultaneous Yield, Crop Condition and Quality Estimation

1. Background

Accurate yield estimation is a key part of horticultural production, with supply chains and fruit value significantly impacted when production volume doesn't match expectations. The wine industry is no different in this respect, with everything from winery intake planning to sales reliant on estimated yield. Wine grape pricing is also reliant on the yield of a variety, especially in the warm inland regions. Improved regional estimates on a variety basis would provide an improved basis on which to set pricing, with the adoption of technology allowing this information to be provided earlier than is currently feasible (Alex Sas, Senior RD&E Program Manager, Wine Australia, pers. comm., February 2022).

Current yield estimates rely on the experience of the vineyard manager, are labour intensive and typically have an error rate of up to 30%. Most cost is associated with sampling labour, yield loss to sampling is less significant (Ashley Keegan, FABAL Group, pers. comm., November 2021). Improvements in yield prediction and estimation offer significant value to the industry.

More than any other perennial crop, the commercial value of winegrapes depends on fruit composition (e.g., brix, acid, colour), with the same variety fetching a ten-fold difference in price depending on its quality[1]. Objective assessment of fruit quality is, therefore, paramount. If objective assessment of quality can be completed in the field prior to harvest and transport, winery planning can be optimised, potential points of friction between the grower and the winemaker can be minimised, and additional opportunities made available to produce fruit of a desired specification. Similarly, accurate and objective pre-harvest assessment of crop condition (e.g., disease status, sunburn, berry shrivel) would minimise winery rejection and provide the best opportunity for a profitable harvest.

With the recent revolution in low cost sensors and data analytics, together with the prevalence of online computing infrastructure suitable for 'big data' analysis, there is opportunity to provide grape growers with cost-effective tools to predict inter-seasonal variation in yield from early in the season, to monitor fruit ripening and quality during maturation, and to estimate yield and fruit condition prior to harvest. Furthermore, these tools could be based on whole vineyard assessments using non-destructive measurements, rather than few, small, labour intensive, destructive samples.

A project to investigate non-destructive, non-contact technologies for estimating yield, crop composition, and condition was part of a suite of eight sub-projects managed by Wine Australia with funding support from the Australian Government's Rural R&D for Profit (Rural R&D4P) Program.

2. Summary of Projects

Table 2.1 provides a description of the project in a logical framework.

[1] In this analysis 'grape quality' refers to grape composition (Baume and acid), or integrity (fruit damage, disease level etc), in relation to standards in a grape purchase agreement, and not the final wine quality (Murray Leake, Group Viticulturalist, Shaw & Smith, pers. comm., November 2021).

Table 2.1 Project Description

CSA 1602: New Non-destructive Techniques for Simultaneous Yield, Crop Condition and Quality Estimation	
Project Details	Research Organisation: CSIRO Agriculture and Food Period: July 2016 to March 2020 Principal Investigator: Everard Edwards
Rationale	This project was established to develop and test new non-destructive, non-contact technologies for yield prediction, monitoring of fruit composition and in-field estimation of fruit condition for the benefit of both the grape grower and the wine maker. Colour digital video, stereo, and hyperspectral imaging (HSI), and low power radar were all used to collect in-field data for yield prediction to measure grape composition and quality, at commercial vineyards. It was anticipated that results from a successful project would be equally applicable to both high value 'iconic' vineyards and higher yielding vineyards found in warm irrigated areas.

Objectives	The objectives of the project were:
	• To evaluate new vineyard methods and sensors for the collection of
	  • yield data from vineyards using novel imaging hardware (FoPEN and 3D stereo imaging) at different time points prior to harvest, and
	  • bunch condition and quality data (digital imaging and HSI).
	• To develop and evaluate new data analysis pipelines and algorithms for
	  • rapid feature extraction to identify bunches and inflorescences to determine their number and estimate volume for yield estimation, and
	  • identification of spectral signatures and features that provide a quantitative estimate of bunch condition (fruit damage (shrivel) & disease) and berry composition (Brix, colour, acid).

Activities and Outputs	• Formation of an Industry Reference Group with representation from viticulture management companies including FABAL Group, Pridham Viticulture, and Shaw & Smith as well as Pernod Ricard. • Project commencement meeting with industry collaborators and CSIRO staff. Industry collaborators were recruited from Accolade Wines, Rymill and Wingara Wine Group. CSIRO staff assigned to the project included individuals with expertise in viticulture, sensors, robotics, computer science, quantitative image analysis, and hyperspectral signature identification. The project commencement meeting was used to identify trial sites in commercial vineyards. • Sensory equipment was purchased, and engineering work undertaken to mount sensors on vineyard vehicles. A small trial was completed using existing CSIRO sensors (3D stereo imaging, radar, and hyperspectral imaging) to collect preliminary data for analysis. • Year 2, 3 and 4 of the project were used to collect data from vineyards using sensors. The data was analysed and validated. Each year improvements were made to sensors, hardware, data collection methods, software, and analysis techniques using results from the previous year. • For yield information, data at multiple points during the growing season (pre-flowering to harvest) was collected. Radar that can see through canopy foliage was tested in different configurations and mount positions to determine the optimum set up for data collection. Ground-truthing was used to validate yield estimates.

	• The data collected on fruit condition and quality measures using hyperspectral imaging was validated by industry standard measures for estimating bunch condition with chemical analysis of the berries completed with an FTIR OenoFOSS machine to measure brix and acid levels. Colour (anthocyanin) levels were measured spectrophotometrically using a standard CSIRO approach (developed by Sommers and Evans). Fruit from vineyards and glasshouse grown material were used to develop spectral libraries. • The lab-based hyperspectral imaging system used to develop detailed calibrations of fruit composition (quality) was trailed as a field device. A cheaper and more robust field system was also developed using dual point-spectrometers and the same data analytics. • Bespoke data-processing capabilities were developed to produce grower relevant data from the sensor outputs. • The project demonstrated the viability of using colour digital video and machine learning to count inflorescences at scale in the vineyard and thereby provide a yield prediction shorty after budburst. The same method works reliably for bunch counting on green or red grapes but needs further optimisation for vineyards with heavier canopies. Low-power radar was able to detect fruit irrespective of canopy, but its ability to reliably quantify fruit mass still needs to be demonstrated. • Hyperspectral data analytics were able to accurately quantify key fruit maturity and quality parameters such as sugar content and total organic acids, across a broad range of wine grape varieties and fruit development stages but estimates of berry nitrogen parameters were only effective on a per genotype basis. Although the calibrations were lab-based, their use with field imaging was demonstrated and field devices to collect the relevant data developed and trialled. • Further significant investment is required to determine the commercial potential of the technology assessed in the project. Further investment would include a multi-region trial at significant cost (Philip Deverell, National Technical Manager, Pernod Ricard, pers. comm., November 2021). RGB video+ML cost unknown. Inflorescence counting could be integrated and optimised in a few weeks of a suitable person's time, including the work underway in later timepoints extending to the whole of season. To deal with the occlusion problem and accurate bunch mass estimation could be $0.5 million or more, depends how broad an industry application is required. Radar is still unproven, perhaps $100-220k to prove quantification and excluding commercial production. Spectral work maybe $250k+ to get to a potential commercialisation point. (Everard Edwards, CSIRO Principal Investigator, pers. comm., December 2021).
Outcomes	• Progress toward delivery of a suite of digital tools that can more accurately and cost-effectively predict vineyard yield, fruit composition, and quality. • A strategic resource (technologies and skilled individuals) for future grape and wine research. Applications may include disease management, nutrition, spraying, and spatial analysis.

Impacts (potential)[2]	• Economic – progress toward grape growers using accurate yield, composition, and condition forecasts to improve decision-making and achieve higher profit levels. Additional profit may be associated with volume and quality better tailored to winery requirements, regional forecasts assisting with price setting, avoided costs associated with disagreement with wineries on wine grape value, labour cost savings, the creation and use of vineyard benchmarking data and minor cost savings associated with subjective and destructive vineyard sampling (any increase in profit will be net of costs associated with new project-generated technology adoption). • Economic – progress toward wine makers receiving expected grape qualities and quantities from growers using accurate yield, composition, and condition forecasts with resulting profit improvements. Additional profit may be associated with the opportunity to produce more wine that meets market requirements, avoided costs associated with disagreement with grape growers on wine grape value, and cost savings associated with more efficient use of winery capital equipment and labour. • Economic – progress toward supply chain efficiencies with winery customers assured of the quality and quantity of wine available for sale. Supply chain efficiencies might include improved planning and more efficient and profitable sales programs. • Environmental – when accurate and early forecasts of yield, composition, and condition are available, they will allow increased transport efficiency and coordination with wineries, enabling fermentation space to be optimised and energy to be saved. Energy savings will help reduce the industry's carbon footprint and GHG emissions. • Capacity – additional research skills including sensors, imaging, radar, 'big data' analysis and algorithm development for use in the Australian wine industry and other Australian industries. • Capacity – a dataset available for future wine industry research (NB: growers note the need to consider unintended market consequences of asymmetry of knowledge and the potential for that information to negatively impact on the market and grower's ability to negotiate – Ashley Keegan, FABAL Group, pers. comm., November 2021[3]). • Social – when accurate yield, composition, and condition forecasts are available there should be less anxiety due to earlier and better certainty of pricing and income. • Social – when accurate yield, composition, and condition forecasts are available and applied, they will add to industry confidence, investment certainty, income, and employment in regional Australia (spill-over impact).

[2] If followed through and taken up by the wine industry the labour savings associated with this project's outputs would be substantial and results far more accurate if the system works. Less contractual disputes are also likely. This technology has potential for most other horticultural sectors and may be adapted to grains (Ben Pridham, Proprietor Pridham Viticulture, pers. comm., December 2021).

3 The point is valid, but the ACCC's recent report into the sector implies that the asymmetry already exists. The availability of regional crop estimates – especially in the inland regions – may be of benefit to all (Alex Sas, Senior RD&E Program Manager, Wine Australia, pers. comm., March 2022).

3. Match with Government Priorities

Table 3.1 Strategic Science/Research Priorities and Rural R&D Research Priorities

Australian Government	
Strategic Science/Research Priorities	**Rural R&D Priorities**
1. **Food** – optimising food and fibre production and processing, agricultural productivity and supply chains within Australia and global markets 2. **Soil and water** – improve use of soil and water resources, both terrestrial, marine 3. **Transport** – moving essential commodities, alternative fuels, lowering emissions. 4. **Cybersecurity** – for individuals, businesses, government, national infrastructure 5. **Energy** – improve efficiency, reduce emissions and integrate diverse sources into the grid. 6. **Resources** – support exploration traditional resources, rare earths and new technologies. 7. **Advanced manufacturing** – high value and innovative industries in Australia. 8. **Environmental change** – mitigating, managing or adapting to changes. 9. **Health** – improving health outcomes for all Australians.	1. **Advanced technology**: to enhance innovation of products, processes and practices across the food and fibre supply chains through technologies such as robotics, digitalisation, big data, genetics and precision agriculture. 2. **Biosecurity**: to improve understanding and evidence of pest and disease pathways to help direct biosecurity resources to their best uses, minimising biosecurity threats and improving market access for primary producers. 3. **Soil, water and managing natural resources:** to manage soil health, improve water use efficiency and certainty of supply, sustainably develop new production areas and improve resilience to climate events and impacts. 4. **Adoption of R&D:** focussing on flexible delivery of extension services that meet primary producers' needs and recognising the growing role of private service delivery.

Source: OCS 2015 and DAWE 2021 (both checked for currency December 2021)

The Wine Australia project has addressed Strategic Science/Research Priority 1 and potentially Priorities 2, 3 and 5. The major focus of the project has been on the first of the Rural R&D Priorities.

4. Identification of Potential Costs and Benefits

4.1 Costs

4.1.1 R&D Investment

The R&D investment costs comprised:

- Direct financial outlays by Wine Australia and the Australian Government through the Rural R&D4P Program, the project funding bodies. These costs include both project and overhead expenditures.
- In-kind contributions to the research project – provided by CSIRO.
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia (project overhead costs).

4.1.2 Administration

No additional administration costs were identified.

4.1.3 Extension

The project was focussed on sensors, imaging, radar, 'big data' analysis and algorithm development, interaction was required with industry collaborators, and this was included in the project budget. The project did not produce a commercial product. Further research, development, and extension (RD&E) investment will be required to realise potential project impacts. Wine Australia advise that they will shortly release an expression of interest for potential commercialisation of this technology (Alex Sas, Senior RD&E Program Manager, Wine Australia, pers. comm., February 2022).

4.1.4 Adoption

The project has created tools for forecasting yield, composition, and condition with commercial potential. Additional RD&E investment will be required. Grape grower adoption costs may, in time, include equipment

purchase and installation (e.g., sensors), training, data collection and access costs for "cloud" processing of vineyard data.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The potential impact pathway for the project is:

1. Promising approach identified through the current project (CSA 1602).
2. Wine Australia and CSIRO assessment of project outputs for potential commercialisation with grape growers, vineyard contractors, and winemakers.
3. Favourable feedback received and follow-up projects required to deliver commercial technology for wine grape yield, composition, and condition.
4. In November 2021, CSIRO report that the organisation has continued the radar work, but it has not moved fast and is not ready for commercialisation, CSIRO have continued the RGB video + ML and this is at a point where they are starting to talk about commercialisation pathways (although various parts of it still require development/co-development). CSIRO have continued the fruit composition hyperspec work and expect that to be in a position where the organisation can consider commercialisation options in 2022 (Everard Edwards, Principal Investigator, CSA 1602, pers. comm., November 2021).
5. In time, tools such as sensors will be sold commercially, and a central 'cloud'-based data analysis and reporting system established.
6. Wine grape growers will access their analysed data through an electronic device (e.g., mobile phone) or through a service provider. Technical support and extension supplied to ensure grape grower adoption.
7. Grape growers, wine makers and the supply chain benefit from accurate yield, composition, and condition data.

4.2.2 Triple Bottom Line Benefits

A summary of potential benefits from the project in triple bottom line categories is shown in Table 4.1.

Table 4.1 Triple Bottom Line Categories Benefits from Project Investment

Levy Paying Industry	**Spillovers**		
	Other Industries	**Public**	**Foreign**
Economic Benefits			
Progress toward grape growers using accurate yield, composition, and condition forecasts to improve decision-making and achieve higher profits. Regional forecasts assisting with price setting. Progress toward wine makers receiving expected grape qualities and quantities from growers using accurate yield, composition, and condition forecasts with resultant profit improvements.	Technology developed as part of this project will be relevant to a range of agricultural industries including horticulture and grain growing.	Nil.	If industry choses to share or licence the technology, it will be relevant to overseas wine producing countries.

Progress toward supply chain efficiencies with winery customers assured of quality and quantity of wine available for sale.			
Environmental Benefits			
Accurate and early forecasts of yield, composition, and condition will allow increased transport efficiency and coordination with wineries, enabling fermentation space to be optimised and energy to be saved. Energy savings will help reduce the industry's carbon footprint and GHG emissions.	Nil	Nil	Nil
Social Benefits			
Capacity – additional skills including sensors, imaging, radar, 'big data' analysis and algorithm development for use in the Australian wine industry. Capacity – a dataset available for future industry research. When accurate yield, composition, and condition forecasts are available there should be less anxiety due to earlier and better certainty of pricing and income When accurate yield, composition, and condition data forecasts are available and applied, they will add to industry confidence, investment certainty, income, and employment in regional Australia (spill-over impact).	Capacity developed during the project may assist with production forecasting for other horticultural industries and sensor use in industries as diverse as manufacturing and environmental monitoring.	Nil	Nil

4.2.3 Public versus Private Benefits

The majority of benefits that will arise from project investment will be private in nature. The private benefits will be captured by wine grape growers, wine makers, and the supply chain. Private benefits will be realised as increased profit. Potential public benefits will include additional researcher and industry capacity, a reduction in uncertainties and anxieties regarding pricing and income, and regional spill-over benefits.

4.2.4 Distribution of Benefits along the Supply Chain

The benefits to the wine industry from investment in this project will be shared along the supply chain with wine grape growers, wine makers, wholesalers, retailers, and exporters all sharing in some of the benefits. Supply chain specific benefits may include progress toward efficiencies associated with assured quality and quantity of wine available for sale.

4.2.5 Benefits to other Primary Industries

Capacity developed during the project may assist with production forecasting tools and models for other agricultural industries including horticulture and grains.

4.2.6 Benefits Overseas

If Wine Australia and CSIRO choose to share or licence the technology, it will be relevant to overseas wine producing countries.

4.3 Summary of Costs and Benefits

A summary of principal categories of costs and benefits from the project is shown in Table 4.2.

Table 4.2 Incremental Cost and Benefit Categories

Costs	Benefits
R&D investment costs (cash and in-kind) as well as project administration costs.	Economic – grape grower additional profit with accurate yield, composition, and condition forecasts. Regional forecasts assisting with price setting.
Overhead costs including time associated with meetings between the researchers and Wine Australia.	Economic – wine maker additional profit with accurate yield, composition, and condition forecasts.
Research costs – additional investment will be required to further investigate the commercial merit of the forecasting technology as well as investment to refine sensors, 'cloud'-based tools, and delivery systems. Who bears the cost of this investment will depend on the commercialisation model adopted.	Economic – supply chain efficiencies with winery customers assured of the quality and quantity of wine available for sale.
Adoption costs incurred by wine grape growers including technology purchase, training, and use (e.g., licence fees and data collection costs). These costs will be net of any savings associated with current labour intensive yield and quality estimation expenses.	Environmental – increased transport efficiency and coordination with wineries enabling tank space to be optimised and energy to be saved.
	Capacity – additional sensor, imaging, radar, 'big data' analysis and algorithm development skills for use in the Australian wine industry and other Australian industries.
	Capacity – a dataset available for future wine industry research.
	Social - less seasonal variation in production will reduced anxiety due to earlier and better certainty of pricing and income.
	Social – a more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

Table 5.1 shows annual investment in the project by Wine Australia, the Australian Government (Rural R&D4P Program managed by Wine Australia) and CSIRO.

Table 5.1 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia	Rural R&D4P	CSIRO (in-kind)	Total
2017	229,892	113,231	229,706	572,829
2018	216,156	155,860	337,017	709,033
2019	217,141	163,808	347,802	728,751
2020	135,888	85,609	197,004	418,501
Total	**799,077**	**518,508**	**1,111,529**	**2,429,114**

Source: Data provided by Wine Australia RD&A Administrator, November 2021

5.1.2 Overhead Costs including Meetings between the Researchers and Wine Australia

Wine Australia overhead costs are in addition to those shown in the above tables and are estimated at 12%.

5.1.3 Research, Adoption and Maintenance Costs

Further research is required for the development of the yield and quality assessment technology. Using information provided by Principal Investigator Everard Edwards (pers. comm., December 2021) further research costs of between $1.5 M and $2 M are estimated[4]. Investment will then be needed to purchase and install sensors and establish the system as a centralised 'cloud'-based resource. The resource will require technical support and extension to ensure grape grower adoption. These costs are accounted for in the analysis through the application of a research benefit attribution factor – see Table 5.4 below.

5.2 Benefits

Counterfactual: in the absence of this project, there is a possibility that other research investments deliver the impacts described to this project. For example, between 2014 and 2019 Wine Australia invested in "Accurate and early yield predictions through advanced statistical modelling". Consequently, a counterfactual of 30% has been assumed i.e., it is 70% likely that potential project benefits would have been realised in the absence of project investment.

5.2.1 Grape Grower Profit Increase with Accurate Yield, Condition and Quality Forecasts

The project has delivered progress toward grape growers using accurate yield, condition, and quality forecasts to improve decision making and realising a more profitable harvest. Profit increase may be associated with volume and quality better tailored to winery requirements, avoided costs associated with disagreements with wineries on wine grape value, the creation and use of vineyard benchmarking data, and cost savings (especially labour savings) associated current subjective and destructive vineyard sampling. A long-term profit increase of 10%, realised after completion of further research, has been modelled.

5.2.2 Wine Maker Efficiencies with Accurate Yield, Condition and Quality Forecasts that in turn Result in Improved Profit

The project has delivered progress toward wine makers receiving expected grape qualities and quantities from growers using accurate yield, condition, and quality forecasts with resulting profit improvements. Additional profit may be associated with the opportunity to produce more wine that meets market requirements, avoided costs associated with disagreement with grape growers on wine grape value, and cost savings associated with more efficient use of winery capital equipment and labour. A long-term profit increase of 1%, realised after further research, has been modelled. Most of the long term profit increase associated with project technology is captured by wine grape growers.

[4] Who incurs these research costs has not been established and it may not be levy payers. Wine Australia and CSIRO are actively seeking commercial partners to take the technology further (Alex Sas, Senior RD&E Program Manager, Wine Australia, pers. comm., March 2022).

A summary of key assumptions used to quantify increased grape grower and wine maker long-term profit is summarised in Table 5.4.

Table 5.4 Summary of Assumptions

Variable	Assumption	Source
Benefit 1: Grape Grower Profit Increase with Accurate Yield, Condition and Quality Forecasts		
Wine grape grower area.	146,128 ha	AgEconPlus and Gillespie Economics (2019).
Profit on wine grape production.	$1,394/ha	AgEconPlus and Gillespie Economics (2019).
Increase in wine grape grower profit with adoption of CSA 1602 yield, condition, and quality forecast technology.	10%	Analyst's estimate.
Maximum share of wine grape production adopting CSA 1602 technology.	50%	Analyst's estimate.
Year in which CSA 1602 technology first adopted.	2027	Analyst's estimate - five years required to complete additional research plus two years for commercialisation and systems establishment.
Year in which maximum adoption of CSA 1602 technology occurs.	2032	Analyst's estimate - five years required for peak adoption.
Benefit 2: Wine Maker Profit with Accurate Yield, Condition and Quality Forecasts		
Total wine production.	1.29 billion litres.	AgEconPlus and Gillespie Economics (2019).
Profit on wine production.	$1.22/litre	AgEconPlus and Gillespie Economics (2019).
Increase in wine maker profit when CSA 1602 yield, condition, and quality forecast technology has been adopted.	2%	Analyst's estimate.
Assumptions Common to the Quantification of Both Benefits		
Attribution of benefits to this project (CSA 1602).	50%	Further research investment estimated at between $1.5 M and $2 M is required (funding source unknown) and costs will be incurred adopting the commercial technology on farm.
Probability of valuable outputs.	70%	Further investment in yield, condition and quality forecasting technology is not assured.
Probability of valuable outcomes (if outputs are delivered).	75%	Technology developed as part of CSA 1602 shows considerable promise.

Probability of impact (if outcomes are delivered).	80%	There is some relatively minor risk that forecasting technology will not increase grape grower and wine maker profit.
Counterfactual	30%	See above explanation.

5.2.3 Other Potential Benefits

Other potential benefits identified but not valued include:

- Supply chain efficiencies with winery customers assured of the quality and quantity of wine available for sale.
- Transport efficiency and coordination with wineries enabling space and energy to be saved.
- Additional sensor, imaging, radar, 'big data', analysis and algorithm development skills for use in the wine industry and other Australian industries.
- A dataset available for future wine industry research.
- When accurate yield, composition, and condition forecasts are available there should be less anxiety due to earlier and better certainty of pricing and income uncertainties, tensions and anxieties between growers and grape buyers.
- Additional industry confidence, investment certainty, income, and employment in regional Australia (spill-over impact).

Other potential benefits were not quantified due to their relatively minor contribution to total impact and difficulty in securing data for quantification.

6. Results

All past costs were expressed in current dollar terms using the implicit price deflator for GDP. All costs and benefits from 2021 onwards were discounted to current dollar terms using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base run used the best estimates of each variable, notwithstanding a high level of uncertainty for some of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2020).

Table 6.1 and Table 6.2 show the investment criteria estimated for the different periods of benefits for both the total investment and for Wine Australia investment. The present value of benefits (PVB) for the Wine Australia investment, shown in Table 6.2, is estimated by multiplying the total PVB by the Wine Australia proportion of investment.

Table 6.1 Investment Criteria for Total Investment by Wine Australia and Project Partners (discount rate 5%)

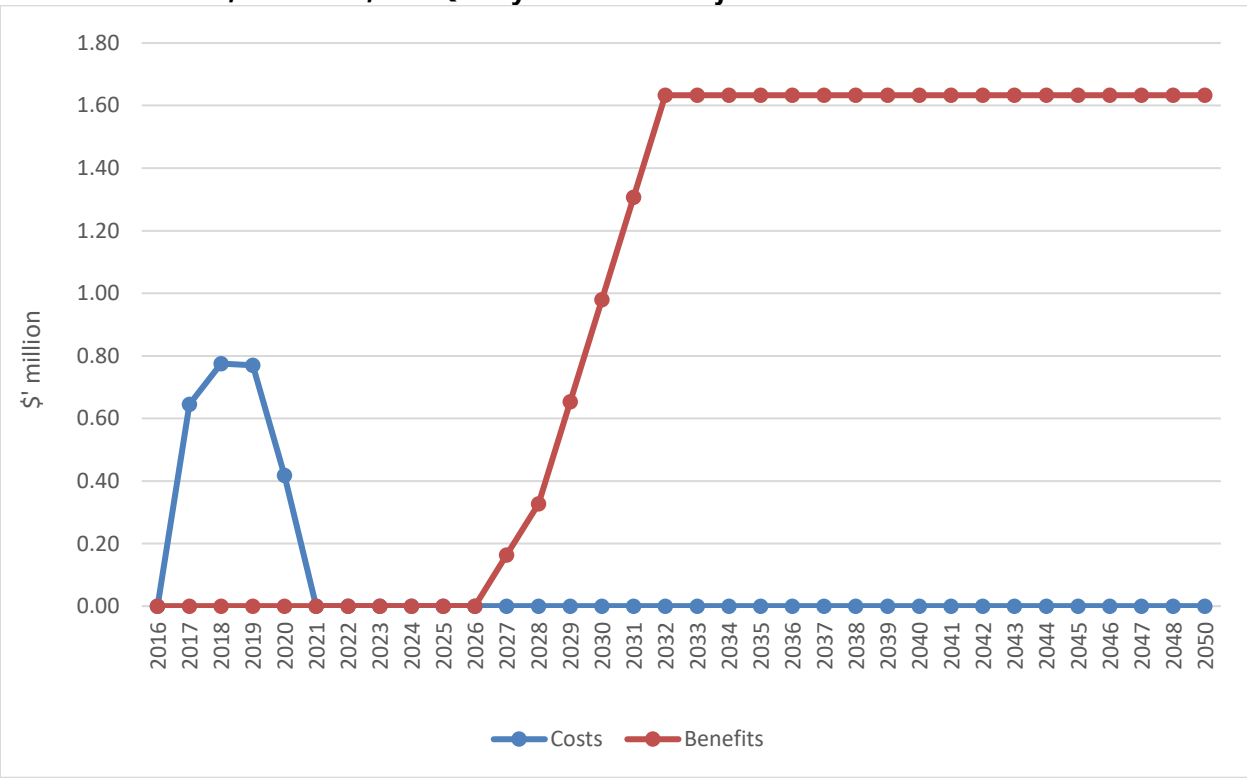
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.00	1.43	5.79	9.36	12.15	14.35
Present value of costs ($m)	2.97	2.97	2.97	2.97	2.97	2.97	2.97
Net present value ($m)	-2.97	-2.97	-1.54	2.82	6.39	9.18	11.38
Benefit–cost ratio	0.00	0.00	0.48	1.95	3.15	4.09	4.83
Internal rate of return (%)	Negative	Negative	Negative	10.3	13.0	14.0	14.4
MIRR (%)	Negative	Negative	Negative	8.7	10.1	10.2	10.0

Table 6.2 Investment Criteria for Wine Australia (discount rate 5%)

Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.00	0.50	2.03	3.29	4.27	5.04
Present value of costs ($m)	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Net present value ($m)	-1.05	-1.05	-0.55	0.98	2.24	3.22	3.99
Benefit–cost ratio	0.00	0.00	0.48	1.94	3.13	4.07	4.81
Internal rate of return (%)	Negative	Negative	Negative	10.2	12.9	13.9	14.4
MIRR (%)	Negative	Negative	Negative	8.7	10.1	10.2	10.0

The annual undiscounted benefits and cost cash flows for the total investment for the duration of the investment period plus 30 years from the last year of the initial investment are shown in Figure 6.1.

Figure 6.1 Annual Undiscounted Cash Flows for Estimated Total Benefits and Total RD&E Investment Costs for the Yield, Condition, and Quality Estimation Project



7. Sensitivity Analysis

A sensitivity analysis was carried out for the central analysis results reported in Section 6 and variations in the discount rate. Table 7.1 presents the results. The results are highly sensitive to the discount rate due to the lag between project investment and technology commercialisation.

Table 7.1 Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	34.46	14.35	6.75
Present value of costs ($m)	2.61	2.97	3.37
Net present value ($m)	31.85	11.38	3.38
Benefit-cost ratio	13.21	4.83	2.00

Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria. The analyses were performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values.

For this project, the greatest uncertainties related to the increase in grape grower and wine maker profits and the attribution of benefits to CSA 1602 – Table 7.2 and Table 7.3. Results show that even if the increase in grape grower profits was a modest 2.5% and wine maker profit increase was 0.5% return on investment would still be positive. Likewise, attribution of benefits to CSA 1602 would need to fall to 10% before project costs would equal project benefits.

Table 7.2 Sensitivity to Increase in Profit Associated with CSA 1602 (Total investment, 30 years)

Investment Criteria	Increase in Profit Grape Growers and Wine Makers		
	Growers 2.5%, Makers 0.5%	Growers 5%, Makers 1%	Growers 10%, Makers 2% (base)
Present value of benefits ($m)	3.59	7.17	14.35
Present value of costs ($m)	2.97	2.97	2.97
Net present value ($m)	0.62	4.20	11.38
Benefit-cost ratio	1.21	2.42	4.83

Table 7.3 Sensitivity to Attribution of Benefits to CSA 1602 (Total investment, 30 years)

Investment Criteria	Share of Benefits Attributable to CSA 1602 (%)		
	10%	25%	50% (base)
Present value of benefits ($m)	2.87	7.17	14.35
Present value of costs ($m)	2.97	2.97	2.97
Net present value ($m)	-0.10	4.20	11.38
Benefit-cost ratio	0.97	2.42	4.83

8. Confidence Ratings

The results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 8.1). The rating categories used are High, Medium, and Low, where:

- High: denotes a good coverage of benefits or reasonable confidence in the assumptions made
- Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions made
- Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 8.1 Confidence in Analysis of Program

Coverage of Benefits	Confidence in Assumptions
High	Medium

9. Summary of Results

Funding for CSA 1602 'new non-destructive techniques for simultaneous yield, crop condition and quality estimation' had a total cost of $2.97 million (present value terms) and is expected to produce aggregate total benefits of approximately $14.35 million (present value terms). This gives an estimated net present value of $11.38 million, a benefit-cost ratio of approximately 4.83, an internal rate of return of 14% and a modified internal rate of return of 10%.

Analysis results are dependent on assumptions made and are positive for core assumptions and most assumptions used during sensitivity testing.

Abbreviations

DAWR	Department of Agriculture and Water Resources
GHG	Greenhouse gas
HSI	Hyper-Spectral Imaging
OCS	Office of Chief Scientist
R&D	Research and Development
R&D4P	R&D for Profit Program operated by the Australian Government
RD&A	Research, Development and Adoption

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Murray Leake, Group Viticulturalist, Shaw & Smith
Ben Pridham, Proprietor Pridham Viticulture
Alex Sas, Senior RD&E Program Manager, Wine Australia

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Appendix 2: Economic Analysis Wine Australia's Investment in Managing the Impact of Vintage Advancement and Compression

1. Background

Recent vintages in Australia have been characterised by rapidly maturing fruit and compression of the ripening window. This means that varieties that used to ripen over 4 to 6 weeks in the 1990s are now maturing over a much shorter time period. This places significant pressure on harvest logistics, with growers struggling to find sufficient harvesters and wineries being forced to delay harvest due to a lack of fermenter capacity. Delays in harvest may result in yield loss due to berry dehydration, elevated grape sugar and wine ethanol concentration, in addition to other negative impacts on fruit composition and wine style.

On the other hand, some producers may perceive the increase in the concentration of grape compounds (especially grape and wine phenolics) associated with delayed harvest, together with other changes in wine volatile profile and sensory properties, as a potential improvement for wine quality attributes. This is of particular importance where the issue of higher wine ethanol can be overcome by using pre-ferment water addition. Recent changes in regulation (FSANZ 2017) permit the addition of water to must under specific conditions.

This project built on previous work in the area of climate adaptation completed by Petrie, McCarthy, Sadras and others (e.g., SAR 1304). The project tied in with examination of 'jammy'/'raisin' overripe characteristics reported in AWR 1701-3.1.1 (*Identification and control of volatile compounds responsible for important sensory attributes*).

2. Summary of Projects

Table 2.1 provides a description of the project in a logical framework.

Table 2.1 Project Description

AWR 1701-4.1.1: Managing the Impact of Vintage Advancement and Compression	
Project Details	Research Organisation: Australian Wine Research Institute (AWRI) Period: July 2017 to September 2020 Principal Investigators: Keren Bindon and Paul Petrie
Rationale	This project was to investigate changes in wine quality from grapes grown in a warming environment, that have higher sugar (and corresponding ethanol) concentrations. The project was to recommend strategies to maintain wine quality in a warming climatic environment.
Objectives	This project, together with others underway in the Australian grape and wine industry, will on completion, contribute to the following broad objectives: • An improved industry understanding of how increased temperature, increased CO2 and reduced water can affect grape and wine production. • The development of climate change adaptation strategies to alleviate the impact of long-term warming and prolonged seasonal heat events.
Activities and Outputs	• Project collaborators included AWRI, SARDI and Treasury Wine Estates. • Data was collected across three vintages – 2018, 2019 and 2020. Commercial data sets spanning the period 1993 to 2018 were also sourced and analysed. • Trends in pH and titratable acid (TA) across the seasons 1993-2018 were shown to be similar to previous research for total soluble solids (sugar), i.e., higher pH and lower TA values were being recorded earlier in the season. However, the sugar:acid ratio showed no significant trends, implying that

	these maturity parameters remain synchronised despite warmer conditions and accelerated ripening. • Sugar content per berry under Australian conditions plateaus for Shiraz at 13°Baume (a measure of dissolved sugar and therefore wine alcohol content) and for Cabernet Sauvignon at 14.5°Baume. Any sugar accumulation above these amounts is likely due to a loss in berry volume (shrivel), rather than sugar import from the vine. • Delaying harvest further than 13°Baume in Shiraz showed some increases in wine phenolics and improvement in sensory properties, which were retained even after water addition, but no further increases in phenolics were found beyond 15.5°Baume. Potential wine quality attributes (e.g., phenolics, aroma precursors) which can be gained by extending hang time beyond 13°Baume must be weighed against the decrease in yield which occurs once grapes start to dehydrate. • Water addition, regardless of mode, is a simple strategy to control wine ethanol in Shiraz without impacting key properties but should be used in moderation. Water addition will not necessarily restore the wine volume to what would be achieved by harvesting earlier nor ameliorate the 'dried fruit' or 'jammy' characters of dehydrated berries. In addition, higher levels of water addition were associated with increase in negative 'off' odours. • For Chardonnay, delaying harvest did not achieve clear gains in many important wine sensory properties. Water addition did not unduly influence key wine sensory properties and is a viable option for reducing ethanol concentration but meeting a targeted commercial Baume rather than relying on water addition would be preferable. Introducing skin contact did not consistently improve sensory outcomes when used with water addition. • Must sugar measurements can change significantly following skin contact (red varieties) or standard enzyme and settling treatments (white varieties). Sugar measurements, on which water additions are based, should be taken as close as possible to the point of water addition. • Project findings were communicated to industry via an AWRI roadshow seminar – '*water into wine – when to use and how much?*' and the relevant AWRI fact sheet was updated and posted on the AWRI website. Presentations were made to the Australian Wine Industry Technical Conference and papers published in the Wine Viticulture Journal and the Australian Journal of Grape Wine Research. Current project SAR 1701-2.2 (*understanding the causes of vintage compression and developing vineyard management options that increase the proportion of fruit harvested at optimal maturity*) builds on the outputs from this project, and AWR 1701-3.1.1 was ongoing in November 2021.
Outcomes	• An understanding of how fruit quality is affected by earlier and accelerated ripening with guidelines provided to industry to mitigate these effects. • An understanding of how allowing fruit to hang longer on the vine impacts fruit and wine quality and the balance between potential gains and yield loss. • Knowledge on the timing, amount, and method for addition of water to Shiraz and Chardonnay musts and juice impacts on wine quality when fruit has to be harvested at higher sugar concentration.

	• Growers can now more accurately predict the ripeness level for the principal red varieties grown in Australia (Shiraz and Cabernet Sauvignon) using a combination of sugar concentration and berry weight. • Knowing the critical point at which sugar accumulation stops and dehydration begins in red grape varieties provides guidance for harvest decisions in the vineyard. • Taken together, the improved understanding of the processes that affect grape ripening and fruit maturity and the development of wine making processes to manage fruit that has been harvested with high sugar concentrations will support industry efforts to maintain wine quality under warmer climatic conditions.
Impacts (potential)	• Economic – avoided loss of quality and revenue from wine made with grapes containing elevated sugars. Avoided loss of wine quality will be relevant to current overall 'warm year' vintages as well as inherently warmer regions and increasingly relevant as temperature increases in Australian wine grape growing areas. • Economic – avoided loss of price received by growers for wine grapes with elevated sugar concentrations. Project findings will be particularly relevant to growers of Shiraz[5]. • Environment – avoided increase in chemical inputs for the treatment of low acid ferments associated with high-sugar grapes. With less chemical use there is both a cost saving and less risk of damage to the winery environment. • Capacity – new scientific knowledge in relation to wine making and new wine maker skills in dealing with high sugar fruit. • Health – increased availability and consumption of flavoursome, moderate alcohol wines. • Social – a more profitable grape and wine industry will contribute to income and employment growth in regional Australia (spill-over impact).

3. Match with Government Priorities

Table 3.1 Strategic Science/Research Priorities and Rural R&D Research Priorities

Australian Government	
Strategic Science/Research Priorities	**Rural R&D Priorities**
1. **Food** – optimising food and fibre production and processing, agricultural productivity and supply chains within Australia and global markets 2. **Soil and water** – improve use of soil and water resources, both terrestrial, marine 3. **Transport** – moving essential commodities, alternative fuels, lowering emissions. 4. **Cybersecurity** – for individuals, businesses, government, national infrastructure 5. **Energy** – improve efficiency, reduce emissions, and integrate diverse sources into the grid.	1. **Advanced technology**: to enhance innovation of products, processes and practices across the food and fibre supply chains through technologies such as robotics, digitalisation, big data, genetics and precision agriculture. 2. **Biosecurity**: to improve understanding and evidence of pest and disease pathways to help direct biosecurity resources to their best uses, minimising biosecurity threats and improving market access for primary producers. 3. **Soil, water and managing natural resources:** to manage soil health, improve water use efficiency and certainty of supply, sustainably develop new production areas and improve resilience to climate events and impacts.

[5] Shiraz plateaus at a lower Baume and has a greater propensity to shrivel. If growers have a greater understanding of the trade-off in loss by going over key Baume values, they could avoid losses simply by harvesting at a fixed, and potentially lower Baume (Dr Keren Bindon, Project Principal Investigator, pers. comm., December 2021).

6. **Resources** – support exploration traditional resources, rare earths and new technologies. 7. **Advanced manufacturing** – high value and innovative industries in Australia. 8. **Environmental change** – mitigating, managing or adapting to changes. 9. **Health** – improving health outcomes for all Australians.	4. **Adoption of R&D:** focussing on flexible delivery of extension services that meet primary producers' needs and recognising the growing role of private service delivery.

Source: OCS 2015 and DAWE 2021 (both checked for currency December 2021)

The Wine Australia project has addressed Strategic Science/Research Priority 1, 8 and 9. The project has also addressed Rural R&D Priority 1 and 3.

4. Identification of Potential Costs and Benefits

4.1 Costs

4.1.1 R&D Investment

The R&D investment costs comprised:

- Direct financial outlays by Wine Australia including both project and overhead expenditures.
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia (project overhead costs).

4.1.2 Administration

No additional administration costs were identified.

4.1.3 Extension

The project was communicated to wine makers via relevant online fact sheets and wine making technical forums. A large corporate wine maker, Treasury Wine Estates, was a project collaborator. Given the importance of the issue i.e., maintaining wine quality in a warming climate, it is anticipated that there will be a high level of interest in the project and no further extension investment will be required.

4.1.4 Adoption

Adoption of project findings will require relatively minor process changes at the winery. Capital costs will not be incurred.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The possible impact pathway for the project is:

1. This project (AWR 1701-4.1.1) developed wine making processes to manage fruit that has been harvested with high sugar concentrations.
2. Strategies to maintain wine quality under warmer environmental conditions communicated to wine makers via relevant reports, fact sheets and wine making technical forums.
3. Wine makers adjust production practices to maintain wine quality starting with the 2020-21 vintage (Noting that both the 2020-21 and 2021-22 vintages were, on average, not warm production years).

4.2.2 Triple Bottom Line Benefits

A summary of potential benefits from the project in triple bottom line categories is shown in Table 4.1.

Table 4.1 Triple Bottom Line Categories Benefits from Project Investment

Levy Paying Industry	**Spillovers**		
	Other Industries	**Public**	**Foreign**
Economic Benefits			
Avoided loss of quality and revenue from wine made with grapes containing elevated sugars. Avoided loss of price received by growers of wine grapes with elevated sugar concentrations.	Nil.	Nil.	Project findings will be adopted by overseas wine makers especially those producing in warmer production areas (e.g., Southern Europe).
Environmental Benefits			
Avoided increase in chemical inputs for the treatment of low acid ferments associated with high-sugar grapes. With less chemical use there is both a cost saving and less risk of damage to the winery environment.	Nil	Nil	Nil
Social Benefits			
Capacity – new scientific knowledge in relation to wine making and new wine maker skills in dealing with high sugar fruit. Health – increased availability and consumption of flavoursome, moderate alcohol wines. Social – a more profitable grape and wine industry will contribute to income and employment growth in regional Australia (spill-over impact).	Capacity – scientific knowledge garnered in relation to how vines store and accumulate sugar may be applicable to other Australian tree fruit crops e.g., table grapes and summerfruit.	Nil	Nil

4.2.3 Public versus Private Benefits

The majority of benefits that will arise from project investment will be private in nature. The private benefits will be captured by wine grape growers, wine makers, and the supply chain. Private benefits will be realised as avoided loss. Potential public benefits will include additional researcher and industry capacity, health benefits from consumption of flavoursome, moderate alcohol wines, and regional spill-over benefits.

4.2.4 Distribution of Benefits along the Supply Chain

The benefits to the wine industry from investment in this project will be shared along the supply chain with wine grape growers, wine makers, wholesalers, retailers, and exporters all sharing in some of the benefits.

4.2.5 Benefits to Other Primary Industries

Scientific knowledge developed during the project in relation to how vines store and accumulate sugar may be relevant to other Australian perennial crops such as table grapes and summerfruit.

4.2.6 Benefits Overseas

Project findings will be relevant to the wine industries of other countries especially those with warm production areas and/or those experiencing further warming e.g., countries in southern Europe.

4.3 Summary of Costs and Benefits

A summary of principal categories of costs and benefits from the project is shown in Table 4.2.

Table 4.2 Incremental Cost and Benefit Categories

Costs	Benefits
R&D investment costs (cash and in-kind) as well as project administration costs.	Economic – wine maker avoided loss of wine quality and revenue from wines made with grapes containing elevated sugars.
Overhead costs including time associated with meetings between the researchers and Wine Australia.	Economic – avoided loss of grape grower revenue from grapes with elevated sugars.
Adoption costs – relatively minor for this project and not entailing capital investment.	Environmental – avoided increase in chemical inputs for the treatment of low acid ferments associated with high-sugar grapes. With less chemical use there is both a cost saving and less risk of damage to the winery environment.
	Capacity – new scientific knowledge in relation to wine making and new wine maker skills in dealing with high sugar fruit.
	Health – increased availability and consumption of flavoursome, moderate alcohol wines.
	Social – a more profitable grape and wine industry will contribute to income and employment growth in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

Table 5.1 shows annual investment in the project by Wine Australia and AWRI.

Table 5.1 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia	Other	Total
2018	132,935	5,002	137,937
2019	119,306	8,562	127,868
2020	22,839	5,138	27,977
Total	**275,080**	**18,702**	**293,782**

Source: AWR 1701-4.1.1 End of Project Financial Statement (provided by Wine Australia, November 2021)

5.1.2 Overhead Costs including Meetings between the Researchers and Wine Australia

Wine Australia overhead costs are in addition to those shown in the above tables and are estimated at 12%.

5.2 Benefits

Counterfactual: in the absence of this project, it is possible that another research investment would have been made outside of Wine Australia to deal with the impact of vintage advancement and compression and the maintenance of wine quality. Consequently, a counterfactual of 70% has been assumed.

5.2.1 Avoided Loss of Quality and Revenue from Wine Made from Grapes Containing Elevated Sugars

The project has developed a wine making process that will avoid loss of quality in wine made from grapes with elevated sugars. Findings will be relevant to grapes, particularly Shiraz, grown in warm years, in moderate-warm climates like the Barossa Valley and Langhorne Creek. Avoided loss is net of any cost savings realised by the wine maker who may pay less for grapes that do not meet specification.

5.2.2 Avoided Loss of Grape Grower Revenue from Grapes with Elevated Sugars

If wine makers can produce wine of targeted quality without 'jammy' or 'raisin' flavours from grapes with elevated sugars, they will be less likely to discount the fruit that they receive. Adoption of project findings has the potential to maintain the price received by growers in warm years when fruit has high sugar levels.

A summary of key assumptions used to quantify avoided losses for both the wine maker and the grape grower are summarised in Table 5.4.

Table 5.4 Summary of Assumptions

Variable	Assumption	Source/explanation
Benefit 1: Avoided Loss of Quality and Revenue from Wine Made with Grapes Containing Elevated Sugars		
Total production of wine from Shiraz grapes.	455,419 litres	5-year average 2017 to 2021 (https://marketexplorer.wineaustralia.com/vintage-survey).
Proportion of Shiraz grapes grown in a moderate to warm environment where high sugar may be an issue.	60%	Major focus of benefits will be moderate to warm climates such as Barossa Valley and Langhorne Creek (Dr Keren Bindon, Principal Investigator AWR 1701-4.1.1, pers. comm., December 2021).
Frequency of warm years with elevated sugar.	20% (1 in 5 years)	Not all vintages will be 'warm', with vintage advancement and compression. For example, both 2020-21 and 2021-22 were cool years. A 20% estimate allows for increasing frequency of warm vintages over the 30 year analysis period.
Share of Shiraz production in warm areas affected by high sugar in a warm year.	30%	Not all grapes in affected areas will be late harvested or have accumulated excessive sugar.
Price received by the wine maker for Shiraz	$4.67/litre	Wine Australia 2019 with data sourced from the Ready Reckoner.
Price loss in absence of project findings.	50%	Analyst's estimate that recognises significant loss in value associated with 'jammy', 'raisin', and 'off' flavours.

Benefit 2: Avoided Loss of Grape Grower Revenue from Grapes with Elevated Sugars		
Price received by growers for Shiraz grapes.	$858/tonne	5 year average of Shiraz grapes 2017 to 2021 (Wine Australia National Vintage Report various years).
Price discount in the absence of this project.	5%	Analyst assumption.
Assumptions Common to the Quantification of Both Benefits		
Attribution of benefits to this project (AWR 1701-4.1.1).	50%	Project build on findings from SAR 1304, AWR 1701-3.1.1 and current project AWR 1701-3.1.1.
Year in which grape growers and wine makers start to realise benefits.	2021	Findings communicated to industry in 2020.
Probability of valuable outputs.	100%	Project complete and all reports made available to Wine Australia.
Probability of valuable outcomes.	100%	Findings communicated to industry in 2020.
Probability of impact.	80%	There is some risk that wine makers will not adopt project findings.
Counterfactual	70%	See above explanation.

5.2.3 Other Potential Benefits

Other potential benefits identified but not valued include:

- Avoided increase in chemical inputs for the treatment of low acid ferments associated with high-sugar grapes. With less chemical use there is both a cost saving and less risk of damage to the winery environment.
- New scientific knowledge in relation to wine making and new wine maker skills in dealing with high sugar fruit.
- Health benefits to wine consumers with increased availability and consumption of flavoursome, moderate alcohol wines.
- A more profitable grape and wine industry will contribute to income and employment growth in regional Australia (spill-over impact).

Other potential benefits were not quantified due to their relatively minor contribution to total impact and difficulty in securing data for quantification.

6. Results

All past costs were expressed in current dollar terms using the implicit price deflator for GDP. All costs and benefits from 2021 onwards were discounted to current dollar terms using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base run used the best estimates of each variable, notwithstanding a high level of uncertainty for some of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2020).

Table 6.1 and Table 6.2 show the investment criteria estimated for the different periods of benefits for both the total investment and for Wine Australia investment. The present value of benefits (PVB) for the

Wine Australia investment, shown in Table 6.2, is estimated by multiplying the total PVB by the Wine Australia proportion of investment.

Table 6.1 Investment Criteria for Total Investment by Wine Australia and Project Partners (discount rate 5%)

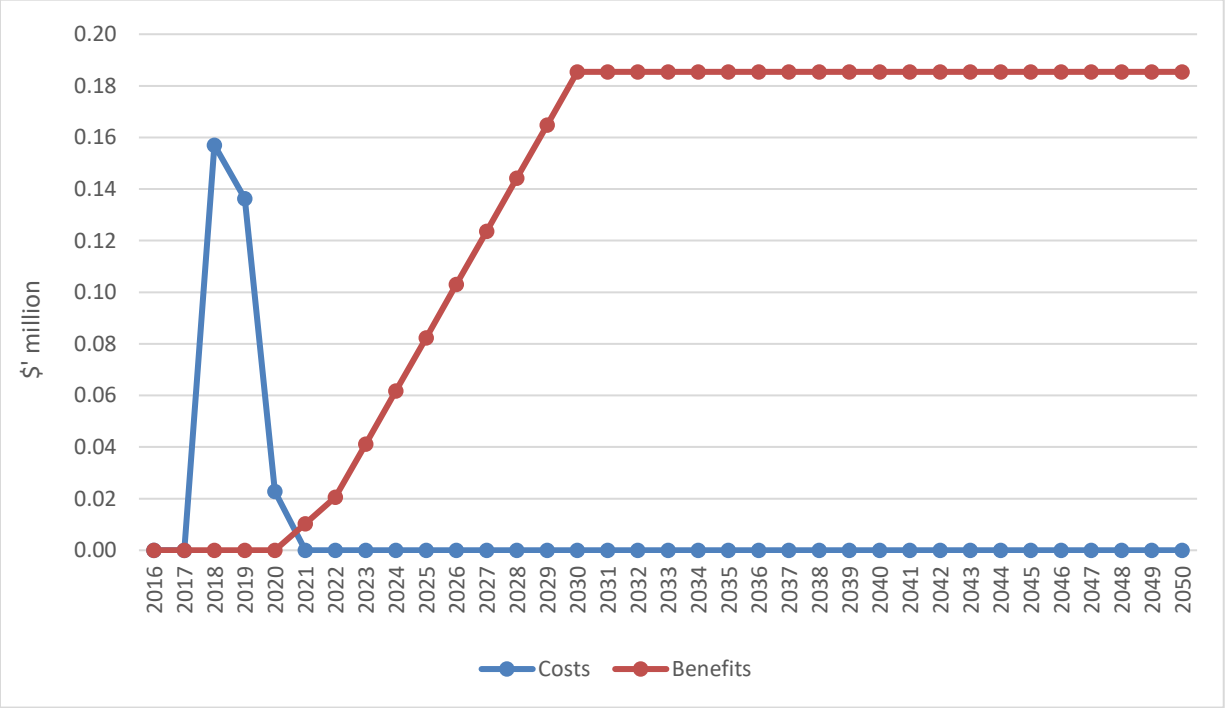
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.19	0.70	1.21	1.62	1.94	2.19
Present value of costs ($m)	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Net present value ($m)	-0.38	-0.19	0.32	0.84	1.24	1.56	1.81
Benefit–cost ratio	0.00	0.50	1.84	3.22	4.29	5.14	5.80
Internal rate of return (%)	Negative	Negative	13.1	17.7	19.0	19.4	19.6
MIRR (%)	Negative	Negative	9.7	11.7	11.6	11.1	10.6

Table 6.2 Investment Criteria for Wine Australia (discount rate 5%)

Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.18	0.66	1.14	1.53	1.83	2.06
Present value of costs ($m)	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Net present value ($m)	-0.36	-0.18	0.30	0.79	1.17	1.47	1.71
Benefit–cost ratio	0.00	0.50	1.84	3.21	4.29	5.13	5.79
Internal rate of return (%)	Negative	Negative	13.1	17.7	19.0	19.4	19.6
MIRR (%)	Negative	Negative	9.7	11.7	11.6	11.1	10.6

The annual undiscounted benefits and cost cash flows for the total investment for the duration of the investment period plus 30 years from the last year of the initial investment are shown in Figure 6.1.

Figure 6.1 Annual Undiscounted Cash Flows for Estimated Total Benefits and Total RD&E Investment Costs for the Vintage Advancement and Compression Project



7. Sensitivity Analysis

A sensitivity analysis was carried out for the central analysis results reported in Section 6 and variations in the discount rate. Table 7.1 presents the results. The results are moderately sensitive to discount rate.

Table 7.1 Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	4.65	2.19	1.20
Present value of costs ($m)	0.34	0.38	0.42
Net present value ($m)	4.32	1.81	0.78
Benefit-cost ratio	13.87	5.80	2.84

Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria. The analyses were performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values.

For this project, the greatest uncertainties related to the share of Shiraz production impacted by warm seasons and the frequency of warm years with elevated sugar – Table 7.2 and Table 7.3. Results show that the benefit cost ratio remains positive if share of production impacted by warm seasons is reduced to 40% and frequency of elevated sugar is reduced to 1 in 10 years (10%).

Table 7.2 Sensitivity to Share of Shiraz Production Impacted by Warm Seasons (Total investment, 30 years)

Investment Criteria	Share of Production		
	40%	60 % (base)	80%
Present value of benefits ($m)	1.46	2.19	2.92
Present value of costs ($m)	0.38	0.38	0.38
Net present value ($m)	1.08	1.81	2.54
Benefit-cost ratio	3.87	5.80	7.73

Table 7.3 Sensitivity to Frequency of Warm Years with Elevated Sugar (Total investment, 30 years)

Investment Criteria	Frequency of Warm Years (% of total vintages)		
	10%	20% (base)	40%
Present value of benefits ($m)	1.09	2.19	4.37
Present value of costs ($m)	0.38	0.38	0.38
Net present value ($m)	0.72	1.81	4.00
Benefit-cost ratio	2.90	5.80	11.60

8. Confidence Ratings

The results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 8.1). The rating categories used are High, Medium, and Low, where:

High: denotes a good coverage of benefits or reasonable confidence in the assumptions made

Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions made

Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 8.1 Confidence in Analysis of Program

Coverage of Benefits	Confidence in Assumptions
High	Medium

9. Summary of Results

Funding for AWR 17-4.1.1 'managing the impact of vintage advancement and compression' had a total cost of $0.38 million (present value terms) and is expected to produce aggregate total benefits of approximately $2.19 million (present value terms). This gives an estimated net present value of $1.81 million, a benefit-cost ratio of approximately 5.80, an internal rate of return of 20% and a modified internal rate of return of 11%.

Analysis results are dependent on assumptions made and are positive for core assumptions and assumptions used during sensitivity testing.

Abbreviations

AWRI	Australian Wine Research Institute
CO2	Carbon dioxide
FSANZ	Food Standards Australia and New Zealand
OCS	Office of Chief Scientist
R&D	Research and Development
RD&A	Research, Development and Adoption
SARDI	South Australia Research and Development Institute
TA	Titratable Acid

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Appendix 3: Economic Analysis Wine Australia's Investment in Integrated Management of Established Grapevine Phylloxera

1. Background

Grape phylloxera (*Daktulsphaira vitifoliae*) is a tiny insect pest, akin to aphids, that destroys grapevines by feeding on their roots. It is ranked in the top ten pests and diseases of the Australian viticulture industry. *Vitis vinifera* cultivars, commonly known as 'own roots', die within six years once vines are infested with phylloxera and effects on yields are felt much sooner. A lack of chemical or biological controls for phylloxera means that pulling out infested vines and replanting with new vines grafted onto phylloxera-resistant rootstock (non-*vinifera*) is the only control option. Replanting into phylloxera-resistant rootstocks can cost up to $50,000/ha and results in loss of production for up to five years while the new vineyard establishes.

In addition to vineyard replacement, there are significant ongoing costs with containment of phylloxera to Phylloxera Infested Zones (PIZ). Examples include treatment and accreditation of machinery and equipment leaving the zone in line with state regulations, staff training, incidentals such as disinfestation clothing and footbaths, establishment, and maintenance of disinfestation facilities (heat sheds, bin dipping) and investment in dedicated on-site vehicles. Grape growers in Phylloxera Risk Zones (PRZ), who do not have phylloxera in their vineyards, also incur cost. The Yarra Valley Wine Growers Association estimate annual regulation compliance and management costs of $10,000 per grape grower for heat treating machinery, equipment, and grape bins during harvest. Meeting regulation compliance alone can increase management costs by nearly 20%.

Although historically limited in its distribution to quarantine areas in Victoria and NSW, phylloxera has been increasing its geographic range since around 2005 and poses a major threat to the national viticulture industry. The pest is currently found in nine quarantine zones in Australia. The national industry is still predominantly planting phylloxera-susceptible ungrafted European grapevines. Maintaining phylloxera research capacity is an industry priority to ensure that specialists are available to advise on future outbreaks in new areas.

This project built on previous work at Agriculture Victoria (AgVic Research) on phylloxera management. A new project (DJP 2001) was commissioned by Wine Australia with AgVic Research in May 2021. The new project is to further explore findings from DED 1701 and to address some of the remining gaps in management strategies for phylloxera.

2. Summary of Projects

Table 2.1 provides a description of the project in a logical framework.

Table 2.1 Project Description

DED 1701: Integrated Management of Established Grapevine Phylloxera	
Project Details	Research Organisation: AgVic Research, Department of Jobs, Precincts, Regions Period: January 2018 to June 2021 Principal Investigator: Catherine Wanjiru Clarke
Rationale	Research was needed to develop tools, technologies, and practices to improve the integrated management of phylloxera in Australia.
Objectives	The objectives of the project were to: • Enhance early detection systems. • Provide region- and genotype-specific rootstock recommendations. • Develop improved quarantine protocols.

	• Address key knowledge gaps on the biology of phylloxera endemic strains. • Re-evaluate biocontrol options.
Activities and Outputs	• Formation of an Industry Reference Group to provide strategic input and receive regular updates on research findings. • Investigation of a commercial electronic nose (e-nose) for the detection of phylloxera-infested vine roots. The e-nose technology did not prove advanced enough to be used as an on-site tool for the detection of phylloxera on infested roots. Practical considerations (time, labour, and the logistics of sample preparation) were also significant barriers to e-nose use. • An industry survey was completed on the practicality, feasibility, priority, and cost of using phylloxera sniffer dogs. Industry did not think that sniffer dogs would be a practical solution for phylloxera detection and this part of the project was terminated. • LAMP (loop-mediated isothermal amplification) is a portable molecular technology that AgVic has developed for rapid and accurate diagnosis of phylloxera. This project focussed on validating and applying LAMP for in-field phylloxera detection. Surveillance trapping was conducted using 'bucket traps' and on root samples dug up from infested vineyards. • Screening of a common grapevine rootstock, 5C Teleki, showed that it is tolerant to five of six phylloxera strains. Insects can survive and reproduce on excised roots of 5C Teleki, though at a much lower level than on common ungrafted grapevine. Rootstocks 101-14 and Schwarzmann are susceptible to the virulent phylloxera strain G38. • Dettol is a suitable substitute to bleach for disinfestation of footwear and handheld tools. Growers resist the use of bleach due to hazards posed by chlorine odours and residues, and the damage it causes to footwear and tools. • Phylloxera can survive for up to 29 days without a food source (previously it was thought to be a maximum of 21 days). • Fermentation for 48 hours is sufficient to kill phylloxera in white wine and red wine ferments with commercial yest added. However, phylloxera is able to survive in 'wild' ferments for longer and wild fermented grape products should not be moved from a Phylloxera Infested Zone (PIZ). • The King Valley, Victoria contains a total of 36 phylloxera genotypes instead of the single strain detected during the last survey in the 1990s, which was geographically localised to regions within the PIZ. This increases the number of phylloxera strains detected in Australian vineyards from 86 to 115 and suggests that sexual reproduction may be occurring. • Phylloxera in Australia appears to be sensitive to temperatures above 30^{o}C and below 18^{o}C, with the mid-20 temperature range being optimal for development and reproduction. Phylloxera is susceptible to dry conditions. Some variation between strains may explain their geographical distribution. • The project found that biocontrol approaches for phylloxera control warrant further development. • Project findings were communicated through regular stakeholder and industry engagement activities, mainly in Victoria. Findings were publicised via a joint AgVic Research, and Wine Australia press release 22 September

	2021. Findings were also published in two editions of the Australian Journal of Grape and Wine Research.
Outcomes	• New more effective/cost effective ways of detecting/managing phylloxera. • Recommendations and tools that when implemented will reduce the rate of spread of phylloxera in Australia.
Impacts (potential)	• Economic – reduction in the rate of spread of phylloxera into the PIZs and PRZs with grape growers more likely to undertake sufficient hygiene/disinfestation and trained regulatory personnel more likely to detect new infestations. • Environmental – movement toward more environmentally benign phylloxera disinfestation with a shift from bleach to Dettol. • Capacity – wine grape growers with additional knowledge of improved quarantine practices and suitable rootstocks for their enterprise. • Capacity – a large AgVic research and regulatory team with additional skills in phylloxera detection and management. • Social – a reduction in uncertainty and anxiety for grape growers with an improved outlook for phylloxera detection and management. • Social – improved workplace health and safety with the substitution of Dettol for bleach and removal of the chlorine odour and residue hazard. • Social - a more profitable and sustainable wine industry generating additional income and employment in regional Australia (spill-over impact).

3. Match with Government Priorities

Table 3.1 Strategic Science/Research Priorities and Rural R&D Research Priorities

Australian Government	
Strategic Science/Research Priorities	**Rural R&D Priorities**
1. **Food** – optimising food and fibre production and processing, agricultural productivity and supply chains within Australia and global markets 2. **Soil and water** – improve use of soil and water resources, both terrestrial, marine 3. **Transport** – moving essential commodities, alternative fuels, lowering emissions. 4. **Cybersecurity** – for individuals, businesses, government, national infrastructure 5. **Energy** – improve efficiency, reduce emissions and integrate diverse sources into the grid. 6. **Resources** – support exploration traditional resources, rare earths and new technologies. 7. **Advanced manufacturing** – high value and innovative industries in Australia. 8. **Environmental change** – mitigating, managing or adapting to changes. 9. **Health** – improving health outcomes for all Australians.	1. **Advanced technology**: to enhance innovation of products, processes and practices across the food and fibre supply chains through technologies such as robotics, digitalisation, big data, genetics and precision agriculture. 2. **Biosecurity**: to improve understanding and evidence of pest and disease pathways to help direct biosecurity resources to their best uses, minimising biosecurity threats and improving market access for primary producers. 3. **Soil, water and managing natural resources:** to manage soil health, improve water use efficiency and certainty of supply, sustainably develop new production areas and improve resilience to climate events and impacts. 4. **Adoption of R&D:** focussing on flexible delivery of extension services that meet primary producers' needs and recognising the growing role of private service delivery.

Source: OCS 2015 and DAWR 2015 (both checked for currency December 2021)

The Wine Australia project has addressed Strategic Science/Research Priority 1 and potentially Priority 9. The major focus of the project has been on the first and second of the Rural R&D Priorities.

4. Identification of Potential Costs and Benefits

4.1 Costs

4.1.1 R&D Investment

The R&D investment costs comprised:

- Direct financial outlays by Wine Australia and AgVic Research. These costs include both project and overhead expenditures.
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia (project overhead costs).

4.1.2 Administration

No additional administration costs were identified.

4.1.3 Extension

Project findings have been communicated through regular stakeholder and industry engagement activities. Systems are in place to ensure that information from the project will be incorporated into industry tools, protocols, and regulations, which is ongoing. No other extension costs were incurred.

4.1.4 Adoption

Relatively minor adoption costs will be incurred to incorporate findings into industry tools, protocols, and regulations. Minor adoption costs may also be incurred on-farm by wine grape growers e.g., changes to improve quarantine protocols.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The potential impact pathway for the project is:

1. This project (DED 1701) has delivered new knowledge on phylloxera detection and management aimed at reduction in the rate of the pest's spread.
2. DED 1701 findings will be further explored in new AgVic project (DJP 2001) and remaining gaps in phylloxera management strategies will be addressed.
3. Information from DED 1701, DJP 2001 and other R&D projects will be incorporated into extension, management and regulatory systems including the Grapevine Rootstock Selector tool, the National Phylloxera Management Protocol, and relevant regulations managed by VineHealth, State and National biosecurity agencies.
4. Growers and trained regulatory personnel, especially those operating in Phylloxera Risk Zones, will adopt project findings and reduce the rate of phylloxera spread.

4.2.2 Triple Bottom Line Benefits

A summary of potential benefits from the project in triple bottom line categories is shown in Table 4.1.

Table 4.1 Triple Bottom Line Categories Benefits from Project Investment

Levy Paying Industry	**Spillovers**		
	Other Industries	**Public**	**Foreign**
Economic Benefits			
Reduction in the rate of spread and cost of phylloxera in the PIZs and PRZs with grape growers more likely to undertake sufficient hygiene/disinfestation and	New technology for more effective and cost effective ways of detecting and managing phylloxera	Nil.	Phylloxera is a devastating wine grape pest worldwide and project generated

trained regulatory personnel more likely to detect new infestations.	available to other grape industries i.e., table and dried grape production.		technologies can be adapted to grape growing in other countries.
Environmental Benefits			
Movement toward more environmentally benign phylloxera disinfestation with a shift from bleach to Dettol.	Nil	Nil	Nil
Social Benefits			
Capacity – grape growers with additional quarantine and rootstock knowledge. Capacity –AgVic team with additional skills in phylloxera detection, management, and regulation. Reduced uncertainty, anxiety for grape growers with an improved outlook for phylloxera detection and management. Improved workplace OHS with the substitution of Dettol for bleach. A more profitable and sustainable wine industry generating additional income and employment in regional Australia (spill-over impact).	Capacity – researcher and regulatory skills developed may be applied to other primary industries.	Nil	Nil

4.2.3 Public versus Private Benefits

The benefits that will arise from project investment will be both private and public in nature. Private benefits will be realised as a reduction in the rate of spread and cost of phylloxera in the PIZs and PRZs (costs associated with vine replanting and grape production loss). Potential public benefits will include additional grower, researcher, and regulatory officer capacity, improved OHS/anxiety outcomes, and regional spill-over benefits.

4.2.4 Distribution of Benefits along the Supply Chain

The benefits to the wine industry from investment in this project will be shared along the supply chain with wine grape growers, wine makers, wholesalers, retailers, and exporters all sharing in some of the benefits.

4.2.5 Benefits to other Primary Industries

New phylloxera detection and management technologies will be relevant to other grape industries (i.e., table and dried). Capacity developed during the project may, in time, move to other primary industries and contribute to research outcomes in these sectors.

4.2.6 Benefits Overseas

New technology for more effective and cost effective ways of detecting and managing phylloxera will be relevant to other countries where the pest is present.

4.3 Summary of Costs and Benefits

A summary of principal categories of costs and benefits from the project is shown in Table 4.2.

Table 4.2 Incremental Cost and Benefit Categories

Costs	Benefits
R&D investment costs as well as project administration costs.	Economic – reduction in the rate of spread and cost of phylloxera in PIZs and PRZs (avoided replant and production loss costs).
Overhead costs including time associated with meetings between the researchers and Wine Australia.	Environmental – movement towards more environmentally benign phylloxera disinfestation agent.
Adoption costs will be incurred by wine grape growers implementing improved quarantine protocols and AgVic employing improved phylloxera detection methods.	Capacity – growers, researchers, regulators with new phylloxera detection and management skills.
	Health – improved workplace OHS and a reduction in uncertainty/anxiety associated with phylloxera infestation.
	Social – a more profitable and sustainable wine industry generating additional income, and employment in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

Table 5.1 shows annual investment in the project by Wine Australia and AgVic Research, part of the Victoria Department of Jobs, Precincts, and Regions.

Table 5.1 Investment in the Project for Years Ending June 2018 to June 2020

Project Code	2018	2019	2020	2021	Total
DED 1701 – Wine Australia	181,274	354,651	225,244	134,324	**895,493**
AgVic Research	117,292	209,655	206,138	50,010	**583,095**
Total	**298,566**	**564,306**	**431,382**	**184,334**	**1,478,588**

Source: Data provided by Wine Australia RD&A Administrator, November 2021.

5.1.2 Overhead Costs including Meetings between the Researchers and Wine Australia

Wine Australia overhead costs are in addition to those shown in the above tables and are estimated at 12%.

5.1.4 Adoption Costs

Adoption costs will be incurred by wine grape growers and AgVic regulators incorporating project recommendations into quarantine protocols. These relatively minor costs are accounted for in the analysis through the application of a research benefit attribution factor – see Table 5.4 below.

5.2 Benefits

Counterfactual: if this project had not been funded by Wine Australia, it is likely that a similar investment would have been made – the spread of phylloxera is an important industry issue. Consequently, a counterfactual of 50% has been assumed i.e., it is 50% likely that potential project benefits would have been realised in the absence of DED 1701 project investment.

5.2.1 Reduction in the Rate of Spread and Cost of Phylloxera in the PRZs

This project is expected to contribute to a reduction in the risk of phylloxera spread in the PRZs.

Wine grape production in the PRZs was assessed by overlaying Wine Australia's region maps and Vine Health Australia's Phylloxera Management Zone maps https://vinehealth.com.au/tools/maps/phylloxera-management-zones/. Wine regions in PRZs and their area of production is shown in Table 5.4.

Table 5.4 Area of Wine Grape Production in PRZs

Wine Region	Area of Wine Grape Production (ha)
Mornington Peninsula	976
Sunbury	102
Heathcote	1,836
Goulburn Valley	1,263
Upper Goulburn	267
Strathbogie Ranges	534
Gippsland	191
Yarra Valley	2,837
Total	**8,006**

Source: Australian Wine Regions and Varieties https://www.wineaustralia.com/market-insights/regions-and-varieties

A modest decrease in phylloxera risk in the PRZs of 10% has been assumed as a result of an updated National Phylloxera Management Protocol (NPMP) and revised phylloxera regulations (through VineHealth Australia, state and national biosecurity agencies). Wine Australia project DED 1701 has been assumed to have contributed 35% of the risk reduction benefit. A summary of key assumptions used to quantify this benefit is provided in Table 5.5.

Table 5.5 Summary of Assumptions

Variable	Assumption	Source
Benefit: Reduction in the Rate of Spread and Cost of Phylloxera in the PRZs		
Wine grape growing area in the PRZs.	8,006 ha	Table 5.4 above.
Cost of phylloxera to wine grape growers.	$56,970/ha	Vineyard replant cost of $50,000/ha plus annual profit on production of $1,394/ha foregone for 5 years.
Reduction in risk of phylloxera spread in the PRZs as a result of an updated NPMP and revised regulations.	10%	Analyst's assumption to be tested using sensitivity analysis.
Year in which the NPMP and revised regulations are first enacted.	2024	Following completion of DJP 2001 which commenced in May 2021.
Maximum area of PRZs making use of NPMP and/or impacted by AgVic regulation.	50%	Analyst's assumption.
Year in which maximum adoption occurs.	2028	Analyst's assumption.
Year in which project outcomes are replaced with new approaches and technology.	2038	Analyst's assumption.
Attribution of benefits to this project.	35%	Estimate prepared after considering contribution made by DED 1701, DJP

		2001, and the cost incurred to adopt project findings.
Probability of valuable outputs.	75%	DED 1701 has delivered what appear to be valuable findings that will reduce the risk of phylloxera spread.
Probability of valuable outcomes.	70%	DED 1701 findings need to be confirmed through DJP 2001.
Probability of impact.	65%	Wine grape growers and AgVic regulators must adopt DED 1701 findings.
Counterfactual	50%	See above explanation.

5.2.3 Other Potential Benefits

Other potential benefits identified but not valued include:

- Movement toward more environmentally benign phylloxera disinfestation with a shift from bleach to Dettol.
- Wine grape growers with additional knowledge of improved quarantine practices and suitable rootstocks for their enterprise.
- A large AgVic research and regulatory team with additional skills in phylloxera detection and management.
- A reduction in uncertainty and anxiety for grape growers with an improved outlook for phylloxera detection and management.
- Improved workplace OHS with the substitution of Dettol for bleach and removal of the chlorine odour and residue hazard.
- A more profitable and sustainable wine industry generating additional income and employment in regional Australia (spill-over impact).

Other potential benefits were not quantified due to their relatively minor contribution to total impact and difficulty in securing data for quantification.

6. Results

All past costs were expressed in current dollar terms using the implicit price deflator for GDP. All costs and benefits from 2021 onwards were discounted to current dollar terms using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base run used the best estimates of each variable, notwithstanding a high level of uncertainty for some of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2021).

Table 6.1 and Table 6.2 show the investment criteria estimated for the different periods of benefits for both the total investment and for Wine Australia investment. The present value of benefits (PVB) for the Wine Australia investment, shown in Table 6.2, are estimated by multiplying the total PVB by the Wine Australia proportion of investment.

Table 6.1 Investment Criteria for Total Investment by Wine Australia and Project Partners (discount rate 5%)

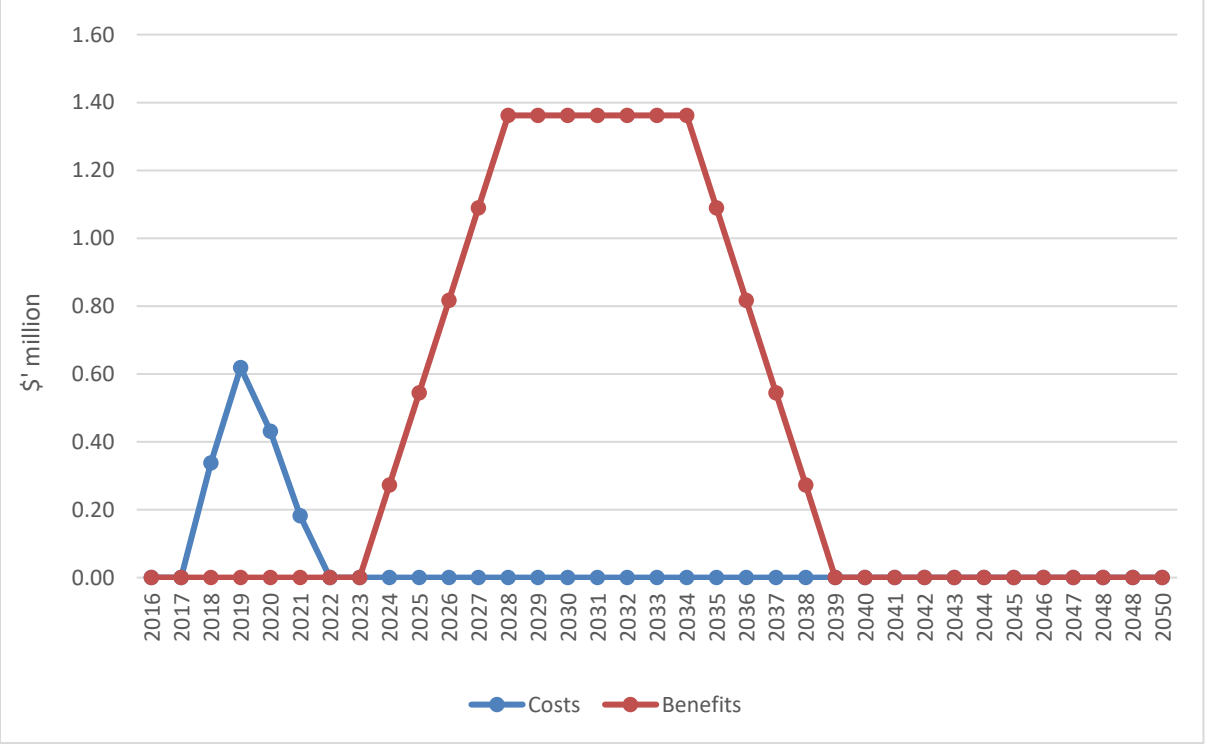
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	1.32	5.74	8.96	9.33	9.33	9.33
Present value of costs ($m)	1.71	1.71	1.71	1.71	1.71	1.71	1.71
Net present value ($m)	-1.71	-0.38	4.03	7.25	7.62	7.62	7.62
Benefit–cost ratio	0.00	0.77	3.36	5.25	5.46	5.46	5.46
Internal rate of return (%)	Negative	0.7	20.8	23.7	23.8	23.8	23.8
MIRR (%)	Negative	2.4	13.8	14.1	12.4	11.1	10.2

Table 6.2 Investment Criteria for Wine Australia (discount rate 5%)

Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.82	3.57	5.58	5.81	5.81	5.81
Present value of costs ($m)	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Net present value ($m)	-1.06	-0.24	2.51	4.51	4.74	4.74	4.74
Benefit–cost ratio	0.00	0.77	3.36	5.24	5.46	5.46	5.46
Internal rate of return (%)	Negative	0.7	20.7	23.6	23.8	23.8	23.8
MIRR (%)	Negative	2.4	13.8	14.1	12.4	11.1	10.2

The annual undiscounted benefits and cost cash flows for the total investment for the duration of the investment period plus 30 years from the last year of the initial investment are shown in Figure 6.1.

Figure 6.1 Annual Undiscounted Cash Flows for Estimated Total Benefits and Total RD&E Investment Costs for the Phylloxera Project



7. Sensitivity Analysis

A sensitivity analysis was carried out for the central analysis results reported in Section 6 and variations in the discount rate. Table 7.1 presents the results. The results are sensitive to discount rate.

Table 7.1 Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	14.98	9.33	6.10
Present value of costs ($m)	1.57	1.71	1.86
Net present value ($m)	13.41	7.62	4.24
Benefit-cost ratio	9.54	5.46	3.29

Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria. The analyses were performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values.

For this project, the greatest uncertainties related to the reduction in risk of phylloxera spread in the PRZs as a result of an updated NPMP and revised regulations (estimated at 10%) and the attribution of this benefit to the project (estimated at 35%) – Table 7.2 and Table 7.3. Results show that the benefit cost ratio remains positive if the reduction in risk is 2% and the contribution of DED 1701 10%.

Table 7.2 Sensitivity to Reduction of Phylloxera Risk in the PRZs (Total investment, 30 years)

Investment Criteria	Phylloxera Risk Reduction (%)		
	2%	5%	10% (base)
Present value of benefits ($m)	1.87	4.66	9.33
Present value of costs ($m)	1.71	1.71	1.71
Net present value ($m)	0.16	2.96	7.62
Benefit-cost ratio	1.09	2.73	5.46

Table 7.3 Sensitivity to DED 1701's Contribution to Reduced Phylloxera Risk (Total investment, 30 years)

Investment Criteria	DED 1701 Contribution to Reduced Phylloxera Risk (%)		
	10%	20%	35% (base)
Present value of benefits ($m)	2.67	5.33	9.33
Present value of costs ($m)	1.71	1.71	1.71
Net present value ($m)	0.96	3.62	7.62
Benefit-cost ratio	1.56	3.12	5.46

8. Confidence Ratings

The results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 8.1). The rating categories used are High, Medium, and Low, where:

High: denotes a good coverage of benefits or reasonable confidence in the assumptions made

Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions

made

Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 8.1 Confidence in Analysis of Program

Coverage of Benefits	Confidence in Assumptions
Medium	Medium

9. Summary of Results

Funding for DED 1701 'integrated management of established grapevine phylloxera' had a total cost of $1.71 million (present value terms) and is expected to produce aggregate total benefits of approximately $9.33 million (present value terms). This gives an estimated net present value of $7.62 million, a benefit-cost ratio of approximately 5.46, an internal rate of return of 24% and a modified internal rate of return of 10%.

Analysis results are dependent on assumptions made and are positive for core assumptions and assumptions used during sensitivity testing.

Abbreviations

DEDJTR	Victoria Department of Economic Development, Jobs, Transport and Resources
LAMP	Loop mediated isothermal amplification
NPMP	National Phylloxera Management Protocol
OCS	Office of Chief Scientist
OHS	Occupational Health and Safety
PIZ	Phylloxera Infested Zone
PRZ	Phylloxera Risk Zone
R&D	Research and Development
RD&A	Research, Development and Adoption

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