AgEconPlus CONSULTING

WINE AUSTRALIA

Benefit Cost Analysis of Wine Australia R&D Investments 2022-23

Report

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Australian Government
Wine Australia

Wine Australia for Australian Wine

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Executive Summary

Economic analyses of six 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 six 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 six projects yielded positive results at a 5% discount rate and a 30 year analysis period (Table ES1).

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

Table ES1: Benefit Cost Analyses Six Wine Australia R&D Investments 2022-23 (discount rate 5%)

Investment Criteria	Investment Project					
	Rootstock genetics and improvement: new improved rootstocks with durable resistance to root-knot nematodes and phylloxera. (CSA 1701-1.3)	**Best practice management of grapevine viruses in Australia. (PFR 2001)**	**Rapid surveillance and assessment of fire damage in South Australian vineyards for decision making. (WA 2003)**	**Plant sensor-based precision irrigation for improved vineyard water use efficiency, grape and wine composition and quality, and vineyard profitability. (UA 1701-1.3)**	**Using glycosides and other flavour precursors for improved wine flavour. (AWR 1701-3.1.2)**	**Grapevine trunk disease management for vineyard longevity in diverse climates of Australia. (SAR 1701-1.1)**
Benefit–cost ratio	2.63	4.55	4.22	5.21	3.76	1.61
Benefit-cost ratio range - core assumption sensitivity	1.04 to 7.49	1.12 to 6.44	2.42 to 8.77	2.11 to 8.77	1.68 to 9.66	0.73 to 4.11
Quantified benefits	Reduced risk of production loss due to root pests (root-knot nematode and phylloxera). Rootstocks are an insurance policy for growers reliant on 'own roots' and may prevent future business disruption.	Reduction in the cost of lost production in vineyards affected by grapevine viruses.	Savings in the cost of assessing vineyard damage post bushfire.	Improved winegrape grower profitability with irrigation water savings, consistent yield, and quality.	Winemaker profit on additional sales of no and low alcohol (NOLO) products.	Improved yield from older vines that would otherwise have been impacted by grapevine trunk disease (GTD). Reduced cost of GTD remediation including surgery on diseased vines.
Unquantified benefits	Minimisation of chemical residues on-farm from largely ineffective pesticide applications.	Increased efficiency in Wine Australia research investment with additional information on grapevine virus research priorities.	More informed vineyard management with targeted and rapid interventions to boost long-term productivity.	Improved winemaker profitability with a more certain supply of quality grapes.	Winemaker profit on additional sales of conventional wine with additional flavour, aroma, and consumer appeal.	Reduced use of fungicide adjuvants that may have harmful impacts on the farm environment e.g., damage to insect pollinators.
	Additional researcher skills in the use of new genotyping-by-sequencing techniques and genetic mapping programs.	Additional researcher and winegrape grower skills in virus surveillance, sampling, testing, extent, and impact.	Rapid assessment of bushfire loss to inform grape grower insurance claims.	Increased water use efficiency with less demand for water from the inland environment (including rivers and aquafers).	Valorisation of by-products, and potentially a reduction in waste (marc or grapes not utilized for wine production).	Additional researcher skills in DNA-based molecular diagnostic tools, assessing and managing grapevine pathogens.
	Additional profitable grape and wine production and	Additional profitable grape and wine	Generation of additional researcher, industry, and	Additional researcher skills in the use of plant-based	Additional researcher skills in juice, wine	Additional winegrape grower knowledge in

	sales which will generate income, and employment benefits in regional Australia (spill-over impact).	production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	grape grower knowledge and skills.	sensors and unmanned aerial vehicle (UAV) systems.	marc, and wine chemical and sensory analysis enabling development of premium NOLO products.	relation to management of grapevine trunk diseases.
			Social benefits including less stress, greater acceptance of Agtech, regional spill-over benefits, and more informed/improved government policy.	Additional winegrape grower knowledge and application of data-driven irrigation management and scheduling tools.	Additional winemaker knowledge of techniques to improve the flavour of NOLO products and conventional wine.	Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).
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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 36. An online random number generator was used to select projects. The results of random project selection are shown in Table 1.

Table 1 Projects Randomly Selected for Benefit Cost Analysis 2022-23

Code	Project Title	Investment
CSA 1701-1.3	Rootstock genetics & improvement: new improved rootstocks with durable resistance to root-knot nematodes and phylloxera	$2,173,287
PFR 2001	Best practice management of grapevine viruses in Australia	$70,602
WA 2003	Rapid surveillance and assessment of fire damage in South Australian vineyards for decision making	$263,500
UA 1803-1.3	Plant sensor-based precision irrigation for improved vineyard water use efficiency, grape and wine composition and quality, and vineyard profitability	$577,219
AWR 1701-3.1.2	Using glycosides and other flavour precursors for improved wine flavour	$586,735
SAR 1701-1.1	Grapevine trunk disease management for vineyard longevity in diverse climates of Australia	$1,922,573
	Investment in projects for analysis	$5,593,916
	Total of Wine Australia investment in completed projects	$45,306,092
	Analysis projects share of total investment	12%

Documentation for each of these projects was assembled with assistance from Wine Australia personnel and included project plans, progress reports, 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 six 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 2023 dollar terms. Future costs and benefits were discounted to the 2023 year while past costs were inflated to 2023 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 2023 dollar terms. Given the assumptions made for each evaluation, all six investments are expected to produce positive net benefits over 30 years from the last year of investment.

Table 2: Benefit Cost Analyses for Six Wine Australia R&D Investments 2022-23 (discount rate 5%)

Investment Criteria	Investment Project					
	Rootstock genetics and improvement: new improved rootstocks with durable resistance to root-knot nematodes and phylloxera. (CSA 1701-1.3)	**Best practice management of grapevine viruses in Australia. (PFR 2001)**	**Rapid surveillance and assessment of fire damage in South Australian vineyards for decision making. (WA 2003)**	**Plant sensor-based precision irrigation for improved vineyard water use efficiency, grape and wine composition and quality, and vineyard profitability. (UA 1701-1.3)**	**Using glycosides and other flavour precursors for improved wine flavour. (AWR 1701-3.1.2)**	**Grapevine trunk disease management for vineyard longevity in diverse climates of Australia. (SAR 1701-1.1)**
Benefit–cost ratio	2.63	4.55	4.22	5.21	3.76	1.61
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Quantified benefits	Reduced risk of production loss due to root pests (root-knot nematode and phylloxera). Rootstocks are an insurance policy for growers reliant on 'own roots' and may prevent future business disruption.	Reduction in the cost of lost production in vineyards affected by grapevine viruses.	Savings in the cost of assessing vineyard damage post bushfire.	Improved winegrape grower profitability with irrigation water savings, consistent yield, and quality.	Winemaker profit on additional sales of no and low alcohol (NOLO) products.	Improved yield from older vines that would otherwise have been impacted by grapevine trunk disease (GTD). Reduced cost of GTD remediation including surgery on diseased vines.
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	Additional researcher skills in the use of new genotyping-by-sequencing techniques and genetic mapping programs.	Additional researcher and winegrape grower skills in virus surveillance, sampling, testing, extent, and impact.	Rapid assessment of bushfire loss to inform grape grower insurance claims.	Increased water use efficiency with less demand for water from the inland environment (including rivers and aquafers).	Valorisation of by-products, and potentially a reduction in waste (marc or grapes not utilized for wine production).	Additional researcher skills in DNA-based molecular diagnostic tools, assessing and managing grapevine pathogens.
	Additional profitable grape and wine production and	Additional profitable grape and wine	Generation of additional researcher, industry, and	Additional researcher skills in the use of plant-based	Additional researcher skills in juice, wine	Additional winegrape grower knowledge in

	sales which will generate income, and employment benefits in regional Australia (spill-over impact).	production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	grape grower knowledge and skills.	sensors and unmanned aerial vehicle (UAV) systems.	marc, and wine chemical and sensory analysis enabling development of premium NOLO products.	relation to management of grapevine trunk diseases.
			Social benefits including less stress, greater acceptance of Agtech, regional spill-over benefits, and more informed/improved government policy.	Additional winegrape grower knowledge and application of data-driven irrigation management and scheduling tools.	Additional winemaker knowledge of techniques to improve the flavour of NOLO products and conventional wine.	Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).
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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.

Six 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 six projects. A brief conclusion is provided in Section 4. Appendices 1 to 6 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 36. An online random number generator was used to select six projects. The results of random project selection are shown in Table 2.1.

Table 2.1 Projects Randomly Selected for Benefit Cost Analysis 2022-23

Code	Project Title	Investment
CSA 1701-1.3	Rootstock genetics & improvement: new improved rootstocks with durable resistance to root-knot nematodes and phylloxera	$2,173,287
PFR 2001	Best practice management of grapevine viruses in Australia	$70,602
WA 2003	Rapid surveillance and assessment of fire damage in South Australian vineyards for decision making	$263,500
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	Investment in projects for analysis	$5,593,916
	Total of Wine Australia investment in completed projects	$45,306,092
	Analysis projects share of total investment	12%

2.2 Individual Analyses

Each investment was evaluated through the following steps:

1. Information from the original project plan, progress reports, 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 2023 dollar terms. Future costs and benefits were discounted to the 2023 year while past costs were inflated to 2023 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 Six Projects

Project	Benefits
Rootstock genetics and improvement: new improved rootstocks with durable resistance to root-knot nematodes and phylloxera. (CSA 1701-1.3)	Economic • Reduced risk of production loss due to root-knot nematode and phylloxera. Rootstocks are an insurance policy for growers reliant on 'own roots' and may prevent future business disruption. Environmental • Minimisation of chemical residues on-farm from largely ineffective pesticide applications. Social • Additional researcher skills in the use of new genotyping-by-sequencing techniques and genetic mapping programs. • Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).
Best practice management of grapevine viruses in Australia. (PFR 2001)	Economic • Reduction in the cost of lost production in vineyards affected by grapevine viruses. • Increased efficiency in Wine Australia research investment with additional information on grapevine virus research priorities. Environmental • Nil. Social • Additional researcher and winegrape grower skills in virus surveillance, sampling, testing, extent, and impact. • Additional profitable grape and wine sales which will generate income, and employment benefits in regional Australia (spill-over impact).
Rapid surveillance and assessment of fire damage in South Australian vineyards for decision making. (WA 2003)	Economic • Savings in the cost of assessing vineyard damage post bushfire. • More informed vineyard management with targeted and rapid interventions to boost long-term productivity. • Rapid assessment of bushfire loss to inform grape grower insurance claims. Environmental • Nil. Social • Capacity – generation of additional researcher, industry, and grape grower knowledge and skills. • Other social benefits including less stress, greater acceptance of Agtech, regional spill-over benefits, and improved government policy.

Plant sensor-based precision irrigation for improved vineyard water use efficiency, grape and wine composition and quality, and vineyard profitability. (UA 1701-1.3)	Economic • Improved winegrape grower profitability with irrigation water savings, consistent yield, and quality. • Improved winemaker profitability with a more certain supply of quality grapes. Environmental • Increased water use efficiency with less demand for water from the inland environment (including rivers and aquafers). Social • Capacity - additional researcher skills in the use of plant-based sensors and UAV systems. • Capacity - additional winegrape grower knowledge and application of data-driven irrigation management and scheduling tools. • Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).
Using glycosides and other flavour precursors for improved wine flavour. (AWR 1701-3.1.2)	Economic • Winemaker profit from additional sales of NOLO products. • Winemaker profit from additional sales of conventional wine with additional flavour, aroma, and consumer appeal. Environmental • Valorisation of by-products, and potentially a reduction in waste (marc or grapes not utilized for wine production). Social • Capacity - additional researcher skills in juice, wine marc, and wine chemical and sensory analysis enabling development of premium NOLO products. • Capacity - additional winemaker knowledge of techniques to improve the flavour of NOLO products and conventional wine. • Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).
Grapevine trunk disease management for vineyard longevity in diverse climates of Australia. (SAR 1701-1.1)	Economic • Improved yield from older vines that would otherwise have been impacted by grapevine trunk disease (GTD). • Reduced cost of GTD remediation including surgery on diseased vines. Environmental • Reduced use of fungicide adjuvants that may have harmful impacts on the farm environment e.g., damage to insect pollinators. Social • Capacity - additional researcher skills in DNA-based molecular diagnostic tools, assessing and managing grapevine pathogens. • Capacity - additional winegrape grower knowledge in relation to management of grapevine trunk diseases. • Additional profitable grape and wine production and sales which will generate income, and employment benefits 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 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 6).

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

Investment Criteria	Investment Project					
	Rootstock genetics and improvement: new improved rootstocks with durable resistance to root-knot nematodes and phylloxera. (CSA 1701-1.3)	**Best practice management of grapevine viruses in Australia. (PFR 2001)**	**Rapid surveillance and assessment of fire damage in South Australian vineyards for decision making. (WA 2003)**	**Plant sensor-based precision irrigation for improved vineyard water use efficiency, grape and wine composition and quality, and vineyard profitability. (UA 1701-1.3)**	**Using glycosides and other flavour precursors for improved wine flavour. (AWR 1701-3.1.2)**	**Grapevine trunk disease management for vineyard longevity in diverse climates of Australia. (SAR 1701-1.1)**
Present value of benefits ($m)	16.96	0.44	1.6	16.54	3.64	6.76
Present value of costs ($m)	6.46	0.1	0.38	3.17	0.97	4.18
Net present value ($m)	10.51	0.34	1.22	13.37	2.67	2.57
Benefit–cost ratio	2.63	4.55	4.22	5.21	3.76	1.61
Benefit-cost ratio range - core assumption sensitivity	1.04 to 7.49	1.12 to 6.44	2.42 to 8.77	2.11 to 8.77	1.68 to 9.66	0.73 to 4.11
Internal rate of return (%)	10.4	36.0	22.2	32.3	14.6	7.8
Modified internal rate of return (%)	8.1	10.1	10.0	10.7	9.4	6.4

4. Conclusion

All six investment analyses yielded positive results at the 5% discount rate, with B/C Ratios of 2.63, 4.55, 4.22, 5.21, 3.76, and 1.61.

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 analyses.

Appendix 1: Economic Analysis of Wine Australia's Investment in Rootstock Genetics and Improvement – New Rootstocks with Durable Resistance to Root-knot Nematodes and Phylloxera

1. Background

Root-knot nematode (*Meloidogyne spp.*) is a microscopic roundworm that produces grapevine root galls that restrict nutrient and water uptake and facilitate fungal infection. Root-knot nematode may cause 60% yield loss and there are few effective controls for the pest. Root-knot nematode is best controlled through resistant rootstocks such as 'Ramsey'. However, current nematode resistant rootstocks may impart undesirable attributes on the grafted grapevine e.g., high vigour growth and pest resistance may breakdown over time (AWRI 2010).

Phylloxera (*Daktulsphaira vitifoliae*) is a tiny insect pest that destroys grapevines by feeding on their roots. *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 controls for phylloxera means that pulling affected vines and replanting with vines grafted onto phylloxera-resistant rootstock (non-*vinifera*) is the most effective control option. As with nematode resistant rootstocks, phylloxera resistant rootstock may impart undesirable attributes on the grafted grapevine (CW Clarke et al. 2020).

Improved root-knot nematode and phylloxera resistant rootstocks are critical to sustainable grapevine production and new technology makes rootstock breeding to impart multiple desirable attributes more efficient. With the development of genotyping-by-sequencing techniques and the application of new genetic mapping programs, tools are now available to combine root-knot nematode and phylloxera resistance loci from different genetic backgrounds to develop new rootstocks with durable resistance to both pests.

A previous Wine Australia project CSP 1304 completed by the CSIRO Rootstock Breeding team identified genetic markers for root-knot nematode (MJ1) and phylloxera resistance (RDV2). To build on this research, *Vitis* species with root-knot nematode and phylloxera resistance that is phylogenetically ('evolutionary') distant to *Vitis cinerea* (American native grape) were to be identified and next generation mapping used to identify markers linked to new root-knot nematode and phylloxera resistance loci.

Elite breeding lines containing multiple resistance genes were then to be produced for developing rootstock genotypes with durable pest resistance. In vitro ('test tube') root-knot nematode and phylloxera screens were to be completed to identify germplasm that maintains pest resistance at moderate to high soil temperatures.

The current project is part of a program of genetic research addressing both scion and rootstock improvement. A sister project completed by the research team addressed rootstock tolerance to abiotic/environmental stress (CSA 1701-1.4).

2. Summary of Projects

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

Table 2.1 Project Description

CSA 1701-1.3: Rootstock Genetics and Improvement: New Improved Rootstocks with Durable Resistance to Root-knot Nematodes and Phylloxera	
Project Details	Research Organisation: CSIRO Period: July 2017 to September 2022 Principal Investigator: Dr Harley Smith
Rationale	The project was to identify genotypes that maintain pest resistance and incorporate these genotypes into the durable pest resistant breeding program.

Objectives	Specific objectives included: • Evaluate nematode/phylloxera resistant rootstocks selected for release from CSP 1304. Rootstocks to be assessed for yield, vigour, fruit, and wine quality. • Use next generation mapping to identify other markers linked to new root-knot nematode and phylloxera resistance loci. • Produce elite breeding lines containing multiple resistance genes for developing rootstock genotypes with durable pest resistance. • Develop in vitro root-knot nematode and phylloxera screens to identify germplasm that maintains pest resistance at moderate to high temperatures.
Activities and Outputs	• Establish the first set of F1 populations to map new root-knot nematode (MJ2) and phylloxera (RDV3) resistance loci in grapevine. • Develop an in vitro root-knot nematode screening assay. • Determine the biological basis of root-knot nematode resistance and the impact of abiotic stress on resistance. • Data from four CSP 1304 field trials collected and analyses to support the selection of new rootstocks. Rootstocks tested for yield, berry composition, and dormant vine pruning weight (to measure rootstock vigour). • Data from four CSP 1304 field trials collected on the response of selected genotypes to reduced irrigation and the ability to exclude salt. Long term monitoring planned to determine rootstock performance in a hot climate, irrigated with moderately saline water, and subject to mechanical pruning. • Evaluation completed on rootstock selections from CSP 1304 which performed well under reduced irrigation. The project team recommended the release of four 'C-series' rootstocks (C113, C114, C20, and C7). Mother vine plantings of these rootstocks have been established to facilitate adoption. • The current project continued to monitor these new rootstock releases along with other prospects from the trials. • New root-knot nematode/phylloxera resistant material was identified to combine with MJ1 and RDV2 loci to create rootstocks with durable resistance. • Field populations were established for genetic mapping and phenotyping of new rootstock. • Elite rootstocks, which perform well under reduced irrigation were registered for Plant Breeders Rights (PBR). • Markers linked to new root-knot nematode and phylloxera resistant loci validated. • Elite second-generation marker-assisted rootstock selections containing stacked genes for root-knot nematode and phylloxera resistance identified. Genetic material sourced from *V. aestivalis* accessions, *V. acerifolia* accessions, *V. moniticola* hybrid, *V. cordifolia* hybrid, *V. caribaea* accessions, and *V. champinii x M. rotundifolia* hybrid. • Molecular markers and genetic information for key traits available for screening rootstocks and germplasm material for ideal genotype used for rootstock development. • First generation rootstocks released and building blocks in place for second and third generation durable root-knot nematode and phylloxera resistance. • Conference and symposium presentations delivered in Australia (e.g., Roots and Rhizosphere Symposium Waite SA 2018) and overseas (e.g., Phylloxera and Nematode Conference University of California Davis USA). • The project also produced multiple publications and articles, a project plan, three AOPs, eight mid-year and EOFY reports and a final project document.

Outcomes	• Progress toward the creation of new, durable root-knot nematode and phylloxera resistant rootstocks that are also resistant to abiotic stress. These rootstocks will also deliver grapevines that do not sacrifice other desirable production traits (e.g., yield, vigour, fruit, and wine quality). • Improved vineyard performance through the development and adoption of new rootstocks with durable resistance to root-knot nematode and phylloxera under Australian conditions.
Impacts	• Economic – reduced risk of production loss due to root-knot nematode and phylloxera. Pest resistant rootstocks are an insurance policy for growers presently reliant on 'own roots' and may prevent future business disruption. • Environmental – minimisation of chemical residues on-farm from largely ineffective nematicide and insecticide applications used to limit the impact of root-knot nematodes and phylloxera. • Capacity – additional CSIRO skills in the use of new genotyping-by-sequencing techniques and genetic mapping programs. • Social – additional profitable wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

3. Match with National Priorities

Table 3.1 Australian Government Research Priorities

Australian Government Strategies and Priorities	
National Science and Research Priorities[1]	**National Agricultural Innovation Priorities[2]**
1. Food – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets. **2. Soil and Water** – improving the use of soils and water resources, both terrestrial and marine. **3. Transport** – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions. **4. Cybersecurity** – improving cybersecurity for individuals, businesses, government, and national infrastructure. **5. Energy and Resources** – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries. **6. Manufacturing** – supporting the development of high value and innovative manufacturing industries in Australia. **7. Environmental Change** – mitigating, managing, or adapting to changes in the environment. **8. Health** – improving the health outcomes for all Australians.	On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030. These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper. **1.** Australia is a trusted exporter of premium food and agricultural products by 2030. **2.** Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030. **3.** Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030. **4.** Australia is a mature adopter, developer, and exporter of digital agriculture by 2030.

[1] See: 2015 Australian Government Science and Research Priorities. https://www.industry.gov.au/data-and-publications/science-and-research-priorities

[2] See: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment

The Wine Australia project has addressed National Science/Research Priority 1. The project also contributed to the first and third National Agricultural Innovation 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, the project funding body. These costs include both project and overhead expenditures.
- In-kind contributions to the research project – non-cash contributions made by the research partner (CSIRO).
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia and other project collaborators including Ag VIC which contributed phylloxera screening capability to the project.

4.1.2 Administration

No additional administration costs were identified.

4.1.3 Extension

The project did not generate outputs that were immediately suitable for extension to grape growers i.e., rootstocks ready for grafting and planting. However, it did extend project findings to researchers and others with an interest in rootstock development and adoption. The cost of this activity was covered in the project budget.

4.1.4 Adoption

No incremental additional adoption costs have been identified. Grape growers will eventually incur costs replacing vines grown on 'own roots' with vines grafted onto project generated rootstock. However, no incremental additional costs are anticipated – under the base case counterfactual, 'own root' vines would be replaced with grafted 'Ramsey' rootstock (or similar) while under the 'with project' case, they will be replaced with project rootstocks made available to growers at a similar cost.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The key outputs from the project include both valuable 'C-series' rootstocks, as well as molecular markers and genetic information for incorporation into second and third generation rootstocks. Together these outputs are expected to confer durable grapevine resistance to root-knot nematode and phylloxera.

The impact pathway for the project is:

1. Rootstocks with durable resistance to root-knot nematode and phylloxera developed using project (CSA 1701-1.3) and other research project findings (e.g., CSP 1304, CSA 1701-1.4, and future rootstock research investment).
2. Rootstocks released to the nursery industry and used to produce commercially appealing scion and rootstock combinations.
3. Vines purchased and planted by winegrape growers in vineyards vulnerable to root-knot nematode and phylloxera.

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			
Reduced risk of production loss due to root-knot nematode and phylloxera. Pest resistant rootstocks are an insurance policy for growers presently on 'own roots' and may prevent future business disruption.	Root-knot nematode and phylloxera also impact the table grape industry and rootstocks developed with project outputs may also be adopted by table grape growers.	Nil.	Most rootstocks used in Australia originate in Europe, so it is conceivable that improved rootstocks may also find a market in the EU and other wine growing regions.
Environmental Benefits			
Minimisation of chemical residues on-farm from largely ineffective nematicide and insecticide applications used to limit the impact of root-knot nematodes and phylloxera.	Nil.	Minimisation of chemical residues downstream with the potential to adversely impact biodiversity and water catchments.	Nil.
Social Benefits			
Additional CSIRO skills in the use of new genotyping-by-sequencing techniques and genetic mapping programs. Additional profitable wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	Skills developed during the project in genotyping-by-sequencing and in the use of new genetic programs will be relevant to breeding programs in other plant and animal industries.	A larger and more profitable wine industry will contribute employment and income multipliers to the Australian economy.	Nil.

4.2.3 Public versus Private Benefits

The project will generate a combination of private and public benefits. The principle private benefit is reduced risk of production loss due to root-knot nematode and phylloxera. Public benefits will include minimisation of chemical residues with fewer pest treatments, additional CSIRO genetic research capacity, and flow on income and employment benefits for regional communities.

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 winegrape growers, winemakers, wholesalers, retailers, and exporters all sharing some of the benefits.

4.2.5 Benefits to other Primary Industries

Table grapes and dried grapes are also susceptible to root-knot nematode and phylloxera. Pest resistant rootstocks progressed through this project may also be relevant to these industries.

4.2.6 Benefits Overseas

Most rootstocks used in Australia originate in Europe or the USA, so it is conceivable that improved rootstocks may also find a market in the EU, USA, and other wine growing regions.

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) incurred by Wine Australia and CSIRO as well as project administration costs.	Reduced risk of production loss due to root-knot nematode and phylloxera.
Overhead costs including time associated with meetings between the researchers, Wine Australia and collaborating organisations including Ag VIC.	Minimisation of chemical residues on-farm from largely ineffective nematicide and insecticide applications used to limit the impact of root-knot nematodes and phylloxera.
	Additional CSIRO skills in the use of new genotyping-by-sequencing techniques and genetic mapping programs.
	Additional profitable wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

The following table shows annual investment in the project by Wine Australia (Table 5.1).

Table 5.1 Investment by Wine Australia in the Project for Years Ending June 2018 to June 2022

Project Code	2018	2019	2020	2021	2022	Total
CSA 1701-1.3	383,629	411,819	476,699	446,013	455,127	**2,173,287**
Total						

Source: Wine Australia record of project expenditure

The other investor in AWR 1701-1.3 was CSIRO (Table 5.2).

Table 5.2 Investment by Others in the Project for Years Ending June 2018 to June 2022

Project Code	2018	2019	2020	2021	2022	Total
CSA 1701-1.3	393,166	406,694	445,202	429,438	440,640	**2,115,140**
Total						

Source: Wine Australia record of project expenditure

Table 5.3 provides the total investment by year for both sources.

Table 5.3 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia	Others	Total
2018	383,629	393,166	**776,795**
2019	411,819	406,694	**818,513**
2020	476,699	445,202	**921,901**
2021	446,013	429,438	**875,451**
2022	455,127	440,640	**895,767**
Total	**2,173,287**	**2,115,140**	**4,288,427**

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 Industry and Agency Costs

Industry and agency contributions to the project include time associated with meetings between the researchers and Wine Australia and other project collaborators including Ag VIC which contributed phylloxera screening capability to the project. These costs are estimated at $10,000 per annum each year of the project.

5.2 Benefits

Counterfactual: in the absence of this project, pest resistant rootstocks may have been developed through an alternative channel e.g., an overseas research program. For this reason, it is not appropriate to "claim" all the benefits of the reduced risk of production loss due to nematode and phylloxera for the project and a counterfactual of 75% has been assumed. That is, it is 25% likely that potential project benefits would have been realised in the absence of project investment.

5.2.1 Reduced Risk of Production Loss Due to Root-knot Nematode and Phylloxera

CSA 1701-1.3 has delivered progress toward the creation of new, durable root-knot nematode and phylloxera resistant rootstocks. The beneficiaries of this research will be the majority of winegrape growers whose vines are grown on 'own roots' and are vulnerable to quarantine zone breakdown. 'Own roots' account for 95% of Australian winegrape production. Root-knot nematode and phylloxera resistant rootstocks are an insurance policy for winegrape growers and offset the risk of future business disruption (Alex Sas, Senior RD&E Manager, Wine Australia, pers. Comm., January 2024).

A summary of key assumptions used to quantify this benefit is shown in Table 5.4.

Table 5.4 Summary of Assumptions

Variable	Assumption	Source
Reduced Risk of Production Loss Due to Root-knot Nematode and Phylloxera		
Vineyard area vulnerable to root-knot nematode and phylloxera.	139,293 ha	Equivalent to 95% of total Australian vineyard area of 146,624 ha (National Vineyard Scan 2019).
Reduced risk of grapevine production loss with adoption of pest resistant rootstock.	One in five chance of pest infestation (20%) reduced to one in ten chance (10%)	Analyst's assumption informed by recent spread of phylloxera into the Yarra Valley, Victoria.
Profit on winegrape production no longer at risk from root-knot nematode and phylloxera.	$1,455/ha	Average grape price of $642/t[3] X average yield of 12.59t/ha X 18% long term average profit on winegrape sales (Wine Australia National Vintage Report 2023 and AgEconPlus 2019).
Year in which new pest resistant rootstocks start to reduce the risk of root-knot nematode and phylloxera.	2031	Further research required to deliver and grow pest resistant rootstocks.
Year in which maximum adoption of new pest resistant rootstocks occurs.	2034	Analyst's assumption.

[3] The analyst notes 2024 prices are well below this average especially in warm inland areas.

Attribution of benefits to this project.	20%	Estimate prepared after considering contribution made by this project (CSA 1701-1.3), CSP 1304, CSA 1701-1.4, and the need for future rootstock research investment.
Probability of valuable outputs.	100%	CSA 1701-1.3 has delivered second generation marker-assisted rootstock selections for root-knot nematode and phylloxera resistance.
Probability of valuable outcomes.	80%	Rootstock selections require further R&D investment.
Probability of impact.	75%	It is not certain that pest resistant rootstocks will provide sustained root knot nematode and phylloxera protection.
Counterfactual	75%	See above explanation.

5.2.2 Other Potential Benefits

Other potential benefits identified but not valued are summarised in Table 4.2. 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 2023 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 (2022).

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%)

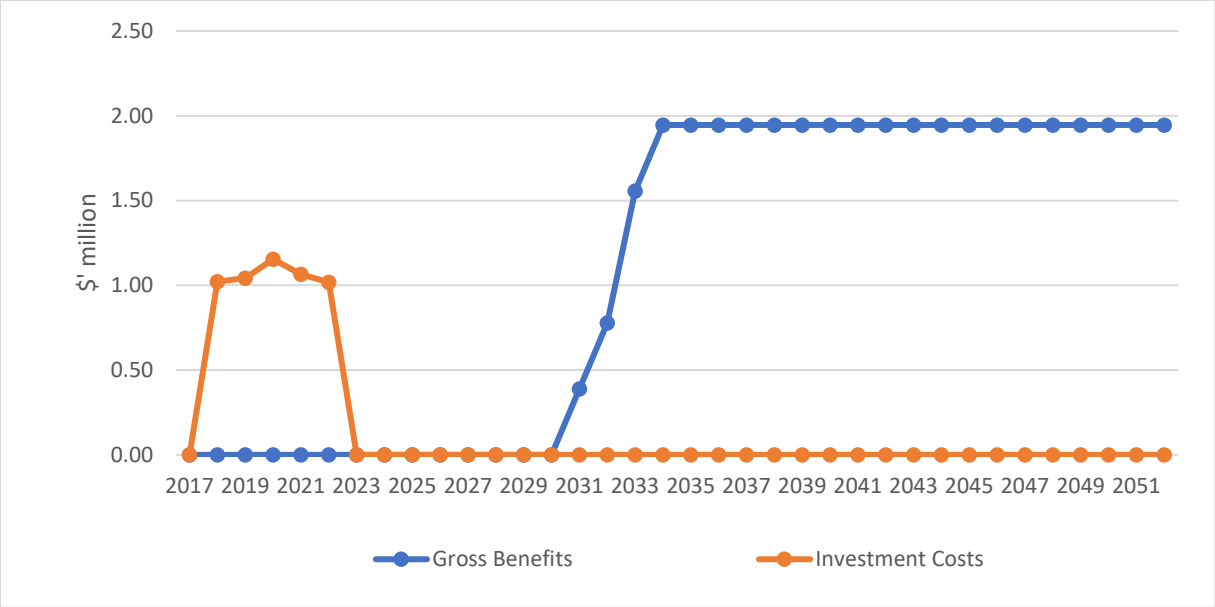
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.00	0.80	6.25	10.72	14.22	16.96
Present value of costs ($m)	6.46	6.46	6.46	6.46	6.46	6.46	6.46
Net present value ($m)	-6.46	-6.46	-5.65	-0.20	4.26	7.76	10.51
Benefit–cost ratio	0.00	0.00	0.12	0.97	1.66	2.20	2.63
Internal rate of return (%)	Negative	Negative	Negative	4.1	8.1	9.6	10.4
MIRR (%)	Negative	Negative	Negative	4.2	7.3	8.0	8.1

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 ($m)	0.00	0.00	0.42	3.31	5.67	7.52	8.97
Present value of costs ($m)	3.42	3.42	3.42	3.42	3.42	3.42	3.42
Net present value ($m)	-3.42	-3.42	-2.99	-0.11	2.26	4.11	5.56
Benefit–cost ratio	0.00	0.00	0.12	0.97	1.66	2.20	2.63
Internal rate of return (%)	Negative	Negative	Negative	4.1	8.1	9.6	10.4
MIRR (%)	Negative	Negative	Negative	4.2	7.3	8.0	8.1

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 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 the discount rate and the project approaches 'breakeven' at a discount rate of 10%. This is due to the long lag between project investment and root knot nematode and phylloxera risk reduction.

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

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	39.69	16.96	8.13
Present value of costs ($m)	5.30	6.46	7.83
Net present value ($m)	34.39	10.51	0.30
Benefit-cost ratio	7.49	2.63	1.04

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 uncertainty related to the reduction in risk of production loss due to nematode/phylloxera and the area of vineyard vulnerable to these pests - Table 7.2 and Table 7.3. Results show that the benefit cost ratio is somewhat sensitive to both these key assumptions. If reduction in risk attributable to pest resistant rootstocks is halved to 5% then project benefits will continue to exceed project costs. If area of 'own roots' is reduced to 38% the project fails to breakeven.

Table 7.2 Sensitivity to Reduction in Risk of Production Loss (Total investment, 30 years)

Investment Criteria	Reduction in Risk due to Nematode/Phylloxera Resistant Rootstocks (%)		
	5%	10% (base)	20%
Present value of benefits ($m)	8.48	16.96	33.93
Present value of costs ($m)	6.46	6.46	6.46
Net present value ($m)	2.02	10.51	27.47
Benefit-cost ratio	1.31	2.63	5.25

Table 7.3 Sensitivity to Area of Vineyard Vulnerable to Root-knot Nematode and Phylloxera (Total investment, 30 years)

Investment Criteria	Area of 'Own Roots' Winegrape Production (% of 146,624 ha)		
	38%	50%	95% (base)
Present value of benefits ($m)	6.25	8.93	16.96
Present value of costs ($m)	6.46	6.46	6.46
Net present value ($m)	-0.21	2.47	10.51
Benefit-cost ratio	0.97	1.38	2.63

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 CSA 1701-1.3 investment in 'rootstock genetics and improvement – new rootstocks with durable resistance to root-knot nematodes and phylloxera' had a total cost of $6.46 million (present value terms) and is expected to produce aggregate total benefits of approximately $16.96 million (present value terms). This gives an estimated net present value of $10.51 million, a benefit-cost ratio of approximately 2.63, an internal rate of return of 10.4% and a modified internal rate of return of 8.1%.

Analysis results are dependent on assumptions made and are positive for core assumptions and do not become negative until 'lower end' assumptions are applied.

Abbreviations

AWRI	Australian Wine Research Institute
EOFY	End of Financial Year
EU	European Union
OCS	Office of Chief Scientist
PBR	Plant Breeders Rights
RD&E	Research, Development and Extension

Persons Contacted

Angelica Crabb, Senior Analyst, Wine Australia
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Suzanne McLoughlin, Acting CEO, Vinehealth Australia
Alex Sas, Senior RD&E Program Manager, Wine Australia
Harley Smith, Principal Researcher, CSIRO

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Appendix 2: Economic Analysis of Wine Australia's Investment in Best Practice Management of Grapevine Viruses in Australia

1. Background

The potential impact of viruses in grapevines on productivity and grape quality is becoming increasingly recognised in Australia. Australia has twelve endemic viruses. Worldwide there are 80 grapevine viruses.

Two viruses of particular economic importance in Australia are Leafroll (caused by $GLRaV_1$ and $GLRaV_3$) and Shiraz Disease (caused by GVA). Both are rising in incidence and perceived as having economic impact in many grape growing regions. The negative effects of these viruses include reduced vine vigour as well as reduced grape quality and yield, providing a challenge for grape growers and wine companies.

Minimising the impact and spread of endemic viruses, and preventing the establishment of new exotic viruses, is a priority for the Australian wine industry. Viruses appear to be spread readily within and between vineyards by insect vectors (e.g., mealybugs and soft scale insects) and through the use of infected propagation material. Australia has at least two species of mealybug and up to ten species of soft scale insect that are potential vectors of grapevine viruses. Multiple accreditation schemes attempt to regulate the quality of vineyard planting material.

The rapid expansion of vineyard area in Australia in the late 1990s is believed to have resulted in an equally rapid spread of virus throughout winegrowing regions. Demand outstripped supply of certified high health propagation material and led to the supply and use of untested propagation material.

The spread of viruses is also likely to be due to the limitations in virus testing technology and the cost of such tests to the producer. While improvements have been made with the adoption of more sensitive diagnostics, further work is required to determine best practice for sampling and assessment of results.

There is a need to better understand and manage the effects of grapevine viruses both in the propagation supply chain and in commercial vineyards. Best management practices are required to inform management of not only viruses but also their vectors in new vineyard plantings and more mature vineyards, as well as develop decision support tools for growers.

In addition to the project considered here, Wine Australia has recently invested in:

- Research into the epidemiology and physiology of some viruses ($GLRaV_1$ and $GLRaV_3$, GVA, GPGV).
- Improved detection and diagnostics of grapevine viruses, including supporting proficiency testing of diagnostic laboratories.
- Activities under the National Grapevine Collection program to develop a national vine propagation and supply standard and fill gaps in knowledge on surveillance and management of grapevine viruses.
- Revision of Part 1 of the National Vine Accreditation Scheme by the South Australian Vine Improvement Association.
- Research into the biology and control of grapevine scale, a significant vector of viruses in vineyards.

2. Summary of Projects

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

Table 2.1 Project Description

PFR 2001: Best Practice Management (BPM) of Grapevine Viruses in Australia	
Project Details	Research Organisation: New Zealand Institute for Plant and Food Research (NZIPFR) Period: February 2021 to August 2022 Principal Investigator: Dr Vaughn Bell
Rationale	Management of viruses is challenging, and growers require standard protocols for virus and vector control that are tried and tested. A standard protocol for management of leafroll viruses was produced by Treasury Wine Estates. Wine Australia wished to develop this protocol into a whole-of-sector guidance, thereby increasing industry awareness and capability to manage grapevine viruses and reduce the impact of grapevine viruses on Australian viticulture.
Objectives	1. Develop a BPM guide for virus management in Australian vineyards and nurseries. 2. Identify gaps in knowledge re surveillance, sampling, testing, extent, and impact of viruses on the Australian wine industry. 3. Scope options including research questions and priorities to address virus knowledge gaps.
Activities and Outputs	• Consult with Aust and New Zealand collaborators to develop a project plan. • Establish a project steering committee and determine meeting frequency. • Review the existing draft of the Vineyard Best Practice Standard. • Review the relevant Australian grapevine virus literature including sector reports, factsheets, and other publications. • Consult Vine Industry Nursery Association, Australian Vine Improvement Associations, Vinehealth Australia, National Vine Biosecurity Committee, Plant Health Committee of the government National Biosecurity Committee, relevant researchers and experts in grapevine virology, the Australian Table Grape Association, and Dried Fruit Australia. • Write the draft BPM guide for virus management in Aust vineyards/nurseries. • Identify gaps in knowledge and prioritise virus research questions/projects. • Submit a draft final report to Wine Australia including the BPM Guide, gap analysis and linked information. • Present the draft report to Wine Australia and relevant sector stakeholders. • Revise deliverables as per stakeholder feedback on the draft report. • A guide titled: *Grapevine Leafroll Disease and Shiraz Disease: Interim Recommendations for Management in Australian Vineyards, August 2022* was prepared by the researcher and released by Wine Australia. • The guide details an integrated (multi-tactic), whole-of-industry response which includes: 1. Detection of virus infection in grapevines. 2. Identification and removal of diseased grapevines. 3. Monitoring and managing insect vectors of grapevine viruses. 4. Using vines certified as virus-free when planting. • Underpinning an integrated response is the development of a vine propagation and supply standard. The standard is being developed in a separate project and once adopted across the supply chain, will provide access to certified virus free grapevine planting material. Continued interchange between the standard and other parts of the integrated response offers growers the best prospect for managing viruses effectively. • Knowledge gaps requiring further study were highlighted and a separate gap analysis document provided to Wine Australia.

	• The current interim guide will be regularly reviewed to provide legitimacy, ensure it remains fit-for-purpose, and to incorporate improvement to practice standards.
Outcomes	• A call to action for the Australian grape and wine industry to better manage the viruses affecting production and vineyard longevity. • A call to action for the Australian grape and wine industry to better monitor and manage the insect vectors of viruses negatively altering grape production and vineyard longevity. • Tools to restrict the spread of grapevine viruses and their impact on winegrape production. • Targeted research that when delivered will further reduce the impact of viruses on grape growers and wine companies.
Impacts	• Economic – reduction in the cost of lost production in vineyards affected by grapevine viruses. • Economic – increased efficiency in Wine Australia research investment with additional information on grapevine virus research priorities. • Capacity – additional researcher and winegrape grower skills in virus surveillance, sampling, testing, extent, and impact. • Social – additional profitable wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

3. Match with National Priorities

Table 3.1 Australian Government Research Priorities

Australian Government Strategies and Priorities	
National Science and Research Priorities[4]	**National Agricultural Innovation Priorities[5]**
1. **Food** – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets. 2. **Soil and Water** – improving the use of soils and water resources, both terrestrial and marine. 3. **Transport** – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions. 4. **Cybersecurity** – improving cybersecurity for individuals, businesses, government, and national infrastructure. 5. **Energy and Resources** – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries. 6. **Manufacturing** – supporting the development of high value and innovative manufacturing industries in Australia. 7. **Environmental Change** – mitigating, managing, or adapting to changes in the environment.	On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030. These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper. 1. Australia is a trusted exporter of premium food and agricultural products by 2030. 2. Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030. 3. Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030. 4. Australia is a mature adopter, developer, and exporter of digital agriculture by 2030.

[4] See: 2015 Australian Government Science and Research Priorities. https://www.industry.gov.au/data-and-publications/science-and-research-priorities

[5] See: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment

8. Health – improving the health outcomes for all Australians.	

The Wine Australia project has addressed National Science/Research Priority 1. The project also addresses National Agricultural Innovation Priority one and three.

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, the project funding body. These costs include both project and overhead expenditures.
- Research partner contributions to the project – no contributions were made by NZIPFR to this project.
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia and other project collaborators including vine improvement and biosecurity associations and agencies, the Australian Table Grape Association and Dried Fruit Australia.

4.1.2 Administration

No additional administration costs were identified.

4.1.3 Extension

The project generated guide, *Grapevine Leafroll Disease and Shiraz Disease: Interim Recommendations for Management in Australian Vineyards, August 2022* was made available on the Wine Australia website and its importance along with the need to control grapevine viruses communicated through industry channels.

4.1.4 Adoption

Winegrape growers who adopt guide recommendations will incur management costs testing for virus infection, removing diseased vines if/when these are identified, and monitoring/managing insect vectors.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The key output from the project is the Grapevine Leafroll Disease and Shiraz Disease guide. The impact pathway for the guide is:

1. Guide communicated to winegrape growers.
2. Some winegrape growers adopt guide recommendations, incur costs testing for viruses and insect vectors.
3. Winegrape growers with virus infections who have adopted guide recommendations, avoid loss of production caused by unmanaged viruses.
4. Winegrape growers source clean planting material from reputable sources when establishing new vineyards.

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 cost of lost production in vineyards affected by grapevine viruses. Increased efficiency in Wine Australia research investment with additional information on grapevine virus research priorities.	Guide principles are equally applicable to other Australian grape industries including table grapes and dried grapes.	An 'efficiency dividend' for public funds invested in wine research with improved understanding of grapevine research priorities.	Guide content may be suitable for adaptation to growing grapes in other countries in the same way that this project drew on NZ research.
Environmental Benefits			
Nil.	Nil.	Nil.	Nil.
Social Benefits			
Additional researcher and winegrape grower skills in virus surveillance, sampling, testing, extent, and impact. Additional profitable wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	Spill-over impacts may also be generated in regions where table grapes and grapes suitable for drying are grown.	Nil.	Nil.

4.2.3 Public versus Private Benefits

The project will generate both private and public benefits. The principle private benefit is reduction in the cost of lost grapevine production. Increased efficiency in Wine Australia research investment is both a private (industry levy) and public (Commonwealth matching) benefit. Other public benefits include increased research capacity and spill-over benefits for winegrape growing communities.

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 winegrape growers, winemakers, wine tourism operators, wholesalers, exporters, and retailers all sharing some of the benefits.

4.2.5 Benefits to other Primary Industries

Guide content in relation to virus surveillance, sampling, testing, and management in winegrapes is equally relevant to other grape industries including the table grape industry (GVP $722.2M) and the dried grape industry (GVP $19.8M).

4.2.6 Benefits Overseas

Guide content may be suitable for adaptation to growing grapes in other countries in the same way that this project drew on NZ research.

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) incurred by Wine Australia and other project investors including project administration costs.	Reduction in the cost of lost production in vineyards affected by grapevine viruses.
Overhead costs including time associated with meetings between the researchers, Wine Australia and collaborating organisations.	Increased efficiency in Wine Australia research investment with additional information on grapevine virus research priorities.
	Additional researcher and winegrape grower skills in virus surveillance, sampling, testing, extent, and impact.
	Additional profitable wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

The following table shows annual investment in the project by Wine Australia (Table 5.1).

Table 5.1 Investment by Wine Australia in the Project for Years Ending June 2021 to June 2023

Project Code	2021	2022	2023	Total
PFR 2001	30,268	37,862	2,472	**70,602**
Total	30,268	37,862	2,472	**70,602**

Source: Wine Australia contract and contract variation with Plant and Food NZ

There was no other investor in PFR 2001 (Table 5.2).

Table 5.2 Investment by Others in the Project for Years Ending June 2021 to June 2023

Project Code	2021	2022	2023	Total
PFR 2001	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

Source: Wine Australia contract and contract variation with Plant and Food NZ

Table 5.3 provides the total investment by year for both sources.

Table 5.3 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia	Others	Total
2021	30,268	0	30,268
2022	37,862	0	37,862
2023	2,472	0	2,472
Total	**70,602**	**0**	**70,602**

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 Project Collaborator Costs

Time commitments to the project by collaborators including vine improvement and biosecurity associations and agencies, the Australian Table Grape Association and Dried Fruit Australia have a cost. These costs are estimated at $10,000 per annum each year of the project and are included in the quantitative component of the benefit cost analysis.

5.2 Benefits

Counterfactual: in the absence of this project, alternative sources of guidance on identification and management of viruses in vineyards may have been prepared. For example, Treasury Wine Estates prepared a standard protocol for management of leafroll virus prior to the project[6]. For this reason, it is not appropriate to "claim" all of the benefits associated with virus guidelines for the project and a counterfactual of 25% has been assumed. That is, it is 75% likely that potential project benefits would have been realised in the absence of project investment.

5.2.1 Reduction in Lost Winegrape Production Due to Grapevine Viruses

PFR 2001 BPM of Grapevine Viruses in Australia has delivered a call to action for the Australian grape and wine industry to better manage the viruses affecting vineyard production. Tools delivered by the project address virus detection, removal of diseased grapevines, monitoring/managing insect vectors and highlighting the importance of using certified virus-free planting material. With adherence to these BPM guidelines, and the improved availability of certified planting material, winegrape growers will be in an improved position to mitigate lost production. One New Zealand data modelling study has shown that the annual cost of lost production from viral disease is NZ$8,236/ha over 20 years while the cost of virus treatment (and residual production loss) is a modest NZ$131/ha per annum. The area of virus affected grapevine production in Australia is unknown and a conservative estimate of 7,312 ha (5% of total production area of 146,244 ha) has been assumed in this cost benefit analysis[7].

A summary of key assumptions used to quantify this benefit is shown in Table 5.4.

Table 5.4 Summary of Assumptions

Variable	Assumption	Source
Benefit: Reduction in Lost Winegrape Production Due to Grapevine Viruses		
Australian winegrape growing with viral infection.	7,312 ha	Analyst assumption based on 5% of total winegrape growing area and Bell et al. 2022 which notes widespread positive test results for Leafroll and Shiraz Disease.
Percentage of viral infected area with at least 10% production loss.	40% of virus infected area.	Analyst estimate after review of Bell et al. 2022.
Net value of recovered production following vineyard virus control	$7,529/ha/year ($NZ8,105/ha/year)	Bell et al. 2022.
Year of first benefit.	2024	12 months after project completion and widespread distribution of the project generated guide *Grapevine Leafroll Disease and Shiraz Disease: Interim Recommendations for Management in Australian Vineyards*.
Maximum uptake of project recommendations on virus impacted vineyards.	15%	Analyst's assumption.

[6] NB: this was not a public document. Treasury Wine Estates shared it with Wine Australia for the purposes of the project. Otherwise, Wine Australia would not have known it existed.

[7] Bell et al. 2022 notes "Grapevine leafroll disease (GLD) and Shiraz disease (SD) have been observed in many grape growing regions of Australia. A wide-ranging survey estimating GLD and SD incidence and distribution has not been undertaken, but in 2008 and 2009, 218 grapevine samples from vineyards in New South Wales, Queensland, South Australia, Victoria, and Western Australia showed the presence of GLRaV-1, GLRaV-3, and GVA in all five states. In a recent study, SD has been identified in South Australia vineyards".

Year in which maximum uptake occurs.	2026	Analyst's assumption.
Year in which project outcomes are replaced with new approaches and technology.	2034	Analyst's assumption – the findings from new research replace interim recommendations.
Attribution of benefits to this project.	20%	Estimate prepared after considering that a vine propagation and supply standard, which was not part of this project, will have a major bearing on the reduction in vineyard production loss.
Probability of valuable outputs.	80%	PFR 2001 has delivered what appear to be valuable findings that will reduce the impact of grapevine viruses.
Probability of valuable outcomes.	80%	Industry needs to respond to the "call for action" contained within the interim guide.
Probability of impact.	80%	Implementation of measures within the guide must reduce losses associated with grapevine viruses.
Counterfactual	25%	See above explanation.

5.2.2 Other Potential Benefits

Other potential benefits identified but not valued are summarised in Table 4.2. 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 2023 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 (2023).

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%)

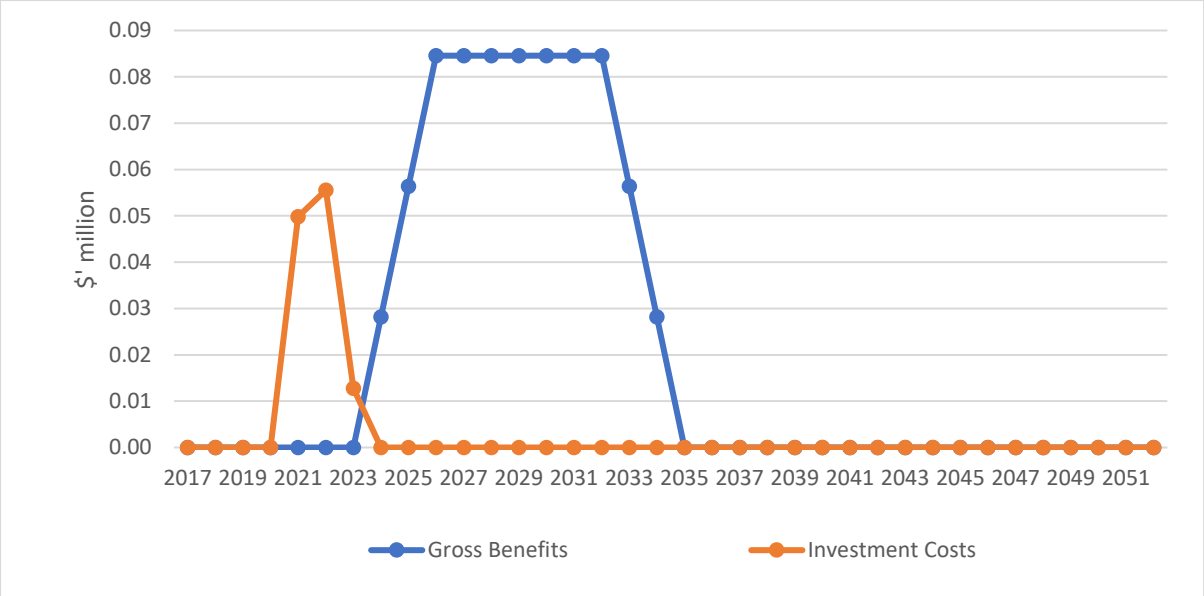
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.30	0.58	0.60	0.60	0.60	0.60
Present value of costs ($m)	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Net present value ($m)	-0.13	0.17	0.45	0.47	0.47	0.47	0.47
Benefit–cost ratio	0.00	2.28	4.42	4.55	4.55	4.55	4.55
Internal rate of return (%)	Negative	27.0	35.9	36.0	36.0	36.0	36.0
MIRR (%)	Negative	19.6	19.7	15.1	12.6	11.1	10.1

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 ($m)	0.00	0.22	0.43	0.44	0.44	0.44	0.44
Present value of costs ($m)	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Net present value ($m)	-0.10	0.12	0.33	0.34	0.34	0.34	0.34
Benefit–cost ratio	0.00	2.28	4.42	4.55	4.55	4.55	4.55
Internal rate of return (%)	Negative	27.0	35.9	36.0	36.0	36.0	36.0
MIRR (%)	Negative	19.6	19.7	15.1	12.6	11.1	10.1

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 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 not sensitive to the discount rate. This is because project benefits are rapidly realised and of relatively short duration.

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

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	0.76	0.60	0.49
Present value of costs ($m)	0.12	0.13	0.15
Net present value ($m)	0.64	0.47	0.34
Benefit-cost ratio	6.44	4.55	3.31

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 uncertainty related to the area of vineyard effected by viruses and the net value of recovered production - Table 7.2 and Table 7.3. Results show that the total area of virus impacted grapevine would need to be as low as 1,800 ha before project benefits would approach project costs (all other assumption held constant). While the net value of recovered production from use of the project generated guideline would need to be as little as $1,500/ha before project costs exceed project benefits (all other assumption held constant).

Table 7.2 Sensitivity to Australian Vineyard Area Affected by Viruses (Total investment, 30 years)

Investment Criteria	Area of Vineyard Virus (ha)		
	1,800 ha	3,600 ha	7,312 ha (base)
Present value of benefits ($m)	0.15	0.30	0.60
Present value of costs ($m)	0.13	0.13	0.13
Net present value ($m)	0.02	0.16	0.47
Benefit-cost ratio	1.12	2.24	4.55

Table 7.3 Sensitivity to Value of Recovered Vineyard Production (Total investment, 30 years)

Investment Criteria	Value of Recovered Production ($/ha)		
	$1,500/ha	$3,500/ha	$7,529/ha (base)
Present value of benefits ($m)	0.12	0.28	0.60
Present value of costs ($m)	0.13	0.13	0.13
Net present value ($m)	-0.01	0.15	0.47
Benefit-cost ratio	0.91	2.11	4.55

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 - Low

9. Summary of Results

Funding for PFR 2001 'investment in best practice management of grapevine viruses in Australia' had a total cost of $0.13 million (present value terms) and is expected to produce aggregate total benefits of approximately $0.6 million (present value terms). This gives an estimated net present value of $0.47 million, a benefit-cost ratio of approximately 4.55, an internal rate of return of 36% and a modified internal rate of return of 10.1%.

Analysis results are dependent on assumptions made and are positive for core assumptions and do not become negative until 'lower end' assumptions are applied.

Abbreviations

GVP	Gross Value of Production
PBM	Best Practice Management
OCS	Office of Chief Scientist
NZIPFR	New Zealand Institute for Plant and Food Research
R&D	Research and Development
RD&E	Research, Development and Extension

Persons Contacted

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Mara Khem, Research and Innovation Administrator, Wine Australia
Sharon Harvey, Senior RD&E Program Manager, Wine Australia

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Appendix 3: Economic Analysis of Wine Australia's Investment in Rapid Surveillance and Assessment of Fire Damage in South Australian Vineyards for Decision Making

1. Background

In December 2019, the Adelaide Hills, South Australia (SA) experienced a bushfire that burnt through 25,000 ha, including some vineyards. Bushfire impacted vineyards experienced different degrees of damage.

The ability to coordinate and plan recovery after a bushfire relies on robust and timely data. The current practice for measuring the scale and distribution of fire damage is to walk or drive the vineyard and score individual vines based on visual observation. The process is time consuming, subjective, and at best only semi-quantitative.

Following the 2019 bushfires, Wine Australia and the SA Government identified a gap in the ability of industry to rapidly determine the extent to which vineyards had been damaged in order to aid government response efforts, grower insurance claims, and vineyard recovery plans. A major reason for SA Government support for this research was the need to be able to rapidly deploy a tool to provide financial and social assistance as soon as possible after a bushfire. The challenge facing emergency services after the 2019 bushfire was that it took many weeks for them to determine the extent of damage to horticultural enterprises.

To rapidly assess the impacts of future bushfires on vineyards it was proposed that an approach based on satellite imagery and machine learning might be developed and to this end three linked projects were supported by Wine Australia. The first project (WA2003 delivered by the University of Adelaide) would evaluate the health and productivity of burnt vines using performance assessments, vitality stains, bud fertility and carbohydrate analysis performed at different development stages. The second project (WA 2004 delivered by GAIA Innovations Pty Ltd) would use these assessments and others provided through another agreement (WA 2005, Colin Hinze, Pinon Advisory) to develop a machine learning model to predict vine damage using satellite imagery. The GAIA technology had been used successfully to assess the extent of trunk disease in Eden Valley and Barossa vineyards.

Potentially, the fire assessment tool developed from these projects could also be used by growers to assess and respond to vine damage from increasingly frequent frost and hail events.

2. Summary of Projects

Table 2.1 provides a description of the three projects in a logical framework.

Table 2.1 Project Description

WA 2003, WA 2004, and WA 2005: Rapid Surveillance and Assessment of Fire Damage in South Australian Vineyards for Decision Making	
Project Details	Research Organisations: Uni of Adelaide, GAIA Innovations, and Pinon Advisory Period: May 2020 to June 2022 Principal Investigator WA 2003: Dr Cassandra Collins, University of Adelaide Principal Investigator WA 2004: Saisai Ma and Andy Clarke, GAIA Innovations Principal Investigator WA 2005: Colin Hinze, Pinon Advisory
Rationale	After the December 2019 Adelaide Hills bushfires, it took many months to access properties and estimate the area of vineyard damaged. The purpose of this study was to compare the rapid assessment and mapping of bushfire damage using high-resolution satellite imagery with more traditional ground-based measures.
Objectives	WA 2003 and WA 2004 objectives were:

	1. Develop a new tool to map bushfire damage rapidly, objectively, and cost-effectively at block level using high-resolution satellite imagery. 2. Provide growers with a better understanding of the likely effect of fire damage on vine health and productivity, to improve grower knowledge and vineyard management after a bushfire. 3. Understand the relationship between satellite imagery captured after a fire event and the long-term viability and productivity of damaged vines. WA 2005 objectives were: 1. Contact winegrape growers who participated in the SA Wine Industry Development Scheme (SAWIDS) funded project *Vineyard Mapping and Assessment*. 2. Obtain written consent to share their vineyard assessment data with Wine Australia to ground truth satellite imagery of fire damage. 3. Meet with Wine Australia's project partners to discuss the data capture and interpretation process.
Activities and Outputs	• Identify fire-damaged sites in the Adelaide Hills and visually rate these sites to allow monitoring of vineyard recovery and validation of satellite imagery. • Pinon Advisory completed ground truthing of the data in April and May 2020, three to four months after the December 2019 bushfire. • Forty vineyards were assessed, and bushfire severity scored from 0 to 4. A score of 4 indicated that all vine canopy had been destroyed in the blaze. • Machine learning models were repurposing to calculate area of fire-damaged vineyards and develop a bushfire assessment function in the GAIA platform. • Data collected from a separate Wine Grape Council of SA (WGCSA) SAWIDS fire assessment project was incorporated into the machine learning model. • Pre and immediately post bushfire satellite imagery was acquired and interpreted using the GAIA platform. Imagery was shared with Wine Australia, Adelaide Hills Regional Association and impacted grape growers. • Each bushfire impacted grower participating in the projects was provided with four images of each of their vineyard blocks covering both the 2020/21 and 2021/22 growing seasons. • Satellite analysis of all affected vineyards included: (i) comparisons between before and immediately after the fire and grading burn severity; and (ii) assessment of grapevine canopy recovery in subsequent seasons. • The University of Adelaide evaluated the health and productivity of burnt vines using vitality stains, bud fertility, and carbohydrate measures. Analyses were performed at different stages of vine development. • Comparisons of subjective walk/drive assessment of bushfire damage to satellite/machine learning approaches were made and results presented across SA wine regions. Findings were communicated to bushfire affected growers and researchers at the National Wine Sector Bushfire Conference, Australian Wine Technical Conference, and the International Terroir Congress. A journal article was also prepared and published. • Correlations between ground visual fire damage (walk/drive) assessments and post-fire NDVI (-0.7 to 0.04) and VARIgreen (-0.333 to 0.074 for only the University of Adelaide trial blocks) satellite imagery were significant but showed no correlation to a moderate or weak negative correlation. • Delays of 3 to 4 months gathering the ground truth data set, coordinated in a separate project through WGCSA had an impact on the reliability of this data relative to the imagery captured immediately post-fire due to vine regrowth.

	Vine regrowth, and the relatively small ground truth data sets, limited the ability to create a reliable multi-class variable damage model. • However, several models were created that were capable of determining a binary value for damage on known vineyard sites. In the event of future fires, these models can be immediately deployed. • The project has developed tools that can rapidly and cost-effectively capture the extent and severity of bushfire damage over large areas of vineyard to allow growers, industry bodies and government to make more efficient decisions during the post-fire recovery.
Outcomes	• Following bushfire, poorly recovered, or dead grapevines are readily identified by the tool as gaps in the continuous canopy. • Growers reported being able to use the satellite analysis to locate underperforming vines and apply additional remedial practices or replant. • Growers indicate that imagery captured at critical growing stages, including onset of ripening and harvest, provided insights that allowed improved vineyard management and reducing spatial variability. • The technology has been used to monitor the recovery of fire-affected grapevines after reworking or replanting. • Growers reported using the technology as a basis for discussions with management on strategic decisions for underperforming blocks post fire. • Results show acceptance of Agtech in the Adelaide Hills, and the project has further enhanced the awareness and adoption of Agtech in the region.
Impacts (potential)	• Economic – savings in cost of assessing vineyard damage post bushfire i.e., savings in labour required to walk/drive partially damaged vineyards less the cost of accessing machine learning/satellite image systems. • Economic – accurate assessment of bushfire loss to inform grape grower insurance claims. • Economic – more informed vineyard management with targeted and rapid interventions to boost long term productivity. • Economic – a machine learning/satellite image system that can also be used to respond to vine damage from other sources including increasingly frequent frost and hail events. • Environmental – nil positive or negative impacts identified. • Capacity – additional researcher and industry skills in interpretation of high resolution satellite images and the training of machine learning systems. • Capacity – winegrape growers with additional understanding of the likely effect of fire damage on vine health and productivity. • Social – increased acceptance by SA winegrape growers of Agtech and the potential benefits that it brings. • Social – less stress for winegrape growers who can more rapidly understand the extent of loss and plan for recovery. • Social – government better able to design and deliver policy for the winegrape industry with more timely and accurate fire loss information. • Social – additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

3. Match with National Priorities

Table 3.1 Australian Government Research Priorities

Australian Government Strategies and Priorities	
National Science and Research Priorities[8]	**National Agricultural Innovation Priorities[9]**
1. Food – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets. **2. Soil and Water** – improving the use of soils and water resources, both terrestrial and marine. **3. Transport** – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions. **4. Cybersecurity** – improving cybersecurity for individuals, businesses, government, and national infrastructure. **5. Energy and Resources** – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries. **6. Manufacturing** – supporting the development of high value and innovative manufacturing industries in Australia. **7. Environmental Change** – mitigating, managing, or adapting to changes in the environment. **8. Health** – improving the health outcomes for all Australians.	On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030. These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper. **1.** Australia is a trusted exporter of premium food and agricultural products by 2030. **2.** Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030. **3.** Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030. **4.** Australia is a mature adopter, developer, and exporter of digital agriculture by 2030.

The Wine Australia project has addressed National Science/Research Priority 1 and 7. The project also addresses National Agricultural Innovation Priority one, two, and four.

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, the funding body for the projects. These costs include both project and overhead expenditures.
- Research partner contributions to the projects – no contributions were made by the University of Adelaide, GAIA Innovations, or Pinon Advisory to these projects.
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia and other project collaborators including bushfire impacted grape growers and the Adelaide Hills Regional Association.

4.1.2 Administration

No additional administration costs were identified.

[8] See: 2015 Australian Government Science and Research Priorities. https://www.industry.gov.au/data-and-publications/science-and-research-priorities

[9] See: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment

4.1.3 Extension

Findings were broadly communicated across the Australian wine industry through both grower forums and technical congresses and conferences. A final report was made available on the Wine Australia website. The cost of these extension and communication activities was met from project budgets.

4.1.4 Adoption

Industry stakeholders (growers, insurance companies, government, etc.) who make use of the machine learning/satellite imagery tool created by these projects will save cost over the current labour-intensive walk/drive bushfire loss assessment process.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The key output from the project is a set of tools that can rapidly and cost-effectively capture the extent and severity of bushfire damage. The impact pathway for these tools is:

1. Commercialisation of the tools by a service provider such as GAIA Innovations.
2. A post bushfire service offered to winegrape growers and potentially insurance companies and government to rapidly assess vineyard loss.
3. Winegrape growers and others who make use of the tools save cost in assessing vineyard damage post bushfire.

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			
Savings in cost of assessing vineyard damage post bushfire. Accurate assessment of bushfire loss to inform grape grower insurance claims. More informed vineyard management with targeted and rapid interventions to boost long term productivity. A machine learning/satellite image system that can also be used to respond to vine damage from other sources including increasingly frequent frost and hail events.	A machine learning/satellite image system for the assessment of bushfire loss is also applicable to other perennial tree and vine crops.	Nil.	A machine learning/satellite image system for assessment of bushfire loss may be suitable for adaptation by winegrape growers in other countries – Southern European and Californian industries all experience bushfire in wine producing regions.
Environmental Benefits			
Nil.	Nil.	Nil.	Nil.
Social Benefits			
Additional researcher and industry skills in interpretation of high resolution satellite images and the training of machine learning systems.	Researcher skills developed in these projects may be used to improve the competitiveness of	Government better able to design and deliver policy for the winegrape industry with more timely and	Nil.

Winegrape growers with additional understanding of the likely effect of fire damage on vine health, productivity. Increased acceptance by SA winegrape growers of Agtech and the potential benefits that it brings. Less stress for winegrape growers who can more rapidly understand the extent of loss and plan for recovery.	other primary industries.	accurate fire loss information. Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	

4.2.3 Public versus Private Benefits

The project will generate both private and public benefits. Private benefits will include cost savings in vineyard damage assessment, improved vineyard management post bushfire, along with rapid and accurate insurance claims. Public benefits include capacity building and improved social outcomes.

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 winegrape growers, winemakers, wholesalers, exporters, and retailers all sharing some of the benefits. Other supply chain beneficiaries will include service providers such as the insurance industry and agencies of government assisting with post-bushfire recovery.

4.2.5 Benefits to other Primary Industries

A machine learning/satellite image system for the assessment of bushfire loss may be adapted and be applicable to other perennial tree and vine crops. Relevant tree crops include apple and pear, also grown in the Adelaide Hills, along with vine crops such as table grape and the dried grapes.

4.2.6 Benefits Overseas

A machine learning/satellite image system for assessment of bushfire loss may be suitable for adaptation by winegrape growers in other countries – Southern European and Californian industries all experience bushfire in wine producing regions.

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) incurred by Wine Australia and other project investors including project administration costs.	Savings in the cost of assessing vineyard damage post bushfire.
Overhead costs including time associated with meetings between the researchers, Wine Australia, bushfire impacted grape growers and the Adelaide Hills Regional Association.	More informed vineyard management with targeted and rapid interventions to boost long term productivity.
	Rapid assessment of bushfire loss to inform grape grower insurance claims.
	Generation of additional researcher, industry, and grape grower knowledge and skills.
	Social benefits including less stress, greater acceptance of Agtech, regional spill-over benefits, and improved government policy.

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

The following table shows annual investment in the project by Wine Australia (Table 5.1).

Table 5.1 Investment by Wine Australia in the Project for Years Ending June 2020 to June 2022

Project Code	2021	2022	Total
WA 2003	51,980	62,020	**114,000**
WA 2004	71,750	71,750	**143,500**
WA 2005	6,000	0	**6,000**
Total	**129,730**	**133,770**	**263,500**

NB: project totals provided by Wine Australia for WA 2003 and WA 2004, annual expenditure estimated by AgEconPlus

There were no other investors in WA 20023, WA 2004, and WA 2005 (Table 5.2).

Table 5.2 Investment by Others in the Project for Years Ending June 2020 to June 2022

Project Code	2021	2022	Total
WA 2003	0	0	**0**
WA 2004	0	0	**0**
WA 2005	0	0	**0**
Total	**0**	**0**	**0**

Source: Wine Australia

Table 5.3 provides the total investment by year for both sources.

Table 5.3 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia (WA 2003, WA 2004, WA 2005)	Others	Total
2021	129,730	0	129,730
2022	133,770	0	133,770
Total	**263,500**	**0**	**263,500**

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 Project Collaborator Costs

Time commitments to the project by collaborators including bushfire impacted grape growers and the Adelaide Hills Regional Association have a cost. These costs are estimated at $5,000 per annum each year of the project and are included in the quantitative component of the benefit cost analysis.

5.2 Benefits

Counterfactual: in the absence of these projects, it is possible that alternative research on the application of detailed satellite imagery and machine learning to bushfire damage assessment would have been completed. For this reason, it is not appropriate to "claim" all the benefits associated with these projects and a counterfactual of 20% has been assumed. That is, it is 80% likely that potential project benefits would have been realised in the absence of project investment.

5.2.1 Savings in the Cost of Assessing Vineyard Damage Post Bushfire

The projects have developed tools that can rapidly and cost-effectively capture the extent and severity of bushfire damage over large areas of vineyard to allow growers, industry bodies, and government to make more efficient decisions during post-fire recovery. Tools have the potential to replace current

practice which is time consuming and expensive. Colin Hinze, Pinon Advisory estimates that current practice costs $750/ha including preparation, travel, field assessment and data processing.

A summary of key assumptions used to quantify this benefit is shown in Table 5.4.

Table 5.4 Summary of Assumptions

Variable	Assumption	Source
Benefit: Savings in the Cost of Assessing Vineyard Damage Post Bushfire		
Frequency of bushfire in a vineyard somewhere in Australia.	Once every second year (50% probability).	Analyst assumption noting that major bushfire events seem to be increasing in frequency.
Area of vineyard burnt in a typical bushfire.	500 ha.	Analyst estimate that will be tested using sensitivity analysis.
Net saving in the cost of assessing bushfire damage.	$700/ha (current cost $750 less $50/ha to use satellite imagery).	Analyst estimate developed in consultation with Colin Hinze, Senior Consultant, Agribusiness, Pinion Advisory.
Year of first benefit.	2023	Tools available for use 12 months after projects were completed.
Year in which maximum uptake occurs.	2025	Analyst's assumption.
Attribution of benefit to these projects.	90%	Some commercialisation work required.
Probability of valuable outputs.	100%	Valuable tools have been created.
Probability of valuable outcomes.	90%	Tools need to be adopted and this is not 100% certain.
Probability of impact.	90%	Tools need to be effective and this is not 100% certain.
Counterfactual	20%	See above explanation.

5.2.2 Other Potential Benefits

Other potential benefits identified but not valued are summarised in Table 4.2. 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 2023 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 (2022).

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%)

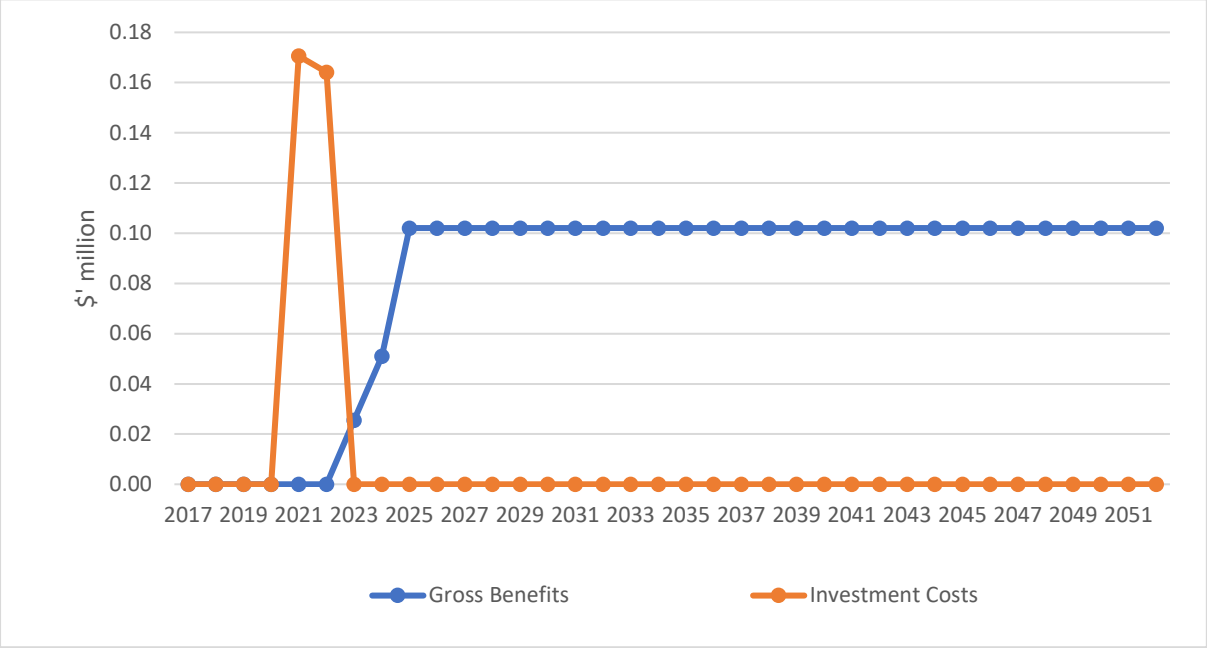
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.36	0.74	1.04	1.27	1.45	1.60
Present value of costs ($m)	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Net present value ($m)	-0.38	-0.02	0.36	0.66	0.89	1.08	1.22
Benefit–cost ratio	0.00	0.94	1.95	2.74	3.36	3.84	4.22
Internal rate of return (%)	Negative	1.6	17.7	20.9	21.8	22.1	22.2
MIRR (%)	Negative	2.6	11.7	11.9	11.3	10.6	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 ($m)	0.00	0.34	0.71	1.00	1.23	1.41	1.55
Present value of costs ($m)	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Net present value ($m)	-0.37	-0.02	0.35	0.64	0.86	1.04	1.18
Benefit–cost ratio	0.00	0.94	1.95	2.74	3.36	3.84	4.22
Internal rate of return (%)	Negative	1.6	17.7	20.9	21.8	22.1	22.2
MIRR (%)	Negative	2.6	11.7	11.9	11.3	10.6	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 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 the discount rate. This is because project benefits are realised over the full 30 year analysis period.

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

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	2.93	1.60	1.03
Present value of costs ($m)	0.33	0.38	0.43
Net present value ($m)	2.60	1.22	0.60
Benefit-cost ratio	8.77	4.22	2.42

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 uncertainty related to the area of Australian vineyard affected by bushfire and the cost saving from use of project generated assessment tools - Table 7.2 and Table 7.3. Results show that the total area of vineyard impacted by bushfire every second year would need to be as low as 120 ha before project benefits approach project costs (all other assumption held constant). While the cost saving from using project generated tools would need to be as little as $175/ha before project costs approach project benefits (all other assumption held constant).

Table 7.2 Sensitivity to Australian Vineyard Area Affected by Bushfire (Total investment, 30 years)

Investment Criteria	Area of Vineyard Burnt Every Second Year (ha)		
	120 ha	250 ha	500 ha (base)
Present value of benefits ($m)	0.38	0.80	1.60
Present value of costs ($m)	0.38	0.38	0.38
Net present value ($m)	0.01	0.42	1.22
Benefit-cost ratio	1.01	2.11	4.22

Table 7.3 Sensitivity to Cost Saved in Bushfire Assessment (Total investment, 30 years)

Investment Criteria	Cost Saving Realised ($/ha)		
	$175/ha	$350/ha	$700/ha (base)
Present value of benefits ($m)	0.40	0.80	1.60
Present value of costs ($m)	0.38	0.38	0.38
Net present value ($m)	0.02	0.42	1.22
Benefit-cost ratio	1.06	2.11	4.22

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 three projects that delivered 'rapid surveillance and assessment of fire damage in South Australian vineyards for decision making' had a total cost of $0.38 million (present value terms) and is expected to produce aggregate total benefits of approximately $1.6 million (present value terms). This gives an estimated net present value of $1.22 million, a benefit-cost ratio of approximately 4.29, an internal rate of return of 22.2% and a modified internal rate of return of 10%.

Analysis results are dependent on assumptions made and are positive for core assumptions and remain positive when 'lower end' assumptions are applied.

Abbreviations

GVP	Gross Value of Production
OCS	Office of Chief Scientist
R&D	Research and Development
RD&E	Research, Development and Extension
SA	South Australia
SAWIDS	SA Wine Industry Development Scheme
WGCSA	Wine Grape Council of SA

Persons Contacted

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Casandra Collins, Project Principal Investigator, University of Adelaide
Angelica Crabb, Senior Analyst, Wine Australia
Colin Hinz, Pinon Advisory
Mara Khem, Research and Innovation Administrator, Wine Australia
Alex Sas, Senior RD&E Program Manager, Wine Australia

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Appendix 4: Economic Analysis of Wine Australia's Investment in Plant Sensor-based Precision Irrigation for Improved Vineyard Water Use Efficiency, Grape and Wine Composition and Quality, and Vineyard Profitability

1. Background

At the current time, winegrape growers manage the supply of water to their grapevines using a combination of soil moisture sensing, observing vines for signs of water stress, responding to weather events, and historical irrigation regimes. However, these approaches can result in either over-watering or under-watering, which in turn leads to either excessive growth or vine water stress, both of which can lower yield and fruit quality.

In addition, prudent water management in Australian vineyards has become increasingly important with high-cost energy, low winegrape prices, and inefficiencies in irrigation infrastructure all demanding attention. Increasing the efficiency of irrigation water use to maximise yield and/or quality is one strategy to address some of these issues. Increasing water use efficiency can be achieved by precise monitoring of soil and vine moisture levels, and applying irrigation based on cultivar-specific thresholds relevant to phenological stage.

This project evaluated the benefits associated with implementing irrigation schedules on Cabernet Sauvignon (Wynns Estate) and Shiraz (Katnook Estate) grapevines in the Coonawarra region of South Australia. The project was to deliver new tools that will allow growers to schedule irrigation precisely based on real-time measurements of vine water status in conjunction with drone/Unmanned Aerial Vehicle (UAV)-based remote sensing.

2. Summary of Projects

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

Table 2.1 Project Description

UA 1803-1.3: Plant Sensor-based Precision Irrigation for Improved Vineyard Water Use Efficiency, Grape and Wine Composition and Quality, and Vineyard Profitability	
Project Details	Research Organisation: University of Adelaide Period: July 2018 to September 2022 Principal Investigator: Vinay Pagay
Rationale	Increasing pressure on winegrape grower profits, especially in warm inland regions, has reinforced the need to improve the efficiency with which irrigation water is applied and the yield and quality of resultant fruit. In warm inland areas, irrigation water can account for one quarter (25%) of winegrape production costs (AgEconPlus 2019).
Objectives	The overarching objective of this project was to assess the value of plant-sensor-based precision irrigation on grapevine performance, water use efficiency and grape and wine composition of Cabernet Sauvignon and Shiraz grapevines. Specific objectives included evaluation of: 1. Various irrigation scheduling methods available to grape growers. 2. Two new commercial crop water status sensors. 3. A new high-resolution remote sensing platform for canopy assessment. 4. Financial performance of different irrigation scheduling strategies. 5. Survey of current Coonawarra wine region irrigation practices. 6. Knowledge dissemination to industry via seminars and scientific papers.
Activities and Outputs	• Procure and test a new UAV-based platform for remote sensing of vine water status. Acquire and test Transmit Data (TD) sensors and micro-tensiometers. • Construct thermal towers in Coonawarra Cab Sauvignon/Shiraz vineyards.

	• Source and test plant water index algorithm. Validate the algorithm against conventional measures under different irrigation scheduling regimes (based on percentage evapotranspiration (ET), and soil moisture).
	• Collect and analyse plant performance data over four growing seasons.
	• Survey Coonawarra grape growers to determine current irrigation practice.
	• Complete financial analysis of sensor-driven vs conventional irrigation.
	• In the first three seasons (2018/19, 2019/20, and 2020/21), five irrigation strategies were investigated:
	  • Two conventional or grower-driven approaches (CONV) – 2 x CONV for 'well-watered' vines (CONV+).
	  • Three data-driven (sensor-based) irrigation strategies – vine water status based on proximal thermal sensors (PWS/PWS1), soil water status (SWS), and crop ET.
	• In the fourth season (2021/22), an additional plant sensor-based irrigation strategy using continuous measurement of trunk water potential (PWS2) was also evaluated.
	• Additionally, UAV-based remote sensing was employed to obtain high resolution (vine level) estimates of grapevine crop coefficients, soil and water status, and canopy gas exchange.
	• For measuring plant performance and water status, various instruments for direct, proximal, and remote sensing were used at key phenological stages of grapevine development.
	• The evidence or sensor-based irrigation strategies had a clear advantage of saving irrigation water in Cab Sauvignon and Shiraz grown in Terra Rossa soil and Rendzina soils. For instance, in 2020/21 Cab Sauvignon grown in Terra Rossa soil, ET (evapotranspiration) PWS (measurement of trunk water potential)-treated vines received only 38% and 67% of the total irrigation of CONV+ (conventional or grower-driven) vine treatments.
	• However, despite significantly lower soil and plant water status, ET and PWS treated vines showed similar net carbon assimilation, stomatal conductance, leaf intrinsic water use efficiency, yield, and berry anthocyanin and phenolics concentrations relative to conventionally treated vines.
	• Overall, the project showed that both ET and plant sensor-based irrigation scheduling are superior approaches for high-quality grape/wine production for Cab Sauvignon, while in Shiraz, the plant sensor-based irrigation scheduling approach improved water use efficiency without yield or quality penalties.
	• Using UAV-based thermal and multispectral remote sensing in conjunction with a machine learning model, the project obtained spatial (vine-level) and temporal (phenology-specific) information on soil moisture and wine physiological parameters. These data can be used to inform precision irrigation. The spatial maps can also be used to inform sensor placement.
	• Financial analysis of data driven vs conventional approaches to irrigation showed strong dependence of gross margin on yield and/or irrigation application rates. Data driven approaches had the highest returns when water application rates were low as yields were similar across different strategies.
	• The survey of Coonawarra growers revealed that over 70% use experience or historical schedules to irrigate and only 6% use plant-based sensors to inform irrigation decisions. The greatest barriers to adoption of new technology for irrigation decision-making were a lack of understanding of the technology's value and the high cost of the technology.

	• Four manuscripts were produced and published in peer reviewed journals. Presentations were made to the ASEV Precision Viticulture Symposium, and the Crush Conference. Extension included an irrigation podcast, and webinar along with presentations to major wine companies (e.g. Treasury, Accolade, Wynns, and Katnook Estate).
Outcomes	• The real-time reporting of plant water status is an important development for the viticulture industry as, for the first time, growers can quantitatively assess vine responses to rainfall, irrigation applications, extreme weather events, and management practices. The ability to monitor vine water status in real time provides a higher level of control of irrigation and the ability to optimise and predict grapevine irrigation requirements through accurate weather forecast data (from Bureau of Meteorology) coupled with irrigation models. • When implemented, project findings are likely to deliver water use efficiencies (WUE = yield/irrigation) with more consistent yield and quality.
Impacts	• Economic – improved winegrape grower profitability with irrigation water savings along with more consistent yield and quality. This impact is particularly relevant to inland production areas and the benefit will be net of the capital and operating cost of plant sensor-based irrigation systems. • Economic – improved winemaker profitability with a more certain supply of quality winegrapes. • Environmental – increased water use efficiency with less demand for water from the inland environment (including rivers and aquafers). • Capacity – additional researcher skills in the use of plant-based sensors and UAV systems. • Capacity – additional winegrape grower knowledge and application of data-driven irrigation management and scheduling tools. • Social – additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

3. Match with National Priorities

Table 3.1 Australian Government Research Priorities

Australian Government Strategies and Priorities	
National Science and Research Priorities[10]	**National Agricultural Innovation Priorities[11]**
1. Food – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets. **2. Soil and Water** – improving the use of soils and water resources, both terrestrial and marine. **3. Transport** – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions.	On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030. These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper. **1.** Australia is a trusted exporter of premium food and agricultural products by 2030.

[10] See: 2015 Australian Government Science and Research Priorities. https://www.industry.gov.au/data-and-publications/science-and-research-priorities

[11] See: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment

4. **Cybersecurity** – improving cybersecurity for individuals, businesses, government, and national infrastructure. 5. **Energy and Resources** – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries. 6. **Manufacturing** – supporting the development of high value and innovative manufacturing industries in Australia. 7. **Environmental Change** – mitigating, managing, or adapting to changes in the environment. 8. **Health** – improving the health outcomes for all Australians.	2. Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030. 3. Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030. 4. Australia is a mature adopter, developer, and exporter of digital agriculture by 2030.

The Wine Australia project has addressed National Science/Research Priority 1 and 7. The project has also addressed National Agricultural Innovation Priorities 1, 2, and 4.

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, the project funding body. These costs include both project and overhead expenditures.
- Cash and in-kind contributions to the research project – contributions made by the research partner (University of Adelaide).
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia and other project collaborators including the vineyards who hosted the research, Coonawarra grape growers who provided survey responses and industry members who attended project presentations.

4.1.2 Administration

No additional administration costs were identified.

4.1.3 Extension

Project findings were communicated through conferences and symposia. Extension included an irrigation podcast and webinar. Presentations were made to major wine companies. A final report was posted on the Wine Australia website. The cost of these communication and extension activities were met from project budgets.

4.1.4 Adoption

Winegrape growers who make use of plant sensor-based precision irrigation systems will incur both capital and operating costs for these systems.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The key output from this project is knowledge of the net benefit of plant sensor-based precision irrigation over conventional irrigation decision making.

The impact pathway for the project is:

1. Knowledge generated by the project and its communication to winegrape growers.
2. Winegrape growers, especially those growing red wine varieties in warm inland areas, consider the findings. A share of these growers subsequently adopt precision irrigation systems.
3. Growers who adopt precision irrigation systems improve their profitability with irrigation water savings along with more consistent yield and quality.

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			
Improved winegrape grower profitability with irrigation water savings along with more consistent yield and quality. Improved winemaker profitability with a more certain supply of quality winegrapes.	Project generated knowledge on precision irrigation systems for wine-grapes may also be applicable to production of table grapes and fruit for dried grape production.	Nil.	Irrigation system knowledge generated by the project was presented at international conferences and symposia and may be relevant to irrigated winegrape production in Europe, Africa, Asia, and the Americas.
Environmental Benefits			
Increased water use efficiency with less demand for water from the inland environment (including rivers and aquafers).	If project findings are adopted in other industries, there may be further reductions in demand for water from inland rivers and aquafers.	Nil.	Nil.
Social Benefits			
Additional researcher skills in the use of plant-based sensors and UAV systems. Additional winegrape grower knowledge and application of data-driven irrigation management and scheduling tools. Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	Skills developed during the project in plant-based sensors and UAV systems will be relevant to research in other plant industries.	A larger and more profitable wine industry will contribute employment and income multipliers to the Australian economy.	Nil.

4.2.3 Public versus Private Benefits

The project will generate both private and public benefits. Private benefits include more profitable winegrape growing and winemaking in warm inland areas. Public benefits will include environmental gain associated with improved water use efficiency, additional researcher and winegrape grower capacity, and spill-over benefits for regional communities.

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, winemakers, wholesalers, retailers, and exporters all realising some of the benefits.

4.2.5 Benefits to other Primary Industries

Precision irrigation systems demonstrated through this project may also benefit the table grape and dried grape industries.

4.2.6 Benefits Overseas

Irrigation system knowledge generated by the project was presented at international conferences and symposia and may be adopted in overseas wine industries reliant on irrigated production e.g., Southern Europe and California.

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) incurred by Wine Australia and the University of Adelaide as well as project administration costs.	Improved winegrape grower profitability with irrigation water savings along with more consistent yield and quality.
Overhead costs including time associated with meetings between the researchers, Wine Australia and collaborating organisations.	Improved winemaker profitability with a more certain supply of quality winegrapes.
	Increased water use efficiency with less demand for water from the inland environment (including rivers and aquafers).
	Additional researcher skills in the use of plant-based sensors and UAV systems.
	Additional winegrape grower knowledge and application of data-driven irrigation management and scheduling tools.
	Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

The following table shows annual investment in the project by Wine Australia (Table 5.1).

Table 5.1 Investment by Wine Australia in the Project for Years Ending June 2019 to June 2022

Project Code	2019	2020	2021	2022	Total
UA 1803-1.3	189,949	131,595	135,543	120,132	**577,219**
Total	**189,949**	**131,595**	**135,543**	**120,132**	**577,219**

Source: Wine Australia record of project expenditure

The other investor in UA 1803-1.3 was the University of Adelaide (Table 5.2).

Table 5.2 Investment by Others in the Project for Years Ending June 2019 to June 2022

Project Code	2019	2020	2021	2022	Total
UA 1803-1.3 – cash	13,856	12,750	12,750	12,750	**52,106**
UA 1803-1.3 – in-kind	375,422	395,776	417,247	434,874	**1,623,319**
Total	**389,278**	**408,526**	**429,997**	**447,624**	**1,675,425**

Source: Wine Australia record of project expenditure

Table 5.3 provides the total investment by year for both sources.

Table 5.3 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia	Others	Total
2019	189,949	389,278	**579,227**
2020	131,595	408,526	**540,121**
2021	135,543	429,997	**565,540**
2022	120,132	434,874	**567,756**
Total	**577,219**	**1,675,425**	**2,252,644**

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 Industry and Agency Costs

Industry and agency contributions to the project include costs incurred by grape and wine producers hosting precision irrigation trials and completing project surveys. These costs are estimated at $5,000 per annum each year of the project.

5.2 Benefits

Counterfactual: in the absence of this project, the value of plant sensor-based precision irrigation may have been communicated to winegrape growers via alternative channels. For example, the commercial developers of the technology may have sponsored local tests and trials. For this reason, it is not appropriate to "claim" all of the benefits associated with improved winegrape grower profitability through use of precision irrigation for the project and a counterfactual of 70% has been assumed. That is, it is 30% likely that potential project benefits would have been realised in the absence of project investment.

5.2.1 Improved Grower Profitability with Irrigation Water Savings, Consistent Yield and Quality

UA 1803-1.3 has demonstrated real-time reporting of plant water status so that winegrape growers can quantitatively assess vine responses to rainfall, irrigation applications, extreme weather events, and management practices. The ability to monitor vine water status in real time provides a higher level of control of irrigation and the ability to optimise and predict grapevine irrigation requirements through accurate weather forecast data coupled with irrigation models. When implemented, project findings are likely to deliver water use efficiencies with consistent yield and quality.

A summary of key assumptions used to quantify this benefit is shown in Table 5.4.

Table 5.4 Summary of Assumptions

Variable	Assumption	Source
Benefit: Improved Grower Profit with Irrigation Water Savings, Consistent Yield and Quality		
Production area with the potential to benefit from precision irrigation systems i.e., 'warm inland' production.	55,000 ha.	Data from the National Vineyard Scan: https://www.wineaustralia.com/market-insights/national-vineyard-scan
Share of 'warm inland' production adopting precision irrigation systems.	50%	Analyst assumption – not all inland areas pay for irrigation water, skill will be required to operate precision systems, and adoption will favour large growers who can offset the investment over large areas of production.
Value of irrigation water saving after allowing for the cost of precision irrigation.	$307/ha (a).	AgEconPlus 2019 identified an average irrigation and drainage cost of $1,535/ha and a 20% saving has been assumed in this analysis.
Cost of precision irrigation system.	$55/ha (b).	Pagay (August 2022) estimate and made up of $23/ha annualised capital cost plus $32/ha annual operating cost.
Net saving from adoption of precision irrigation.	$252/ha.	(a) – (b).
Year in which precision irrigation project finding first adopted.	2024	One year after project completion in September 2022.
Year in which maximum adoption occurs.	2026	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.	80%	Findings will require further investment in demonstration and communication to secure adoption.
Probability of valuable outputs.	100%	UA 1803-1.3 has delivered valuable findings.
Probability of valuable outcomes.	90%	It is not certain that valuable outputs will translate into valuable outcomes.
Probability of impact.	60%	Other factors may determine total cost of irrigation to grape growers.
Counterfactual	70%	See above explanation.

5.2.2 Other Potential Benefits

Other potential benefits identified but not valued are summarised in Table 4.2. 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 2023 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 (2022).

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%)

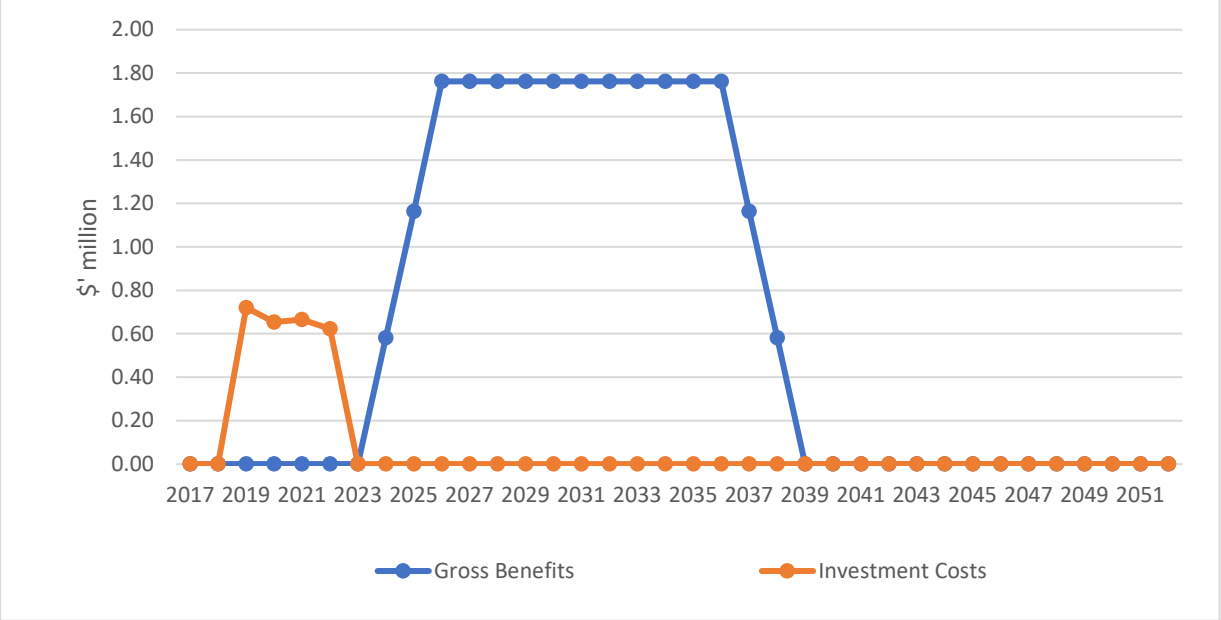
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	4.81	11.40	16.25	16.54	16.54	16.54
Present value of costs ($m)	3.17	3.17	3.17	3.17	3.17	3.17	3.17
Net present value ($m)	-3.17	1.64	8.23	13.07	13.37	13.37	13.37
Benefit–cost ratio	0.00	1.52	3.59	5.12	5.21	5.21	5.21
Internal rate of return (%)	Negative	14.8	30.1	32.2	32.3	32.3	32.3
MIRR (%)	Negative	12.4	18.4	16.5	13.6	11.8	10.7

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 ($m)	0.00	1.34	3.17	4.51	4.59	4.59	4.59
Present value of costs ($m)	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Net present value ($m)	-0.88	0.45	2.28	3.63	3.71	3.71	3.71
Benefit–cost ratio	0.00	1.52	3.59	5.12	5.21	5.21	5.21
Internal rate of return (%)	Negative	14.8	30.1	32.2	32.3	32.3	32.3
MIRR (%)	Negative	12.4	18.4	16.5	13.6	11.8	10.7

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 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 the 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 ($m)	22.87	16.54	12.53
Present value of costs ($m)	2.66	3.17	3.76
Net present value ($m)	20.21	13.37	8.78
Benefit-cost ratio	8.59	5.21	3.34

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 uncertainty related to the share of warm inland winegrape production adopting precision irrigation and the resultant water cost saving - Table 7.2 and Table 7.3. Results show that the share of warm inland winegrape production adopting precision irrigation would need to be as little as 10% for project benefits to approach project costs with all other assumptions held constant. The value of water saved, after allowing for the cost of precision systems, would need to be as little as $50/ha before project costs will equal project benefits, all other assumptions held constant.

Table 7.2 Sensitivity to Share of Warm Inland Production Adopting Precision Irrigation (Total investment, 30 years)

Investment Criteria	Share of Production Adopting Precision Irrigation (%)		
	10%	25%	50% (base)
Present value of benefits ($m)	3.31	8.27	16.54
Present value of costs ($m)	3.17	3.17	3.17
Net present value ($m)	0.14	5.10	13.37
Benefit-cost ratio	1.04	2.61	5.21

Table 7.3 Sensitivity to Net Irrigation Water Saving (Total investment, 30 years)

Investment Criteria	Net Saving After Allowing for Cost of Precision System ($/ha)		
	$50/ha	$126/ha	$252/ha (base)
Present value of benefits ($m)	3.28	8.27	16.54
Present value of costs ($m)	3.17	3.17	3.17
Net present value ($m)	0.11	5.10	13.37
Benefit-cost ratio	1.03	2.61	5.21

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

UA 1803-1.3 'plant sensor-based precision irrigation for improved vineyard water use efficiency, grape and wine composition and quality and vineyard profitability' had a total cost of $3.17 million (present value terms) and is expected to produce aggregate total benefits of approximately $16.54 million (present value terms). This gives an estimated net present value of $13.37 million, a benefit-cost ratio of approximately 5.21, an internal rate of return of 32.3% and a modified internal rate of return of 10.7%.

Analysis results are dependent on assumptions made and are positive for core assumptions. The project does not reach 'breakeven' until low end assumptions on adoption and water savings are applied.

Abbreviations

BOM	Bureau of Meteorology
EV	Evapotranspiration
OCS	Office of Chief Scientist
R&D	Research and Development
RD&E	Research, Development and Extension
TD	Transmit Data
UAV	Unmanned Aerial Vehicle
WUE	Water Use Efficiency

Persons Contacted

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Vinay Pagay, Principal Investigator, University of Adelaide

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Appendix 5: Economic Analysis of Wine Australia's Investment in Using Glycosides and Other Flavour Precursors for Improved Wine Flavour

1. Background

The route from grape to wine flavour occurs via many different pathways. Many classes of compounds are present in the grape in a non-volatile form, bound to sugars or amino acids. For them to be perceived as flavour or aroma, they must firstly be broken down and the volatile portion released. Traditionally, this occurs via the action of yeast during alcoholic fermentation or via slow chemical hydrolysis during wine storage.

However, there is a possibility to isolate 'flavour precursors' from juice, grape marc, or wine and use these as flavour supplements. It has previously been demonstrated that purified (i.e., phenolic/bitterness-free) monoterpene glycosides (flavour enhancers) present a valuable, novel opportunity to add flavour, through enzymatic release during winemaking but also via in-mouth breakdown during wine consumption, contributing flavour intensity and flavour persistence (Parker *et al*. 2017). This work showed that when a panel of tasters was provided with different glycosides, they varied in their ability to perceive flavour. Additionally, an ability to perceive flavour from one glycoside did not relate to the perception of flavour from others.

2. Summary of Project

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

Table 2.1 Project Description

AWR 1701-3.1.2 Glycosides and Other Flavour Precursors for Improved Wine Flavour	
Project Details	Research Organisation: Australian Wine Research Institute (AWRI). Period: July 2017 to September 2022 (final report date). Principal Investigator: Dr Leigh Francis and Dr Markus Herderich.
Rationale	Much of the flavour in wine comes from non-flavour-active precursors that must be broken down to provide known varietal attributes. Through chemical, sensory, and winemaking experiments, the potential of different unrealised flavour precursors to improve wine flavour was to be determined.
Objectives	1. Investigate grape glycosides as a potential wine additive, including the timing of additions and dose rates to achieve measurable sensory effects during wine consumption. 2. Investigate additional precursor systems such as thiol precursors to provide a complementary avenue for building additional flavour during wine consumption. 3. Develop a better understanding of the factors underlying individual variability in sensory response to in-mouth release of precursors.
Activities and Outputs	• Material available from prior work included synthetic glycosides, grape marc derived glycosides, and wines with added glycoside-rich extracts. • Project activities focused on grape marc extractions, winemaking and storage trials, chemical analysis, sensory analysis, understanding drivers of in-mouth flavour release, industry consultation on the potential use of glycoside in winemaking, assessment of thiol precursors, and testing of research products. • Deliverable A: Isolation procedures for phenol-free monoterpene glycosides from floral varieties and knowledge about their sensory significance in winemaking applications.

	• Deliverable B: Knowledge about the sensory effect of glycosides from non-floral varieties and their flavour contributions after storage in-bottle. • Deliverable C: Understanding of the effects of glycosides in alternative products especially no alcohol and low alcohol (NOLO) wine. • Deliverable D: Understanding of the sensory significance of thiol precursors and processing options. • Deliverable E: Practical advice and extension materials for winemakers. • Extension included industry articles, webinars, and roadshow talks. Researchers presented to the 18th AWITC, and findings were incorporated into supporting Australian Wine projects 2.1.1 (Extension) and 2.1.2 (Communication and Awareness Raising Activities). • The principal output from this project was an extraction method for the isolation of purified glycosidic material that can be added to wine or NOLO products. The method has been developed for use in a winery setting and involves materials that are accessible to a winery. • The development of the glycosidic extract has undergone significant industry consultation, specifically looking at segments of the wine industry that would be amenable to integrating it into their usual practices, with several large wine companies indicating they would use such as extract if it were available. • Furthermore, there appears to be a natural fit between glycoside-rich extracts and a desire to achieve greater flavour outcomes in NOLO products.
Outcomes (potential)	• More flavoursome wine, especially NOLO products, with greater appeal to Australian wine consumers.
Impacts (potential)	• Economic – progress toward additional profitable sales of NOLO products with additional flavour, aroma, and consumer appeal. • Economic – progress toward additional profitable sales of conventional Australian wine with additional flavour, aroma, and consumer appeal. • Environmental – valorisation of by-products, and potentially a reduction in waste (marc or grapes not utilized for wine production). • Capacity – additional researcher skills in juice, wine marc, and wine chemical, and sensory analysis enabling development of premium NOLO products. Project included completion of a PhD. • Capacity – additional winemaker knowledge of techniques to improve the flavour of NOLO products and conventional wine. • Social – additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

3. Match with National Priorities

Table 3.1 Australian Government Research Priorities

Australian Government Strategies and Priorities	
National Science and Research Priorities[12]	**National Agricultural Innovation Priorities[13]**
1. Food – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets.	On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030.

[12] See: 2015 Australian Government Science and Research Priorities. https://www.industry.gov.au/data-and-publications/science-and-research-priorities

[13] See: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment

2. **Soil and Water** – improving the use of soils and water resources, both terrestrial and marine. 3. **Transport** – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions. 4. **Cybersecurity** – improving cybersecurity for individuals, businesses, government, and national infrastructure. 5. **Energy and Resources** – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries. 6. **Manufacturing** – supporting the development of high value and innovative manufacturing industries in Australia. 7. **Environmental Change** – mitigating, managing, or adapting to changes in the environment. 8. **Health** – improving the health outcomes for all Australians.	These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper. 1. Australia is a trusted exporter of premium food and agricultural products by 2030. 2. Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030. 3. Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030. 4. Australia is a mature adopter, developer, and exporter of digital agriculture by 2030.

The Wine Australia project has addressed National Science/Research Priority 1. The project also addresses National Agricultural Innovation Priority one.

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, the project funding body. These costs include both project and overhead expenditures.
- Research partner contributions to the project – no contributions were made by AWRI to this project.
- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia and other project collaborators including members of a pre-commercialisation wine innovation group and winemakers from Pernod Ricard, Treasury Wine Estate, and Accolate Wines. Grape marc provided to the project by Accolade Wines, SARDI/PIRSA, and K1 Wines (Geoff Hardy). Equipment required for large-scale extractions and purification supplied by Memstar/VA Filtration.

4.1.2 Administration

No additional administration costs were identified.

4.1.3 Extension

The project budget included extension and communication activities and findings were incorporated into dedicated technology transfer projects at no additional cost.

4.1.4 Adoption

The project has delivered an extraction method for the isolation of purified glycosidic material that can be employed in a winery setting to improve wine and NOLO flavour. Additional investment will be required to commercialise the process and costs will be incurred by winemakers in modifying production practices. Winemaker costs may, in time, include changes to infrastructure, purchase and use of additional equipment, and the training and deployment of winery staff.

4.2 Benefits

4.2.1 Research Output and Impact Pathway

The key output from the project is an understanding of how to use glycoside to improve NOLO and conventional wine flavour. The impact pathway for this output is:

1. The benefits of using glycoside communicated to winemakers.
2. Some winemakers invest in glycoside extraction and use to improve NOLO and wine flavour.
3. Winemakers who adopt project outcomes realise additional profitable sales.

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 additional profitable sales of NOLO products with additional flavour, aroma, and consumer appeal. Progress toward additional profitable sales of conventional Australian wine with additional flavour, aroma, and consumer appeal.	Nil.	Nil.	Understanding of glycosides generated by this project may inform winemaking in other countries.
Environmental Benefits			
Valorisation of by-products, and potentially a reduction in waste (marc or grapes not utilized for wine production).	Nil.	Nil.	Nil.
Social Benefits			
Additional researcher skills in juice, wine marc, and wine chemical, and sensory analysis enabling development of premium NOLO products. Project included completion of a PhD. Additional winemaker knowledge of techniques to improve the flavour of NOLO products and conventional wine. Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	Skills developed in sensory analysis may be applicable to the production of other beverages e.g., apple and pear cider.	Increased NOLO consumption may improve the health of the Australian community.	Nil.

4.2.3 Public versus Private Benefits

The project has the potential to generate both private and public benefits. However, the principal benefit will be private – additional profitable sales of more flavoursome NOLO and conventional wine. Potential public benefits include use of products that would otherwise enter the industry's waste stream, increased researcher and winemaker capacity and spill-over benefits for winemaking communities.

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 winegrape growers, winemakers, wine tourism operators, wholesalers, exporters, and retailers all sharing some of the benefits.

4.2.5 Benefits to other Primary Industries

Capacity developed during the project may assist with NOLO production in other horticultural industries including apple and pear cider production.

4.2.6 Benefits Overseas

Understanding of glycosides generated by this project may inform winemaking in other 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) incurred by Wine Australia and other project investors including project administration costs.	Winemaker profit from additional sales of NOLO products.
Overhead costs including time associated with meetings between the researchers, Wine Australia and collaborating organisations.	Winemaker profit from additional sales of conventional wine with additional flavour, aroma, and consumer appeal.
	Valorisation of by-products, and potentially a reduction in waste (marc or grapes not utilized for wine production).
	Additional researcher skills in juice, wine marc, and wine chemical and sensory analysis enabling development of premium NOLO products.
	Additional winemaker knowledge of techniques to improve the flavour of NOLO products and conventional wine.
	Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

The following table shows annual investment in the project by Wine Australia (Table 5.1).

Table 5.1 Investment by Wine Australia in the Project for Years Ending June 2018 to June 2023

Project Code	2018	2019	2020	2021	2022	Total
AWR 1701-3.1.2	120,441	117,473	132,937	117,092	98,792	**586,735**
Total	**120,441**	**117,473**	**132,937**	**117,092**	**98,792**	**586,735**

Source: AWRI 1701-3.1.2 Full project report

There was no other investor in AWR 1701-3.1.2 (Table 5.2).

Table 5.2 Investment by Others in the Project for Years Ending June 2018 to June 2023

Project Code	2018	2019	2020	2021	2022	Total
AWR 1701-3.1.2	0	0	0	0	0	**0**
Total	**0**	**0**	**0**	**0**	**0**	**0**

Source: AWRI 1701-3.1.2 Full project report

Table 5.3 provides the total investment by year for both sources.

Table 5.3 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia	Others	Total
2218	120,441	0	120,441
2019	117,473	0	117,473
2020	132,937	0	132,937
2021	117,092	0	117,092
2022	98,792	0	98,792
Total	**586,735**	**0**	**586,735**

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 Project Collaborator Costs

Time and resource commitments to the project by collaborators including Pernod Ricard, Treasury Wine Estate, Accolate Wines, SARDI, PIRSA, K1 Wines, and Memstar/VA Filtration have a cost. These costs are estimated at $5,000 per annum each year of the project and are included in the quantitative component of the benefit cost analysis.

5.2 Benefits

Counterfactual: in the absence of this project, there is a possibility that large Australian wine companies would have invested in R&D to identify flavour enhancing compounds. Consequently, a counterfactual of 75% has been assumed i.e., it is 25% likely that potential project benefits would have been realised in the absence of project investment.

5.2.1 Winemaker Profit on Additional Sales of NOLO Products

The project has developed a glycosidic extract that segments of the wine industry have responded positively to, indicating that they would incorporate it into their product range. The glycosidic extract is a natural fit for winemakers looking for more flavoursome NOLO products. Commercialisation of the R&D is required before the extract can be made available to winemakers and winemaker profit is likely to be less than that achieved for full strength wine. Consumers are not prepared to pay a premium for NOLO wines and production is more expensive than full strength wine e.g., alcohol removal cost and purchase of wine additives (Pearson 2021).

Forecast growth in Australian NOLO sales is shown in Table 5.4.

Table 5.4 Australian NOLO Wine Sales Globally

Year	Sales Volume (million litres)
2017	7.2
2018	7.7
2019	8.0
2020	9.9
2021	12.3
2022	11.3
2023	12.4
2024	13.6
2025	14.6
2026	15.6
2027	16.6

Source: International Wine and Spirits Research (IWSR). IWSR data provided by Wine Australia (Angelica Crabb, pers. comm., April 2024).

A summary of key assumptions used to quantify winemaker profit associated with additional wine-like NOLO sales is summarised in Table 5.5.

Table 5.5 Summary of Assumptions

Variable	Assumption	Source
Winemaker Profit on Additional Sales of NOLO Products		
Year of first benefit – NOLO products incorporating the glycosidic extract developed as part of AWR 1701-3.1.2 available to consumers.	2026	Glycosidic extract requires commercialisation and experimentation by winemakers before a NOLO product can be produced and marketed to consumers.
Wine-like NOLO production with research project findings in 2026.	15.6 million litres (a)	Table 5.4 above for sales data which is the best available proxy for NOLO production.
Wine-like NOLO production without research AWR 1701-3.1.2 findings in 2026.	13.3 million litres (b)	Analyst's estimate – 15% less than forecast if NOLO flavour not improved.
Research contribution including the current project.	2.3 million litres	(a) – (b)
Profit on additional NOLO production.	$1/litre	Derived from net revenue estimate of $1.22/litre (Wine Australia 2019) after allowing for additional production costs and consumer expectations that NOLO should not cost more than full strength wine.
Attribution of benefits to this project (AWR 1701-3.1.2).	35%	Glycosidic extract requires commercialisation and investment by winemakers in developing more flavoursome NOLO products. More flavoursome NOLO products are also linked to other Wine Australia projects including AWR 1701-3.1.10 Technical and Sensory Research.
Probability of valuable outputs.	100%	Outputs have been delivered.

Probability of valuable outcomes.	75%	Winemakers have indicated their interest in incorporating glycosidic extract into production. However, commercial use is not 100% assured.
Probability of impact.	70%	It is likely that improved wine-like products will generate additional profitable sales for winemakers. There is also a relatively small risk that this will not occur.
Counterfactual	75%	See above explanation.

5.2.2 Other Potential Benefits

Other potential benefits identified but not valued are summarised in Table 4.2. 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 2022 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 (2022).

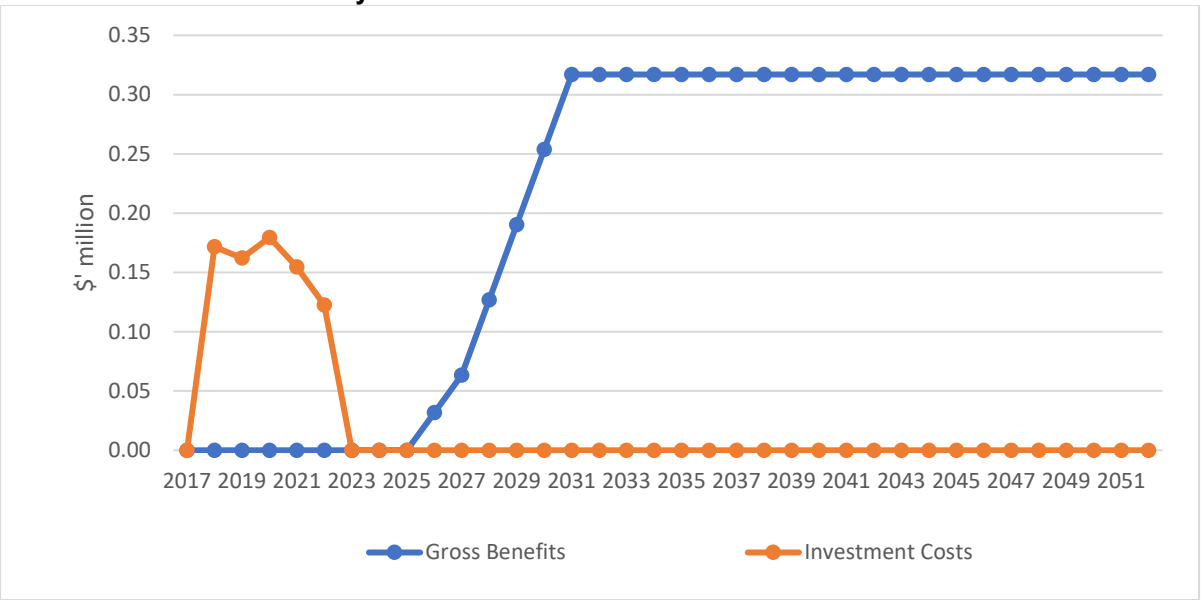
Table 6.1 shows the investment criteria estimated for the different periods of benefits for total investment. Wine Australia was the only investor in the project.

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 ($m)	0.00	0.08	0.97	1.89	2.62	3.19	3.64
Present value of costs ($m)	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Net present value ($m)	-0.97	-0.89	0.00	0.93	1.65	2.22	2.67
Benefit–cost ratio	0.00	0.09	1.00	1.95	2.71	3.29	3.76
Internal rate of return (%)	Negative	Negative	3.9	11.2	13.4	14.3	14.6
MIRR (%)	Negative	Negative	4.1	9.2	9.9	9.8	9.4

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 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 the discount rate. This is because project benefits are not realised until sometime after project investment and extend throughout the analysis period. Nevertheless, results remain positive at the higher 10% 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 ($m)	7.64	3.64	1.99
Present value of costs ($m)	0.79	0.97	1.18
Net present value ($m)	6.85	2.67	0.81
Benefit-cost ratio	9.66	3.76	1.68

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 uncertainty related to the increase in profitable NOLO sales attributable to research and the subsequent profit on those sales – Table 7.2 and Table 7.3. Results show that the benefit cost ratio is sensitive to both these key assumptions and additional NOLO sales would need to fall to 4% or profit on additional wine-like NOLO products be as low at $0.27/litre before project costs equal project benefits.

Table 7.2 Sensitivity to Increase in Sales of NOLO due to Research (Total investment, 30 years)

Investment Criteria	Additional Sales Due to AWR 1701-3.1.2 (%)		
	4%	10%	15% (base)
Present value of benefits ($m)	0.99	2.47	3.64
Present value of costs ($m)	0.97	0.97	0.97
Net present value ($m)	0.02	1.50	2.67
Benefit-cost ratio	1.02	2.55	3.76

Table 7.3 Sensitivity to Profit Earned on Wine-like NOLO Sales (Total investment, 30 years)

Investment Criteria	Profit Earned by Winemakers on Additional NOLO Sales ($/litre)		
	$0.27/litre	$0.50/litre	$1/litre (base)
Present value of benefits ($m)	0.98	1.82	3.64
Present value of costs ($m)	0.97	0.97	0.97
Net present value ($m)	0.01	0.85	2.67
Benefit-cost ratio	1.01	1.88	3.76

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 AWR 1701-3.1.2 'investment in using glycosides and other flavour precursors for improved wine flavour' had a total cost of $0.97 million (present value terms) and is expected to produce aggregate total benefits of approximately $3.64 million (present value terms). This gives an estimated net present value of $2.67 million, a benefit-cost ratio of approximately 3.76, an internal rate of return of 14.6% and a modified internal rate of return of 9.4%.

Analysis results are dependent on assumptions made and are positive for core assumptions and do not become negative until 'lower end' assumptions are applied.

Abbreviations

AWITC Australian Wine Industry Technical Conference
AWRI Australian Wine Research Institute
GVP Gross Value of Production
IWSR International Wine and Spirits Research
NOLO No and low alcohol (wine)
OCS Office of Chief Scientist
RD&E Research, Development and Extension

Persons Contacted

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Markus Herderich, Director of Research, AWRI
Paul Smith, Senior RD&E Program Manager, Wine Australia

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Appendix 6: Economic Analysis of Wine Australia's Investment in Grapevine Trunk Disease Management for Vineyard Longevity in Diverse Climates in Australia

1. Background

Eutypa dieback (ED) and Botryosphaeria dieback (BD) are worldwide grapevine trunk diseases (GTDs), causing significant yield loss and threatening the sustainability of the Australian wine industry. The causal pathogens infect vines through pruning wounds. GTD pathogens colonise wood, causing dieback, and in the case of ED, stunting and yellowing of shoots and leaves, eventually killing the vine.

Reports of increasing prevalence of GTDs in Australian vineyards, coinciding with maturing and aging vines, are causing industry concern. In an economic study commissioned by Wine Australia trunk disease was ranked as a 'top 5 disease of priority' for Australian winegrape growers (GWRDC 08/04).

Many advances have been made in understanding the extent and distribution of GTD pathogens, pruning wound management, and control of GTDs in past Wine Australia projects. However, due to the climatic diversity of Australian wine regions, there are gaps in knowledge in relation to inoculum dispersal and wound susceptibility. These gaps have implications for GTD management.

Wound coverage is correlated to efficacy of pathogen control, so there is potential to maximise coverage with fungicide adjuvants. Remedial surgery is an effective method of controlling ED affected vines but is yet to be proven as a control of BD dieback. Methods to improve the rate of vine regrowth are lacking.

Evaluating disease susceptibility of clones and rootstocks could lead to identification of GTD tolerant planting material. Concerns with the role of grapevine propagation in the spread of trunk disease need to be addressed, particularly with understanding the threshold of infection and abiotic factors that lead to vine decline using highly sensitive molecular marker tools.

By improving GTD management, the project was to reduce costs associated with grapevine yield loss and the cost of GTD remedial action.

2. Summary of Project

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

Table 2.1 Project Description

AWR 1701-1.1.1 Grapevine Trunk Disease Management for Vineyard Longevity in Diverse Climates in Australia	
Project Details	Research Organisations: South Australia Research and Development Institute (SARDI) and the National Wine and Grape Industry Centre (Charles Sturt University). Period: January 2018 to July 2022 (final report date). Principal Investigator: Dr Mark Sosnowski.
Rationale	The project was to develop grapevine trunk disease management strategies for vineyard longevity in diverse Australian climates.
Objectives	4. Develop climate specific recommendations to minimise GTD infection. 5. Optimise wound protection and remedial surgery techniques. 6. Assess susceptibility of clones and rootstocks to GTD. 7. Investigate infection thresholds for grapevine propagation material.
Activities and Outputs	• Develop an inexpensive field test (spore tape analysis) to determine the presence and quantity of GTD pathogen spores across a range of Australian wine climates and throughout the year under different weather conditions.

	• Determine the length of time that grapevine wounds are susceptible to infection by spores of GTD pathogens at key times during the pruning season under different climatic conditions. • Evaluate the addition of adjuvants to fungicide to improve spray coverage on wounds and the efficacy of fungicide. • Evaluate the efficacy of biocontrols and natural alternatives for sustainable control of GTDs. • Monitor established and new remedial surgery trials to manage BD infected vines and evaluate novel methods of water shoot induction to improve the success of the technique. • Assess clones of common cultivars and scion/rootstock combinations for signs of GTD and GTD tolerance. • Quantify the amount of BD pathogen in nursery propagation material followed by planting under various stress conditions and monitor for disease expression. • The project developed rapid, low-cost, DNA-based molecular diagnostic tools (LAMP) to detect pathogens in the vineyard and in spore traps. • Pathogen spores were present all year round in association with rain, and dispersal patterns varied between climatic regions. • Pruning wounds are most susceptible to infection in the first two weeks, with reduced susceptibility during late winter months in the Adelaide Hills. • There is no benefit in adding adjuvants to increase coverage and improve efficiency of fungicides. • Tested biocontrols and alternative products did not provide adequate wound protection against GTD pathogens in the vineyard. • Short-term control of BD was achieved with remedial surgery, with grafting the only method evaluated to significantly increase shoot return, and spore detection was reduced in the vineyard following remediation. • There was no evidence of tolerance to GTD pathogen infection in the clones and rootstocks tested. • Microbiome studies detected relatively low abundance of young vine decline and BD pathogens along with beneficial organisms in nursery vines. • Water-deficit stress increased the susceptibility of young vines to BD pathogen infection, particularly under high disease pressure, but vines with low level of infection were able to withstand disease for at least three seasons when provided with sufficient water. • Project outputs provide new information that has been extended to industry as GTD management strategies relevant to diverse climatic regions.
Outcomes (potential)	• Winegrape grower adoption of project generated tools and knowledge for the formulation of management strategies to improve control of GTDs. Once adopted, management strategies will increase vineyard longevity, reduce grapevine yield loss, and reduce the cost of GTD remedial action.
Impacts (potential)	• Economic –improved yield from older vines that would otherwise have been impacted by GTD. • Economic – reduced cost of GTD remediation including surgery on diseased vines. • Environmental – reduced use of fungicide adjuvants that may have harmful impacts on the farm environment e.g., damage to insect pollinators. • Capacity – additional researcher skills in DNA-based molecular diagnostic tools, assessing and managing grapevine pathogens.

	• Capacity – additional winegrape grower knowledge in relation to management of grapevine trunk diseases. • Social – additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over).

3. Match with National Priorities

Table 3.1 Australian Government Research Priorities

Australian Government Strategies and Priorities	
National Science and Research Priorities[14]	**National Agricultural Innovation Priorities[15]**
1. Food – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets. **2. Soil and Water** – improving the use of soils and water resources, both terrestrial and marine. **3. Transport** – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions. **4. Cybersecurity** – improving cybersecurity for individuals, businesses, government, and national infrastructure. **5. Energy and Resources** – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries. **6. Manufacturing** – supporting the development of high value and innovative manufacturing industries in Australia. **7. Environmental Change** – mitigating, managing, or adapting to changes in the environment. **8. Health** – improving the health outcomes for all Australians.	On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030. These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper. **1.** Australia is a trusted exporter of premium food and agricultural products by 2030. **2.** Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030. **3.** Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030. **4.** Australia is a mature adopter, developer, and exporter of digital agriculture by 2030.

The Wine Australia project has addressed National Science/Research Priority 1. The project does not align with any of the National Agricultural Innovation 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, the project funding body. These costs include both project and overhead expenditures.
- Research partner contributions to the project – cash and in-kind was contributed to the project by SARDI.

[14] See: 2015 Australian Government Science and Research Priorities. https://www.industry.gov.au/data-and-publications/science-and-research-priorities

[15] See: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment

- In-kind contributions to the research project – time associated with meetings between the researchers and Wine Australia and other project collaborators including representatives from diverse climatic regions where GTD management strategies were tested.

4.1.2 Administration
No additional administration costs were identified.

4.1.3 Extension
The project budget included communication and extension activities and findings were published in scientific journals, the Wine Australia website and industry magazines.

4.1.4 Adoption
The project has delivered tools and knowledge for the formulation of strategies to improve control of GTDs. These outputs have been communicated to winegrape growers across growing regions (hot-dry, hot-wet, warm-dry, warm-wet, and cool). Follow up communication and extension may be required to secure adoption. Some management costs will be incurred by winegrape growers who adopt GTD management practices.

4.2 Benefits
4.2.1 Research Output and Impact Pathway
The key output from the project is tools and knowledge to better manage GTDs. The impact pathway for this output is:

1. Tools and knowledge communicated to winegrape growers.
2. Some winegrape growers formulate and adopt GTD management strategies.
3. In vineyards adopting management strategies, there is an improved yield from older vines that would otherwise have been impacted by GTD and a reduction in cost of GTD remedial action.

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			
Improved yield from older vines that would otherwise have been impacted by GTD. Reduced cost of GTD remediation including surgery on diseased vines.	Tools and knowledge generated by the project may also be relevant to the table grape and dried grape industries.	Nil.	GTDs impact vine longevity and yield around the world. Tools and knowledge generated by the project may be applicable overseas.
Environmental Benefits			
Reduced use of fungicide adjuvants that may have harmful impacts on the farm environment e.g., damage to insect pollinators.	Nil.	Nil.	Nil.
Social Benefits			
Additional researcher skills in DNA-based molecular diagnostic tools, assessing and	Skills developed in diagnostic tools and pathogen	Skills developed in diagnostic tools and pathogen	Nil.

managing grapevine pathogens. Capacity – additional winegrape grower knowledge in relation to management of grapevine trunk diseases. Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).	management will be applicable to research in other primary industries.	management may be applicable to human health research.	

4.2.3 Public versus Private Benefits

The project has the potential to generate both private and public benefits. However, the principal benefits will be private – additional yield from older vines that would otherwise have been impacted by GTD and reduced cost of GTD remediation including surgery on diseased vines. Potential public benefits include on-farm environmental gain with less use of adjuvants, increased researcher and winegrape grower capacity, and spill-over benefits for winemaking communities.

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 winegrape growers, winemakers, wholesalers, exporters, and retailers all sharing some of the benefits.

4.2.5 Benefits to other Primary Industries

Skills developed in diagnostic tools and pathogen management may be applied to research projects in other primary industries.

4.2.6 Benefits Overseas

GTDs impact vine longevity and yield around the world. Tools and knowledge generated by the project may be applicable to overseas wine industries.

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) incurred by Wine Australia and other project investors including project administration costs.	Improved yield from older vines that would otherwise have been impacted by GTD.
Overhead costs including time associated with meetings between the researchers, Wine Australia and collaborating organisations.	Reduced cost of GTD remediation including surgery on diseased vines.
	Environmental benefits from reduced use of adjuvants.
	Additional researcher skills in DNA-based molecular diagnostic tools, assessing and managing grapevine pathogens.
	Additional winegrape grower knowledge in relation to management of grapevine trunk diseases.

	Additional profitable grape and wine production and sales which will generate income, and employment benefits in regional Australia (spill-over impact).

5. Valuation of Costs and Benefits

5.1 Costs

5.1.1 R&D Investment Costs including Administration

The following table shows annual investment in the project by Wine Australia (Table 5.1).

Table 5.1 Investment by Wine Australia in the Project for Years Ending June 2018 to June 2022

Project Code	2018	2019	2020	2021	2022	Total
SAR 1701-1.1.1	365,789	374,709	383,907	393,937	404,231	**1,922,573**
Total	365,789	374,709	383,907	393,937	404,231	**1,922,573**

Source: SAR 1701-1.1.1 contract documents and contract variations

SARDI investment in the project, cash and in-kind, is shown in Table 5.2.

Table 5.2 Investment by Others in the Project for Years Ending June 2018 to June 2022

Project Code	2018	2019	2020	2021	2022	Total
SAR 1701-1.1.1	126,607	130,155	133,746	210,489	213,058	**814,055**
Total	126,607	130,155	133,746	210,489	213,058	**814,055**

Source: SAR 1701-1.1.1 contract documents and contract variations

Table 5.3 provides the total investment by year for both sources.

Table 5.3 Annual Investment in the Project (nominal $)

Year Ending 30 June	Wine Australia	Others	Total
2218	365,789	126,607	**492,396**
2019	374,709	130,155	**504,864**
2020	383,907	133,746	**517,653**
2021	393,937	210,489	**604,426**
2022	404,231	213,058	**617,289**
Total	**1,922,573**	**814,055**	**2,736,628**

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 Project Collaborator Costs

Time commitments to the project by collaborators including representatives from diverse climatic regions where GTD management strategies were tested. These costs are estimated at $5,000 per annum each year of the project and are included in the quantitative component of the benefit cost analysis.

5.2 Benefits

Counterfactual: in the absence of this project, there is only a small likelihood that long term research on the management of GTDs across diverse Australian climates would have been completed. Consequently, a counterfactual of 80% has been assumed. That is, it is only 20% likely that potential project benefits would have been realised in the absence of project investment.

5.2.1 Benefit 1: Improved Yield from Older Vines Otherwise Impacted by GTD

The project has delivered tools and knowledge that can be used to formulate GTD management strategies. Strategies are relevant to winegrape growing in climatically diverse regions – hot-dry, hot-wet, warm-dry, warm-wet, and cool growing areas. Some winegrape growers will adopt project findings,

increase vineyard longevity, and reduce grapevine yield loss. In 2010, Grape and Wine R&D Corporation (GWRDC) project 08/04, surveyed winegrape growers and concluded that GTD yield loss was most likely between 0.5% to 20%, with an average of 10%. Area of production impacted by GTD was between 5% and 10% of vineyard area. Some of this yield loss caused by GTD will be recovered with adoption of project outputs.

5.2.2 Benefit 2: Reduced Cost of GTD Remediation Including Surgery on Diseased Vines

A second project benefit is associated with a reduction in the cost of GTD remediation following adoption of improved management practices. GWRDC 08/04 showed that 1% of GTD impacted vineyards incur remedial surgery costs of $2,800/ha/year to remove disease impacted trunk. Some of this cost will be avoided with adoption of project outputs.

Key assumptions used to quantify both benefits are summarised in Table 5.4.

Table 5.4 Summary of Assumptions

Variable	Assumption	Source
Benefit 1: Improved Yield Older Vines Otherwise Impacted by GTD		
Australian vineyard area.	146,624 ha.	National Vineyard Scan 2019.
Percentage of Australian vineyard area impacted by GTD.	10%	GWRDC 08/04.
Loss of yield in GTD impacted area.	7.5% (between 5% and 10%)	GWRDC 08/04.
Profit on recovered yield.	$1,455/ha	Average grape price of $642/t[16] X average yield of 12.59t/ha X 18% long term average profit on winegrape sales (Wine Australia National Vintage Report 2023 and AgEconPlus 2019).
Benefit 2: Cost Saving on GTD Treatment		
Share of GTD impacted area requiring remedial surgery.	1%	GWRDC 08/04.
Cost of remedial surgery.	$2,800/ha	GWRDC 08/04.
Additional Assumptions		
Share of GTD impacted production adopting project recommendations.	50%	Analyst's assumption.
Year of first benefit.	2026.	Outputs communicated to winegrape growers prior to project completion in July 2022, with practice change such as wound and water stress management in place in 2023 and yielding benefits by 2026.
Attribution of benefits to this project (SAR 1701-1.1.1).	90%	Further investment in communication and extension will be required to achieve forecast adoption of project outputs.
Probability of valuable outputs.	100%	Outputs have been delivered via a final project report, communication, and extension activities.

[16] The analyst notes 2024 prices are well below this average especially in warm inland areas.

Probability of valuable outcomes.	90%	There is a high probability that tools and knowledge generated by the project will create valuable outcomes.
Probability of impact.	90%	It is likely that tools and knowledge adopted as management strategies will reduce the incidence of GTD.
Counterfactual	80%	See above explanation.

5.2.3 Other Potential Benefits

Other potential benefits identified but not valued are summarised in Table 4.2. 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 2023 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 (2022).

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%)

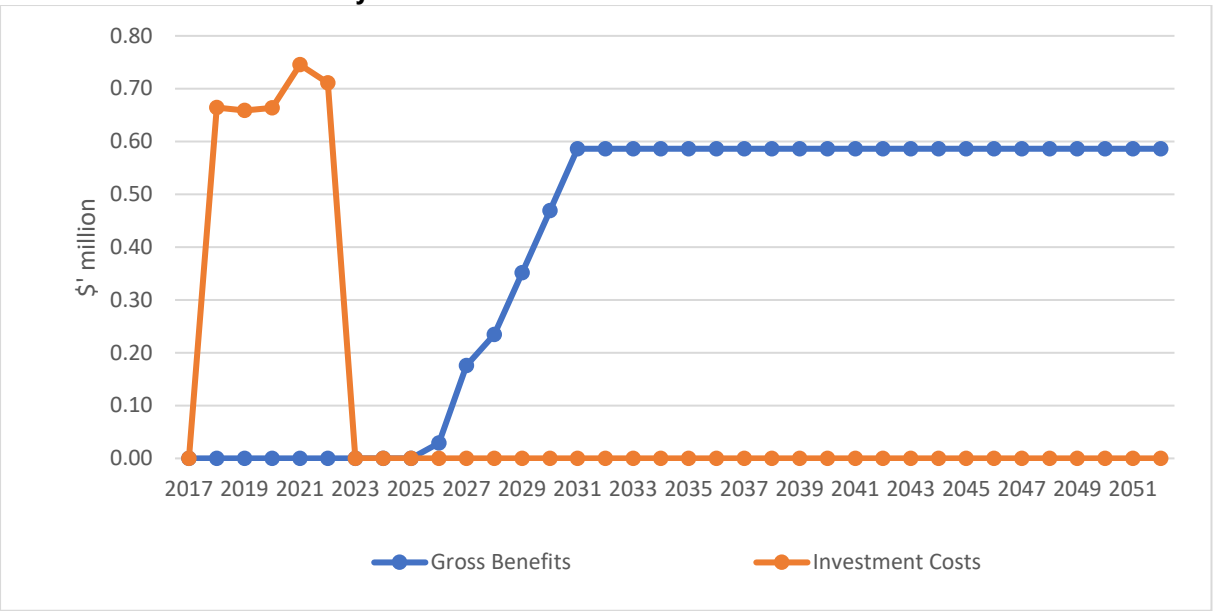
Years	0 years	5 years	10 years	15 years	20 years	25 years	30 years
Present value of benefits ($m)	0.00	0.18	1.81	3.53	4.87	5.93	6.76
Present value of costs ($m)	4.18	4.18	4.18	4.18	4.18	4.18	4.18
Net present value ($m)	-4.18	-4.01	-2.37	-0.66	0.69	1.75	2.57
Benefit–cost ratio	0.00	0.04	0.43	0.84	1.17	1.42	1.61
Internal rate of return (%)	Negative	Negative	Negative	2.5	5.6	7.0	7.8
MIRR (%)	Negative	Negative	Negative	3.3	5.4	6.1	6.4

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 ($m)	0.00	0.13	1.31	2.55	3.52	4.28	4.87
Present value of costs ($m)	3.02	3.02	3.02	3.02	3.02	3.02	3.02
Net present value ($m)	-3.02	-2.89	-1.71	-0.47	0.50	1.26	1.86
Benefit–cost ratio	0.00	0.04	0.43	0.84	1.17	1.42	1.61
Internal rate of return (%)	Negative	Negative	Negative	2.5	5.6	7.0	7.8
MIRR (%)	Negative	Negative	Negative	3.3	5.4	6.1	6.4

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 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 somewhat sensitive to the discount rate and at a discount rate of 10%, project costs exceed project benefits.

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

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	14.16	6.76	3.70
Present value of costs ($m)	3.44	4.18	5.06
Net present value ($m)	10.72	2.57	-1.36
Benefit-cost ratio	4.11	1.61	0.73

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 uncertainty related to the area of vineyard effected by GTD and the value of recovered production - Table 7.2 and Table 7.3. Results show that if the percentage of Australian vineyard area affected by GTD was only 5% (all other assumption held constant) then the project would fail to break even. While if the net value of recovered production from use of GTD management strategies was only $727/ha, reflecting a grape price of $321/t the project would fail to break even (all other assumption held constant).

Table 7.2 Sensitivity to Australian Vineyard Area Affected by GTD (Total investment, 30 years)

Investment Criteria	Percentage of Australian Vineyard Area Affected by GTD		
	5%	10% (base)	20%
Present value of benefits ($m)	3.38	6.76	13.51
Present value of costs ($m)	4.18	4.18	4.18
Net present value ($m)	-0.80	2.57	9.33
Benefit-cost ratio	0.81	1.61	3.23

Table 7.3 Sensitivity to Value of Recovered Vineyard Yeild (Total investment, 30 years)

Investment Criteria	Value of Recovered Production ($/t)		
	$321/t or profit of $727/ha	$500/t or profit of $1,133/ha	$642/t or profit of $1,455/ha (base)
Present value of benefits ($m)	4.07	5.57	6.76
Present value of costs ($m)	4.18	4.18	4.18
Net present value ($m)	-0.12	1.38	2.57
Benefit-cost ratio	0.97	1.33	1.61

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 SAR 1701-1-1 'grapevine trunk disease management for vineyard longevity in diverse climates in Australia' had a total cost of $4.18 million (present value terms) and is expected to produce aggregate total benefits of approximately $6.76 million (present value terms). This gives an estimated net present value of $2.57 million, a benefit-cost ratio of approximately 1.61, an internal rate of return of 7.8% and a modified internal rate of return of 6.4%.

Analysis results are dependent on assumptions made and are positive for core assumptions. However, sensitivity testing showed that the project fails to breakeven under possible alternatives including currently depressed winegrape prices.

Abbreviations

BD	Botryosphaeria dieback
ED	Eutypa dieback
GTD	Grapevine Trunk Disease
GVP	Gross Value of Production
GWRDC	Grape and Wine R&D Corporation (now Wine Australia)
OCS	Office of Chief Scientist
R&D	Research and Development
RD&E	Research, Development and Extension
SARDI	South Australia R&D Institute

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