ECONOMIC ASSESSMENT OF SIX RESEARCH, DEVELOPMENT AND EXTENSION INVESTMENTS BY THE DEPARTMENT OF AGRICULTURE AND FISHERIES (QUEENSLAND)

FINAL Summary Report

to

Department of Agriculture and Fisheries Queensland

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by

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Abbreviations

BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries (Queensland)
GDP	Gross Domestic Product
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
PVB	Present Value of Benefits
PVC	Present Value of Investment Costs
RDC	Research and Development Corporation
R&D	Research and Development
RD&E	Research, Development and Extension

Glossary of Economic Terms

Cost-benefit analysis - A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs) to Australia, regardless of to whom they accrue.

Investment criteria - Measures of the economic worth of an investment such as Net Present Value, Benefit Cost Ratio, and Internal Rate of Return.

Present Value of Costs -The discounted value of R&D investment costs

Present Value of Benefits - The discounted value of benefits.

Net Present Value - The discounted value of the bene*fits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.

Benefit-Cost ratio - The ratio of the present value of investment benefits to the present value of investment costs.

Internal Rate of Return (IRR) - The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits is equal to present value of costs.

Modified Internal Rate of Return (MIRR) - The MIRR is a modified IRR estimated so that any cash inflows from an investment are assumed re-invested at the rate of the cost of capital (a designated re-investment rate).

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Executive Summary

This report presents the results of a series of cost-benefit analyses (CBA) of completed research, development and extension (RD&E) investments made by the Department of Agriculture and Fisheries, Queensland (DAF).

DAF required an analysis of six project and project cluster investments. The project and project cluster investments were:

- Investment 1: Chickpea breeding (cluster)
- Investment 2: Prawn farming
- Investment 3: Mango production
- Investment 4: Irrigation water use efficiency (MDB)
- Investment 5: Forestry pest management (Sirex wasp)
- Investment 6: Forestry pest surveillance

The analyses were carried out to demonstrate accountability and the value of the Queensland Government's contribution to RD&E investment across a range of industries and disciplines. The six investments were all supported by DAF resources, as well as by Research and Development Corporations (RDCs) including those representing grains, fisheries, horticulture and other Commonwealth, State and industry organisations. As each of the six investments were all partly funded by DAF, this report addresses the individual return to:

- The total investment in each project including funding by DAF, other funding agencies, and any investment provided by researchers and other parties,
- The specific resource investment provided by DAF.

Available documentation was assembled on each project with assistance from DAF personnel and others involved with the investment and associated industry. Documentation included the original project proposals, milestone reports, budgetary information for each investment including variations, and other relevant reports.

Each of the six analyses provides a description of the individual project or cluster including objectives, costs, outputs, activities, outcomes, and potential and/or actual impacts. Impacts are first described qualitatively according to their contribution to the triple bottom line of economic, environmental and social impacts. Some of the identified impacts were then valued.

The economic analyses were carried out using the current guidelines of the Council of Rural Research and Development Corporations (CRRDC). Impacts were estimated for up to 30 years from the year of last investment in each project. Total costs for each project included the investment in the project by DAF and others. The DAF contribution to the total investment made in each of the six projects/clusters varied from 15% to 81%.

The analyses produced investment criteria by project for the total investment as well as separate investment criteria for the DAF investment. A degree of conservatism was used when finalising assumptions. Sensitivity analyses were 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 impacts were not quantified mainly due to:

- A suspected weak or uncertain scientific or causal relationship between the research investment and the actual research and development (R&D) outcomes and associated impacts.
- The magnitude of the value of the impact was thought to be only minor.
- A lack of data on which to base assumptions.

Once each of the six individual analyses were completed, individual undiscounted cash flows (benefits and costs) were combined to generate a set of aggregate investment criteria for all six investments.

The tables below present the investment criteria for the total investment and the DAF investment in each of the six investments evaluated using a 5% discount rate, with benefits valued over 30 years from the last year of investment, all costs and benefits expressed in 2016/17 dollar terms and discounted to 2017/18 (the year of analysis). In addition, the bottom line in each table includes investment criteria for the aggregate investment across all six individual investments.

Investment Criteria for Total Investment

Project/Cluster Investment	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
Chickpea breeding (cluster)	932.68	57.20	875.49	16.31	48.4	19.3
Prawn farming	1.61	0.68	0.93	2.38	12.6	7.5
Mango production	21.03	3.15	17.88	6.67	31.2	12.2
Water use efficiency	19.31	4.08	15.23	4.73	19.8	10.0
Forestry pest management	2.27	0.78	1.49	2.92	12.9	9.0
Forestry pest surveillance	2.04	0.50	1.54	4.09	18.7	10.1
Aggregate (Total investment in all Project/Cluster Investments)	978.95	66.38	912.57	14.75	55.5	15.6

Investment Criteria for DAF Investment

Investment Project	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
Chickpea breeding (cluster)	140.68	9.06	131.62	15.52	41.8	17.4
Prawn farming	0.73	0.31	0.42	2.38	12.6	7.5
Mango production	5.45	0.82	4.63	6.67	31.2	12.2
Water use efficiency	5.72	1.21	4.51	4.73	19.8	10.0
Forestry pest management	0.83	0.27	0.55	3.03	13.7	8.0
Forestry pest surveillance	1.65	0.40	1.24	4.09	18.7	10.1
Aggregate (DAF investment in all Project/Cluster Investments)	155.05	12.07	142.98	12.85	41.7	17.7

1. Introduction

This report presents the results of cost-benefit analyses (CBA) of a discrete set of research, development and extension (RD&E) investments made by the Department of Agriculture and Fisheries, Queensland (DAF) and its predecessors, with support from other research funding bodies.

Ascertaining the extent of impacts that have accrued as a result of these investments can demonstrate to others that research investments made by DAF are delivering impacts. In addition, it can inform DAF RD&E management about performance from past investments as well as possible guidance for future allocation of RD&E resources.

The investments were made in one cluster of projects and five individual projects. They were:

- Investment 1: Cluster of chickpea breeding investments
- Investment 2: Prawn farming
- Investment 3: Mango production
- Investment 4: Water use efficiency
- Investment 5: Forestry pest management
- Investment 6: Forestry pest surveillance

A summary of methods used in the analysis is provided in Section 2, including the steps involved in the evaluation of each individual investment. Section 3 reports the investment criteria for each of the six investments as well as investment criteria for the aggregate investment in the six projects. A brief conclusion is provided in Section 4. Appendices A to F provide the detailed impact assessments and analyses for each of the six investments.

2. Methods

The evaluation approach used in this analysis follows guidelines that are now well entrenched within the Australian primary industry research sector including Rural Research and Development Corporations (RDCs), Cooperative Research Centres and some Universities. The evaluation includes both qualitative and quantitative approaches with the latter using Cost-Benefit Analysis (CBA). These approaches are in accord with the current guidelines of the Council of Rural Research and Development Corporations (CRRDC, 2014).

Each investment was evaluated through the following steps:

1. Information from any original project proposals and schedules, progress reports, and other relevant reports assembled with assistance from DAF personnel.
2. An initial description of the relevant background, objectives, costs, activities, outputs, and expected outcomes and impacts was drafted for each of the six investments. Additional information needs were identified.
3. The potential impacts from each investment were identified and described in a triple bottom line context. Some of these impacts were then valued as part of the CBA.
4. Telephone and/or email contact was made with relevant Project Principal Investigators and the initial draft project description sent to them for perusal and comment, together with specific information requests.
5. Interactions and discussions followed with a number of DAF researchers, as well as with personnel who were familiar with the research outputs and their adoption by industry.
6. Further information was assembled where appropriate from publications, industry personnel and other RD&E personnel.
7. Some analyses proceeded through several drafts, both internally within the project team as well as externally via Principal Investigators and other reviewers.
8. Draft reports for each investment were provided to DAF management for comment.
9. Comments on each of the draft reports were addressed and incorporated into a final report that was provided to DAF management.

The factors that drive the investment criteria for research and development (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 any additional costs of implementation/usage.
- The quantity of production affected by the R&D, in turn a function of the size of the target audience and/or applicable area, and the level of initial and maximum adoption ultimately expected, the expected commencement year of adoption and the level of adoption in the intervening years.
- The discount rate.
- An attribution factor that can apply when the specific project or investment being considered is only one of several pieces of research or activity that have contributed to the impact being valued.
- The assumptions associated with the ‘without R&D’ scenario, referred to as the ‘counterfactual’.

CBAs were conducted individually on all six investments to generate investment criteria by project or project cluster. The Present Value of Benefits (PVB) and Present Value of Investment Costs (PVC) were used to estimate investment criteria of Net Present Value (NPV) and Benefit-Cost Ratio (BCR) at a discount rate of 5%. The Internal Rate of Return (IRR) was estimated from the annual net cash flows. The Modified Internal Rate of Return (MIRR) for each investment also was estimated. The MIRR is a modified IRR estimated so that any positive cash inflows from an investment are re-invested at the rate of the cost of capital (the re-investment rate). For these analyses, the re-investment rate was set at 5% as required by the CRRDC. These terms are defined in the Glossary of Economic Terms at the beginning of this report.

All dollar costs and benefits were expressed in 2016/17 dollar terms using the Implicit Price Deflator for GDP and discounted to the 2017/18 year. A 30-year benefit time frame was used in all analyses, with benefits estimated for up to 30 years from the year of last investment in each project. Total investment costs for each project included the expenditure on the project by DAF and the industry RDC (where applicable), as well as any other resources contributed by third parties. Investment criteria were estimated and reported for the total investment as well as for the investment by DAF.

A degree of conservatism was used when making specific assumptions. Sensitivity analyses were 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 impacts were not quantified mainly due to factors such as:

- A suspected weak or uncertain scientific or causal relationship between the research investment and the associated outputs, outcomes and impacts.
- The magnitude of the value of the impact was thought to be only minor.
- A lack of data on which to base credible assumptions for valuation.

Once each of the six individual analyses were finalised, the six individual undiscounted cash flows (benefits and costs) were combined to provide the basis for the calculation of aggregate investment criteria, generated for the total investment and for the DAF investment separately, for all six investments combined.

3. Summary of Results

Aggregate investment criteria estimated for both the total investment and the DAF investment alone and summarised in Table 1 (Total) and Table 2 (DAF) for each of the six investments analysed at a 5% discount rate first individually and then with the cash flows for the six investments aggregated.

Further details on each of these investments and the associated results are provided in the individual investment evaluation reports and analyses (Appendices A to F).

Table 1: Investment Criteria for Total Investment by Project/Cluster
(discount rate 5%, 30 years from last year of investment)

Project/Cluster Investment	PVB ($m)	PVC ($m)	NPV ($m)	BCR	IRR (%)	MIRR (%)
Chickpea breeding	932.68	57.20	875.49	16.31	48.4	19.3
Prawn farming	1.61	0.68	0.93	2.38	12.6	7.5
Mango production	21.03	3.15	17.88	6.67	31.2	12.2
Water use efficiency	19.31	4.08	15.23	4.73	19.8	10.0
Forestry pest management	2.27	0.78	1.49	2.92	12.9	9.0
Forestry pest surveillance	2.04	0.50	1.54	4.09	18.7	10.1
Aggregate (Total investment in all Project/Cluster Investments)	978.95	66.38	912.57	14.75	55.5	15.6

Table 2: Investment Criteria for the DAF Investment by Project/Cluster
(discount rate 5%, 30 years from last year of investment)

Investment Project	PVB ($m)	PVC ($m)	NPV ($m)	BCR	IRR (%)	MIRR (%)
Chickpea breeding	140.68	9.06	131.62	15.52	41.8	17.4
Prawn farming	0.73	0.31	0.42	2.38	12.6	7.5
Mango production	5.45	0.82	4.63	6.67	31.2	12.2
Water use efficiency	5.72	1.21	4.51	4.73	19.8	10.0
Forestry pest management	0.83	0.27	0.55	3.03	13.7	8.0
Forestry pest surveillance	1.65	0.40	1.24	4.09	18.7	10.1
Aggregate (DAF investment in all Project/Cluster Investments)	155.05	12.07	142.98	12.85	41.7	17.7

The aggregate PVCs in Table 2 (DAF) compared to those in Table 1 (Total) demonstrate the importance of DAF funding in most of the six investments. As a proportion of total funding in each investment, DAF funding varied from approximately 15% to 81% with a weighted average of 18% across all six investments.

The aggregate performance was dominated by the large investment in chickpea breeding that also produced the highest BCR of all six investments.

4. Conclusions

All six of the investments analysed provided positive net present values at the 5% discount rate. The individual benefit-cost ratios varied from 2.4 to 16.3 for the total investment analysis and for the 30-year period from the year of last investment. The highest BCR was for the relatively high investment in chickpea breeding.

Any comparisons between the results for the individual investments should be made with some caution due to the uncertainties involved in some assumptions and the differing frameworks used across the individual six evaluations.

Across the six investments the aggregate benefit-cost ratio for the total aggregate investment was 14.8 to 1, the aggregate internal rate of return was 18.7%, and the aggregate modified internal rate of return 15.6%.

References

CRRDC 2014, Impact Assessment Guidelines – Version 1, May 2014, CRRDC, Canberra.

Appendices

Appendix A: An Impact Assessment of DAF Investment into Chickpea Breeding (July 2001 to June 2018)

Acknowledgments

Wayne Hall, Executive Director, Agri-Science Queensland, Department of Agriculture and Fisheries

Lynda Bull, Executive Support Officer, Agri-Science Queensland, Department of Agriculture and Fisheries

Chickpea breeding team personnel

Abbreviations

BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
GDP	Gross Domestic Product
ICARDA	International Centre for Agriculture Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
NSW	New South Wales
NSWDPI	New South Wales Department of Primary industries
PVB	Present Value of Benefits
PVC	Present Value of Costs
QLD	Queensland
R&D	Research and Development
RD&E	Research, Development and Extension
RDC	Research and Development Corporation

Executive Summary

The Report

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in a series of research projects associated with chickpea varietal improvement. The series of projects was jointly funded principally by the DAF, the NSW Department of Primary Industries (NSWDPI), and the Grains Research and Development Corporation (GRDC) from July 2001 to June 2018.

Methods

There were five projects in the series. Each of the projects was analysed qualitatively using a logical framework that included project objectives, activities and outputs, outcomes and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts were then valued.

Benefits were estimated for a range of time frames up to 30 years from the last year of investment (2017/18) in the series of projects. Past and future cash flows in 2016/17 dollars were discounted to the year 2017/18 using a discount rate of 5% to estimate the investment criteria.

The cost-benefit analysis (CBA) was conducted according to the Impact Assessment Guidelines of the Council of Rural Research and Development Corporations (CRRDC, 2014).

Findings

The investment in varietal improvement through past investment in breeding was instrumental in driving the significant growth in chickpea production in Australia over the period from 2002 to 2018 and for some time afterwards.

A number of new varieties of chickpea were released from the breeding program. Most were rapidly adopted by chickpea growers due to their improved disease resistance, yield and seed quality. Together with increased grower experience, improved agronomic information, grower confidence from disease management, and market conditions, the varietal improvements have been responsible for a significant increase in the Australian chickpea area. As chickpea is a winter legume crop and is commonly grown in rotation with wheat, the increased chickpea area has been responsible for increased rotational profits from the cereal disease break and the additional nitrogen contributed by the legume.

Impacts

The major impacts identified were of a financial/economic nature. However, some social and environmental impacts were identified also but not valued.

There have been private benefits delivered also along the product supply chain due to increased economic activity in cleaning, grading, transport and handling, and exporting.

There are likely to be some public benefits produced, some mainly environmental in nature from lowered fungicide and pesticide chemical use with potential implications for water quality off-farm. Other public benefits have accrued with community spillovers from increased farm incomes and the generation of increased regional infrastructure and employment.

It is expected that QLD and NSW chickpea producers will be the primary beneficiaries of the investment as it is in these states that the majority of Australian chickpeas are grown.

Investment Criteria

Total funding from all sources for the project was approximately $57 million (present value terms). The value of total benefits was estimated at $933 million (present value terms). This result generated an estimated net present value of $876 million, and a benefit-cost ratio of over 16 to 1.

As there were a number of impacts identified that were not valued in economic terms (e.g. increases in seed size, regional community spillovers) the investment criteria reported are likely to have undervalued the full set of benefits delivered by the investment.

1. Evaluation Methods

The evaluation approach follows general evaluation guidelines that now are well entrenched within the Australian primary industry research sector including Research and Development Corporations (RDCs), Cooperative Research Centres, State Departments of Agriculture, and some Universities. This impact assessment uses Cost-Benefit Analysis (CBA) as its principal tool. The approach includes both qualitative and quantitative descriptions that are in accord with the Impact Assessment Guidelines of the Council of Rural Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and potential and actual outcomes and impacts. The principal economic, environmental and social impacts were then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, or the likely low relative significance of the impact compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Industry Background

Two types of chickpea (desi and kabuli) are grown in Australia. Desi chickpeas contribute the majority of Australian production. The desi type produces small brown seeds that are used for split pea (dahl) or flour after the hulls are removed. The dominant desi chickpeas are grown mainly in northern NSW and Queensland , while the kabuli type (seeds are larger and creamy white) are more common in the south-east part of Australia (e.g. Victoria).

Chickpeas are favoured in rotations with cereals where, as a legume, they can contribute nitrogen to the next cereal crop, as well as provide a disease break and help control weeds in the following cereal crop. Chickpeas are generally sown in winter and harvested in late spring or summer. Until the year ending June 2016, NSW has been the largest producing state with an average annual production of 345,000 tonnes over the previous 6 years. Queensland (QLD) was next largest producing state over that period. In the year ended June 2017 Queensland became the largest producing state (ABARES, 2017).

The major market for chickpeas is the human consumption market. Chickpeas are suitable also for both ruminant and non-ruminant livestock feeds but are not commonly used for these purposes due to the higher prices obtained from human consumption use. Most chickpeas produced in Australia are exported.

Pulse Australia is a peak industry body that represents all sectors of the pulse industry in Australia, from growers and agronomists through to researchers, merchants, traders and exporters (Pulse Australia, 2018).

Areas, yields and total tonnages for Australian chickpeas since a serious commercial industry commenced are provided in Table A1. Yield per ha has been volatile over the period and has exhibited a ten-year average of 1.3 tonnes per ha. Areas, yield per ha and annual production levels have fluctuated significantly due to factors such as disease, price volatility, and drought. Phytophthora root rot (PRR) and Ascochyta blight (AB) have been particularly damaging to chickpea production. Despite these disease impacts, there has been significant growth in the Australian chickpea area over the past few years. For example, the linear trend in area since the year 2006 (over 11 years) has been 40,000 ha per year (Figure A1). An estimate of the chickpea area for the 2017 year was over 1 million ha (ABARES, 2017).

Yield per ha has continued to fluctuate. The low yields reported in 2003 and 2007 (Table A1) were caused by drought and in 2011 by a wet spring (Kristy Hobson, pers. comm., 2012). However, the annual trend in yield from 2002 to 2017 (15 years) has been positive at 0.04 t per ha per year (Figure A2).

Table A1: Areas, Yields and Tonnages for Australian Chickpea Production

Year ended June	Area ('000 ha)	Yield (t/ha)	Production ('000 t)
1984	3.1	1.16	3.6
1985	6.4	0.92	5.9
1986	26.4	1.38	36.4
1987	67.3	0.94	63.4
1988	54.9	0.99	54.1
1989	67.5	1.27	86.0
1990	93.1	1.18	109.4
1991	178.1	1.08	191.7
1992	250.2	0.89	223.1
1993	151.8	1.17	176.9
1994	126.5	1.24	156.9
1995	208.9	0.33	68.9
1996	216.4	1.33	286.9
1997	256.0	1.09	278.0
1998	205.0	0.93	191.0
1999	308.5	0.61	187.6
2000	218.0	1.05	229.9
2001	261.5	0.62	162.4
2002	195.0	1.32	258.0
2003	201.0	0.68	136.0
2004	151.5	1.20	178.0
2005	113.3	1.00	115.6
2006	131.3	1.10	149.7
2007	284.1	0.80	229.2
2008	306.0	1.00	313.0
2009	338.2	1.30	442.5
2010	429.0	1.10	487.0
2011	653.0	0.80	513.0
2012	456.0	1.50	673.0
2013	574.0	1.40	813.0
2014	508.0	1.20	629.0
2015	425.0	1.30	555.0
2016	677.0	1.30	875.0
2017	1,069.0	1.90	2,004.0
Simple average last 10 years	544.0	1.28	730.4
Simple average last 5 years	651.0	1.42	975.2

Source: ABARES 1989, 1994, 1998, 2001, 2005, 2011, 2017

Figure A1: Australian Chickpea Area (2006-2016)

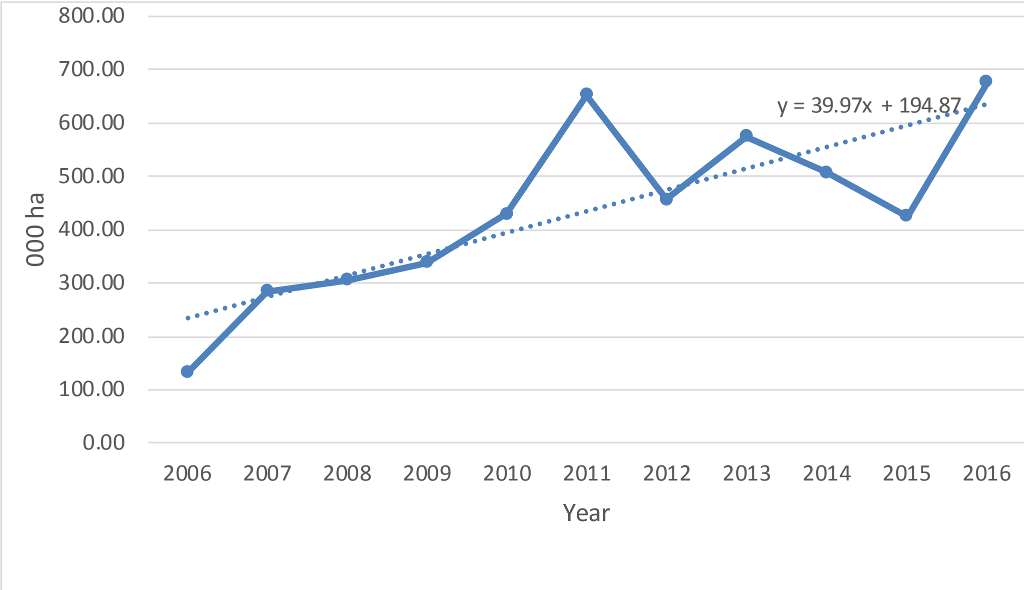
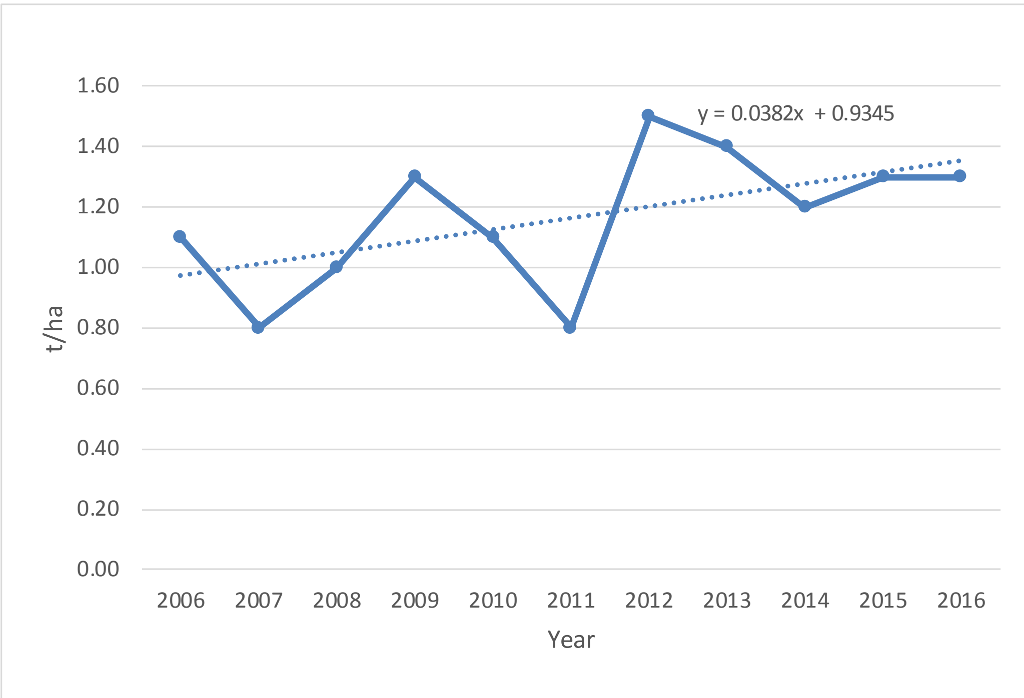


Figure A2: Australian Chickpea Yield (2002-2016)



The proportion of chickpea area grown in QLD has varied from 21% to 57% of the total Australian area. Chickpea yields per ha in QLD have been generally higher than the overall Australian average (in seven of the last ten years).

Varietal Improvement Pre-2002

The Australian chickpea improvement program commenced in the early 1970s with the testing of six Indian introductions, followed by collections introduced from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). One of these introductions was released jointly by CSIRO and DAF as cultivar - Tyson. Releases of other desi types followed including Amethyst (NSW 1988), Dooen (Victoria 1988), Semsen (NSW and QLD 1989) and Barwon (NSW and QLD 1992) (Wood et al, 1994). Since 1983 chickpea breeding has been a continuous collaborative effort between the NSW Department of Primary Industries (NSWDPI) and QLD DAF and supported financially by the grains industry levy and matching Commonwealth funds. More recently, other states also have been involved in the program.

In 1996 the Australian Coordinated Chickpea Improvement Program commenced as a nationally focused program. Further improvements to cultivars and management were developed between 1996 and 2005 that partly overcame the constraints to production imposed by such factors as yield potential, disease, harvestability, and abiotic factors. A number of varieties were released: for example, Howzat and Jimbour, both moderately resistant to PRR, produced yields 12-17% higher than the existing industry standard lines at that time. Lines also were introduced with resistance to AB. In 2003 the variety Moti was released by the Western Australia Department of Agriculture specifically for production in Central QLD where AB was not a constraint.

3. Investment Details

Summary of Projects

Five projects contributed to the total investment being analysed over the period from July 2001 to June 2018. NSWDPI was the lead agency for all five projects. Codes (NSWDPI is coded DAN), Titles, Project Leaders and Funding Periods are provided in Table A2.

Table A2: Summary of Projects Included in the Impact Assessment

Project Code	Title	Project Leader	Funding Period
DAN467	Coordinated improvement of chickpeas in Australia	Merrill Ryan, DAF	July 2001 to June 2004
DAN00065	National Desi Chickpea Program	Merrill Ryan, DAF	July 2004 to Dec 2005
DAN00094	Australian chickpea Breeding Program	Col Douglas, DAF	Dec 2005 to June 2011
DAN00151	PBS Chickpea-National Breeding Program	Col Douglas, DAF Rex Williams, DAF	July 2011 to Dec 2017
DAN00172	Managing Crop disease improving Chickpea pathogen resistance	Merrill Ryan, DAF	June 2013 to June 2018

Logical Frameworks

Tables A3 to A7 provide a description of the investment by project in a logical framework format.

Table A3: Logical Framework for Project DAN467: Coordinated improvement of chickpeas in Australia

Objectives	• To introduce a high level of Ascochyta blight resistance into chickpeas for the Northern Region. • To improve the yield potential, harvestability, resistance to disease (other than Ascochyta blight) and seed quality of chickpeas for the Northern Region.

	• To coordinate the activities of the national breeding program including collaboration with the International Centre for Agriculture Research in the Dry Areas (ICARDA).
Activities and Outputs	• The project continued previous breeding efforts to develop breeding lines and varieties for the Northern Region of Australia. • The project followed the rapid adoption of Jimbour and Howzat that showed yield increases of 6-11%, as well as a higher price ($15 per tonne) for seed quality (largely from the larger seed type). • The international collaboration component of the project relied heavily on the exchange of genetic material between ICARDA and the Tamworth Agricultural Institute (NSWDPI). • Breeding lines that had a high level of resistance to PRR and AB were developed from the existing germplasm sourced from ICARDA. These lines were developed for the Northern Region and included: o Desi lines with yield, plant type and seed quality equivalent or superior to Jimbour and Howzat. o Kabuli lines with yield, plant type and seed quality equivalent or superior to Bumper. • Variety releases for resistance against PRR and AB were not achieved during this project but were planned from 2005 onwards. • While some lines resistant to root-lesion nematode (RLN) and fusarium wilt (FW) were developed, they were not advanced to the stage where release strategies in the future could be considered.
Outcomes	• Contribution to new chickpea varietal releases post 2005. • When new varieties were released, it was expected that they would be rapidly adopted by producers due to their yield and quality improvements. • Other advantages foreseen were the increased resistance to diseases such as AB and PRR. • The new varieties would increase the confidence of producers in growing chickpea and potentially expand the chickpea area; at that time chickpea accounted for only 5% of the area sown to winter crops. • The increased chickpea area was foreseen to increase the profitability of crop rotations through adding nitrogen to the soil as well as from the disease break that would assist control of cereal diseases. • At that time up to eight fungicide applications were required to control AB, costing up to $65 per ha in an average year. • Prospective enhanced value of germplasm for ongoing use (compared with value at the start of the project).
Impacts	• Potentially increased profitability of winter crop rotations in the northern region post-2005 from yield, quality and rotational benefits. • Fungicide costs could potentially fall from $65 to $16 per ha. • Use of farm fungicides could fall meaning less chemicals would be exported to off-farm environments.

Table A4: Logical Framework for Project DAN00065: Northern Desi Chickpea Breeding Program

Rationale	Previously to 2005 the area of Australian chickpeas had been static for a number of years (Table A1) and yields remained variable. While there had been some PRR resistant varieties developed, AB had begun to threaten this PRR resistance advance from 1998 and varieties with both PRR and AB

	resistance were then pursued more strongly in the breeding program. This project followed Project DAN467.
Objectives	• To develop breeding lines and varieties for Area 1 (Darling Downs and NE NSW) having significantly increased AB resistance (3-4 rating) combined with moderate-high PRR resistance (4-5 rating), reduced susceptibility to other diseases, high yield potential and marketable seed quality. • To develop breeding lines and varieties for Area 2 (Western Darling Downs, Maranoa, and N and CW NSW Plains) having moderate PRR resistance (4-5 rating), combined with moderate-high AB resistance (3-6 rating, depending on target district), reduced susceptibility to other diseases, high yield potential and marketable seed quality. • To develop breeding lines and varieties for Area 3 (Central Qld) combining early flowering/podding (up to 15 days earlier then Jimbour) with improved harvestability (at least equal to Jimbour) and increased yield potential (up to 10% higher yielding than Jimbour).
Activities and Outputs	• A single seed descent breeding methodology, early production of pedigree seed, and off-season seed increases were used to accelerate the development of the required resistant breeding lines. • Eighty percent of breeding resources were allocated to developing breeding lines with increased resistance to AB and PRR as well as significantly earlier maturity for Area 3, with specific lines targeted at the three northern region growing areas. • Evaluation of the new lines was conducted at a network of sites across the three target areas as defined in the objectives. Varieties developed were: Area 1: • Flipper – moderately resistant to AB • Yorker – yield increase with reduced susceptibility to AB and increased resistance to PRR Area 2: • Kyabra – high yielding (4% yield increase) and moderately resistant to PRR Promising lines were: • CICA0512 – increased AB and PRR resistance, high yielding and widely adapted to both Areas 1 and 2. • Three lines with high yield with improved harvestability and seed quality suited to Area 3. • Early cross lines (F) with improved resistance to two RLN pathogens and with resistance to both AB and PRR. • Germplasm enhancement for a number of other important characters.
Outcomes	• Three new varieties of desi chickpeas were released during the duration of this short project (Flipper, Yorker and Kyabra). • Commercialisation contracts for the three varieties were executed between NSWDPI and Seednet (formerly AWB Seeds) and DPI QLD and Seedmark (formerly Plantech). • Potential for increased area of chickpeas was evident due to higher profitability. • Prospective enhanced value of germplasm for ongoing use (compared with value at the start of the project).

Impacts	• Potential for reduced fungicide use against AB so increasing profitability of chickpeas. • Increased yield due to increased PRR resistance. • Increased yield potential and product value. • Potentially increased rotational benefits to cereals due to increased area of chickpeas.

Table A5: Logical Framework for Project DAN00094: Australian Chickpea Breeding Program

Rationale	This project continued the breeding program from Project DAN00065 under the new Pulse Breeding Australia (PBA) structure.
Objectives	• To increase the profitability of chickpea production in Australia by delivering varieties having increased yield potential and stability, improved quality and lower production costs. Specific objectives were: o To develop high yielding, AB resistant desi varieties commercialised by 2007 for release to growers in north eastern and southern/western Australia in 2009. o To develop an AB resistant, high yielding and large seeded kabuli variety commercialised by 2009 for release to growers in southern Australia in 2011. o To develop enhanced desi and kabuli chickpea germplasm with new traits or combination of traits and associated information available for breeding and/or release in the next chickpea breeding project in 2011.
Activities and Outputs	• The definitions of the target regions changed from the target areas applying in DAN00065; Region 1 was now central Qld, Region 2 was southern Qld; Region 3 was northern NSW, Region 4 was southern NSW, Victoria and South Australia and Region 5 was Western Australia. • ICARDA and ICRISAT continued to supply new breeding material Varietal releases were: Regions 2 and 3: • PBA HatTrick: released in 2009 for regions 2 and 3 and first grown in 2010 - increased resistance to AB. Regions 4 and 5: • PBA Slasher: released in 2009 for regions 4 and 5 and first grown in 2010 – increased resistance to AB. Promising lines and germplasm enhancement: • CICA0702 (PBA Pistol): increased yield potential for Region 1. • CICA0511 (PBA Boundary): increased yield potential for Regions 2 and 3. • CICA0857: kabuli type with higher grain value for Regions 4 and 5. • CICA0603 and CICA0604 as higher yielding (10%). • CICA0717 and CICA0819 have improved seed quality. • Lines with improved AB resistance, higher yield potential, harvestability and seed quality. • Early cross lines with improved resistance to two RLN pathogens and with resistance to both AB and PRR. • Germplasm enhancement for a number of other important characters.
Outcomes	• Two new varieties of desi chickpeas were released during the duration of this project (HatTrick and Slasher); both had increased resistance to AB.

	• Progress towards release of other varieties including CICA0857 (Kabuli type), PBA Pistol and PBA Boundary. • Commercialisation pipeline arrangements for new releases were executed between NSWDPI and commercial interests for desi and between VIC DPI and commercial interests for kabuli. • Potential for increased area of chickpeas due to higher profitability.
Impacts	• Reduced fungicide use against AB so reducing costs and increasing profitability of chickpeas. • Increased yield potential and product value. • Potentially increased rotational benefits to cereals due to increased area of chickpeas. • Prospective enhanced value of germplasm (cf start of project).

Table A6: Logical Framework for DAN00151: PBA Chickpea: National Breeding Program

Rationale	This project continued the breeding program from Project DAN00094 under the PBA structure.
Objectives	• To increase the profitability of chickpea production in Australia by delivering varieties having higher and more stable yield, fewer input requirements and improved seed quality. Specific objectives were: o To develop desi varieties and elite lines for the subtropical region with increased resistance to AB in a high yielding background and increased yield potential through water use efficiency. o To develop desi varieties and/or elite lines for the northern temperate region with increased resistance to AB in a PRR resistant background and increased yield potential through increased PRR and virus resistance and tolerance to salt, chilling and herbicides. o To develop kabuli varieties and/or breeding lines adapted to different regions with regard to AB resistance, high yield, medium large seed and moderately resistant to PRR for the northern temperate region only.
Activities and Outputs	Regional definitions were the same as described in Project DAN00094. Varietal releases included: Region 1: • PBA Pistol: increased yield potential (10% increase over Moti and Kyabra); improved harvestability and seed quality, released in 2011 and first grown in 2012. Regions 2 and 3: • PBA Boundary: 4% higher yield than PBA HatTrick and improved AB resistance; released in 2011 and first grown in 2012. Regions 1, 2 and 3 • PBA Seamer: improved AB resistance saving an increased number of fungicide sprays; released 2016 and first grown 2017. Regions 4 and 5: • PBA Striker: Desi type, with good adaptation in short season years in regions 4 and 5; released in September 2012. • PBA Monarch: Kabuli type with increased seed size over Genesis 090 released in 2013 and first grown in 2014. • PBA Maiden: Desi type, released in 2013 and first grown in 2014. Expected future releases were:

	• RLN Variety: Desi type, improved resistance to two RLN pathogens and with resistance to AB and PRR; applicable to regions 2 and 3, to be released in 2017; higher yield likely. In addition, potential further yield gains in the future were mooted through: • combining other traits identified in parental breeding material (e.g. salt and chilling tolerance). • a project to better understand the interaction of waterlogging and phytophthora
Outcomes	• A number of new varieties of desi and kabuli chickpeas were released during this project, including PBA Pistol, PBA Boundary, PBA Seamer, PBA Striker, PBA Monarch, and PBA Maiden. • Pipeline arrangements for these varieties with commercial interests were executed. • The releases provide further potential for an increased area of chickpeas due to higher profitability and greater confidence experienced by growers.
Impacts	• Reduced fungicide usage for controlling AB so reducing costs and increasing profitability of chickpeas. • Increased yield potential and product value; for example. significant yield gains (up to 10%) have been demonstrated for all regions. • Potentially increased rotational benefits for cereals have been experienced from the increased area of chickpeas.

Table A7: Logical Framework for Project DAN00172: Managing Crop Disease - Improving Chickpea Pathogen Resistance

Rationale	This project overlapped timewise with the previous national breeding program but focused specifically on developing varieties with improved resistance to PRR. Northern region chickpea production incurs losses from PRR. DAN00172 set out to develop chickpea varieties with improved resistance to PRR. The project was a collaborative project between NSWDPI, the University of Adelaide and DAF.
Objectives	• To reduce the impact of chickpea PRR in eastern Australia through development of varieties with improved resistance to Phytophthora medicaginis (Pm). Specific objectives were: o To identify and validate resistance to Pm in wild relatives of chickpea and their derivatives o To identify genomic regions associated with PRR resistance in mapping populations and develop breeding friendly markers for genes/regions of interest o To identify individuals from recombinant inbred line (RIL) populations with improved PRR resistance and cross into elite, locally adapted chickpea germplasm
Activities and Outputs	• Identification and validation of resistance from wild relatives of chickpeas and their derivatives was carried out. • Existing germplasm (including lines with the identified source of resistance) were assessed against Pm at different field locations; this was achieved for three populations over the period 2014-2016. • Resistance to Pm was confirmed in both field and glasshouse trials. • The required phenotyping was completed; however, alternative phenotyping methods applied did not adequately predict field performance and activity in this area is still ongoing.

	• Multiple-environment *Quantitative trait locus* (QTL) analyses have been carried out on the three populations using phenotypic data from 2014 and 2015. • This allowed loci associated with PRR resistance to be identified in the three populations. • Nine markers for genomic regions of interest have been developed, validated and used in screening two F2 populations from the 2016 crossing. • F3 populations have been sown in 2018 for phenotyping and the presence of major QTLs will be confirmed using the markers • Individual lines from the mapping populations with improved PRR resistance have been identified and then crossed into locally adapted chickpea germplasm. • Crossing of selections of superior PRR resistant genotypes commenced in September 2016. • A second season of crossing in 2017 used F2 lines from the 2016 crosses.
Outcomes	• Significant progress has been made towards the end goal of developing increased resistance to PRR in chickpea. • Potentially, new varietal releases with enhanced resistance to PRR will be developed and released at some future time.
Impacts	• Depending on the resulting extent of resistance in any new varieties released, there could be significant savings to chickpea growers, with the current cost of PRR at $8.2 million per year.

4. Project Investment

Nominal Investment

Table A8 shows the annual investment (cash and in-kind) for each of the five projects.

Table A8: Annual Investment (nominal $)

Year ending 30th June	Project	DAF	NSWDPI	GRDC	Other (a, b, c)	Total
2002	DAN467	282,479	461,201	377,990	35,000	1,156,671
2003	DAN467	300,043	467,129	385,568	36,400	1,189,140
2004	DAN467	313,774	473,718	405,471	37,856	1,230,819
2005	DAN00065	395,060	725,700	472,588	0	1,593,348
2006	DAN00065	377,350	207,165	248,456	0	832,971
2006	DAN00094	45,794	119,636	457,688	49,864	1,505,953
2007	DAN00094	97,385	248,781	971,352	102,826	1,420,344
2008	DAN00094	102,988	259,477	1,000,494	106,486	1,469,443
2009	DAN00094	109,832	269,082	1,030,507	109,762	1,519,183
2010	DAN00094	116,846	279,846	1,061,426	113,139	1,571,257
2011	DAN00094	122,033	291,031	1,103,485	116,472	1,633,021
2011	DAN00151	0	0	1,350,000	0	1,350,000
2012	DAN00151	457,797	618,239	0	433,119	1,509,245

2013	DAN00151	488,730	667,500	1,300,000	454,341	2,910,571
2014	DAN00151	509,550	720,588	1,300,000	474,507	3,004,645
2015	DAN00151	545,081	777,880	1,300,000	493,050	3,116,011
2016	DAN00151	577,012	839,736	1,300,000	458,334	3,175,082
2013	DAN00172	0	0	250,000	0	250,000
2014	DAN00172	13,516	110,100	0	29,045	152,661
2015	DAN00172	14,701	117,200	250,000	29,916	411,817
2016	DAN00172	15,658	124,800	250,000	158,389	548,847
2017	DAN00172	16,667	132,700	250,000	163,141	562,508
2018	DAN00172	17,731	141,200	250,000	167,835	576,766
Totals ($)		**4,920,027**	**8,052,709**	**15,315,025**	**3,569,482**	**31,857,224**

Sources of other funding included:

(a) DAN467 includes contribution from ICARDA

(b) DAN00094 and DAN00151 includes contributions from Victoria, South Australia and Western Australia state agencies

(c) DAN00172 includes contribution from the University of Adelaide

Program Management Costs

For the DAF and other investment (except GRDC), the management and administration costs for the project are assumed already built into the nominal $ amounts appearing in Table A8. The salary multiplier that had been used by DAF (Wayne Hall, pers. comm., 2017) was a 2.85 multiplier for salaries contributed by DAF.

For GRDC investment, a management cost multiplier (1.12) was applied to the GRDC contributions shown in Table A8. This multiplier was based on information in the GRDC Annual Report (2017).

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 $ terms using the Implicit GDP Deflator index (ABS, 2017). No additional costs of extension were included as the project already involved a high level of industry participation through Pulse Breeding Australia, Pulse Australia and the companies responsible for variety commercialisation.

5. Impacts

The principal outputs from the investment have been the development of new varieties of chickpea targeted at the different chickpea growing regions in Australia where differences in constraints to profitable production of chickpeas existed.

In summary, the principal short-term outcome from these investments is the adoption of new superior varieties being grown or expected to be grown by existing and new chickpea producers.

There are a number of impacts from the chickpea breeding investment that are being captured by chickpea growers throughout the period and sometime thereafter. These include:

Direct Chickpea Impacts

One of the principal direct profitability impacts from the new varieties produced by the breeding investment includes higher yields. Higher yields have been driven by a range of improvements including:

- resistance to lodging and improved harvestability
- reductions in crop failures due to improved resistance to disease such as PRR
- improved adaptability to regional environments and abiotic factors (e.g. soil nutrient deficiencies)

Another major impact has emanated from lowered fungicide use and costs to control AB, due to a greater resistance to the fungus from some of the new varieties. Several sprays may be avoided from some of the new varieties due to this increased resistance or lowered susceptibility.

Some impact also may be derived from improved quality of the chickpeas produced, particularly for the kabuli variety improvement. More generally seed size has increased significantly over the period covered by the breeding investment being analysed. The increase in seed size has assisted in export marketing. Also, the larger seed size may have contributed to improvement in crop establishment when deep sowing into moisture in Central Queensland.

Another impact from the breeding program has been the increase in plant height and the height to the lowest pod, both of which have improved harvestability.

Indirect Chickpea Impacts: Chickpea Area Increase and Rotational Improvements

Indirect impacts may be captured by grain growers who increase their areas of chickpeas or by new growers of chickpeas. In both cases any increased area of chickpea has been assumed not to replace other legume crops.

These indirect impacts will be captured via other crops, such as cereals, in the rotations that now include chickpeas and are likely to include increased yields of other crops in the rotation due to disease breaks, improved weed control and reduced use of nitrogen fertiliser due to the nitrogen fixation by the leguminous chickpea.

Hence, crop rotations incorporating chickpea can be more sustainable and more profitable than alternatives such as fallow or a cereal-cereal rotation in the long term.

If new, improved chickpea varieties merely replace existing varieties, the benefits to the rotation may be minimal. However, if the new varieties elicit an area increase in chickpea via greater confidence in the new varieties due to reduced risk and increased profitability, then there will be an additional impact from the increased area of chickpeas as most are grown in rotations with cereals.

Environmental Impact

The reduced use of fungicides to combat AB is evident and may lead to reduced off-farm export of chemicals to waterways. Maintaining disease breaks and controlling weeds through rotations also can lead to less chemical usage on farm. Such reduced chemical usage may benefit the farm environment and potentially lead to reduced export of chemicals to public waterways.

Social Impact

Some social impact may be derived from improved profitability and sustainability of cropping farms via the maintenance or increase of farm profitability, some of which flows to local families and businesses. Also, improved farmer well-being through reduced chemical use by farmers and any potential reduction in chemicals in the wider environment may provide positive community well-being benefits.

The increased and less variable chickpea production area, partly driven by the breeding investment, has increased infrastructure for cleaning, grading and transport of chickpea, with implications for value-added and regional employment.

Improved Genetic Capital

In the longer term the germplasm capital existing in the program at the end of the investment period (2017/18) is likely to be greater than that at the start in 2001/02. This impact can be interpreted as the germplasm in the program that will exist in 2018 having a greater future potential to produce improved varieties in the future than the germplasm existing at the beginning of the investment. A major reason for this is that essential traits across a wide range are being introduced, such as disease resistance (e.g. PRR), herbicide tolerance, and phenological traits, so that the germplasm existing in 2018 will be more responsive in future to the pursuit of a combination of traits.

Summary of Impacts

An overview of impacts in a triple bottom line categorisation is shown in Table A9.

Table A9: Categories of Impacts from the Investment

Economic	Environmental	Social
Increased profitability of chickpea via increased yields, reduced input costs of fungicides, and improved product quality Increased area of chickpeas grown on cropping farms leading to increased profits from other crops in the rotation Increase in capital value of chickpea germplasm in the program between 2002 and the end of the investment in 2018	Reduced use of chemicals in the farm environment as well as reduced chemical export to waterway environments	Increased infrastructure for cleaning, grading and transport of seed with implications for value-added and regional employment Potentially reduced chemical export to waterways resulting in positive potential impact on regional well-being Spillovers from increased farm incomes to regional communities

Public versus Private Impacts

The impacts identified from the investment are predominantly private, namely accruing to chickpea growers in most Australian chickpea growing regions. Private spillover impacts are likely to be captured by Australian cereal growers who include additional areas of chickpeas in their cropping rotations. Public benefits have been produced, these include environmental benefits from lowered chemical usage as well as spillovers to regional communities from enhanced producer incomes and increased chickpea infrastructure leading to higher regional economic activity and employment.

Impacts Accruing to other Primary Industries

Other primary industries that may benefit from the investment are restricted to cereal growers. While chickpeas are a useful source of energy and protein for livestock, their market for human consumptions usually precludes them from use as animal feeds due to price.

Distribution of Benefits along the Chickpea Supply Chain

Some of the potential benefits from more profitable production of chickpeas will be shared along the supply chain with processors, exporters and consumers. Part of any estimated gross gain achieved by chickpea growers may be returned to breeders via seed royalties or end point royalties through plant breeder's rights.

Impacts Overseas

Growers of chickpeas in overseas countries are unlikely to benefit; however, as Australia is the largest exporter of chickpeas in the world and, to the extent that demand in the rest of the world for Australian product is probably price elastic, it is possible that overseas consumers benefit to a small degree with increased Australian production.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural Research, Development and Extension (RD&E) Priorities are reproduced in Table A10. The investment in chickpea breeding is relevant to Rural RD&E Priorities 1 and 3 and to Science and Research Priority 1.

Table A10: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities[(a)] (est. 2015)	**Science and Research Priorities[(b)] (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

(a) Source: Commonwealth of Australia (2015)
(b) Source: Office of the Chief Scientist (2015)

The QLD Government's Science and Research Priorities, together with the four decision rules for investment that guide evaluation, prioritisation and decision making around future investment are reproduced in Table A11.

The investment addressed QLD Science and Research Priority 1. In terms of the guides to investment, the investment is likely to have a real future impact through improved confidence in the profitability of increased chickpea profitability. The project was well supported and funded by others external to the QLD Government and had a distinctive angle as the QLD chickpea industry will be a major recipient of the impacts.

Table A11: QLD Government Research Priorities

QLD Government	
Science and Research Priorities (est. 2015)	**Investment Decision Rule Guides (est. 2015)**
1. Delivering productivity growth 2. Growing knowledge intensive services 3. Protecting biodiversity and heritage, both marine and terrestrial 4. Cleaner and renewable energy technologies 5. Ensuring sustainability of physical and especially digital infrastructure critical for research 6. Building resilience and managing climate risk 7. Supporting the translation of health and biotechnology research 8. Improving health data management and services delivery 9. Ensuring sustainable water use and delivering quality water and water security 10. The development and application of digitally-enabled technologies.	1. Real Future Impact 2. External Commitment 3. Distinctive Angle 4. Scaling towards Critical Mass

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued in Monetary Terms

The three impacts valued in the quantitative analysis and later described in more detail were:

- Increased producer yields from new chickpea variety releases
- Decreased fungicide use due to more resistant chickpea varieties
- Cropping rotation benefits from the increased chickpea area

Impacts not Valued in Monetary Terms

The impacts identified but not valued included:

- Improved product quality
- Increase in capital value of unexploited chickpea germplasm between the beginning and end of the five projects
- Environmental benefits (on and off farm) from reduced use of fungicides and herbicides
- Increased spillovers to regional communities from sustained or increased farm incomes and additional processing, servicing infrastructure and employment.

A qualitative description of the impacts not valued and reasons for not valuing them are provided below:

Improved product quality including seed size

Only a few varieties attributable to the investment from 2002 to 2018 have improved quality, for example, a small gain in milling yield may have been delivered by variety Pistol but that variety was susceptible to AB. This impact was considered minor in comparison to the principal impacts identified.

While seed size has increased significantly due to the breeding program and has led to an increased export demand, it is difficult to estimate the demand increase without detailed analysis.

Increased germplasm capital

The net increase in germplasm capital is hard to value as existing germplasm capital keeps being exploited and reduced by varietal release. However, the value of the germplasm also keeps increasing from both introductions of new genetic material and by crossing existing material. Furthermore, there was insufficient evidence to allow valuation of such an impact within the scope of this assessment.

Improved farmer and community well-being

Reducing the chemical spraying of crops is likely to benefit the general health and well-being within farming communities. This social benefit is difficult to quantify due to the difficulty in linking the investment with any level of impact, whether on or off-farm.

Increased regional community spillovers

The availability of time and resources and the number of regions involved in chickpea production precluded this impact from valuation. Also, the increased infrastructure and economic activity and employment along the product supply chain would be difficult to value without addressing the extent of supply chain implications of any displaced land uses.

Counterfactual

It is not likely that private seed company investment in genetic improvement of Australian chickpea would have been significant in the absence of the GRDC/NSWDPI/DAF breeding program. This would have been due largely to the relatively small size of the industry, the formidable disease constraints, and long-term investment time frames required. This would have meant that there was a significant probability of generating only a low rate of return. Even if the private commercial private sector had invested, or if there had been some releases based on selections of overseas germplasm, is highly unlikely that the rate of improvement in varietal traits would have been anything like that delivered by the funding of the current five projects.

The extent to which any improvement would have been achieved is uncertain; a subjective assumption has been made in this assessment that 10% of the estimated impact from the existing five projects would have been delivered without the GRDC/NSWDPI/DAF investment.

Increased Yield of Chickpea

Estimates of the trend in chickpea yields over time vary with the start and end points of the data series used (Table A1). Figure A2 shows the upward trend in farm yields of chickpea from 2006 to 2016. This trendline covers approximately the period of the breeding investment referred to in this assessment. Based on this trendline, the yield gain is approximately 38 kg per ha per annum.

The per annum yield gain is assumed to continue up to 2020 where it is assumed to stabilise at that level until 2023. After 2023, the 2020 yield is assumed to gradually deteriorate due to increased disease pressure until, by 2030, all benefits from the breeding program investment up to 2018 are reduced to zero.

Only a proportion of the annual yield gain reflected in the ABARE farm yield data is assumed to be from genetic improvements, with other factors such as agronomic improvements and increasing grower experience with the crop, contributing a significant proportion of the gain.

The specific assumption of 40% and its source for the attribution to genetic improvement is provided in Table A12. The additional yield in any given year has been valued at the farm gate price. All assumptions are summarised in Table A12.

Impact on Rotations

The area of chickpeas has been increasing over time (see Table A1). From the year 2006 (year of first variety release from the five projects) to 2016 the area has increased at a rate of around 40,000 ha per annum (Figure A1).

There are a number of reasons for this area increase such as the new varieties, disease management improvements, other farming system improvements and relative product prices. However, it should be noted that the increase from 2006 to 2016 coincides with the release of a number of new varieties of chickpeas. It is assumed with some confidence that the new varieties played a major role in the chickpea area increase.

Without the breeding program and the release of the new varieties, it is likely that the area increase would have been less. It is conservatively estimated that the new varieties have been responsible for 40% of the increase. Further, it is assumed this area increase (approximately 40,000 ha per annum) will continue until 2023. It is assumed that the increase will gradually fall to zero in 2030, after which the releases from the breeding program investment up to 2018 will have no further impact on the area.

The proportion of chickpea crops grown in rotations has been increasing over the years and now a majority of chickpea crops are grown in rotations. Of the new area of chickpea since 2006, it is conservatively assumed 75% has been grown in rotation with cereals and the new area of chickpea has not replaced other legumes grown in rotations with cereals.

The value of introducing chickpeas in a rotation will depend on a range of factors including the existing rotation sequence, seasonal conditions, relative crop prices, and how the chickpea planting influences the benefits from the following (usually cereal) crop.

Overall it has been assumed that a cereal crop following chickpeas (e.g. wheat) will experience an average gross margin benefit predominantly from a yield increase and a reduced requirement for purchasing fertiliser nitrogen. For example, trials have shown that compared to a wheat-wheat rotation, wheat after chickpeas has been shown to produce higher yields per ha (an additional 0.6-0.7 tonnes per ha) and higher protein levels (GRDC, 2011). However, depending on price, the pulse crop may receive a lower gross margin than wheat when it replaces the first wheat crop so that a conservative estimate of $75 per ha per annum average has been attributed to the chickpea crop impact.

A summary of assumptions is presented in Table A12.

Reduced fungicide usage due to increased resistance of new varieties to AB

Some of the new varieties released from 2006 to 2016 were characterised as having increased resistance to AB, so reducing the number of fungicide sprays and the associated cost of the chemical and its application. Not all new varieties released were AB resistant, so this benefit does not apply to all of the chickpea area. One or two fungicide sprays could be avoided for some of the varieties released. A summary of assumptions is presented in Table A12.

The reduced cost of fungicides was a transparent cost saving for chickpea growers, as opposed to the relatively small yield gains which were long-term and less observable.

Table A12: Summary of Assumptions for Valuing Benefits

Variable	Assumption	Source
Counterfactual		
Estimate of proportion of each benefit delivered without the 5 projects	10%	Agtrans Research
Benefit 1: Increased yield of chickpea		
Annual chickpea yield gain from ABARES statistics	38 kg per ha from 2006 to 2016	See Figure A2
Yield gain for 2016 to 2023	Yield as of 2016	Agtrans Research
Yield gain from 2023 to 2030	Yield as of 2023 reduces to zero by 2030	Agtrans Research
Proportion of chickpea yield gain attributed to genetic improvement	40%	Agtrans Research; based on the attribution to yield of 40% in grain sorghum from genetics associated with sorghum breeding success (Cruickshank and Jordan, 2012)
Chickpea area (ha)	Actual chickpea areas from 2006 to 2016	See Table A1 and Figure A1
Annual chickpea area from 2017 to 2023 (ha)	465,030 ha	Based on ten-year average 2007 to 2016
Last year of full benefits	2023	Agtrans Research
Benefit reduction	Linear decrease 2024 to 2030 (no benefits in 2030 and thereafter)	Agtrans Research
Chickpea price delivered Brisbane Free in Store (FIS) $500 per tonne; less $20 per tonne = $480 per tonne	2009-2015	FIS Price: Pulse Australia (a) Freight: Agtrans Research estimate
Benefit 2: Impact on Rotations		
First possible year of benefits	2007	Based on year of first growing of new varieties
Increase in chickpea area 2006-2016	40,000 ha per annum	See Figure A1
Proportion of growth attributed to genetic gain	40%	Agtrans Research
Proportion of chickpea area increase not replacing	75%	Agtrans Research

existing legumes in the rotation		
Last year of full benefits	2023	Agtrans Research
Benefit reduction	Linear decrease 2024 to 2030 (no benefits in 2030 and thereafter)	Agtrans Research
Increase in gross margin in rotation due to chickpea introduction	$75 per ha	Agtrans Research based on gross margins in NSWDPI (2012)
Benefit 3: Decreased costs from reduced fungicide applications		
Number of sprays reduced for varieties with reduced susceptibility to AB	1-2 depending on variety	Project reports
Avoided cost per spray	$19 per ha	Project reports
Proportion of chickpea area where cost reduction made 2007 to 2011	10% for 1 spray (2007 to 2010)	Mainly from variety Flipper
Proportion of chickpea area where cost reduction assumed 2011 to 2023	50% for 2 sprays	Mainly from varieties HatTrick and Boundary
Last year of full benefits	2023	Agtrans Research
Benefit reduction	Linear decrease 2024 to 2030 (no benefits in 2030 and thereafter)	Agtrans Research

(a) http://www.pulseaus.com.au/storage/app/media/industry/AU-Dchickpea-pricing.pdf

7. Results

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP) (ABS, 2017). All costs and benefits were discounted to 2017/18 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2017/18) to the final year of benefits assumed. As the final year of benefits from the investment was assumed to be 2029, the investment criteria for 15 to 30 years after 2017/18 are the same.

Investment Criteria

Tables A13 and A14 show the investment criteria estimated for different periods of benefits for the total investment and the DAF investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table A14, has been estimated by multiplying the total PVB by the DAF proportion of real investment (15.1%).

Table A13: Investment Criteria for Total Investment in the Five Projects

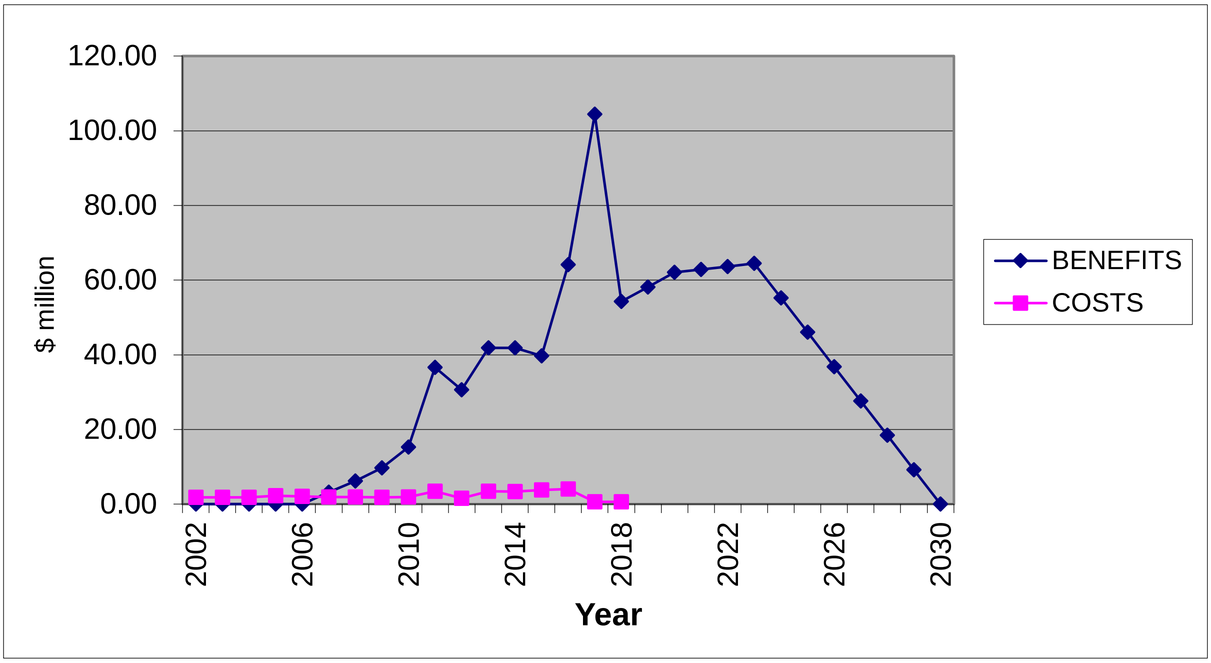
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	530.5	799.3	927.3	932.7	932.7	932.7	932.7
Present value of costs ($m)	57.2	57.2	57.2	57.2	57.2	57.2	57.2
Net present value ($m)	473.3	742.1	870.1	875.5	875.5	875.5	875.5
Benefit-cost ratio	9.3	14.0	16.2	16.3	16.3	16.3	16.3
Internal rate of return (IRR) (%)	47.7	48.3	48.4	48.4	48.4	48.4	48.4
Modified IRR (%)	negative	118.7	53.9	35.5	27.2	21.7	19.3

Table A14: Investment Criteria for DAF Investment in the Five Projects

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	80.0	120.6	139.9	140.7	140.7	140.7	140.7
Present value of costs ($m)	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Net present value ($m)	70.9	111.5	130.8	131.6	131.6	131.6	131.6
Benefit-cost ratio	8.8	13.3	15.4	15.5	15.5	15.5	15.5
Internal rate of return (IRR) (%)	40.8	41.7	41.8	41.8	41.8	41.8	41.8
Modified IRR	negative	98.9	46.7	31.3	24.2	19.5	17.4

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure A3.

Figure A3: Annual Cash Flow of Undiscounted Total Net Benefits and Total Investment Costs



Sources of Benefits

There are three sources of benefits valued in the analysis. Table A15**Error! Reference source not found.** shows the relative contributions to the PVB from each source. The contributions to the PVB are based on the proportion of each benefit in the total value of benefits. The benefit from increased yields is the largest contributor to total benefits.

Table A15: Contribution to Total Benefits from Each Source

Source of Benefits	Contribution to PVB ($m)	Share of benefits (%)
Yield gain	623.5	67%
Rotation profitability	157.1	17%
Fungicide saving	152.1	16%
Total	932.7	100%

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was 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. Table A16 presents the results that showed a differing sensitivity to the discount rate for the different investment criteria. This was largely due to a high impact of the discount rate on costs occurring in the first 16 years, but with benefits spread over the 2006 to 2029 period. As discounting was to the year of analysis (2018), the Present Value of Benefits and Net Present Value were not affected significantly by the discount rate. However, the Benefit-Cost Ratio was favoured strongly by the low discount rate.

Table A16: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	952.3	932.7	963.4
Present value of costs ($m)	38.4	57.2	87.6
Net present value ($m)	913.9	875.5	875.7
Benefit-cost ratio	24.8	16.3	11.0

A sensitivity analysis also was carried out on the counterfactual assumption that 10% of the benefits from breeding would have been delivered without the investment in the five projects (Table A17). Results show only a moderate change across the range of assumptions tested.

Table A17: Sensitivity to Counterfactual Assumption
(Total investment, 30 years)

Investment Criteria	Counterfactual Delivery		
	0%	10%	25%
Present value of benefits ($m)	1,036.3	932.7	777.2
Present value of costs ($m)	57.2	57.2	57.2
Net present value ($m)	979.1	875.5	720.0
Benefit-cost ratio	18.1	16.3	13.6

Confidence Ratings and other Findings

The results produced are highly dependent on the assumptions made, some 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 A18). 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 A18: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Medium	Medium-High

Coverage of benefits was assessed as medium. Most benefits were economic in nature and related to productivity changes such as reduced costs or yield improvements. However, some economic benefits were not valued, such as increased seed size. Also, significant environmental and social impacts were not valued. Hence, the investment criteria as provided by the valued benefits are likely to be underestimated to some degree.

Confidence in assumptions was rated as medium-high. The assumption of the average yield gain over time by chickpea producers was supported by trend yield data. The other two impacts valued were highlighted in the various final reports for the projects.

8. Conclusion

The investment in the series of five chickpea breeding projects has been critical in facilitating growth in the chickpea industry in Australia over the past 16 years, particularly in QLD and northern NSW.

During the investment period (years ending June 2002 to 2018), a number of improved chickpea varieties were released from the breeding program with high adoption levels. Improvements have varied with the variety and have included greater resistance to AB and PRR, as well as higher yield potentials, improved quality and improved harvestability.

The area of chickpeas grown in Australia has been increasing over the past decade. Some of this increase has been assumed due to the advances made in chickpea varietal performance. In turn, this new area of chickpeas has benefits in cropping rotations (fixation of nitrogen and acting as a disease break).

The benefits identified from the investment are predominantly private benefits for chickpea growers in all states, but with a strong bias to the northern region where most chickpeas are grown. Private spillover benefits are likely to be captured by cereal growers who have started growing chickpeas or have expanded their area of chickpeas. Also, there have been private benefits delivered along the product supply chain due to increased economic activity in cleaning, grading, transport and handling, and exporting.

There are likely to be some public benefits produced, some environmental in nature from lowered fungicide and pesticide chemical use with potential implications for water quality off-farm. Other public benefits have accrued with community spillovers from increased farm incomes and the generation of increased regional infrastructure and employment.

Given the assumptions made in the analysis, the cumulative yield benefits make the largest contribution to the overall benefits that were valued. However, the results show that the rotational benefits and the cost reduction from the lowered use of fungicides contributed significantly.

In summary, the total investment in the five projects of has produced a number of benefits most of which have been valued. The total investment of $57 million (present value terms) has been estimated to produce total gross benefits of $933 million (present value terms) providing a net present value of $876 million, a benefit-cost ratio of over 16 to 1 (using a 5% discount rate) and an internal rate of return of 48%.

As there were a number of impacts identified that were not valued in economic terms (e.g. increases in seed size, regional community spillovers) the investment criteria reported are likely to have undervalued the full set of benefits delivered from the investment.

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Appendix B: An Impact Assessment of DAF Investment into National Landcare Program Innovation Grant No. 041: Polybridge: Bridging a Path for Industrialisation of Polychaete-Assisted Sand Filters

Acknowledgments

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Abbreviations

BCR	Benefit-Cost Ratio
BIRC	Bribie Island Research Centre
CBA	Cost-Benefit Analysis
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
DAWR	Australian Government Department of Agriculture and Water Resources
GDP	Gross Domestic Product
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
NSW	New South Wales
PASF	Polychaete-Assisted Sand Filters
PVB	Present Value of Benefits
PVC	Present Value of Costs
QLD	Queensland
R&D	Research and Development
RD&E	Research, Development and Extension
RDC	Research and Development Corporation

Executive Summary

The Report

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in a project to bridge a path for industrialisation of polychaete-assisted sand filters in prawn farms. The project was jointly funded by DAF and the Australian Government Department of Agriculture and Water Resources from March 2014 to March 2016.

Methods

The project was first analysed qualitatively using a logical framework that included project objectives, activities and outputs, and actual and potential outcomes and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts were then valued.

Benefits were estimated for a range of time frames up to 30 years from the last year of investment in the project (2015/16). Past and future cash flows in 2016/17 dollar terms were discounted to the year 2017/18 using a discount rate of 5% to estimate the investment criteria.

The cost-benefit analysis (CBA) was conducted according to the Impact Assessment Guidelines of the Council of Rural Research and Development Corporations (CRRDC, 2014).

Impacts

The major impacts identified were of both financial/economic and environmental. Some social impacts also were identified. It is expected that the Queensland prawn farming industry will be the primary beneficiary of the investment. Some 95% of prawn farms are located in Queensland.

Investment Criteria

Total funding from all sources for the project was approximately $0.68 million (present value terms). The value of total benefits was estimated at $1.61 million (present value terms). This result generated an estimated net present value (NPV) of $0.93 million, and a benefit-cost ratio (BCR) of approximately 2.38 to 1.

1. Evaluation Methods

The evaluation approach follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations (RDCs), Cooperative Research Centres (CRCs), State Departments of Agriculture, and some Universities. This impact assessment uses Cost-Benefit Analysis (CBA) as its principal tool. The approach includes both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and potential and actual outcomes and impacts. The principal economic, environmental and social impacts are then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, or the likely low relative significance of the benefit compared to those benefits that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

Aquaculture prawn farming began in Australia in the 1980s. Approximately 95% of the industry is located in Queensland with the balance in NSW. Australia-wide there are 30 prawn farms employing 300 people. Some prawn farms have their own hatcheries. Others ‘buy-in’ their juvenile stock. Prawn farming is Queensland’s largest aquaculture sector. Most prawn farms are located on flat land adjacent to sea water courses such as tidal rivers or creeks.

Prawn farms draw the water that they use in their aquaculture operations from rivers, creeks and other coastal waterways. The majority of prawn farms hold wastewater in settlement ponds to help reduce suspended solids and nutrient content before being discharged back into the environment.

Discharge licensing in Queensland has been a progressive process over the last 30 years. Only once (in 2005[1]) have regulators and industry come together to agree on consistent limits. Most farms are now operating on previously established licences, and licensing for new farms is more restrictive. In recent years, those farms that have expanded their existing operations have needed to make these developments without overall increases in nutrient discharge from the farm. Environmental off-sets may also be part of new licence conditions, but these are arranged on a case-by-case basis.

Industry production has nevertheless continued to grow over the last decade and this growth has come from efficiencies and production intensifications. However, as farm production methods have intensified, greater pressures have been placed on existing water treatment infrastructures, and farms have begun to find it more difficult to adhere to their licence

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[1] Operational policy, Environmental Protection Agency, Marine prawn aquaculture - Licensing wastewater releases from existing marine prawn farms in Queensland, Approved 04/03 Version 1. 0 Review date 04/05.

conditions. Furthermore, challenges other than nutrient discharge have recently emerged. White spot disease has devastated the production of several prawn farms in southern Queensland in the last two years, and this has the effect of overlaying an additional biosecurity imperative for future water treatment mechanisms.

With an eye to the future of the prawn and fish farming industries, DAF is presently engaged in the identification of suitable new land for aquaculture development. At this stage DAF has identified 9,000 ha with development potential. However, it can be anticipated that investors will look towards potential solutions to nutrient and biosecurity issues facing the industry before committing to the development of new prawn and fish farms.

Consequently, remediation and reuse of prawn farm wastewater holds many potential benefits. On-farm water treatment and recirculation provide positive control of the most important element in an aquaculture operation: the water supply. With 100% reticulation, water and nutrient discharge during the growing season can be minimised and reliance reduced on natural waterways to supply water. In some places – for example, where water quality may be poor during or following heavy rainfall – water reticulation can offer much better surety of supply and quality than adjacent rivers and waterways. For biosecurity, water reticulation can provide better protection from endemic diseases by greatly reducing transmission risk for key vectors.

In Australia, large-scale settlement ponds have provided water treatment services for prawn farms for many years. More than 30% of farm ponded area is often committed to settlement ponds and whilst this generally takes the place of otherwise productive pondage, farmers opt for this approach to nutrient mitigation because it is both technically feasible and accepted best practice.

Alternative aquaculture treatment methods that use lower farm footprints and potentially create valuable commodities from waste nutrients have recently been developed e.g. sand beds and algal/seaweed bio-reactors (MBD Energy, 2015). This project (INNOV 041) was concerned with the further development, demonstration and take up of a technology based on sand beds and the use of sandworms to filter prawn farm wastewater - Polychaete-Assisted Sand Filters (PASF).

Rationale for the Investment

PASF involves the construction of sand beds 'downstream' of the prawn ponds. Wastewater that is treated by the PASF can either be discharged or recirculated. Sand beds are stocked on a yearly basis with juveniles of a species of Moreton Bay sandworm (a species of polychaete). Much of the waste nutrients excreted by prawns is converted in the prawn ponds into small algae and plankton. Wastewater containing small algae and plankton is removed from the prawn ponds and flooded over the sand beds where it is trapped and consumed by the sandworms. This process of sandworms feeding on the surface of the sand keeps the sand bed clean and functional.

Prawn production is seasonal and at the end of the production season sandworms can be harvested and sold. Sandworms are of value as both bait for use by recreational fishers and as a feed for prawn farm broodstock. Instead of bringing worms into the prawn farm that have been harvested from the wild and with the potential to carry disease, prawn farmers are able to harvest their own worms and know that they are disease free. PASF are a way of treating prawn farm wastewater and using the sandworms in the prawn breeding program to offset the cost of wastewater treatment.

DAF have been developing the PASF system of prawn farm wastewater management at the Bribie Island Research Centre (BIRC) in south-east Queensland since this approach first showed promise in 2005. This project made use of a newly constructed PASF facility at the BIRC.

3. Project Details

Summary

Project Title: INNOV 041 Polybridge – Bridging a Path for Industrialisation of Polychaete-Assisted Sand Filters Research Organisation: Department of Agriculture and Fisheries, Queensland Principal Investigator: Paul Palmer Period of Funding: March 2014 to March 2016

Objectives

The objectives of the project were:

1) To further develop a prawn farm wastewater treatment method based on PASF.
2) To demonstrate the method to industry and regulators.
3) To have the method taken up by industry and have industry improve its environmental performance and create sustainable supplies of sandworms.

Logical Framework

Table B1 provides a description of the project in a logical framework developed for the project.

Table B1: Logical Framework for Project INNOV 041

Activities and Outputs	• Prior to commencement, a project steering committee consisting of researchers, regulators and commercial interests was established, a Monitoring, Evaluation, Reporting and Improvement Plan was prepared, and a Communication Strategy was developed. • In early 2014 a reticulated wastewater system was set up to receive wastewater from two commercial-density prawn ponds through a ten bed PASF at BIRC. The system had two sand-bed depths with five replicates. Fortnightly water samples were taken to assess suspended solids, chlorophyll, total nitrogen and total phosphorus. • Operation of the PASF resulted in low levels of sludge production in the prawn ponds. No wastewater was discharged to waterways during prawn culture. However, final harvest resulted in release of some nitrogen and phosphorus to the marine environment, with nutrient release levels between one third and one half the levels permitted under many prawn farm licenses. Zero net nutrition discharge was not achieved but nutrient levels released were the lowest so far reported in the literature. • Prawns from the two commercial ponds were harvested in April 2014 and sold to cover the additional costs of prawn pond operation. Sandworms were harvested in July 2014 and supplied to both the live

	bait and broodstock feed markets. Sandworms were well received in the live bait market. Two leading prawn hatcheries were supplied with 100kg of PASF sandworms and each provided favourable appraisals of their suitability for prawn broodstock. Additional experimental work in collaboration with CSIRO confirmed hatchery appraisal of sandworm suitability for prawn broodstock. • Prawn production, sand bed filtration using PASF, sale of prawns and sale of sandworms were repeated in 2015. • Refinements of the technology developed during the project included use of a coarser geotextile membrane to improve sand bed percolation rates, reduce blockages and ensure that more sand beds remained functional for longer. The project successfully tested higher prawn stocking rates which in turn led to additional interest in the project by prawn farmers. The project also successfully tested lower sandworm stocking rates that created larger sized sandworms and more interest in the product from the bait industry. • Two PASF demonstration days were held in both 2014 and 2015 (a total of four events) – attendees included commercial prawn and barramundi farmers, industry regulators, funding body representatives and researchers. • Media releases were used to publicise the research and the sustainability benefits of the PASF wastewater treatment method. • Publications brought the method to the attention of industry and water quality professionals. Scientific publications included an assessment of the favourable nutritional value of PASF worms (Palmer et al 2014) and two publications on the technology's wastewater remediation potential (Palmer et al 2016; 2018). • The final project report included appendices that addressed PASF construction and operation costs; the usefulness of sandworms in a prawn diet; the reproductive performance of broodstock produced using PASF grown sandworms and the nutrient value to prawns of biofilm produced by the PASF.
Outcomes	• Further development of a prawn farm wastewater treatment method based on sandworm assisted sand filters using commercial stocking rates which in turn peaked prawn farmer interest in the project. • An increase in aquaculture entity knowledge and skills with respect to the use of sandworm assisted sand filters. • The project introduced the concept of sandworm assisted sand filters to 38 aquaculture industry representatives, 9 recreational fishing representatives, 37 scientists, 408 students, 43 water quality professionals, and 42 high level government policy makers. • As of March 2018, there has been no commercial adoption of the technology and industrialisation of the system is as yet untested. The research was completed using commercial prawn farm stocking rates, but findings have not been tested in an 'industrial' setting i.e. on a commercial prawn farm. Further demonstration and extension is required to convince prawn farmers of the merits of PASF.
Impacts	• Potential additional income stream for prawn farmers from the sale of sandworms grown in a PASF system. Sandworms are suitable for sale to both the live bait and broodstock feed markets. • Potential additional prawn production from conversion of existing settlement pond area into additional prawn production ponds. Settlement ponds require six times the room required for an equivalent PASF system.

	• Potential intensification of existing prawn production ponds. PASF offer improved nutrient removal which will allow farms to increase their prawn productivity (more prawns per pond) without increasing their nutrient discharges. • Potential added capital and operating costs for prawn farms associated with PASF adoption, sandworm and additional prawn production. • Potential improved hatchery productivity on prawn farms that also raise their own juvenile stock. In addition to saved hatchery costs from farm grown sandworms, hatchery operations will benefit from inclusion of additional sandworms in the diet of farm broodstock with resultant increases in reproduction rates and juvenile prawn performance. Not all prawn farms operate hatcheries. • The potential for improved prawn farm and hatchery biosecurity. Using feeds sourced from inside the farming system removes a major biosecurity risk that could affect long-term industry viability. • Prawn farm biosecurity impact – reticulation of the prawn farm water supply reduces the need to source water from coastal creeks and estuaries contaminated with White spot disease. White spot disease can cause the loss of a whole prawn farm crop. • Potential facilitation of prawn domestication. Improved hatchery performance will encourage the closing of the prawn breeding and farming cycle and reduce the need to source wild broodstock. Domesticated prawns permit genetic improvement through selective breeding and the creation of disease free status. • Potential environmental gains including the lessening of the need to source sandworms from the wild population and avoidance of associated habitat disturbances. Successful PASF operation will also reduce nutrient outfall into sensitive natural habitats including the Great Barrier Reef. • Potential for economic gains in other land-based aquaculture industries including barramundi production which also uses brackish-water ponds. • Potential for economic gains in overseas aquaculture industries where prawn farming is a major industry and where sandworms may create an additional income stream. Sandworms are needed to feed prawns in hatcheries in Asia. They are also widely consumed by humans in Asia and the Pacific. Project findings are publically available and there are no current plans to pursue commercialisation of the Intellectual Property created.

4. Project Investment

Nominal Investment

Table B2 shows the annual investment (cash and in-kind) for the project funded by DAF and the Australian Government.

Table B2: Annual Investment in Project INNOV 041 (nominal $)

Contributor	2013/14	2014/15	2015/16	Totals
DAF – cash ($)	0	60,000	0	60,000
DAF – in kind ($)	65,344	65,344	65,344	196,032
Aust Government ($)	83,040	125,860	70,500	279,400
Totals ($)	**148,384**	**251,204**	**135,844**	**535,432**

Source: Project documentation (including the signed funding deed and the signed final financial report.

Program Management Costs

For the DAF investment, the management and administration costs for the project are already built into the nominal $ amounts appearing in Table B2**Error! Reference source not found.**. A salary multiplier of 2.85 was used (Wayne Hall, pers. comm., 2017).

For Australian Government investment, the cost of managing the National Landcare Program Innovation Grant was added to the Australian Government contribution via a management cost multiplier (1.1086); this was estimated based on the average reported share of ‘employee benefits’ & ‘supplier’ expenses in total Department of Agriculture and Water Resources (DAWR) expenditure for 2015/16 (DAWR, 2017).

Real Investment, Commercialisation and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 $ terms using the Implicit GDP Deflator index (ABS, 2016).

The research was completed using commercial prawn farm stocking rates, but findings have not been tested in an ‘industrial’ setting i.e. on a commercial prawn farm. Further demonstration and extension is required to convince prawn farmers of the merits of PASF followed by a pilot project on a commercial prawn farm to further ‘fine tune’ the PASF technology and provide an additional platform for adoption. Following discussions with the Principal Investigator the analyst has estimated these costs at $25,000 per annum for two years with investment occurring in 2018/19 and 2019/20 for extension followed by a further $75,000 per annum for two years in 2020/21 and 2021/22 to test the technology on a commercial prawn farm.

5. Impacts

The principal potential impacts from the positive results exhibited by the project from adoption of PASF systems on prawn farms include:

- An additional income stream for prawn farmers from the sale of sandworms.
- Additional prawn production from conversion of existing settlement pond area into additional prawn production ponds.

Table B3 provides a summary of the types of impacts categorised into economic, environmental and social impacts.

Table B3: Triple Bottom Line Categories of Potential Impacts from Project INNOV 041

Economic	• Prawn farmer income from sale of sandworms grown with PASF technology. • Additional prawn production from land previously occupied by settlement ponds. • Additional prawn production from intensification of existing prawn ponds. • Improved hatchery productivity with lower production costs and additional juvenile prawn production. • Improved prawn farm biosecurity when water is no longer sourced externally. • Improved prawn farm biosecurity with less need to source an external water supply potentially contaminated with white spot disease. • Improved hatchery biosecurity when a principal feed ingredient (sandworms) is no longer sourced externally. • Encouragement of prawn domestication with scope for increased selective breeding. • Loss of income from existing sand worm producers
Environmental	• Reduced need to source sandworms from the wild and avoidance of associated habitat disturbances. • Reduced nutrient export into sensitive habitats including the Great Barrier Reef.
Social	• Spill-over benefits in terms of regional community well-being, including regional employment, from increased prawn farmer profitability and/or productivity.

Public versus Private Impacts

Most potential impacts identified in this evaluation are industry related and therefore the benefits are considered private benefits. Some public benefits may be delivered in the future, including the environmental benefits of reduced pressure on wild sandworm stocks and reduced nutrient outfall into sensitive habitats. Social benefits in the form of community spill-overs are also possible.

Distribution of Private Impacts

The primary beneficiaries of the incorporation of PASF technology on a prawn farm are Australian prawn farmers, most of which are located in Queensland.

It can be assumed that the distribution of the benefits from the project findings will be distributed between participants along the commercial supply chains, including final consumers.

Impacts on other Australian industries

It is likely that impacts from the project will be relevant to other land-based aquaculture industries including barramundi production where practiced in brackish waters.

Impacts Overseas

It is likely that PASF technology will be relevant to overseas land-based aquaculture industries. Prawn farming is a major source of protein in Asia and Asian producers need large quantities of worm biomass to service their prawn hatchery needs. Sandworms are also widely consumed by humans in both Asia and the Pacific.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural Research, Development and Extension (RD&E) priorities are reproduced in Table B4. The incorporation of PASF technology on a prawn farm contributes primarily to Rural RD&E Priority 3 and to Science and Research Priorities 1 and 2.

Table B4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities[a] (est. 2015)	**Science and Research Priorities[b] (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

(a) Source: Commonwealth of Australia (2015)
(b) Source: Office of the Chief Scientist (2015)

The Queensland Government's Science and Research Priorities, together with the four decision rules for investment that guide evaluation, prioritisation and decision making around future investment are reproduced in Table B5.

Project INNOV 041 addressed Queensland Science and Research Priorities 1 and 9 (Table B5). In terms of the guides to investment, the project is likely to scale towards critical mass for industrialisation of PASF on prawn farms. The project was supported and funded by others external to the Queensland Government and had a distinctive angle as the Queensland prawn farming industry will be the primary recipient of the impacts.

Table B5: Queensland Government Research Priorities

Queensland Government	
Science and Research Priorities (est. 2015)	**Investment Decision Rule Guides (est. 2015)**
1. Delivering productivity growth 2. Growing knowledge intensive services 3. Protecting biodiversity and heritage, both marine and terrestrial 4. Cleaner and renewable energy technologies 5. Ensuring sustainability of physical and especially digital infrastructure critical for research	1. Real Future Impact 2. External Commitment 3. Distinctive Angle 4. Scaling towards Critical Mass

6. Building resilience and managing climate risk 7. Supporting the translation of health and biotechnology research 8. Improving health data management and services delivery 9. Ensuring sustainable water use and delivering quality water and water security 10. The development and application of digitally-enabled technologies.	

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken on the discount rate as well as for the prospective number of prawn farms adopting the technology and farmer profit on sale of sandworms.

An economic decision tool for application of a PASF to a prawn farm was developed and tested as part of the project Technical Report (Palmer et al 2016). The decision tool identified a number of potential prawn farm benefits from PASF adoption. Two potential impacts were identified as paramount; they were additional prawn farmer income from sale of sandworms and additional prawn production from land previously occupied by settlement ponds. These two potential impacts were valued in this analysis.

Impacts Not Valued

Not all impacts identified in Table B3 could be valued in the assessment.

The economic impacts identified but not valued included:

- Additional prawn production from intensification of existing prawn ponds.
- Improved hatchery productivity with lower production costs and additional juvenile prawn production.
- Improved prawn farm biosecurity when water is no longer sourced externally – less risk of white spot disease.
- Improved hatchery biosecurity when a principal feed ingredient (sandworms) is no longer sourced externally.
- Encouragement of prawn domestication with scope for selective breeding.
- Loss of income by existing sandworm producers.

The above economic impacts were not valued due to an absence of information on what the change in the production system might be e.g. what is the safe increase in pond intensification with a PASF? What is the reduction in the risk of white spot disease with partial replacement of creek sourced farm water?

The potential environmental impacts identified but not valued were the lessening of sandworm wild harvest and associated habitat disturbances and reduced nutrient export into sensitive habitats. These benefits were not valued due to lack of both baseline and marginal impact data.

The social impact identified but not valued was improved community well-being trough spill-over benefits from increasing prawn farmer profitability and/or productivity. This social benefit was not valued due to a lack of time and resources and the greater uncertainty of assumptions required in estimating such secondary impacts.

Valuation of Benefit 1: Prawn Farmer Income from Sale of PASF Grown Sandworms

The PASF technology treats prawn farm wastewater by flooding sand beds stocked with juvenile sandworms. The sandworms consume waste nutrients and are harvested and sold at the end of the prawn production season. To quantify additional prawn farmer income from sale of PASF grown sandworms a representative Australian prawn farm was modelled. The prawn farm had a total productive area of 10 ha and required 1.5 ha of PASF beds. A PASF bed of 1.5 ha is capable of growing 12 tonnes of sandworms in a single prawn production season (Johnston 2016).

Quantification of benefits assumes that harvested sandworms are sold to a combination of markets rather than retained on farm. Small worms (<0.6 g) are mainly sold as frozen product and large worms (>0.6 g) are mainly sold into live markets. The profit on sale of sandworms is sensitivity tested in this analysis to account for the potential depression of market prices that could be caused by dumping large amounts of new product on existing markets. In practice, it is expected that prawn farms would internalise the use of some of their own farm-reared worms, thereby replacing all of those that would otherwise have been purchased from other sources by the business, and then selling surpluses in ways that best maintain existing price structures (Johnston 2016).

The cost of worm production using PASF was estimated for both capital and operating costs. Major cost items included purchase of juvenile sandworms, labour and the cost of capital equipment.

A summary of assumptions for benefit 1 is provided in Table B6.

Valuation of Benefit 2: Additional Prawn Production from Land Previously Occupied by Settlement Ponds

Switching from settlement ponds to use of PASF frees up farm land for additional prawn production. To quantify the increase in farmer income from sale of additional prawns a representative Australian prawn farm of 10 ha was modelled. A 10 ha prawn farm will usually have 3 ha of wastewater treatment area. With use of PASF 50% less wastewater treatment area is required, and an additional 1.5 ha of settlement pond would then be available for prawn production. Settlement ponds are able to be converted to prawn production without incurring additional cost. Australian prawn farms average annual production of 10 t/ha and the increase in prawn production area will yield an additional 15 tonne of prawns per year (Johnston 2016).

Prawns are sold at an assumed price of $13/kg. Production costs are estimated at $10/kg (Johnston 2016).

A summary of assumptions for benefit 2 is provided in Table B6.

Counterfactual

PASF is a novel technology that was not under consideration as an alternative to settlement ponds in Australia or overseas. In the absence of DAF investment, the technology would not have been developed. However, it is likely that within ten years of adoption another technology will have emerged to manage prawn farm wastewater. In March 2018 prawn farmers are actively searching for an alternative to PASF indicating it may be only a partial solution (not all nutrients are removed from the wastewater) and income diversification into sandworm farming has limited appeal (Paul Palmer, pers. comm., March 2018).

Attribution

Prior DAF investment has contributed to quantified project benefits. DAF research on PASF started in 2005 and the BIRC PASF facility was funded and constructed prior to the commencement of this project.

Extension

It is assumed that 'industrialisation' of the technology requires further communication of the benefits to prawn farmers and a pilot project on a commercial prawn farm. These costs are recognised and included in the analysis.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table B6.

Table B6: Summary of Assumptions

Variable	Assumption	Source
General assumptions applying to both benefits 1 and 2		
Number of Australian prawn farms.	30 farms	Australian Prawn Farmers Association website accessed March 2018 and Paul Palmer, interview with My Sunshine Coast News, April 2015.
Number of prawn farms likely to adopt PASF.	3	Consultant estimate and subject to sensitivity testing. Low number assumed given technology is not yet proven at an 'industrial scale'.
Total productive area of a commercial prawn farm (including wastewater treatment area).	10 ha (100,000 m^2)	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Probability of output	100%	Consultant assumption based on review of project reports
Probability of usage	75%	Consultant assumption based on review of project reports
Probability of impact	75%	Consultant assumption based on review of project reports
Year of first impact	2023	Consultant estimate based on the assumption that time is required to both convince industry and deliver a pilot project of commercial scale.
Year when maximum impact first reached	2025	Consultant assumption.

Year in which PASF is replaced by an alternative technology	2032	Consultant assumption.
Attribution of impacts to this project	40%	Consultant assumption after considering that DAF research on PASF started in 2005 and that the BIRC PASF facility was funded and constructed prior to the commencement of this project.
Benefit 1: Additional income from sale of sandworms		
Area of PASF beds for a commercial 10 ha prawn farm.	1.5 ha	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Annual sandworm production from 1.5 ha of PASF beds	12,000 kg (448/3,765 m^2 X 100,000 m^2 = 11,899 kg)	BIRC produced 448 kg of sandworms from a farm with a total productive area of 3,765 m^2. Estimate for a 10 ha (100,000 m^2) farm derived via a simple pro rata.
Price of sandworms	$180/kg	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Cost of sandworm production (capital and operating)	$135.2/kg	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Benefit 2: Additional prawn production from land previously occupied by settlement ponds		
Productive prawn farm area prior to PASF.	7 ha	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Increase in access to wastewater treatment area for prawn production due to PASF.	50%	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Increase in access to wastewater treatment area for prawn production due to PASF.	1.5 ha (50% of 3 ha of current wastewater area)	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Prawn farm production.	10 t/ha	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Increase in harvest on the farm.	15 t	1.5 ha of additional production area X 10 t/ha production.
Price of prawns	$13/kg	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).
Cost of prawn production	$10/kg	Representative prawn farm modelled in 'PASF for Prawn Farms: Economic Decision Tool' (Johnston 2016).

7. Results

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP). All benefits after 2016/17 were expressed in 2016/17 dollar terms. All costs and benefits were discounted to 2016/17 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2015/16) to the final year of benefits assumed.

Investment Criteria

Tables B7, B8 and B9 show the investment criteria estimated for different periods of benefits for the total investment, the DAF and Australian Government investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table B8, has been estimated by multiplying the total PVB by the DAF proportion of real investment (45.3%).

Table B7: Investment Criteria for Total Investment in Project INNOV 041

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	-0.11	0.67	1.61	1.61	1.61	1.61
Present value of costs ($m)	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Net present value ($m)	-0.68	-0.79	-0.01	0.93	0.93	0.93	0.93
Benefit-cost ratio	0.00	-0.16	0.99	2.38	2.38	2.38	2.38
Internal rate of return (IRR) (%)	negative	negative	4.9	12.6	12.6	12.6	12.6
Modified IRR (%)	negative	negative	7.3	10.0	8.8	8.0	7.5

Table B8: Investment Criteria for DAF Investment in Project INNOV 041

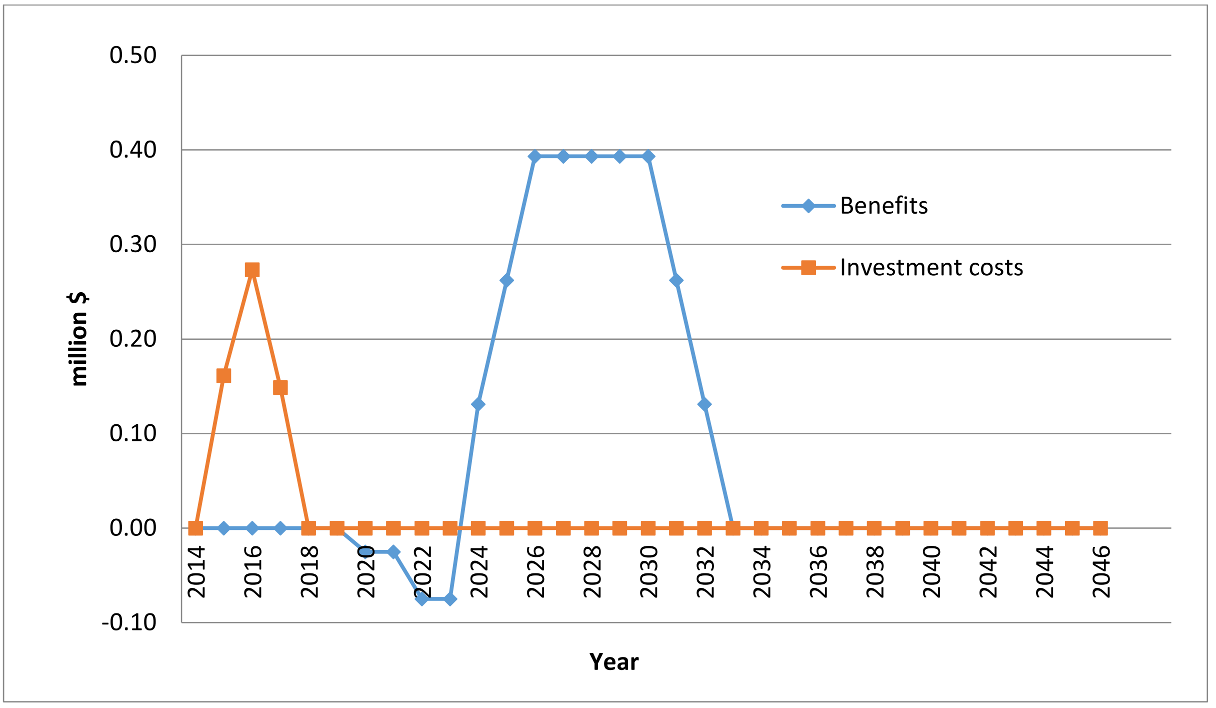
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	-0.05	0.30	0.73	0.73	0.73	0.73
Present value of costs ($m)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Net present value ($m)	-0.31	-0.36	0.00	0.42	0.42	0.42	0.42
Benefit-cost ratio	0.00	-0.16	0.99	2.38	2.38	2.38	2.38
Internal rate of return (IRR) (%)	negative	negative	4.9	12.6	12.6	12.6	12.6
Modified IRR (%)	negative	negative	7.3	10.0	8.8	8.0	7.5

Table B9: Investment Criteria for Australian Government Investment in Project INNOV 041

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	-0.06	0.37	0.88	0.88	0.88	0.88
Present value of costs ($m)	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Net present value ($m)	-0.37	-0.43	0.00	0.51	0.51	0.51	0.51
Benefit-cost ratio	0.00	-0.16	0.99	2.38	2.38	2.38	2.38
Internal rate of return (IRR) (%)	negative	negative	4.9	12.6	12.6	12.6	12.6
Modified IRR (%)	negative	negative	7.3	10.0	8.8	8.0	7.5

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure B1. Extension and commercial development costs have been subtracted from benefits rather than included as R&D investment costs, in line with CRRDC guidelines.

Figure B1: Annual Cash Flow of Undiscounted Total Benefits and Total Investment Costs



Sources of Benefits

There are two sources of benefits valued in the analysis. Table B10 shows the relative contributions to the benefits from each source. As the additional costs required to achieve the benefits (i.e. further extension and investment in a pilot project) could not be apportioned between the two benefits, the contributions to the PVB are based on the proportion of each benefit from the total gross benefits (undiscounted). The benefit of additional income from sale of sandworms is the largest contributor to total benefits by a significant margin.

Table B10: Contribution to Total Undiscounted Benefits from Each Source

Source of Benefits	Contribution ($m)	Share of benefits (%)
Additional income from sale of sandworms (Benefit 1)	2.54	92.4
Additional prawn production from land previously occupied by settlement ponds (Benefit 2)	0.21	7.6
Total	**2.75**	**100.0**

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was 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.

Table B11 presents the results. The results showed some sensitivity to an increasing discount rate, largely due to the delay in realising benefits after the investment.

Table B11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	2.55	1.61	1.04
Present value of costs ($m)	0.58	0.68	0.78
Net present value ($m)	1.97	0.93	0.26
Benefit-cost ratio	4.38	2.38	1.34

A sensitivity analysis was also carried out on the level of adoption. Table B12 presents the results. Two or more prawn farms of average size are needed to build PASFs if investment in the project is to breakeven.

Table B12: Sensitivity to Assumed Level of Adoption
(Total investment, 30 years)

Investment Criteria	Maximum level of adoption		
	A single farm	3 farms (base)	6 farms
Present value of benefits ($m)	0.59	1.61	3.03
Present value of costs ($m)	0.68	0.68	0.68
Net present value ($m)	-0.08	0.93	2.35
Benefit-cost ratio	0.88	2.38	4.47

Finally, a sensitivity analysis was carried out on the profitability of sandworm production for benefit 1, as benefit 1 contributed approximately 92% of the total value of undiscounted benefits. Table B13 presents the results. The results showed a high level of sensitivity to the average profit assumed for sandworm production. Nevertheless, halving the net return from sandworms still results in a positive return from project investment. This is important as, while a conservative sale price has been used, price falls are likely in the future as the supply of sandworms increases.

Table B13: Sensitivity to Estimated Average Profit on Sandworm Sales
(Total investment, 30 years)

Investment Criteria	Average Net Return		
	$22.40/kg	$44.8/kg (base)	$89.60/kg
Present value of benefits ($m)	0.79	1.61	3.26
Present value of costs ($m)	0.68	0.68	0.68
Net present value ($m)	0.11	0.93	2.58
Benefit-cost ratio	1.16	2.38	4.82

Confidence Ratings and other Findings

The results produced are highly dependent on the assumptions made, some 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 B14). 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 B14: Confidence in Analysis of Project

Coverage of Benefits	**Confidence in Assumptions**
Medium	Medium

Coverage of benefits was assessed as medium. While the most important economic benefits were quantified, biosecurity and environmental benefits, the principal drivers for the research, were not valued. Consequently, the investment criteria as provided by the valued benefits are likely to be underestimated to some degree.

Confidence in assumptions was rated as medium. While data for this analysis were drawn mainly from Johnston 2016, a comprehensive decision support model for the project and these data were checked and updated with the Principal Investigator, there remains a measure of uncertainty about some of the estimates.

8. Conclusions

The investment in project INNOV 041 has further developed a new technology for treatment of prawn farm wastewater that, under experimental conditions, has been shown to deliver improved water quality, reduce emissions to the environment and generate a second income stream (sandworms) for prawn farmers. PASF technology also has the potential to 'free up' land on prawn farms that is currently used for settlement ponds and make this area available for additional prawn production.

The research also offers a way of avoiding the need to source water supply for ponds and wild sandworms from the environment. This offers both positive environmental impacts and improved prawn farm biosecurity. Improved farm biosecurity is particularly critical given the emergence of white spot disease in Queensland. Once adopted, research findings will generate benefits to the Australian prawn farming industry which is mainly located in Queensland.

Given the counterfactual scenario assumed, total funding from all sources for the project was approximately $0.68 million (present value terms) after attribution to earlier investment. The value of total benefits was estimated at $1.61 million (present value terms). This result generated an estimated net present value (NPV) of $0.93 million, a benefit-cost ratio (BCR) of 2.38 to 1, an internal rate of return of 12.6% and a modified internal rate of return of 7.5%.

Sensitivity analyses carried out on key variables used in the valuation of impacts indicate that even if only two prawn farms adopt PASFs in the future or if profit from sale of sandworms halves, investment criteria for the project still remain positive. Results remained positive for the higher (10%) discount rate.

The analysis has demonstrated the contribution of ongoing investment in a technology that has both environmental and biosecurity implications for Queensland industry, as well as the potential to increase returns on Queensland prawn farms.

References

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Appendix C: An Impact Assessment of DAF Investment into Horticulture Australia Limited project MG 13016: Improving Consumer Appeal of Honey Gold Mango by Reducing Under Skin Browning and Red Lenticel

Acknowledgments

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Abbreviations

AMIA	Australian Mango Industry Association
BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
GDP	Gross Domestic Product
HAL	Horticulture Australia Limited (now Horticulture Innovation)
IRR	Internal Rate of Return
MeJA	methyl jasmonate
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
NSW	New South Wales
NT	Northern Territory
PVB	Present Value of Benefits
PVC	Present Value of Costs
QLD	Queensland
R&D	Research and Development
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
USB	Under Skin Browning

Executive Summary

The Report

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in a project to improve the consumer appeal of the Honey Gold mango variety by reducing under skin browning and red lenticel. The project was jointly funded by DAF, Piñata Farms and the Australian Government via Horticulture Innovation Australia from March 2014 to May 2017.

Methods

The project was first analysed qualitatively using a logical framework that included project objectives, activities and outputs, and actual and potential outcomes and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts were then valued.

Benefits were estimated for a range of time frames up to 30 years from the last year of investment in the project (2016/17). Past and future cash flows in 2016/17 dollar terms were discounted to the year 2017/18 using a discount rate of 5% to estimate the investment criteria.

The cost-benefit analysis (CBA) was conducted according to the Impact Assessment Guidelines of the Council of Rural Research and Development Corporations (CRRDC, 2014).

Impacts

The major impacts identified were of a financial/economic nature. However, some social impacts were identified also but not valued. It is expected that Honey Gold mango growers in Queensland and the Northern Territory will be the major beneficiaries. Benefits focus on solutions for under skin browning, rather than control of red lenticel. Under skin browning is particularly problematic when Honey Gold mangoes are grown in high day temperature environments primarily in the Northern Territory.

Investment Criteria

Total funding from all sources for the project was approximately $3.15 million (present value terms). The value of total benefits was estimated at $21.03 million (present value terms). This result generated an estimated net present value (NPV) of $17.88 million, and a benefit-cost ratio (BCR) of approximately 6.7 to 1.

1. Evaluation Methods

The evaluation approach follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations (RDCs), Cooperative Research Centres (CRCs), State Departments of Agriculture, and some Universities. This impact assessment uses Cost-Benefit Analysis (CBA) as its principal tool. The approach includes both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and potential and actual outcomes and impacts. The principal economic, environmental and social impacts are then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, or the likely low relative significance of the impact compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

Mangoes are a tropical and subtropical crop grown predominantly in Queensland (QLD) and the Northern Territory (NT). In 2016/17 gross value of production measured at farm gate was $195.7 million. Dominant mango varieties include Kensington Pride, Calypso, R2E2 and Honey Gold (Horticulture Innovation Australia, 2018).

The Honey Gold mango cultivar is being exclusively developed by Piñata Farms for domestic and export markets. Piñata Farms own the variety's Plant Breeders Rights and licence growers to grow the variety on their behalf. Honey Gold has attractive colour, matures later than dominant variety Kensington Pride and possesses good flavour, ripe skin colour and extended shelf life. Market demand is strong. Honey Gold is grown by around 36 businesses across tropical and subtropical environments and accounts for 8% of the total Australian mango crop.

Two previous projects jointly funded by Piñata Farms and DAF (MG 06022, MG 10009) have addressed inconsistent/poor Honey Gold flowering in tropical environments, excessive fruit drop following fruit set, crop forecasting and improving the percentage of fruit of premium grade.

Rationale for the Current Investment

A fruit disorder called under skin browning (USB) first became apparent in Honey Gold around 2003. USB does not affect the eating quality of the mango but gives the fruit a bruised appearance reducing its consumer appeal. USB is more prevalent in Honey Gold than other mango varieties. USB's presence in packed mangoes is not evident until the fruit reaches market. Severely affected fruit cannot be sold on the fresh market. Other fruit must be downgraded and repacking costs are incurred with a loss of confidence and grower/cultivar reputation. USB is particularly problematic in tropical production areas – including Katherine and Darwin and to a lesser extent Mareeba.

Between 2006 and 2011 all NT consignments of Honey Gold had to be repacked at market. Typically, 24% of premium fruit were downgraded in 2011 with a direct cost of $600,000.

Research completed as part of MG 06022 suggested that avoiding damage during transport will reduce USB. Research completed as part of MG 10009 confirmed MS 06022 findings and identified that:

- fruit damage during harvest might also be a factor,
- harvesting early in the morning may reduce USB,
- USB may be associated with low storage temperatures, and that
- there appeared to be differences in USB impact between neighbouring farms.

The lenticel is the porous tissue on the mango through which gasses are exchanged. While lenticel damage affects most mango cultivars, Honey Gold is relatively resistant. However, Honey Gold is susceptible to development of red lenticel (red halos around the lenticel) during the later stages of fruit growth, especially in areas south of Rockhampton. Red lenticel affected fruit are downgraded or rejected. Red lenticel damage is apparent before mangoes are packed. Southern grown Honey Gold is late season and valuable. Typical loss of value caused by red lenticel is estimated at approximately $240,000 per season.

Very little is known about red lenticel mechanisms or potential control strategies. Scale-insect infestation and ethylene damage may be contributing factors. In other mango varieties (e.g. Tommy Atkins) delays between picking and packing, not dipping fruit in de-sapping solution, use of a salt solution, slower cooling and use of modified atmosphere packing have been shown to be helpful in reducing lenticel damage.

Fruit marking and downgrades reduces the overall returns from the Honey Gold crop. Analysing the types of defects causing fruit to be downgraded can identify the reasons for downgrade and inform practices that need to be improved to increase pack out rates i.e. saleable fruit yield. Improved production and harvesting practices can then be implemented on farm.

MG 10009 supported development of a crop forecasting model for Honey Gold which builds on the industry-wide forecasting model. Ongoing data collection for the model is required for robustness and accuracy. A reliable Honey Gold crop forecasting model would allow growers and marketers to plan logistics and investment in promotion.

MG 10009 also started the process of finding more lucrative markets for non-premium fruit. Lightly processed fruit is a fast growing and high value retail sector. Technologies are needed to ensure lightly processed Honey Gold slices retain visual appearance, flavour and nutritive value while also offering a commercial shelf-life.

These previous research findings are also relevant to other Australian mango varieties. Kensington Pride and R2E2 can develop USB and red lenticel is an issue with all Australian mango varieties. A marking and downgrade system is relevant to all Australian mango growers and augmentation of the Honey Gold forecasting model could support whole of industry crop forecasting.

Partners in the project just completed (MG13016) were DAF and Piñata Farms. Piñata Farms contribution was matched with Horticulture Innovation Australia (HIA) funding. The overall aim of the project was to increase the percentage of Honey Gold sold as premium grade by addressing a number of the issues in the foregoing brief review.

3. Project Details

Summary

Project Title: MG 13016 – Improving Consumer Appeal of Honey Gold Mango by Reducing Under Skin Browning and Red Lenticel Research Organisation: Department of Agriculture and Fisheries, Queensland Principal Investigator: Peter Hofman Period of Funding: March 2014 to May 2017

Objectives

The objectives of the project were:

1) To develop commercial recommendations to minimise losses from USB.
2) To better understand and minimise losses from red lenticel.
3) To address Honey Gold marking and downgrades using an on-farm analysis model.
4) To deliver a Honey Gold specific crop forecasting model.
5) To investigate additional higher value uses for non-premium Honey Gold mangoes.

Logical Framework

Table C1 provides a description of the project in a logical framework developed for the project.

Table C1: Logical Framework for Project MG 13016

Activities and Outputs	*Factors Affecting USB* • An analysis of data was completed using information collected from MG 06022 and MG 10009 on production and post-harvest factors affecting USB development. Data were collected and analysed on USB rates in Honey Gold mangoes harvested at different times of the day. Data and time of harvest data showed that time of day and relative humidity have a marked impact on the incidence of USB. Harvest in hot dry conditions increases USB. Harvest at night reduces USB from 60% to 10%. • An investigation into why there are differences in the prevalence of USB in neighbouring farms in tropical Australia was completed. Factors tested included irrigation rates, plant nutrition, rootstock, soil type, time of harvest and heat stress. Investigators hypothesised that differences were due to the cumulative effect of various stresses. • Further testing was completed on the impact that improved inserts, trays and pallets can have on reducing USB. A softer expanded polystyrene insert was tested and found to be partially successful but an insert with more form and depth was required. A new suspension style tray liner was trialled but produced no discernible difference in USB rates. Foam pads fitted between palletised stacks were found to be ineffective in reducing fruit damage. USB rates are influenced by

	transporting truck suspension type – vehicles with air suspension systems had lower levels of USB than vehicles with leaf-spring suspension. • The potential for methyl jasmonate (MeJA) to reduce USB based on its effect in reducing chill injury was tested. MeJA and other natural plant compounds were found to be effective in year 1 trials but this result was not replicated in subsequent years. *Red Lenticel Research* • A literature review on the causes of red lenticel in mangoes was completed. Laboratory and field trials were used to test chemicals and approaches that affect the occurrence of red lenticel. Chemicals and approaches trialled included actions that both promote (e.g. ethylene) and inhibit (e.g. Harvesta^{TM}) skin colour development and prevent water from irritating lenticels and triggering a defence mechanism (e.g. Rain Guard^{TM}). • Year 1 trials showed Rain Guard^{TM} plus use of commercial fruit bags was effective in reducing red lenticel. Use of ethylene plus sugars was effective in increasing blush but the effects were minimal. Subsequent trials showed that pre-harvest bagging to block light from the fruit on its own was the most reliable technique identified to reduce red lenticel damage. Researchers concluded that the use of bagging would need to take into account the costs, time commitment and the associated (negative) reduction in blush on the fruit. Bagging is unlikely to become a commercial solution to red lenticel. *Refining the Downgrade Analysis Model* • An existing outturn assessment model used by wholesalers to provide product feedback to Piñata Farms was modified so that it could be used on-farm by growers to record Honey Gold defects. A better understanding of defects, it was hoped, would identify farm practices requiring improvement and lead to improved pack out rates. • Tropical Horticulture Consulting provided grower training in the use of the downgrade analysis model and regular advice on growing practices to reduce fruit defects at harvest. *Refining the Honey Gold Specific Crop Forecasting Model* • A refinement of the Honey Gold crop forecasting work undertaken as part of MG 10009 was completed. The refinement confirmed the reliability of the existing model's crop forecasting parameters. • Plans to produce an 'app' and have the model widely distributed were not realised because the value of an 'app' would only be realised when orchard temperature data could be remotely uploaded (not available at the time) and when growers were more comfortable with using Apple/android 'apps'. In addition, forecasting calculations can be relatively easily done in the spreadsheet developed by Tropical Horticulture Consulting. The spreadsheet is used by Piñata Farms. *Further Research on Lightly Processed Honey Gold Mangoes* • Further research on lightly processed Honey Gold mangoes undertaken as part of MG 10009 was completed. The research

	identified technologies to prevent sliced fruit degradation and deliver an extended shelf-life. However, the effect was small and the margins were not sufficient, at the time, to warrant further development. *Extension and Communication* • Research results were communicated through Piñata Farms' Golden Issue Newsletter and Piñata Farms' website, pre-season meetings held in growing areas, regular individual farm visits and presentation of results to the annual Honey Gold Congress. • The broader mango industry was engaged through NT Department of Primary Industries and Fisheries (DPIF) and DAF attendance at Honey Gold events, presentation of findings in Mango Matters and at the biannual Australian Mango Industry Association (AMIA) conference.
Outcomes	• Project findings have contributed to a shift by growers to night time/early morning harvest to avoid USB. The largest single Honey Gold grower moved to this practice in 2014-15 following early confirmation of previous study results. The shift to night time/early morning harvest reduced the incidence of USB in tropically grown Honey Gold mangoes. The shift to night time/early morning harvest also increased harvest efficiency - pickers are more productive in the cool early morning. • Bagging of Honey Gold mangoes prior to harvest to avoid red lenticel damage is unlikely to be adopted. Costs, including loss of a desirable blush, are likely to outweigh red lenticel mitigation benefits. However, the project identified the potential for over-tree rain 'shelters' to reduce red lenticel, and also potentially some fruit diseases. The benefit of rain 'shelters' was identified but not tested during the project. • The refined downgrade analysis model was prepared and made available to Honey Gold growers and supported with training by Tropical Horticulture Consulting. However, the project's Principal Investigator reports that there was poor on-farm uptake of the tool. • The refined Honey Gold specific crop forecasting model has been adopted by Piñata Farms. The model is expected to deliver better sales scheduling, improved supply/demand balance and more effective Honey Gold promotions. • Further research on lightly processed Honey Gold mangoes has the potential to deliver additional income for growers from the diversion of Honey Gold mangoes with defects from lower value juice markets to value added sliced mango sales. At the current time price differentials between the two products are insufficient for this benefit to be realised.
Impacts	• Reduction in Honey Gold downgrades caused by USB due to a shift to night time/early morning harvesting. The impact is relevant to Honey Gold grown in the NT and tropical QLD. Further research is required to confirm the benefits of night harvesting to reduce USB in other cultivars. • Reduced stress on pickers (labour) and machinery with a switch to night time/early morning harvest to avoid USB. Pickers prefer to work at night in cool conditions and will not require additional remuneration. • Pickers have been found to be more efficient when working in cooler night time/early morning conditions, requiring fewer breaks and delivering increased productivity. • Saved repack costs on Honey Gold affected by USB. Fruit with less USB does not need to be unpacked from pallets at the wholesale

	market, visually inspected, have downgraded fruit removed, repacked and stacked. Consequently, cost savings are realised by the grower. • The potential for increased seafreight export sales of Honey Gold with the solving of the USB problem. Solving the USB issue will allow seafreight export because of the variety's newly established reliable performance in colder transport conditions. • The long-term potential for a reduction in Honey Gold downgrades caused by red lenticel. Research completed as part of this project may make a future contribution to a commercial control, for example by using over-tree rain 'shelters'. This benefit may also be relevant to other mango varieties. • Increased grower returns as a result of effective crop forecasting. Accurate crop forecasts prepared by Piñata Farms will assist with sales scheduling, improved supply/demand balance and promotions. • The potential for increased grower returns with uptake of effective on-farm downgrades analysis. • The potential for additional income from diverting juice grade fruit into higher value part processed Honey Gold slices. • No commercial intellectual property is expected from this project.

4. Project Investment

Nominal Investment

Table C2 shows the annual investment (cash and in-kind) for the project funded by DAF and Piñata Farms/HIA.

Table C2: Annual Investment in Project MG 13016 (nominal $)

Contributor	2013/14	2014/15	2015/16	2016/17	Totals
DAF ($)	45,020	218,884	224,653	230,951	719,508
Piñata Farms/HIA ($)	84,558	575,164	608,848	603,526	1,872,096
Totals ($)	**129,578**	**794,048**	**833,501**	**834,477**	**2,591,604**

Source: Project documentation (including the executed head agreement).

Program Management Costs

For the DAF investment, the management and administration costs for the project are already built into the nominal $ amounts appearing in Table C2. A salary multiplier of 2.85 was used (Wayne Hall, pers. comm., 2017).

A 10% management cost was included to account for overheads associated with Piñata Farms/HIA's contribution. This cost is in addition to the Piñata Farms/HIA contribution shown in Table C2.

Real Investment, Commercialisation and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 $ terms using the Implicit GDP Deflator index (ABS, 2016). No additional costs of extension were included as the project already encompassed an extension component delivered by Tropical Horticulture Consulting and involved a high level of industry participation via Piñata Farms.

5. Impacts

The principal positive impacts from adoption of project results are:

- Reduction in income loss caused by USB downgrades in tropically grown Honey Gold.
- Saved repack costs caused by USB in tropically grown Honey Gold.
- Increased harvest efficiency from night time/early morning harvest of tropically grown Honey Gold.

Table C3 provides a summary of the types of impacts categorised into economic, environmental and social impacts.

Table C3: Triple Bottom Line Categories of Potential Impacts from Project MG 13016

Economic	• Reduction in income loss caused by USB downgrades in tropically grown Honey Gold. • Saved repack costs caused by USB in tropically grown Honey Gold. • Increased harvest efficiency from night time/early morning harvest of tropically grown Honey Gold. • The potential for seafreight export sales of Honey Gold with the USB issue now resolved and confirmation of the variety performing reliably in cold storage conditions. • The potential in the long term for a reduction in Honey Gold downgrades caused by red lenticel. • Increased grower returns as a result of effective crop forecasting. • The potential for increased grower returns with uptake of effective on-farm downgrades analysis. • The potential for additional income from diverting juice grade fruit into higher value part-processed Honey Gold slices.
Environmental	• Nil.
Social	• Reduced stress on pickers (labour) with a switch to night time/early morning harvest of tropically grown Honey Gold. • Spill-over benefits in terms of regional community well-being from increased grower productivity and/or profitability.

Public versus Private Impacts

Most impacts identified in this evaluation are industry related and therefore the benefits are considered private benefits. Some public benefits may also be delivered including the social benefits of reduced stress on pickers with a switch to cool night time/early morning harvest and community spill-overs from increased grower productivity and/or profitability.

Distribution of Private Impacts

The primary beneficiaries of addressing USB are Australian mango growers growing the Honey Gold variety in tropical Australia.

It can be assumed that the benefits from the project findings will be distributed between participants along the commercial supply chains, including Piñata Farms, wholesalers and final consumers.

Impacts on other Australian industries

It is possible that impacts from the project will, with further research, be relevant to growers of other Australian mango varieties. Other fruit industries are not likely to benefit from this project.

Impacts Overseas

It is not likely that USB and red lenticel research completed as part of this project will be relevant to overseas mango industries. Honey Gold is an Australian variety developed exclusively by Piñata Farms.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural Research, Development and Extension (RD&E) priorities are reproduced in Table C4. USB and red lenticel research contributes primarily to Rural RD&E Priorities 1 and 4 and to Science and Research Priority 1.

Table C4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities[a] (est. 2015)	**Science and Research Priorities[b] (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

(a) Source: Commonwealth of Australia (2015)
(b) Source: Office of the Chief Scientist (2015)

The Queensland Government's Science and Research Priorities, together with the four decision rules for investment that guide evaluation, prioritisation and decision making around future investment are reproduced in Table C5. Project MG 13016 addressed Queensland Science and Research Priority 1. In terms of the guides to investment, the project is likely to deliver real future impact with the control of post-harvest USB in Honey Gold mangoes.

Table C5: Queensland Government Research Priorities

Queensland Government	
Science and Research Priorities (est. 2015)	**Investment Decision Rule Guides (est. 2015)**
1. Delivering productivity growth 2. Growing knowledge intensive services 3. Protecting biodiversity and heritage, both marine and terrestrial 4. Cleaner and renewable energy technologies 5. Ensuring sustainability of physical and especially digital infrastructure critical for research	1. Real Future Impact 2. External Commitment 3. Distinctive Angle 4. Scaling towards Critical Mass

6. Building resilience and managing climate risk 7. Supporting the translation of health and biotechnology research 8. Improving health data management and services delivery 9. Ensuring sustainable water use and delivering quality water and water security 10. The development and application of digitally-enabled technologies.	

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved.

Three impacts for USB control in Honey Gold mangoes were valued. The first was the additional return for growers from reduced Honey Gold downgrades – premium fruit downgraded to class 1 or processing and class 1 fruit downgraded to processing. The second impact valued was saved repack costs with fewer tropically grown Honey Gold mangoes being affected by USB. The third impact valued was increased harvest efficiency from night/early morning harvest of tropically grown Honey Gold.

Sensitivity analyses were undertaken on the discount rate as well as the percentage of tropical Honey Gold production adopting the research findings and the level of reduction in USB linked downgrades achieved.

Impacts Not Valued

Not all impacts identified in Table C3 could be valued in the assessment.

The economic impacts identified but not valued included:

- The potential for seafreight export sales of Honey Gold with the USB issue now solved and confirmation that the variety performs reliably in cold storage conditions.
- The longer-term potential for a reduction in Honey Gold downgrades caused by red lenticel.
- Increased grower returns as a result of effective crop forecasting.
- The potential for increased grower returns with uptake of effective on-farm downgrades analysis.
- The potential for additional income from diverting juice grade fruit into higher value part-processed Honey Gold slices.

The remaining economic impacts were not valued due to difficulty in making credible assumptions on additional research requirements (e.g. solutions for red lenticel) or an absence of data on what the change in profitability might be (e.g. increased grower returns from effective crop forecasting or adoption of an on-farm downgrades analysis tool).

The social impacts identified but not valued were reduced stress on pickers with a switch to night time/early morning harvest (data on changes in picker well-being is not available). The improved community well-being spill-over benefit was not valued due to a lack of time and resources and the greater uncertainty of assumptions required in estimating such secondary impacts.

Valuation of Benefit 1: Additional Return from Reduced Honey Gold Downgrades

Research project benefits accrue from fewer USB affected Honey Gold mangoes being downgraded from higher to lower grades. Honey Gold mangoes affected by USB that would otherwise have been marketed as premium fruit are either downgraded to class 1 or downgraded to processing fruit. Also, some Honey Gold mangoes affected by USB that would otherwise have been marketed as class 1 fruit are downgraded to processing fruit. A large share of total downgrades is avoided with implementation of research findings and USB control that can be attributed to Project MG 13016.

Avoided downgrade in Honey Gold mangoes increases the supply of this fruit on the domestic market. It is assumed that the increase in Honey Gold supply does not change the price received by growers for sound fruit. Honey Gold is less than 10% of the total Australian mango crop and the increased volume is assumed absorbed by the market at ruling market prices.

Data used to quantify this benefit was mostly sourced from an ex-ante benefit cost analysis prepared by DAF for MG 13016. A summary of assumptions for benefit 1 is provided in Table C6.

Valuation of Benefit 2: Saved Repack Costs

USB control directly addresses the cost incurred by growers for the repack of tropically grown Honey Gold mangoes in the wholesale markets. As previously noted USB had become such a problem that all Honey Gold originating from tropical areas required repack. With USB control in place, repack is reduced to 20% of all pallets. The benefit is realised as a saved labour cost.

Data used to quantify this benefit was mostly sourced from an ex-ante benefit cost analysis prepared by DAF for MG 13016. A summary of assumptions for benefit 2 is provided in Table C6.

Valuation of Benefit 3: Increased Harvest Efficiency with Night Harvest

Switching from day time harvest to harvest at night and in the early morning reduces USB. Night time/early morning harvest generates a 10% improvement in picking efficiency with improved worker comfort and concentration and less equipment fatigue (DAF, 2015).

Data used to quantify this benefit was mostly sourced from an ex-ante benefit cost analysis prepared by DAF for MG 13016. A summary of assumptions for benefit 3 is provided in Table C6.

Counterfactual

USB is more prevalent in Honey Gold than other mango varieties. Honey Gold is being developed exclusively by Piñata Farms i.e. Piñata Farms own the variety's Plant Breeders Rights and licence growers to grow the variety on their behalf. In the absence of Piñata Farms' investment in this project a solution to USB would not have been investigated.

Attribution

Prior DAF investment has contributed to quantified project benefits. DAF project MG 06022 included research to improve the percentage of fruit at premium grade and MG 10009 identified factors that might be contributing to USB. A 60% attribution of the quantified benefits to project MG 13016 was agreed following DAF feedback on the draft assessment (Peter Hofman, Senior Principal Horticulturalist and Principal Investigator, DAF, June 2018).

Extension

Extension delivered by Tropical Horticulture Consulting was included in project costs and it is assumed that no additional extension expenses have been incurred.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table C6.

Table C6: Summary of Assumptions

Variable	Assumption	Source/Comment
General assumptions applying to benefits 1, 2 and 3		
Total tropical Honey Gold production (7kg trays).	200,000 trays 2015 250,000 trays 2018	DAF (2015) and Piñata Farms advice (written comm., August 2018).
Forecast increase in tropical Honey Gold Production	10% pa for 10 years commencing 2015-16	Piñata Farms advice (written comm., August 2018).
Probability of output.	100%	Consultant assumption based on review of project reports.
Probability of usage.	100%	Consultant assumption based on review of project reports.
Probability of impact.	90%	Consultant assumption based on review of project reports.
Year of first impact.	2015	Project final report which noted that the largest single Honey Gold grower moved to night harvest to control USB in 2014-15 following early confirmation of previous study results.
Maximum adoption of project recommendations by tropical Honey Gold growers	100%	Piñata Farms advice (written comm., August 2018).
Cost to growers of adopting project recommendations	$0	Major change in farm practice to avoid USB is night time/early morning harvest. Pickers prefer to work at this time and no additional labour costs are incurred (Dr Peter Hofman, Principal Investigator pers. comm., April 2018).
Attribution of impacts to this project.	60%	Peter Hofman, Senior Principal Horticulturalist and Principal Investigator, DAF, June 2018.
Benefit 1: Additional return from reduced Honey Gold downgrades		

Reduction in premium fruit downgrade to class 1 with project in place.	8%	Ex-ante benefit cost analysis of MG 13016 prepared by DAF assumes 10% downgrade reduced to 2% with adoption of project findings.
Reduction in premium fruit downgrade to processing with project in place.	4%	Ex-ante benefit cost analysis of MG 13016 prepared by DAF assumes 4% downgrade reduced to zero with adoption of project findings.
Reduction in class 1 fruit to processing with project in place.	8%	Ex-ante benefit cost analysis of MG 13016 prepared by DAF assumes 10% downgrade reduced to 2% with adoption of project findings.
Farm gate price of premium Honey Gold mangoes (7kg tray)	$37.47/tray	Peter Hofman, Senior Principal Horticulturalist and Principal Investigator, DAF, June 2018.
Farm gate price of class 1 Honey Gold mangoes (7kg tray)	$34.25/tray	Peter Hofman, Senior Principal Horticulturalist and Principal Investigator, DAF, June 2018.
Farm gate price of processing Honey Gold mangoes (7kg tray)	$4.00/tray	Piñata Farms advice (written comm., August 2018).
Benefit 2: Saved repack costs		
Repack of tropically grown Honey Gold mangoes prior to the project.	100%	Ex-ante benefit cost analysis of MG 13016 prepared by DAF.
Repack of tropically grown Honey Gold mangoes with project findings in place.	20%	Ex-ante benefit cost analysis of MG 13016 prepared by DAF.
Cost of repack ($/tray)	$1.50	Ex-ante benefit cost analysis of MG 13016 prepared by DAF.
Benefit 3: Increased harvest efficiency with night harvest		
Cost of picking Honey Gold mangoes.	2.00/tray	Ex-ante benefit cost analysis of MG 13016 prepared by DAF.
Increase in picking efficiency with switch to night time/early morning harvest.	10%	Ex-ante benefit cost analysis of MG 13016 prepared by DAF.

7. Results

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP). All benefits after 2016/17 were expressed in 2016/17 dollar terms. All costs and benefits were discounted to 2017/18 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2016/17).

Investment Criteria

Tables C7, C8 and C9 show the investment criteria estimated for different periods of benefits for the total investment, the DAF and Piñata Farms/HIA investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table C8, has been estimated by multiplying the total PVB by the DAF proportion of real investment (25.9%).

Table C7: Investment Criteria for Total Investment in Project MG 13016

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.43	3.75	8.85	13.08	16.40	19.00	21.03
Present value of costs ($m)	3.15	3.15	3.15	3.15	3.15	3.15	3.15
Net present value ($m)	-2.72	0.60	5.69	9.93	13.25	15.85	17.88
Benefit-cost ratio	0.14	1.19	2.81	4.15	5.20	6.03	6.67
Internal rate of return (IRR) (%)	negative	negative	27.8	30.5	31.1	31.2	31.2
Modified IRR (%)	negative	negative	17.1	16.1	14.5	13.2	12.2

Table C8: Investment Criteria for DAF Investment in Project MG 13016

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits[(a)] ($m)	0.11	0.97	2.29	3.39	4.25	4.92	5.45
Present value of costs ($m)	0.82	0.82	0.82	0.82	0.82	0.82	0.82
Net present value ($m)	-0.70	0.16	1.47	2.57	3.43	4.10	4.63
Benefit-cost ratio	0.14	1.19	2.81	4.15	5.20	6.03	6.67
Internal rate of return (IRR) (%)	negative	negative	27.8	30.5	31.1	31.2	31.2
Modified IRR (%)	negative	negative	17.1	16.1	14.5	13.2	12.2

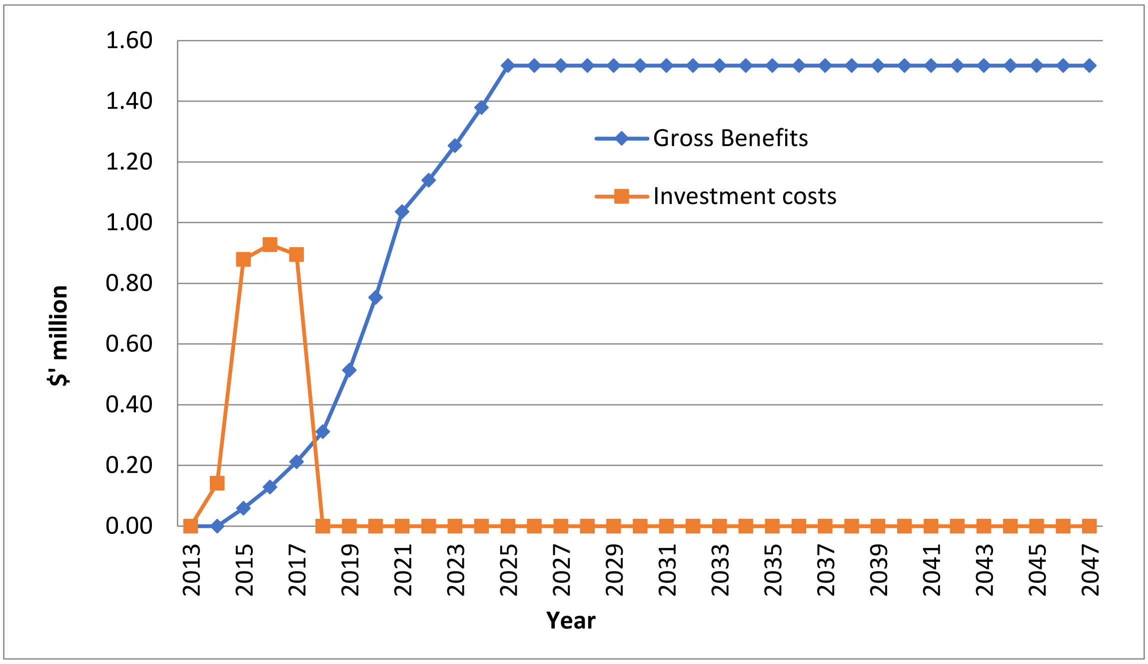
Table C9: Investment Criteria for Piñata Farms/HIA Investment in Project MG 13016

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits[(a)] $m)	0.32	2.78	6.55	9.69	12.15	14.08	15.59
Present value of costs ($m)	2.34	2.34	2.34	2.34	2.34	2.34	2.34
Net present value ($m)	-2.01	0.44	4.22	7.36	9.82	11.74	13.25
Benefit-cost ratio	0.14	1.19	2.81	4.15	5.20	6.03	6.67
Internal rate of return (IRR) (%)	negative	negative	27.8	30.5	31.1	31.2	31.2
Modified IRR (%)	negative	negative	17.1	16.1	14.5	13.2	12.2

(a) The PVB attributable to Piñata Farms/HIA investment has been estimated by multiplying the total PVB by the Piñata Farms proportion of real investment (74.1%).

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure C1.

Figure C1: Annual Cash Flow of Undiscounted Total Gross Benefits and Total Investment Costs



Sources of Benefits

There are three sources of benefits valued in the analysis. Table C10 shows the relative contributions to the PVB from each source. Benefit 3, increased harvest efficiency with night harvest, makes a modest contribution to total benefit.

Table C10: Contribution to Total Benefits from Each Source

Source of Benefits	Contribution to PVB ($m)	Share of benefits (%)
Additional return from reduced Honey Gold downgrades (Benefit 1)	15.60	74.2
Saved repack costs (Benefit 2)	4.66	22.2
Increased harvest efficiency with night harvest (Benefit 3)	0.78	3.7
Total	**21.03**	**100.0**

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was 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. Table C11 presents the results. The results showed a moderate sensitivity to the discount rate. This sensitivity is because the benefits occur over a long period of time whereas the project costs are subject to lesser discounting.

Table C11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	41.69	21.03	12.59
Present value of costs ($m)	2.84	3.15	3.48
Net present value ($m)	38.84	17.88	9.11
Benefit-cost ratio	14.67	6.67	3.61

A sensitivity analysis also was carried out on the maximum level of adoption. Table C12 presents the results. The results showed sensitivity to the maximum adoption level.

Table C12: Sensitivity to Maximum Level of Adoption
(Total investment, 30 years)

Investment Criteria	Maximum level of adoption		
	50%	**75%**	**100% (base)**
Present value of benefits ($m)	10.52	15.86	21.03
Present value of costs ($m)	3.15	3.15	3.15
Net present value ($m)	7.37	12.71	17.88
Benefit-cost ratio	3.34	5.03	6.67

Finally, a sensitivity analysis was carried out on the reduction in downgrades as a result of implementing project recommendations. With only half the base improvement assumed, project benefits continue to exceed project costs.

Table C13: Sensitivity to Reduction in Downgrades
(Total investment, 30 years)

Investment Criteria	Reduction in Mango Downgrades		
	Half Base	**Base(a)**	**Twice Base**
Present value of benefits ($m)	18.43	21.03	22.33
Present value of costs ($m)	3.15	3.15	3.15
Net present value ($m)	15.28	17.88	19.18
Benefit-cost ratio	5.85	6.67	7.09

(a) Premium to class 1 = 2%; Premium to processing = 0%; Class 1 to processing = 2%.

Confidence Ratings and other Findings

The results produced are highly dependent on the assumptions made, some of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of impacts valued. Where there are multiple types of impacts it is often not possible to quantify all impacts 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 C14). The rating categories used are High, Medium and Low, where:

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

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

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

Table C14: Confidence in Analysis of Project

Coverage of Impacts	Confidence in Assumptions
Medium	High

Coverage of impacts was assessed as medium as three economic impacts were valued from eight economic impacts identified, notwithstanding the three most important impacts being quantified. Nevertheless, the investment criteria as provided by the valued impacts are likely to be underestimated to some degree.

Confidence in assumptions was rated as high. Data for this analysis were drawn mainly from DAF's ex-ante benefit cost analysis of the project. Supplementary data were sourced from the project's Principal Investigator. The analysis was cross checked by Piñata Farms.

8. Conclusions

The investment in project MG 13016 has successfully addressed USB, a major constraint to the profitability of tropically grown Honey Gold mangoes. Implementation of project findings has reduced fruit downgrade in the wholesale market and increased grower returns. A reduction in USB has also saved pallet repacking costs and increased the efficiency of picking labour. These benefits are relevant to growers in the NT and tropical QLD.

Solutions to red lenticel are relevant to QLD mango production south of Rockhampton. Further research is required to deliver a commercial outcome for red lenticel on subtropical Honey Gold mangoes.

Given the counterfactual scenario assumed, total funding from all sources for the project was approximately $3.15 million (present value terms). The value of total benefits was estimated at $21.03 million (present value terms). This result generated an estimated net present value (NPV) of $17.88 million, a benefit-cost ratio (BCR) of approximately 6.7 to 1, an internal rate of return of 31.2% and a modified internal rate of return of 12.2%.

The analysis provided a good example of how a partnership can be formed with the private sector (Piñata Farms supported with matching funds from HIA) and through a sequence of projects (MG 06022, MG 10009 and this project MG 13016) issues critical to industry profitability can be identified and successfully addressed.

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Appendix D: An Impact Assessment of DAF Investment into the Murray-Darling Basin Regional Economic Diversification Program: Improved Economic Productivity from Irrigated Agriculture in the Queensland Murray-Darling Basin

Acknowledgments

Wayne Hall, Executive Director, Agri-Science Queensland, Department of Agriculture and Fisheries.

Mark Hickman, Director, Sustainable Farming Systems RD&E, Queensland, Department of Agriculture and Fisheries.

Abbreviations

BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CRDC	Cotton Research and Development Corporation
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
DIRD	Department of Infrastructure and Regional Development
GDP	Gross Domestic Product
GL	Gigalitre
GPWUI	Gross Production Water Use index or Indices
IRR	Internal Rate of Return
IWUI	Irrigation Water Use Index
MDB	Murray-Darling Basin
MDBREDP	Murray-Darling Basin, Regional Economic Diversification Program
MIRR	Modified Internal Rate of Return
ML	Megalitre
NPV	Net Present Value
NSW	New South Wales
PVB	Present Value of Benefits
QLD	Queensland
QMDB	Queensland Murray-Darling Basin
R&D	Research and Development
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
WUE	Water Use Efficiency

Executive Summary

The Report

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment into the Murray-Darling Basin, Regional Economic Diversification Program (MDBREDP): Improved Economic Productivity from Irrigated Agriculture in the Queensland Murray-Darling Basin. The project was jointly funded by DAF and the Australian Government from July 2014 to June 2017.

Methods

The project was first analysed qualitatively using a logical framework that included project objectives, activities and outputs, and actual and potential outcomes and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts were then valued.

Impacts were estimated for a range of time frames up to 30 years from the last year of investment in the project. Past and future cash flows in 2016/17 dollar terms were discounted to the year 2017/18 using a discount rate of 5% to estimate the investment criteria.

The cost-benefit analysis (CBA) was conducted according to the Impact Assessment Guidelines of the Council of Rural Research and Development Corporations (CRRDC, 2014).

Impacts

The major impacts identified were of a financial/economic nature. However, some social and environmental impacts were identified also but not valued. It is expected that irrigators in the Balonne and Border Rivers districts of Queensland, the focus of the project, will be the primary beneficiary of the investment.

Investment Criteria

Total funding from all sources for the project was approximately $4.08 million (present value terms). The value of total benefits was estimated at $19.31 million (present value terms). This result generated an estimated net present value (NPV) of $15.23 million, and a benefit-cost ratio (BCR) of approximately 4.7 to 1.

1. Evaluation Methods

The evaluation approach follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations (RDCs), Cooperative Research Centres, State Departments of Agriculture, and some Universities. This impact assessment uses Cost-Benefit Analysis (CBA) as its principal tool. The approach includes both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Research and Development Corporations (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and both actual and potential outcomes and impacts. The principal economic, environmental and social impacts are then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, or the likely low relative significance of the impact compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

Irrigated agriculture in the Queensland (QLD) portion of the Murray-Darling Basin (MDB) includes a range of both intensive horticultural crops (e.g. stonefruit, apples, wine grapes) and extensive broadacre crops (e.g. cotton, corn, mung beans, wheat, grain sorghum). Production is dominated by irrigated cotton which had a gross value of production of $532 million in 2016/17 (ABS, 2018). Under the MDB Plan a quantity of irrigation water is to be returned to the river system to improve environmental outcomes.

Acquisition of water from willing sellers across the irrigation sector could potentially result in increased risk, reduced productivity and lower economic activity in the affected industries and communities.

Individual irrigators who choose to reduce water entitlements through the MBD Plan will be compensated for the loss of their asset directly through buyback schemes. Subsidies are also available for improvement of farm irrigation infrastructure, e.g. Queensland's Healthy Headwaters Program.

As a complementary measure, improving the overall productivity of irrigated agriculture in the affected districts of the Queensland Murray-Darling Basin (QMDB) provides a direct pathway to ameliorate the economic and social impacts of the MDB Plan.

Rationale for the Investment

Improvements in productivity can be obtained by benchmarking existing water productivity at a farm and field scale to identify the possible improvements and the poorly performing components of the production system, and then implementing improved practices and technologies to remedy the underperforming elements of the system.

Water use efficiency (WUE) in an agricultural context can be measured at different spatial scales, i.e. the field or farm, however in broad terms the measure is of the cropping system's capacity / efficiency in converting water into plant biomass, grain or other harvested outputs. It includes both the applied water through irrigation, the use of water stored in the soil and rainfall during the growing season. In simple terms, WUE can be said to have increased if farm output per unit of water input increases, or if water use can be decreased while maintaining current production levels.

WUE can be measured by several indices, with the Irrigation Water Use Index (IWUI) and Gross Production Water Use Index (GPWUI) two prominent measures (CRDC, 2012). IWUI measures yield against irrigation water applied. While the figure is relatively simple to calculate, it can vary substantially in response to changes in irrigation water application which in turn varies with seasonal rainfall. GPWUI accounts for total water (irrigation, residual soil moisture and rainfall) available to the crop. GPWUI therefore provides a more comprehensive measure, however its theoretically superior accuracy cannot be achieved if accurate data on rainfall and soil moisture are not available.

This project provided the capacity to achieve improved WUE for existing irrigated agricultural enterprises throughout the QMDB, but with a primary focus on the most impacted communities in the Balonne and Border Rivers districts.

3. Project Details

Summary

Project Title: Improved Economic Productivity from Irrigated Agriculture in the Queensland Murray-Darling Basin Research Organisation: Department of Agriculture and Fisheries, Queensland Principal Investigator: Graham Harris Period of Funding: July 2014 to June 2017

Objectives

The objectives of the project were:

1) To benchmark existing water productivity at a farm and field scale on irrigation properties in the Balonne and Border Rivers districts.
2) To identify poorly performing components and possible improvements to the farm irrigation production system.
3) To implement improved practices and technologies on participating farms.

Logical Framework

Table D1 provides a description of the project in a logical framework developed for the project.

Table D1: Logical Framework for MDBREDP Project

Activities and Outputs	• Consultation with individual irrigators in the Balonne and Border Rivers districts was undertaken and provision of grants of up to $10,000 per business entity made available to assist with improvement in on-farm water monitoring and irrigation efficiency assessment. In total 101 grants

	valued at a total of $972,684 were provided to 72 different business entities over three funding rounds, one in each of the project's cropping seasons. Some business entities irrigated more than one location and were eligible for a second grant. • Grant recipients were required to participate in WUE benchmarking. Baseline benchmarking was completed using the whole farm irrigation water management tool WaterTrack Divider™ and was completed using historical data from the 2013/14 season. • Two field days / farm-walks were completed each year for three years to demonstrate the value of benchmarking and water use efficiency practices and technologies. Field days / farm walks were completed for the 2014/15, 2015/16 and 2016/17 seasons. • Seasonal irrigator and annual regional benchmark reports were prepared for individual irrigators on water productivity at the field and farm scale. Benchmarking reports were prepared and provided to 72 irrigators and covered 274 individual irrigation fields. • Benchmarking reports showed that most fields were sown to cotton (77%) while other crops included corn, mungbean, wheat, grain sorghum and various horticultural enterprises. The data showed a significant range in water use efficiencies measured using GPWUIs. GPWUIs for cotton ranged from 0 (for an abandoned crop) through to 3.04 bales per megalitre (ML). The best crops achieved GPWUI figures exceeding 1.5 bales/ML. Both overhead and surface irrigation systems achieved high GPWUI figures. • Grants were provided to assist irrigators to improve their WUE through the purchase of meters and/or irrigation benchmarking/management services from consultants. Irrigators funded the balance of the cost when capital items and consulting service costs exceeded the $10,000 grant limit. • Five case studies demonstrating benchmarking, improved practices and use of improved irrigation technologies were completed and communicated to irrigators. Detailed economic analysis was also undertaken to demonstrate the benefits of these practices and technologies. Written material and videos were produced and distributed to irrigators to assist with adoption decisions to improve their individual irrigation efficiencies. • Eight on-farm validation trials using the online irrigation scheduling tool waterSCHED2 were completed. WaterSCHED2 was updated throughout the project using irrigator and irrigation consultant feedback.
Outcomes	• Increased awareness of WUE and WUE variation amongst participating irrigators. • A better understanding by DAF of the capabilities and limitations of the WUE measuring tool WaterTrack Divider™. • Further refinement of the irrigation scheduling tool waterSCHED2 for use in research, extension and in on-farm decision making. • The potential for improved WUE at the field and farm scale amongst participating irrigators. Productivity improvements were measured using the IWUI and the GPWUI.
Impacts	• The potential for participating irrigators in the Balonne and Border Rivers districts to have more profitable and resilient enterprises. • Increased irrigator well-being through reduced stress from more profitable and resilient irrigated enterprises. • Increased community well-being through spill-over benefits from increased grower profitability and resilience.

	• Improved environmental outcomes with some irrigators more aware of WUE, addressing inefficiencies and taking up voluntary water acquisition offers made through the MDB Plan. Additional take up of voluntary acquisitions increases the volume of flow retained in the Murray-Darling Basin. • The potential for increased irrigation efficiencies Australia wide with the refinement of the irrigation scheduling tool water SCHED2 using data gathered through the project.

4. Project Investment

Nominal Investment

Table D2 shows the annual investment (cash and in-kind) for the project funded by DAF, the Australian Government and irrigators.

Table D2: Annual Investment in MDBREDP Project (nominal $)

Contributor	2014/15	2015/16	2016/17	Totals
DAF – cash ($)	14,845	14,857	13,978	43,680
DAF – in kind ($)	319,686	342,633	365,282	1,027,601
Aust Govt – MDBREDP[(a)]($)	750,540	769,333	680,069	2,199,942
Irrigator contributions[(b)]	91,773	95,304	89,595	276,672
Totals ($)	**1,176,844**	**1,222,127**	**1,148,924**	**3,547,895**

(a) Includes payment of salaries for DAF staff, travel, accommodation, advertising, communication activities, computer lease, conferences, contractors, freight/postage, IT charges, maintenance and repairs, materials and stores, office supplies, telephone, vehicle hire, Water Track Divider[TM] licences, project capital equipment, grants to irrigators and on-costs (Source: signed funding agreement for the project).

(b) Investment in a range of WUE measurement equipment and services in addition to grant monies received through the project. Water use efficiency measurement equipment and services purchased included flow meters, water storage meters, soil moisture meters, automatic weather stations, irrigation system evaluations, water storage topographic surveys, water storage soil surveys and irrigation efficiency improvements (DAF, 2017).

Program Management Costs

For the DAF investment, the management and administration costs for the project are already built into the nominal $ amounts appearing in Table D2. A salary multiplier of 2.85 was used (Wayne Hall, pers. comm., 2017).

For Australian Government investment, the cost of managing the Murray-Darling Basin Regional Economic Diversification Program was added to the Australian Government contribution via a management cost multiplier (1.03); this was estimated based on the average reported share of 'employee benefits' & 'supplier' expenses in total Department of Infrastructure and Regional Development (DIRD) expenditure for 2016/17 (DIRD, 2018).

Real Investment

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 $ terms using the Implicit GDP Deflator index (ABS, 2016).

5. Impacts

The principal potential impact from the positive results exhibited by the project is increased water use efficiency contributing to higher irrigated enterprise productivity and profitability. Table D3 provides a summary of the types of impacts categorised into economic, environmental and social impacts.

Table D3: Triple Bottom Line Categories of Potential Impacts from MDBREDP Investment

Economic	• Increased irrigation water use efficiency contributing to higher productivity and profitability.
Environmental	• Improved environmental outcomes with some irrigators more aware of WUE, addressing inefficiencies and taking up voluntary water acquisition offers made through the MDB. Additional take up of voluntary acquisitions increases the volume of flow retained in the MDB.
Social	• Increased irrigator well-being through reduced stress from more profitable and resilient irrigated enterprises. • Increased community well-being through spill-over benefits from increased irrigator productivity and profitability.

Public versus Private Impacts

Most impacts identified in this evaluation are industry related and therefore the impacts are considered private sector. Some public impacts may also be delivered including increased environmental flows and social impacts from increased irrigator and community well-being.

Distribution of Private Impacts

The primary beneficiaries of improved water use efficiency resulting from this project are irrigators in the Balonne and Border Rivers districts of Queensland. Cotton is the principal crop grown and impacts relating to cotton will be distributed along commercial supply chains including input suppliers, gin operators, exporters, brokers, garment manufacturers and final consumers.

Impacts on other Australian industries

Impacts are relevant to the full gambit of irrigated crops grown in the Balonne and Border Rivers districts (e.g. stonefruit, apples, wine grapes, corn, mungbean, wheat, grain sorghum) as well as irrigated crops grown in other parts of Australia. For example, the project collated data that informed modelling that will create refinement in WaterSCHED2. WaterSCHED2 will assist with irrigation scheduling in all irrigated Australian crops.

Impacts Overseas

Overseas benefits are not expected to be significant, as most research outputs apply to Australian production conditions.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural Research, Development and Extension (RD&E) priorities are reproduced in Table D4. Improved water use efficiency contributes primarily to Rural RD&E Priority 3 and to Science and Research Priority 2.

Table D4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities[(a)] (est. 2015)	**Science and Research Priorities[(b)] (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

(a) Source: Commonwealth of Australia (2015)
(b) Source: Office of the Chief Scientist (2015)

The Queensland Government's Science and Research Priorities, together with the four decision rules for investment that guide evaluation, prioritisation and decision making around future investment are reproduced in Table D5. MDBREDP Project 3 addressed Queensland Science and Research Priorities 1, 6 and 9. In terms of the guides to investment, the project is likely to deliver real future impact and was supported and funded by others external to the Queensland Government.

Table D5: Queensland Government Research Priorities

Queensland Government	
Science and Research Priorities (est. 2015)	**Investment Decision Rule Guides (est. 2015)**
1. Delivering productivity growth 2. Growing knowledge intensive services 3. Protecting biodiversity and heritage, both marine and terrestrial 4. Cleaner and renewable energy technologies 5. Ensuring sustainability of physical and especially digital infrastructure critical for research 6. Building resilience and managing climate risk 7. Supporting the translation of health and biotechnology research 8. Improving health data management and services delivery 9. Ensuring sustainable water use and delivering quality water and water security 10. The development and application of digitally-enabled technologies.	1. Real Future Impact 2. External Commitment 3. Distinctive Angle 4. Scaling towards Critical Mass

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. The principal economic benefit valued was increased water use efficiency contributing to higher productivity and profitability for cotton growers in the Balonne and Border Rivers districts of the Queensland MDB. Sensitivity analyses were undertaken on the discount rate as well as for the increase in water use efficiency realised and the cost of adopting changed irrigation practices.

Impacts Not Valued

Economic impacts not valued include increased water use efficiency contributing to higher productivity and profitability for irrigated crops other than cotton grown in the Balonne and Border Rivers districts and any improvement in water use efficiency attributable to improvements to waterSCHED2 in other irrigation areas. Improvements in irrigated crops other than cotton were not valued as the area of crop grown was relatively minor compared to cotton. Cotton accounted for 77% of production area and the next most widely grown crop was corn which accounted for 6% (DAF, 2017). Improvement in irrigated crop productivity in other areas was not valued as there were no data available on improvements in waterSCHED2 as a result of the project or its subsequent application to other parts of Australia.

The environmental impact identified but not valued was the increased likelihood of irrigators taking up voluntary water acquisition offers made through the MDB Plan with project generated WUE measures in place. Increased take up of voluntary water acquisition offers would result in increased environmental flows in the Murray-Darling river system and would only be realised if water savings were not needed on-farm for crop production. This benefit was not valued due to lack of data on take up rates post adoption of project outputs.

The social impacts identified but not valued were improved irrigator and community well-being through reduced irrigator stress and community spill-over benefits from increasing irrigator productivity and profitability. These social benefits were not valued due to a lack of time and resources and the greater uncertainty of assumptions required in estimating such secondary impacts.

Valuation of Benefit: Increased Water Use Efficiency

Increased WUE contributing to higher productivity and enterprise profitability was valued for the dominant Balonne and Border Rivers crop – irrigated cotton.

To value the impact of increased WUE on irrigated cotton an appropriate index of water use efficiency was required. Obtaining an estimate of the total water available to the crop over time is difficult, whereas substantial data exists regarding irrigation applications. For this reason, the current analysis used increased IWUI as a means for measuring increases in WUE, with a conservative IWUI estimate to account for annual variability in the volume of irrigation water applied relative to other water sources.

The WUE gains from this project have been achieved in two steps. Firstly, project investments combined with co-investments made by irrigators, have been used to diagnose opportunities to improve WUE. Secondly, changed irrigator practices and on-farm investments have been required to realise WUE gains. A review of the list of project grants received by irrigators shows a focus on improved irrigation monitoring and changes to the existing irrigation system. For this reason, the upfront costs of achieving IWUI gain have been assessed at a relatively modest $500/ha. Ongoing costs have been assessed at $25/ha. Both sets of cost estimates are drawn from an Impact Assessment of Cotton Research and Development Corporation (CRDC) Water Use Efficiency Investments 2011-15 (Agtrans Research, 2017).

The estimate of the gain in WUE is drawn from project documentation which targeted a minimum 10% improvement in water productivity. While there is no evidence to support realisation of this target it is noted that the estimate is broadly consistent with Agtrans Research (2017) which identified WUE gains for cotton irrigators of up to 7.5% from irrigation practice change and system update.

Counterfactual

It is likely that some improvement in WUE would have occurred in the absence of investment in this project. This improvement has been captured through the use of an attribution factor.

Attribution

The research findings that deliver increased awareness of WUE and improvements in WUE have not occurred in isolation. Irrigators will have been seeking their own solutions to a loss of productivity and an increase in production risk associated with voluntary sale of irrigation water. Other research projects have addressed irrigation. Gaining a definitive estimate of project contribution to increased WUE compared to other initiatives is difficult. In the absence of specific data, a general attribution factor of 50% has been applied to the impact valued to allow for other contributing factors.

Extension

It is assumed that no additional extension has been required. Project costs include an allowance for working with irrigators in the preparation and interpretation of benchmark data and the recommendation of solutions to improve WUE.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table D6.

Table D6: Summary of Assumptions

Variable	Assumption	Source
Benefit: Increased Water Use Efficiency		
Base IWUI.	1.1 bales/ML.	Conservative estimate drawn from CRDC (2012).
Value of additional output – saved water is used to produce additional cotton.	$400/bale.	Conservative estimate drawn from CRDC (2018) which shows 5-year Australian cotton price average to 30 June 2017 of $466/bale.
Cost of picking, cartage and ginning additional output.	$100/bale.	Estimate drawn from CRDC (2018) which shows a cost per hectare of $1,095 and a yield of 11 bales/ha.
Industry applicable area – irrigated cotton grown in the Darling Downs-Maranoa statistical area.	50,816 ha.	ABS (2016a).

Total water usage in the industry applicable area.	345,549 ML.	ABS (2016b) which shows average water use on irrigated Australian cotton farms is 6.8ML/ha. Estimate derived by multiplying 50,816 ha X 6.8 ML.
IWUI gain.	10%.	DAF project documentation which targeted a '*Minimum 10% improvement in water productivity by 30 June 2017*'. Assumption tested using sensitivity analysis.
Upfront costs of achieving IWUI gain (capital and installations).	$500/ha.	Consultant assumption after considering the list of project grants – grants focussed on improved monitoring and changes to the existing irrigation system.
Ongoing costs of achieving IWUI gain (operation and maintenance).	$25/ha.	Consultant assumption after considering the list of project grants – grants focussed on improved monitoring and changes to the existing irrigation system.
Maximum adoption of project outputs in the industry applicable area.	40%	Consultant assumption based on 72 irrigators participating in the project and the total number of cotton irrigators in the Darling Downs-Maranoa statistical area being 169 (ABS 2016a) i.e. approximately 40% participation.
Year of first adoption.	2016	Round 1 project grants provided in 2014-15 in time for the 2016 cotton season.
Year of maximum adoption.	2019	Consultant assumption.
Attribution to the project	50%	Consultant assumption.
Risk Factors		
Probability of output	100%	Consultant assumption based on review of project reports
Probability of usage	90%	Consultant assumption based on review of project reports
Probability of impact	75%	Consultant assumption based on review of project reports

7. Results

All past costs were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP). All benefits after 2016/17 were expressed in 2016/17 dollar terms. All costs and benefits were discounted to 2017/18 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2016/17) to the final year of benefits assumed.

Investment Criteria

Tables D7, D8, D9 and D10 show the investment criteria estimated for different periods of benefits for the total investment, DAF, Australian Government and irrigator investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table D8, has been estimated by multiplying the total PVB by the DAF proportion of real investment (29.6%). Australian Government and irrigator benefits have been determined on the same basis.

Table D7: Investment Criteria for Total Investment in MDBREDP Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	-0.75	3.45	8.32	12.14	15.13	17.48	19.31
Present value of costs ($m)	4.08	4.08	4.08	4.08	4.08	4.08	4.08
Net present value ($m)	-4.83	-0.63	4.24	8.06	11.05	13.39	15.23
Benefit-cost ratio	-0.18	0.85	2.04	2.97	3.71	4.28	4.73
Internal rate of return (IRR) (%)	negative	1.9	15.4	18.4	19.3	19.7	19.8
Modified IRR (%)	negative	1.4	11.4	11.8	11.2	10.6	10.0

Table D8: Investment Criteria for DAF Investment in MDBREDP Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	-0.22	1.02	2.47	3.60	4.48	5.18	5.72
Present value of costs ($m)	1.21	1.21	1.21	1.21	1.21	1.21	1.21
Net present value ($m)	-1.43	-0.19	1.26	2.39	3.27	3.97	4.51
Benefit-cost ratio	-0.18	0.85	2.04	2.97	3.71	4.28	4.73
Internal rate of return (IRR) (%)	negative	0.9	15.4	18.4	19.3	19.7	19.8
Modified IRR	negative	1.4	11.4	11.8	11.2	10.6	10.0

Table D9: Investment Criteria for Aust. Govt. Investment in MDBREDP Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits[(a)] ($m)	-0.47	2.17	5.22	7.62	9.49	10.96	12.11
Present value of costs ($m)	2.56	2.56	2.56	2.56	2.56	2.56	2.56
Net present value ($m)	-3.03	-0.40	2.66	5.05	6.93	8.40	9.55
Benefit-cost ratio	-0.18	0.85	2.04	2.97	3.71	4.28	4.73
Internal rate of return (IRR) (%)	negative	0.9	15.4	18.4	19.3	19.7	19.8
Modified IRR (%)	negative	1.4	11.4	11.8	11.2	10.6	10.0

(a) The PVB attributable to Australian Government investment has been estimated by multiplying the total PVB by the Australian Government proportion of real investment (62.7%).

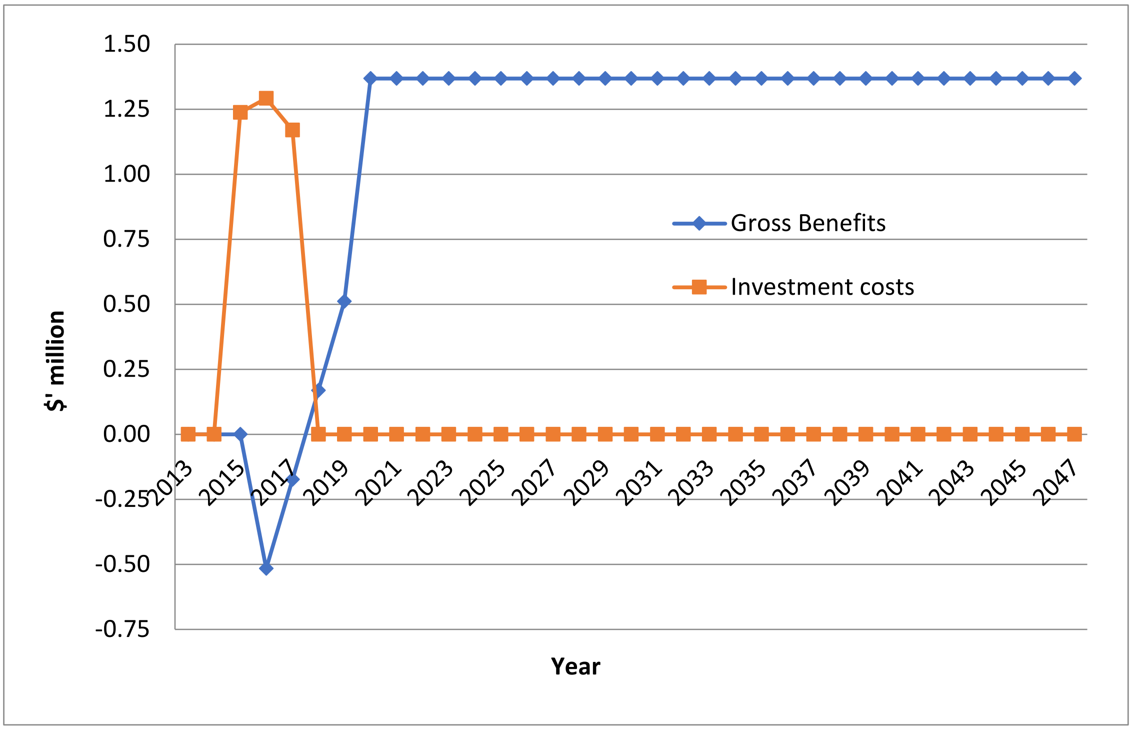
Table D10: Investment Criteria for Irrigator Investment in MDBREDP Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits[(a)] ($m)	-0.06	0.26	0.64	0.93	1.16	1.34	1.48
Present value of costs ($m)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Net present value ($m)	-0.37	-0.05	0.32	0.62	0.85	1.03	1.17
Benefit-cost ratio	-0.18	0.85	2.04	2.97	3.71	4.28	4.73
Internal rate of return (IRR) (%)	negative	0.9	15.4	18.4	19.3	19.7	19.8
Modified IRR (%)	negative	1.4	11.4	11.8	11.2	10.6	10.0

(a) The PVB attributable to irrigator investment has been estimated by multiplying the total PVB by the Irrigator proportion of real investment in the project (7.7%).

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure D1. The investment costs additional to the grants have been subtracted from benefits rather than included as R&D investment costs, in line with CRRDC guidelines. This explains the short period of negative benefits in Figure D1.

Figure D1: Annual Cash Flow of Undiscounted Total Benefits and Costs



Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was 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. Table D11 presents the results. The results showed a moderate sensitivity to the discount rate.

Table D11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	38.29	19.31	11.39
Present value of costs ($m)	3.70	4.08	4.50
Net present value ($m)	34.59	15.23	6.90
Benefit-cost ratio	10.35	4.73	2.53

A sensitivity analysis also was carried out on the increase in WUE realised. Table D12 presents the results. The results show that even if the increase in WUE realised is halved, the project still generates a positive return.

Table D12: Sensitivity to Increase in WUE
(Total investment, 30 years)

Investment Criteria	WUE Delivered by Project		
	5%	**10% (base)**	**15%**
Present value of benefits ($m)	6.47	19.31	32.16
Present value of costs ($m)	4.08	4.08	4.08
Net present value ($m)	2.38	15.23	28.08
Benefit-cost ratio	1.58	4.73	7.87

Finally, a sensitivity analysis was carried out on the cost of adopting changed irrigation practices. Table D13 presents the results. The results show that even with a doubling of both upfront and ongoing cost, results remain strongly positive.

Table D13: Sensitivity to Cost of Changed Irrigation Practices
(Total investment, 30 years)

Investment Criteria	Cost of Implementing Changed Irrigation Practices		
	Upfront is $250/ha Ongoing is $12.5/ha	**Upfront is $500/ha Ongoing is $25/ha (base)**	**Upfront is $1000/ha Ongoing is $50/ha**
Present value of benefits ($m)	22.50	19.31	12.93
Present value of costs ($m)	4.08	4.08	4.08
Net present value ($m)	18.42	15.23	8.85
Benefit-cost ratio	5.51	4.73	3.17

Confidence Ratings and other Findings

The results produced are highly dependent on the assumptions made, some 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 D14). 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 D14: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
High	Medium

Coverage of benefits was assessed as high as most benefits were economic in nature relating to increased WUE contributing to higher productivity and profitability. While some impacts were not valued, their contributions were considered minor compared with those valued. Nevertheless, the investment criteria as provided by the valued benefits are likely to be underestimated to some degree.

Confidence in assumptions was rated as medium. The principal assumptions related to the percentage increase in WUE and the cost of adopting changed irrigation practices. There is some uncertainty around the quantum of these estimates. However, data used are consistent with both project expectations and data used in another impact assessment on WUE prepared for the CRDC.

8. Conclusions

Investment in the MDBREDP Project has delivered increased awareness of WUE and put measures in place that have the potential to improve irrigator WUE in the Queensland portion of the Murray-Darling Basin. Improved WUE has the potential to contribute to higher productivity and enterprise profitability. Irrigated cotton producers in the Balonne and Border Rivers districts are most likely to benefit from this investment.

Given the counterfactual scenario assumed, total funding from all sources for the project was approximately $4.08 million (present value terms). The value of total benefits was estimated at $19.31 million (present value terms). This result generated an estimated net present value (NPV) of $15.23 million, a benefit-cost ratio (BCR) of approximately 4.7 to 1, an internal rate of return of 19.8% and a modified internal rate of return of 10.0%.

Sensitivity analyses carried out on key variables used in the valuation of impacts indicate that, even using conservative assumptions for the increase in water use efficiency and the cost of adopting changed irrigation practices, results remain positive in each case.

The analysis has provided a good example of how the cost of securing environmental gains can be offset with irrigator efficiencies resulting from well designed and targeted research, development and extension.

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Appendix E: An Impact Assessment of DAF Investment into Managing Risks Associated with Range Expansion of Sirex Wood Wasp

Acknowledgments

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Abbreviations

BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
GDP	Gross Domestic Product
GOS	Gross Operating Surplus
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
NSCC	National Sirex Coordination Committee
PVB	Present Value of Benefits
PVC	Present Value of Costs
QLD	Queensland
R&D	Research and Development
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
TTP	Trap Tree Plot
USC	University of the Sunshine Coast

Executive Summary

The Report

This report presents the results of an impact assessment of an investment by the Department of Agriculture and Fisheries Queensland (DAF) in a research project to better manage the risks associated with potential spread of the Sirex wood wasp in Queensland forestry softwood plantations. The five-year project was jointly funded from 1 July 2012 to 30 June 2017 by DAF, the University of the Sunshine Coast (USC), the National Sirex Coordination Committee (NSCC) and HQPlantations P/L.

Methods

The project was first analysed qualitatively using a logical framework that included project objectives, activities and outputs, and actual and potential outcomes and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts were then valued.

Benefits were estimated for a range of time frames up to 30 years from the last year of investment in the project (2016/17). Past and future cash flows expressed in 2016/17 dollars were discounted to the year 2017/18 using a discount rate of 5% to estimate the investment criteria.

The cost-benefit analysis (CBA) was conducted according to the Impact Assessment Guidelines of the Council of Rural Research and Development Corporations (CRRDC) (May, 2014).

Impacts

The project contributed an increased understanding of the Sirex wasp, its symbiotic fungus and its biocontrol nematode, their interactions with other biota and methods of monitoring and surveillance. Recommendations were made for improvements to current practices and industry management of the wasp for Queensland as well as for the remainder of Australia.

These recommendations and associated management responses will build an increased capacity to monitor and manage the wasp in the future and lead to potential cost savings from any future incursions to both Queensland's softwood plantations as well as those in southern Australia.

The major impact identified was the potential future reduction in the damage inflicted by future outbreaks of the Sirex wasp. However, some social and environmental impacts were identified but not valued. It is expected that both the Queensland and southern Australian pine forest industries and their input and product supply chains will be the primary beneficiaries of the investment.

Investment Criteria

Total funding from all sources for the project was approximately $0.78 million (present value terms). The value of total benefits was estimated at $2.27 million (present value terms). This result generated an estimated net present value (NPV) of $1.49 million, and a benefit-cost ratio (BCR) of approximately 2.9 to 1.

1. Evaluation Methods

The evaluation approach follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations (RDCs), Cooperative Research Centres (CRCs), State Departments of Agriculture, and some Universities. This impact assessment uses cost-benefit analysis (CBA) as its primary tool. The approach includes both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Rural Research and Development Corporations (CRRDC) (May 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and potential and actual outcomes and impacts. The principal economic, environmental and social impacts are then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, or the likely low relative significance of the benefit compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

The Sirex wood wasp (*Sirex noctillio*) invades pine plantations world-wide and has been present in Australia since being introduced in 1952 to Tasmania. The wasp has been spreading in other regions of southern Australia since that time.

Pine plantation timber losses in Australia from three previous Sirex outbreaks have been estimated by Cameron et al (2018). These ranged from $7.8 million for the Tasmanian outbreak (1952-1962), $355,000 for an outbreak in Gippsland in Victoria (1972-1979) and $23.8 million for the Green Triangle outbreak (1987-1990). The Green Triangle is a forest estate area located in the South East of South Australia and South Western Victoria.

The damage to trees is through female wasps drilling holes into host trees and injecting fungal spores (*Amylostereum areolatum*) together with a phytotoxic mucus into the hole. The wasps then deposit eggs into adjacent drill holes in the tree. The fungus kills the tree by disrupting its vascular system (DAF, 2018). The Sirex larvae from the wasp eggs feed on the fungus as it spreads, pupate, wasps emerge and then a new life cycle commences.

The wasp has been detected since 2009 in pine trees near the NSW border in the Stanthorpe region of Queensland. The large and significant pine plantations further north in the southern parts of Queensland (Beerburrum, Toolara) are suitable for establishment and are in danger of infestation by the wasp. These forests are owned and managed by HQPlantations P/L who manage 340,000 hectares of forest throughout the state of Queensland including softwood and hardwood plantations. Of this area approximately 195,000 ha are softwood species. The softwood area includes the small Passchendaele forest of 5,400 ha near the NSW border, but the majority of the Queensland softwood pine plantation is further north with hybrid pines covering about 146,000 ha and native hoop pine (*Araucaria sp.*) about 44,000 ha.

Rationale for the Investment

Unthinned stands of pines and stressed or injured trees are particularly susceptible to the Sirex wasps, so thinning and the maintenance of heathy forests are particularly important for management protection (DAF, 2018).

Effective management of the wasp for *Pinus radiata* in southern Australia has been manifest via biocontrol with a nematode, originally named *Deladenus siricidicola.* This nematode has a fungal feeding stage as well as a parasitic stage. The nematode has been renamed *Beddingia siricidicola*, after the scientist (Bedding) who discovered the organism; this was the first nematode that has been used successfully in the control of an insect pest. The nematode can achieve parasitism in the wasp by infecting the gonads of the adult female wasp and suppressing egg development, as well as by entering and disrupting the eggs. The Sirex female can still lay these eggs and in doing so spreads the nematodes to new trees (CSIRO, https://csiropedia.csiro.au/sirex-wasp-eradication/). However, natural spread has had to be supplemented by forest management practices. Trap Tree Plots (TTPs) are used to attract wasps by stressing trees with herbicides, and them felling them and inoculating them with the parasitic nematodes.

Also, the higher temperatures in subtropical areas in Queensland potentially could influence survival of the nematode and there were concerns that nematodes may not successfully parasitise eggs under Queensland conditions.

There was a recognised need therefore to better understand how subtropical conditions as well as *Pinus taeda* and the hybrid pine species used in Queensland (F1 and F2 hybrids of *Pinus elliottii var. elliottii* (Pee) and *Pinus caribaea var. hondurensis* (Pch)) would interact with the biology and behaviour of the Sirex wasp. In addition, there was a need to assess whether the parasitic impact of the nematode used to date in the south will provide effective control under subtropical conditions.

The five-year project was jointly funded by the National Sirex Coordinating Committee (NSCC), the University of the Sunshine Coast (USC), the Department of Agriculture and Fisheries (DAF) Queensland, and HQPlantations P/L. The Queensland Forest and Timber industry Research, Development and Extension (RD&E) Advisory Committee, the NSW Department of Primary Industries and the Forestry Corporation of NSW were also involved in the project.

3. Project Details

Summary

Project Title: Managing Risks Associated with Range Expansion of Sirex Wood Wasp Project Code: USC 2015000417 Research Organisation: University of the Sunshine Coast, Queensland (USC) Principal Investigators: Helen Nahrung, USC Manon Griffiths, DAF Period of Funding: July 2012 to June 2017

Objectives

The overarching objectives of the project were:

1. To determine the susceptibility of key pine taxa, particularly F2 hybrids Pch x Pee and hoop pine to Sirex, Amylostereum, and, in particular, the biocontrol nematode.
2. To determine the impact of subtropical conditions on the lifecycle of Sirex and its obligate fungus, and the potential efficacy of existing biocontrol agents.
3. To assess commercial nematode inoculation success annually, including examining the influence of type and rate of herbicide application, the timing of trap tree plot establishment and determining potential negative interactions with the ips bark beetle and its associated bluestain fungus under subtropical conditions.
4. To detect new and emerging pest species with potential significant management and biosecurity implications through intensive surveillance of Queensland pine trees.

Logical Framework

Table E1 provides a description of the project in a logical framework developed for the project.

Table E1: Logical Framework for Project

Activities and Outputs	*Steering Committee* • A Steering Committee (SC) representing the various funding partner organisations was established and met six monthly, until the end of the project in 2017. *Wasp population studies* • Early in the project Sirex wasps from the Passchendaele State Forest in southern Queensland (near the NSW border) were collected, measured and dissected to record sex ratios, as well as size and parasitoid infection rates. A subset of female wasps was examined to establish the proportion of eggs infected with nematodes and the number of nematodes in each egg. • Panel traps baited with a Sirex lure were installed in the Passchendaele forest and all wasps collected were measured and dissected; this was to assess seasonal population fluctuations and, through comparison, the possible presence of a second generation of wasps; it was postulated that this could potentially occur more readily in subtropical regions compared to temperate regions. • Both Sirex and nematodes performed better in *P. radiata* than in *P. taeda*, possibly due to higher *Ips grandicollis* severity in *P. taeda* affecting nematode survival and spread; *Ips grandicollis* is a bark beetle that has a disruptive effect on the wasp and the nematode. • Assessment and comparison of survival and spread of the free-living form of the biocontrol nematode were completed for *P. taeda* in Passchendaele (*P. taeda* was a known host growing in the Sirex distribution area), as well as for the pine hybrids in Beerburrum where the host status was unknown as trees were growing outside the current area of distribution of Sirex. • Standing and felled trees were inoculated in 2012 with the nematode and ongoing assessments undertaken.

	• The overall nematode parasitism rate of Sirex adults emerging from inoculated billets varied between seasons. • TTPs are used to attract wasps by stressing trees with herbicides and felling them and inoculating them with the parasitic nematodes. • Trap tree strike rate was low and parasitism rates were highly variable. • Sirex and nematodes both performed better in *P. radiata* than in *P. taeda*, possibly due to higher *Ips grandicollis* severity in P. taeda. • The low and variable parasitism results were of concern. The background parasitism rate of field-collected Sirex, and those emerging from uninoculated billets was less than 5%. No females were infected giving an effective background parasitism rate of zero. • This was a major concern following three seasons of nematode inoculations to the area and suggested that the nematode may not be as effective in Queensland as in southern states. • The performance of nematodes in hybrid pine was tested under field and laboratory conditions but with limited success. For the only occasion on which nematodes were recovered from inoculated billets, there was no significant difference in numbers between hybrids and *P. radiata*. Overall however, more nematodes were recovered from *P. radiata*, supporting previous results that nematodes show lower survival in hybrid pine. • Overall, the results suggested that the parasitic nematode may not be as effective in hybrid pine as it is for *P. radiata.* *Use of Trap Tree Plots* • TTPs are used operationally in Sirex management both in Australia and overseas. As trees that are weak or stressed are most attractive to the wasps (as opposed to healthy trees), TTPs are used to attract wasps by stressing trees with herbicides, felling them and inoculating them with the parasitic nematodes. • In case TTPs need to be used in future Queensland management of Sirex, research activities were undertaken to assess TTP management and effectiveness under Queensland conditions. • Trials were established to ascertain whether existing best-practice TTP establishment processes would translate effectively to subtropical conditions and hybrid tree taxa. Data were analysed to compare tree decline and mortality rates within and between sites and taxa and relate them to tree parameters. • *P. radiata* performance was superior to *P. taeda,* both as a host for Sirex and in supporting nematode parasitism. • Planting *P. radiata* for use as TTPs in the future was considered as an alternative but it was noted that such use could result in higher Sirex populations within the target area. Despite this risk, *P. radiata* is still likely to be used in TTPs in Queensland. • Trials were established in *P. taeda* and *P. radiata* at Passchendaele and in hybrid pine species at Beerburrum in Queensland and Whiporie (N NSW); the trials explored the type and rate of herbicide applications for different softwood species and sizes. • Despite no significant difference between the various herbicide treatments trialled in 2014/15 in the average number of parasitised females emerging per TTP, several correlates of Sirex and nematode success were impacted by herbicide timing.

	• On balance, a Glyphosate 0.5mL January treatment appeared the best across both taxa. The use of 1.0 mL in the 2015/16 trials in Passchendaele, Beerburrum and NSW resulted in rapid decline and death of poisoned trees, further supporting a lower dose. Because smaller diameter trees declined faster and were associated with higher Ips and bluestain scores, selecting higher diameter trees was thought to improve TTP success. • One project output was a requirement that felled trap trees needed to be protected from heat as exposed conditions were demonstrated to support very low or zero emergence of Sirex (Helen Nahrung, pers. comm., 2018). • The definition of best practice TTP establishment for the subtropical areas is still indeterminate due to the variability of results, both within and between locations (Helen, Nahrung, pers. comm., 2018). • While best operational practices for *P. taeda* in southern QLD have been improved, further research is necessary for the hybrid pine estate, should control methods be required in future. • The DAF/USC findings led to a national audit of current Sirex management practices as many of the issues reported by the project were also experienced in temperate pine forests. • The national audit led to further follow-up studies being commissioned to develop more effective protocols for TTPs (Ian Last, pers. comm., 2018). *Temperature and climatic conditions* • Temperature conditions were explored to ascertain how subtropical conditions would influence Sirex development. • Controlled-environment chambers were established to examine the influence of differing climatic conditions on Sirex survival, development and nematode parasitism rates for hybrid pine compared to *P. radiata*. • Results showed that hybrids were less-preferred for oviposition in a choice scenario but were accepted in a no-choice scenario; hybrids yielded larger, but fewer, adults. *Vulnerability of the Queensland Species of Pinus* • Subtropical hybrid pines were considered to be at lower risk for losses to Sirex than pines in other states • However, both *P. taeda* and hybrids were both considered suitable hosts for Sirex but were less preferred than *P. radiata*. *Alternative Control Strategies* • As *P. taeda* was not high performing as a TTP host, and with a lack of confidence in effective parasitic nematode survival and spread in hybrid pines, it was concluded that alternative control strategies should be addressed. • The parasitoid wasp *Ibalia leucospoides* offered potential to contribute to Sirex management. Releases of between 300 and 350 Ibalia wasps sourced from NSW and Victoria were conducted in 2015/16. The impact of these wasps is currently being monitored.

	New Pest Surveillance • Surveillance to detect new and emerging pest species in the Queensland pine forests was carried out as part of the project. Surveillance records serve as a reliable record of the presence of new and exotic species, as well as providing important baseline data on the distribution and abundance of existing insects within the plantation. • A total of 5,290 specimens from 27 species were identified. These included 13 native species and 13 established exotic species, and one newly collected exotic, the Granulate Ambrosia beetle (*Xylosandrus crassiusculus*). Assessment of past Sirex trap contents revealed this pest has been present in SE Queensland since at least 2011. *Recommendations* Recommendations were made at the end of the project, including those associated with: o A national audit of TTP practices based on the project results and trialling of any revised TTP establishment techniques used in Australia including herbicide type, timing and dose for use with TTPs, and tree selection and management of tree felling in use of TTPs. The results of the audit are expected to inform revision of the NSCC Sirex Strategy. o Continued monitoring and vigilance in areas where Sirex is not present. o Alternative control methods to the current parasitic nematode. o Monitoring of other exotic pests in pine plantations. *Extension and Industry Involvement* • During the project, project researchers received valuable support and interaction from HQPlantations' staff and field officers. • Towards the end of the project, researchers conducted a 2-day training session for HQPlantations' staff on wasp dissection and nematode recognition and worked closely with them to establish field trials and assemble data. *Communications* • Various communication activities were undertaken during the project; these serviced different purposes and targets included industry, the public and media, Ministerial briefings, workshops, international conference presentations, and both refereed and informal publications.
Outcomes	*Queensland Hybrid Pine Plantation Vulnerability and Risk* • The project has provided improved knowledge of the susceptibilities of the key Queensland plantation pine taxa at risk and the suitability of different locations for potential nematode use (Ian Last, pers. comm., 2018). • Hybrid pines are readily accepted by female Sirex for laying eggs. • The level of perceived of risk of Sirex to hybrid pines is lower now than before the project commenced; however, the risk of control measures

	being ineffective if Sirex establishes in Queensland is higher than before (Helen Nahrung, pers. comm., 2018). • Most importantly, the project received very positive feedback from industry regarding its contribution to furthering the understanding of Sirex in the subtropics. • No Sirex wood wasps have been detected in Beerburrum or Toolara forests to date. In early 2018 the wasp was detected in the small Pechey and Geham estates, about 135 km from Passdhendaele; however, there is no evidence of it in the hybrid pines in those forests (Helen Nahrung, pers. comm., 2018). *Efficacy of Parasitic Nematode in Queensland* • Nematode survival is lower in hybrids than for *P. radiata* and therefore there must be some doubt about the nematode's ability to spread naturally in subtropical forests. • There is also some uncertainty about the ability of management to successfully assist the spread of the nematode via TTPs. • The finding that the nematode was less effective in hybrid pines has led to the suggestion that *P. radiata* could be planted for TTP establishment in Beerburrum and Passchendaele forests. • The project finding concerning the low efficacy of the existing nematode in Queensland plantations also has raised the importance of identifying other potential nematode types that may be more effective in subtropical conditions and hybrid taxa (Ian Last, pers. comm., 2018). *Use of Tree Trap Plots* • TTPs are likely to be used by HQPlantations if Sirex enters the Beerburrum and Toolara softwood forest areas • The NSCC is currently reviewing their National Sirex Control Worksheets and considering increasing the minimum tree diameter for TTP establishment from 10 cm to 15 cm based on the results of the project, as the larger diameter trees increase the Sirex yield (Helen Nahrung, pers. comm., 2018). • HQPlantations is likely to continue monitoring for Sirex movement into the Beerburrum estate using static traps, and they are considering pre-emptive planting of *P.radiata* to use as TTPs if required in the future (Helen Nahrung, pers. comm., 2018). • Best practice herbicide management for developing TTPs has been determined for Queensland pine taxa. • As a result of the project, recommendations have been developed by Queensland industry that reduce the herbicide costs for using TTPs. *New pest discovery* • Biosecurity Queensland reviewed future actions regarding the project discovery of the Ambrosia beetle and concluded that it is non-eradicable due to its current distribution and duration of establishment (Helen Nahrung, pers. comm., 2018). *Ibalia wasp*

	• The Ibalia wasp was established during the course of the project and parasitism levels have been monitored; a recommendation has been made to industry on its continued release (Helen Nahrung, pers. comm., 2018). • Cooperative relationships with groups in the south have been developed to ensure rapid introduction of Ibalia if so required in the future.
Impacts (Potential)	• There have been no significant industry impacts from the project to date, either for subtropical or temperate areas of Australian softwoods. • However, the project has contributed significantly to the capacity to respond more effectively to any future Sirex outbreaks in both temperate and subtropical areas. • Future impacts of Sirex on softwood industries could be reduced by both improved current practices and alternative new management strategies identified by the project, for example: o Contribution to improved future management of Sirex if Sirex establishes in hybrid softwood plantations in Queensland (e.g. improved TTP effectiveness), leading to a slower rate of spread or less damage to the plantations. o Contribution to improved management of future Sirex outbreaks of Sirex in temperate areas of Australia through improved TTP effectiveness. o Increased emphasis on research and development of alternative nematode types that may be more effective than the current nematode used (particularly in subtropical climates). o Increased emphasis on potential alternative management controls to TTPs for control of Sirex such as other parasitic wasps. o Reduced impact on downstream industries including processing and manufacturing industries, and regional softwood forest communities.

4. Project Investment

Nominal Investment

Table E2 shows the annual investment (cash and in-kind) for the project supported by DAF, USC, NSCC, HQPlantations, and Forest Corporation of NSW.

Table E2: Annual Investment in Project (nominal $)

Contributor	2012/13	2013/14	2014/15	2015/16	2016/17	Totals
DAF ($)	12,500	12,500	18,750	100,000	100,000	243,750
USC ($) (a)	21,300	21,300	15,050	8,800	8,800	75,250
NSCC ($) cash	25,000	25,000	25,000	25,000	25,000	125,000
HQPlantations ($) (b)	30,000	30,000	50,000	40,000	40,000	190,000
Forest Corporation-NSW ($) (b)	0	0	0	25,000	0	25,000
Totals ($)	88,800	88,800	108,800	198,800	173,800	659,000

Source: Helen Nahrung and Manon Griffiths
(a) Includes cash and in-kind and an overhead of $8,800 per annum to cover administration and finance etc.
(b) Includes in kind only

Program Management Costs

For the DAF investment, the management and administration costs for the project are already built into the nominal $ amounts appearing in Table E2. The salary multipliers that had been used (Wayne Hall, pers. comm., 2017) were:

- 2.85 multiplier for salaries contributed by DAF
- 1.85 multiplier for salaries paid for by other parties

For the USC investment, an administration/management cost for managing the funding has already been included in the USC contribution in Table E2 as stated in the Table footnote.

For other funders (Forest Corporation NSW and HQPlantations), the management and administration multiplier was assumed to be 1.1 and was applied to the respective amounts in Table E2.

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 dollars using the Implicit GDP Deflator index (ABS, 2017). No additional costs of extension were included as the project already encompassed an extension component and involved a high level of industry involvement via HQPlantations.

5. Impacts

The principal potential impacts from the positive results exhibited by the project include:

- Capacity building, integration of effort, stronger linkages and networks for the future management of the Sirex wasp throughout Australia.
- An expected reduction in damage costs of any Sirex outbreak in future throughout Australia due to:
  - greater emphasis on the protocols for TTP best management practices resulting in their greater efficacy
  - identification and use of new species of parasitic nematodes that may be more efficacious in controlling Sirex, especially in the subtropics
  - an increased effort in the use of other alternative controls, such as parasitic Ibalia wasps, to control Sirex

Table E3 provides a summary of the potential types of impacts categorised into economic, environmental and social impacts.

Table E3: Triple Bottom Line Categories of Potential Impacts from the Project

Economic	• Reduction in potential softwood production damage and control costs if an outbreak of Sirex occurs either in subtropical or temperate softwood plantations
Environmental	• Some minor reduction in the expected loss of environmental services delivered by pine forests if an outbreak of Sirex occurs (e.g. carbon sequestration)
Social	• Potential for reduced negative regional impacts due to reduced softwood production (regional income and employment) • Elevated scientific and research capacity in plantation forest biosecurity

Public versus Private Impacts

Most impacts identified in this evaluation are industry related and therefore the benefits are generally considered to be private benefits. Some public benefits may be delivered in so far as softwood plantations in some states are located on government owned land that is leased to private interests (e.g. Queensland) or where governments have sold harvesting rights (e.g. South Australia). Also, some minor public benefits have been delivered, including a social benefit in the form of a reduction in regional community negative spill-overs from increased pine forest production.

Distribution of Private Impacts

In the case of private impacts, it can be assumed that the benefits from the project findings will be distributed between participants along the commercial forestry supply chains, both input supply and product processing and markets, including final timber consumers.

Impacts on other Australian industries

Because of the nature of the impacts, it is assumed that the impacts will apply to all Australian pine forests, *Pinus Radiata* in the southern states and Southern Pine in Queensland (both *Pinus Taeda* and hybrids)

Impacts Overseas

It is possible that overseas countries with plantation pine areas may benefit also from the research where it results in improved management practices for control of the Sirex wood wasp.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table E4. The Sirex wasp project contributes primarily to Rural RD&E Priorities 1, 2 and 4 and to Science and Research Priority 1.

Table E4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities[(a)] (est. 2015)	**Science and Research Priorities[(b)] (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food (includes fibre) 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

(a) Source: Commonwealth of Australia (2015)
(b) Source: Office of the Chief Scientist (2015)

The Queensland Government's Science and Research Priorities, together with the four decision rules for investment that guide evaluation, prioritisation and decision making around future investment, are reproduced in Table E5. The project addressed Queensland Science and Research Priorities 1 and 3. In terms of the guides to investment, the project is likely to have a real future impact through improved confidence in the management of the sustainability of softwood plantations, both in Queensland and throughout Australia. The project was supported and funded by others external to the Queensland Government and had a distinctive angle as the timber industries in both Queensland and elsewhere in Australia will be the primary recipients of the impacts.

Table E5: Queensland Government Research Priorities

Queensland Government	
Science and Research Priorities (est. 2015)	**Investment Decision Rule Guides (est. 2015)**
1. Delivering productivity growth 2. Growing knowledge intensive services 3. Protecting biodiversity and heritage, both marine and terrestrial 4. Cleaner and renewable energy technologies 5. Ensuring sustainability of physical and especially digital infrastructure critical for research 6. Building resilience and managing climate risk 7. Supporting the translation of health and biotechnology research 8. Improving health data management and services delivery 9. Ensuring sustainable water use and delivering quality water and water security 10. The development and application of digitally-enabled technologies.	1. Real Future Impact 2. External Commitment 3. Distinctive Angle 4. Scaling towards Critical Mass

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were conducted on variables that were considered key drivers of the investment criteria or that were considered particularly uncertain.

Potential Damage to Australian Plantations

The estimated current cost of Sirex to southern Australian softwood plantations has been estimated previously at $78 million per annum (Bedding and Iede, 2005). Given a Queensland plantation pine area of 195,000 ha and a total Australian pine area of 841,000 ha, if an equivalent cost estimate was transferred to Queensland, the equivalent impact cost for Queensland and Australia would be $18 m per annum and $96 m per annum respectively.

However, the estimate appearing in the Bedding 2005 publication appears to be based on a 1992 personal communication “that, in the absence of control agents, Sirex had the potential to cause an average loss of timber from the total pine plantations in Australia valued at between US$16 million, and $60 million per year”.

Subsequent estimates of the actual value of timber loss from past Australian outbreaks appear significantly lower. Pine plantation timber losses in Australia from three previous Sirex outbreaks have been estimated by Cameron et al (2018). These ranged from $7.8 million for the Tasmanian outbreak (1952-1962), $355,000 for an outbreak in Gippsland in Victoria (1972-1979) and $23.8 million for the Green Triangle outbreak (1987-1990). Specific assumptions for the magnitude and frequency of future outbreaks are provided in Table E7.

Damage Reduction due to Findings from the USC Project

Sirex cannot be eradicated, only managed to reduce its spread and the costs of timber losses. The USC project has provided some directions for future management and control including:

- greater emphasis on the protocols for TTP best management practices resulting in their greater efficacy
- identification and use of new species of parasitic nematodes that may be more efficacious in controlling Sirex, especially in the subtropics
- an increased effort in the use of other alternative controls, such as parasitic Ibalia wasps, to control Sirex

There are uncertainties associated with each of these strategies in terms of their future outputs, usage given proven advantageous outputs, and impacts given usage. Table E6 provides some subjective assessments of these uncertainties that are used jointly in the risk assumptions used later in the impact valuation.

Table E6: Subjective Assessments of Uncertainties

Strategy	**Output uncertainty**	**Usage uncertainty given positive output**	**Impact uncertainty given usage**
Changed TTP protocols	Low	Low	Medium
New species of nematodes	High	Low	Medium
Other parasitic wasps	High	Low	Medium
Joint strategy	Medium	Low	Medium

Impacts not Valued

Not all impacts identified in Table E3 could be valued in the assessment.

The extent of environmental services saved by preventing or minimising future outbreaks of Sirex would be expected to be minimal (water quality, biodiversity, carbon sequestration) There may be some lost savings avoided via increased carbon sequestration, but this is considered negligible. Further, Australian cost-benefit analyses require a boundary to be drawn around the economic area of interest, usually the Australian border. As greenhouse gases circulate internationally, any increase or reduction in Australian carbon emissions would not necessarily impact within the Australian border. Australian interests would be more aligned with servicing international agreements.

The social impacts identified but not valued included:

- Reduced negative regional impacts such as regional income and employment
- Increased scientific and research capacity in plantation forest biosecurity

These two social impacts were not valued due to lack of time and resources and the greater uncertainty of assumptions required in estimating such secondary impacts.

Attribution

The USC findings and their potential usage have occurred in close cooperation with industry. However, an attribution factor has been included in the valuation on the basis that the future strategies emanating from the project may have been pursued anyway.

Additional Costs

Additional costs for implementing the strategies identified in the USC project have been allowed for in the valuation. Such costs have been assumed to contribute 10% of the gross benefit estimated as the Sirex damage cost reduction. The current cost of managing Sirex at $0.57 per ha is assumed unchanged.

Extension

As extension and integration between those Australian interests involved with Sirex has been a component of the project throughout the life of the project, it is assumed that adoption of successful strategies will not require additional extension resources to those already undertaken.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table E7.

Table E7: Summary of Assumptions

Variable	Assumption	Source
General		
Annual cost of Sirex to pine plantations from previous large-scale outbreak	$8 million per annum	Agtrans Research (subjectively estimated based on information in Cameron et al (2018))
Probability of a Sirex outbreak post 2017/18	5% per annum	Agtrans Research based on the frequency of past significant outbreaks of Sirex
Duration of outbreak	5 years	Agtrans Research based on information on periods of previous outbreaks reported in Cameron et al (2018)
First year of potential impact	2019/20	Agtrans Research
Impact of USC Managing Risks Project		
Potential cost savings due to more effective TTPs and additional alternative control methods	30% per annum	Agtrans Research
Risk Factors		
Probability of output	50%	Agtrans Research
Probability of usage	100%	
Probability of impact	75%	
Costs of Future Strategies		
Additional cost to agencies and forest operators	10% of benefits estimated	Agtrans Research

Attribution		
Attribution to USC Project	90% on basis that such strategies would have been unlikely to have been pursued without the project	Agtrans Research

7. Results

All past costs were expressed in 2016/17 dollars using the Implicit Price Deflator for Gross Domestic Product (GDP). All benefits after 2016/17 were expressed in 2016/17 dollars. All costs and benefits were discounted to 2017/18 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2016/17) to the final year of benefits assumed.

Investment Criteria

Tables E8, E9 and E10 show the investment criteria estimated for different periods of benefits for the total investment and the DAF and USC investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table E9, has been estimated by multiplying the total PVB by the DAF proportion of real investment (36.5%). Likewise, the PVB attributed to the USC investment in Table E10 has been estimated in a similar manner (11.4%).

Table E8: Investment Criteria for Total Investment in USC Project 2015000417

Investment criteria	Number of years from year of last investment						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.19	0.81	1.32	1.71	2.03	2.27
Present value of costs ($m)	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Net present value ($m)	-0.78	-0.59	0.03	0.54	0.94	1.25	1.49
Benefit-cost ratio	0.00	0.24	1.04	1.69	2.21	2.61	2.92
Internal rate of return (IRR) (%)	negative	negative	5.4	10.2	11.9	12.6	12.9
Modified IRR (%)	negative	negative	5.4	9.0	9.5	9.3	9.0

Table E9: Investment Criteria for DAF Investment in Project USC 2015000417

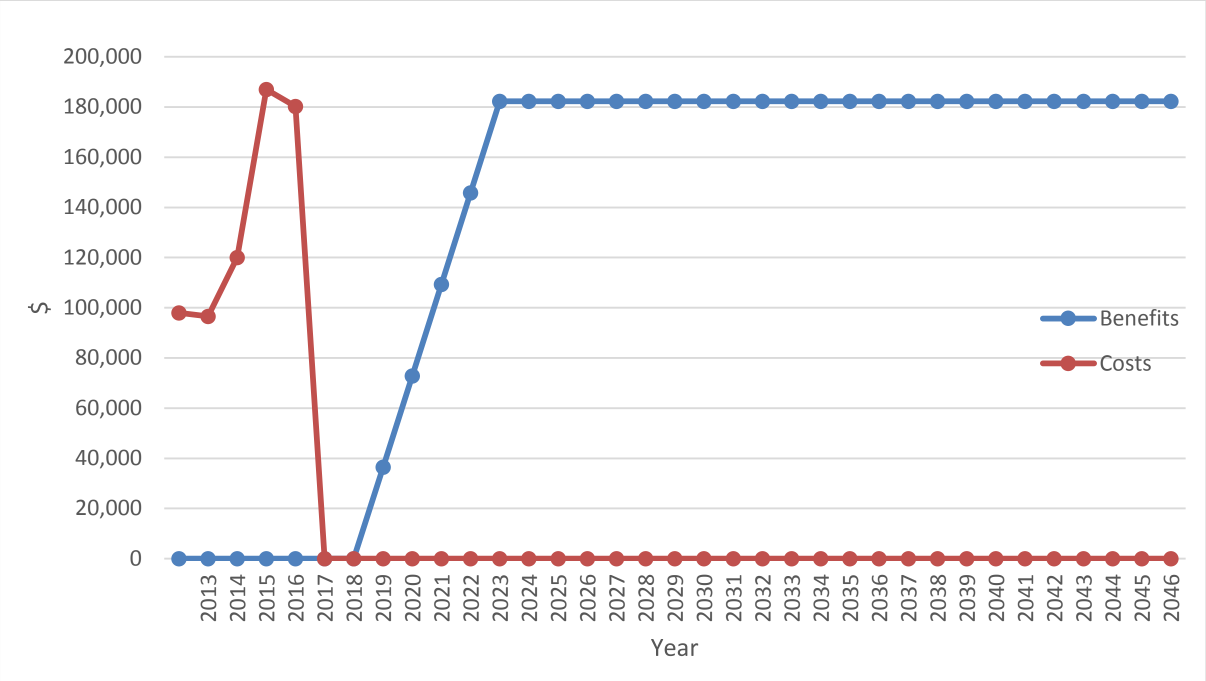
Investment criteria	Number of years from year of last investment						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.07	0.29	0.48	0.63	0.74	0.83
Present value of costs ($m)	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Net present value ($m)	-0.27	-0.21	0.02	0.21	0.35	0.47	0.55
Benefit-cost ratio	0.00	0.25	1.07	1.75	2.28	2.70	3.03
Internal rate of return (IRR) (%)	negative	negative	5.9	11.0	12.7	13.4	13.7
Modified IRR	negative	negative	2.6	7.1	8.1	8.2	8.0

Table E10: Investment Criteria for USC Investment in Project USC 2015000417

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.02	0.09	0.15	0.19	0.23	0.26
Present value of costs ($m)	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Net present value ($m)	-0.09	-0.07	0.00	0.06	0.10	0.14	0.17
Benefit-cost ratio	0.00	0.23	0.99	1.62	2.11	2.50	2.80
Internal rate of return (IRR) (%)	negative	negative	5.0	9.4	11.0	11.7	12.1
Modified IRR (%)	negative	negative	5.0	8.6	9.2	9.1	8.8

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure E1.

Figure E1: Annual Cash Flow of Undiscounted Total Benefits and Total Investment Costs



Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was 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. Table E11 presents the results. The results showed a moderately high sensitivity to the discount rate. The high sensitivity is because many of the benefits may occur well into the future as the SIrex wasp is unlikely to be eradicated, outbreaks, and the benefits from outbreaks due to the project, may occur well into the future.

Table E11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	4.74	2.27	1.27
Present value of costs ($m)	0.68	0.78	0.88
Net present value ($m)	4.06	1.49	0.38
Benefit-cost ratio	6.95	2.92	1.43

A sensitivity analysis also was carried out on the likely damage costs from any future Sirex outbreak. Table E12 presents the results. The results showed a high sensitivity to the damage costs that will be affected by such factors as area, severity, and age of trees affected.

Table E12: Sensitivity to Outbreak Damage Costs
(Total investment, 30 years)

Investment Criteria	Total Damage Costs of an Outbreak		
	Low (50% Base)	**Base ($8m)**	**High (150% Base)**
Present value of benefits ($m)	1.14	2.27	3.41
Present value of costs ($m)	0.78	0.78	0.78
Net present value ($m)	0.36	1.49	2.63
Benefit-cost ratio	1.46	2.92	4.38

Finally, a sensitivity analysis was carried out on the probability of an outbreak in any one year commencing in the 2019/20 year (Table E13). Again, the sensitivity results show a significant sensitivity to the assumed risk of a Sirex outbreak.

Table E13: Sensitivity to Annual Probability of an Outbreak
(Total investment, 30 years)

Investment Criteria	Annual Probability of an Outbreak		
	Low (2%)	**Base (5%)**	**High (10%)**
Present value of benefits ($m)	0.91	2.27	4.54
Present value of costs ($m)	0.78	0.78	0.78
Net present value ($m)	0.13	1.49	3.76
Benefit-cost ratio	1.17	2.92	5.85

Confidence Ratings and other Findings

The results produced are highly dependent on the assumptions made, some 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 E14). 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 E14: Confidence in Analysis of Project

Coverage of Benefits	**Confidence in Assumptions**
Medium	Low

The coverage of benefits was rated as medium, whereas the confidence in assumptions was rated as low, largely because of the difficulty of making sound assumptions concerning the expectations of the frequency, size and damage costs of any future outbreak.

8. Conclusions

The investment in project USC 2015000417 commenced with a focus on better managing any potential spread of the Sirex wood wasp in Queensland forestry softwood plantations. The project has provided two major impacts including capacity and network building and strategies to reduce damage costs from any future Sirex wood wasp outbreaks. These impacts will apply not only to Queensland plantations but also to plantations in temperate southern Australia. The strategies include potentially improved TTP protocols resulting in higher efficacy of spread of the parasitic nematode used to control the wasp. Other avenues for potential SIREX wasp control have also been highlighted including the potential for improved nematode strains and the use of other parasitic wasp species.

Total funding from all sources for the project was approximately $0.78 million (present value terms). Using best-bet assumptions, the value of total benefits was estimated at $2.27 million (present value terms). This result generated an estimated net present value (NPV) of $1.49 million, a benefit-cost ratio (BCR) of 2.92 to 1, an internal rate of return of 12.9% and a modified internal rate of return of 9.0%.

Sensitivity analyses were carried out on key variables affecting the value of impacts. These variables included the frequency and severity of any future Sirex outbreaks. The results demonstrated the importance of such assumptions to the future value of the research investment.

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Appendix F: An Impact Assessment of DAF Investment into Protecting Queensland's timber resource from pest and disease incursions

Acknowledgments

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Wayne Hall, Executive Director, Agri-Science Queensland, Department of Agriculture and Fisheries

Helen Nahrung, University of the Sunshine Coast

Abbreviations

AA	Approved Arrangements
ABS	Australian Bureau of Statistics
BCR	Benefit-Cost Ratio
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
DAF- HFS	Department of Agriculture and Fisheries - Horticulture & Forestry Science
DAFF	Department of Agriculture, Fisheries, and Forestry
DAWR	Department of Agriculture and Water Resources
GDP	Gross Domestic Product
GOS	Gross Operating Surplus
HRST	High-Risk Site Trapping
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
NSW	New South Wales
PQD	Post-Quarantine Detections
PVB	Present Value of Benefits
PVC	Present Value of Costs
QAP	Quarantine Approved Premises
R&D	Research and Development
RD&E	Research, Development and Extension
USC	University of the Sunshine Coast

Executive Summary

The Report

This report presents the results of an impact assessment of an investment by the Department of Agriculture and Fisheries Queensland (DAF) in a research project to develop methods for monitoring high-risk sites for pine forest pest and disease incursions to ensure pest and diseases do not become established within Southern Pine plantations. The three-year project was jointly funded from February 2016 to November 2017 by DAF and the University of the Sunshine Coast (USC).

Methods

The project was first analysed qualitatively using a logical framework that included project objectives, activities and outputs, and actual and potential outcomes and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts were then valued.

Benefits were estimated for a range of time frames up to 30 years from the last year of investment in the project (2017/18). Past and future cash flows expressed in 2016/17 dollars were discounted to the year 2017/18 using a discount rate of 5% to estimate the investment criteria.

The Cost-Benefit analysis was conducted according to the Impact Assessment Guidelines of the Council of Rural Research and Development Corporations (CRRDC) (May, 2014).

Impacts

The project contributed to an increased understanding of where high-risk sites were for pest and disease incursion. Mapping of pine trees around high-risk sites also provided additional information on where incursions may occur. The project also contributed to increased training and improved pest and disease awareness of local council staff.

These findings and associated management responses will improve detection of pine pest and diseases before the pest and diseases can become established in South East Queensland Southern Pine Plantations.

The major impact identified was the reduced probability of a pest or disease establishment in South East Queensland Southern Pine Plantations. Also, some social and environmental impacts were identified but not valued. It is expected that Queensland Southern Pine forests, including their input and product supply chains, will be the primary beneficiaries of the investment.

Investment Criteria

Total funding from all sources for the project was approximately $0.50 million (present value terms). The value of total benefits was estimated at $2.04 million (present value terms). This result generated an estimated Net Present Value (NPV) of $1.54 million and a Benefit-Cost ratio (BCR) of approximately 4.09 to 1.

1. Evaluation Methods

The evaluation approach follows general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations, Cooperative Research Centres, State Departments of Agriculture, and some Universities. This impact assessment uses cost-benefit analysis as its primary tool. The approach includes both qualitative and quantitative descriptions that are in accord with the evaluation guidelines of the Council of Rural Research and Development Corporations (CRRDC) (May 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and actual and potential outcomes and impacts. The principal economic, environmental and social impacts are then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified, were then valued in monetary terms. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, or the likely low relative significance of the benefit compared to those that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Background

Queensland's softwood forestry industry has an estimated gross state product of $205 million for 2015/16 (ABS, 2017). Pest incursions pose a threat to the output of the softwood industry. While Australian Government quarantine policies exist, and border checks are carried out on products imported from other countries, there is still a risk that pests and diseases may enter Queensland and establish populations. Most imported products that may contain pests and disease are opened away from border entry points, so there is a risk of incursion at sites far from the port of entry. Broad-scale monitoring of pests and diseases is often ineffective at detecting threats early enough to prevent them from becoming established.

There has been activity between states in preventing past establishment of several *Pinus spp.* pests in Australia such as:

- Japanese pine sawyer beetle
- Exotic *Bursaphelenchus* nematode
- Giant pine scale

The experience of these incursions suggests that strategic post-border surveillance is likely to achieve improved outcomes than having to implement an eradication and containment program later after the pest or disease has established within a forest environment.

Rationale for the Investment

This project explored specific post-border monitoring of high-risk sites for forest pest incursions and developed a standardised methodology for monitoring such sites. The project explored *Pinus* (hereafter pine) trees as previous forest biosecurity breaches have involved pine pests.

The project was jointly funded (both cash and in-kind) by the Queensland Department of Agriculture and Fisheries (DAF), and the University of the Sunshine Coast (USC).

Checking all locations of unpacking and storage activities away from the port infrastructures would probably eliminate pest incursions, but there are resource constraints to such a strategy. Therefore, high-risk sites need to be identified, so trapping and monitoring can take place preferentially at a restricted number of sites. By identifying critical post-border imported timber consignment opening points in proximity to known current locations of pine trees in greater Brisbane, there was an opportunity to identify high-risk sites.

By using pine trees, as a model for identifying information and processes required for establishing post-border surveillance, it was hoped that the project could inform other targeted pest surveillance activities in Queensland.

3. Project Details

Summary

Project Title: Protecting Queensland's timber resource from pest and disease incursions
Research Organisation: DAF Horticulture & Forestry Science (DAF-HFS)
Principal Investigator: Geoff Pegg
Period of Funding: February 2016 – November 2017

Objectives

The overarching objectives of the project were:

1. To develop standardised methods to enhance early detection and response to post-border pests and diseases
2. To enhance the potential for eradication of pine pests and diseases through targeted detection
3. To detect new and emerging pest species with potential significant management and biosecurity implications through intensive surveillance of greater Brisbane pine trees near high-risk sites.

Logical Framework

Table F1 describes the project in a logical framework developed for the project.

Table F1: Logical Framework for Project

Activities and Outputs	• Mapping of high-risk sites of incursion within the greater Brisbane area took place. The mapping of high-risk sites was achieved by identifying Quarantine Approved Premises (QAPs) where imported forestry items are received. • From the mapping of QAPs (renamed Approved Arrangements (AA)), three main locations were identified as Eagle Farm, Wacol/Richlands, and Coopers Plains/Archerfield. These locations were chosen due to a high concentration of AAs with high quantities of imported goods processed and unpacked, and where previous interceptions of exotic pine pests had been made. • Maps were produced showing the location of AAs and timber distributors and the location of pine trees near the high-risk sites. • Project personnel searched for pine trees around the three main locations. Using Google Street View TM, single and multiple locations of pine trees were identified near high-risk sites and were recorded. There were 46 locations at Eagle Farm, 52 locations at Wacol, and 164 locations at Coopers Plains. • Baseline data on the trees were recorded to establish the status of pests and pathogens and the current condition of each tree. Assessment included tree status (either alive or dead), tree health (percentage of branches dead or with dieback) and trees with symptoms of a disease. • Trees were monitored for branch dieback, resin bleeding, cankers or galls, frass and insect galleries, borer holes, and needle wilt; trees showing any of these symptoms were recorded. • The project continued in conjunction with trapping and monitoring activity associated with the Japanese Pine Sawyer Beetle monitoring at Coopers Plains. The project expanded such monitoring to Eagle Farm and Wacol. • Pest and disease surveys were carried out on pine trees around AA premises at Eagle Farm, Coopers Plains/Archerfield, and Wacol/Richlands in December 2016, with follow up surveys before November 2017. Over 600 pine trees from 260 locations were assessed, with samples from suspect trees taken. • Ten new traps were set as part of the trapping program for the 2016/17 trapping season. One new exotic beetle (Trichoferus campestris (Coleoptera: Cerambycidae)) was trapped. • Previous trapping data were analysed to provide baseline data on pest incursions. • Baseline data were established for High-Risk Site Trapping (HRST). Previous HRST data from 2006 to 2016/17 found 2,414 specimens from 82 species. • By-catch data from a Sirex Wood Wasp trapping exercise from around south-east Queensland and Northern New South Wales (NSW) (from 2010-2016) was sorted and analysed, with the identification of 6,791 specimens from 34 species. • DAF Forest Health provided forest biosecurity training to 232 parks and gardens staff from six south-east Queensland councils from October to December 2016. The training focused on the process of spotting and reporting pine trees with suspect pest incursion and disease symptoms. • Information from the program mapping and council training activities was presented at a biosecurity training workshop held in October 2017 at NSW Department of Primary Industries. The presentation covered how

	to improve the likelihood of pest detection, using standardised information across both NSW and Queensland. • Detection data from the Department of Agriculture and Water Resources (DAWR) was analysed to see if there were any relationships between pest detection from import records from January 2006 to December 2015 from Quarantine Inspection Points and Post-Quarantine Detections (PQD). Some statistics from the DAWR data were: o In general, there were no significant differences between seasons. However, for some species there were seasonal differences, with *Anobiidae* detected in spring and summer as opposed to winter, *Bostrichidae* detected in summer as opposed to over autumn, and *Cerambycidae* detected in autumn as opposed to other seasons. o Imports from China had the highest number of detections, with imports from the United States having the highest diversity of invasive species found. o Seventy-five per cent of detections came from sea transport sources. Beetles were found only in mail from New Zealand and the Americas. o Approximately 60% of detected species were already present in Queensland. o 60% of detections were made at the border while 40% were found at PQD locations. • There are issues with directly relating detections with the country of origin as there is potential for spurious relationships to occur (e.g. large numbers of imports will lead to a large number of detections). • The project recommended that future funding for post-border surveillance be extended to other tree species, as outlined in the National Forest Biosecurity Strategy. A similar project surveillance project for eucalypts and Timber in Service[2] was recommended to see what other timber pests and diseases are entering Queensland. • The project recommended that biosecurity training programs for timber pests be prepared for pest controllers and building certifiers. • A recommendation of the project was an establishment of a long-term high-risk site surveillance program near other Queensland ports, driven by the National Forestry Biosecurity Strategy Surveillance and Implementation Plan. It was recommended that DAWR and other industry groups engage in further post-border surveillance.
Outcomes	• The increased knowledge of high-risk locations of pine trees in South East Queensland has focused surveillance resources on high threat areas for pests/diseases. • There is an increased likelihood of early detection of pests through targeted post- border pest and disease checks at high-risk sites with current resources. • The training programs have provided increased awareness in spotting diseases and pests, so detection of incursions should be more successful than in the past. A pest has already been detected on the Sunshine Coast because of the training undertaken. • There has been further interest in biosecurity training to councils and industry.

[2] Timber in Service - Timber that is used in buildings and field structures, including constructional timbers such as building structures, utility poles, railway sleepers, bridge timbers and other outdoor service timber (DAFF, 2000).

	• Further national high-risk sites surveillance has been planned to take place in NSW, Victoria, and Queensland due to the recommendations of the project. • The baseline tree health data will provide a higher probability of detecting pest and disease. • Brisbane and Logan City councils requested extra training sessions on identifying pests for parks and gardens staff. • There is a lower risk of pest and disease establishment in other Australian states from pests and diseases entering from Queensland. • The information developed from the project is being used to assist in implementing the National High-Risk Site Surveillance program for Forest Biosecurity. Further research in this area is to be funded by the DAWR, with funding available in the first instance for a long-term plan. • The project directly informed the implementation of the National Biosecurity Surveillance Strategy and Implementation Plan (2017-2022) (Helen Nahrung, pers. comm., 2018). The National Biosecurity Surveillance Strategy and Implementation Plan would have gone ahead without the project. • There is a lower probability of pine disease infecting native pine trees. • The project has lowered the risk of new pine pest and diseases establishing as well as the risk of losing access to some forest product export markets
Impacts	• Increased effectiveness in detecting pine pests and diseases at post border locations in south-east Queensland. • Reduction in the probability of impact of pests/diseases on pine forestry plantations in south-east Queensland’s Southern Pine plantations (avoided productivity losses and lowered management and eradication costs). • Potential reduced negative impacts in pine plantations outside of south-east Queensland Southern Pine plantations. • Lowered probability of negative biodiversity impacts. • Maintained export income to south-east Queensland pine producers. • Increased effectiveness in national biosecurity surveillance. • Increased scientific research capacity.

4. Project Investment

Nominal Investment

Table F2 shows the annual investment (cash and in-kind) for the project funded by DAF-HFS, DAF Forestry Industries and USC.

Table F2: Annual Investment in the Project (nominal $)

Contributor	2015/16	2016/17	2017/18	Totals
DAF-HFS (in kind, incl. overheads)	68,128	125,351	45,044	238,523
DAF-Forest Industries (cash to DAF-HFS)	14,047	34,049	22,212	70,308
DAF-Forest Industries (cash to USC)	6,000	6,000	17,775	29,775
DAF-HFS (cash to USC)	10,025	20,050	10,026	40,101
USC ($) (in-kind – overheads on salary)	22,710	45,420	22,711	90,841
Totals ($)	120,910	230,870	117,768	469,548

Source: Helen Nahrung, pers. comm., 2018

Program Management Costs

For the DAF investment, the management and administration costs for the project are built into the nominal $ amounts appearing in Table F2. The salary multipliers that had been used (Wayne Hall, pers. comm., 2017) were:

- 2.85 multiplier for salaries contributed by DAF
- 1.85 multiplier for salaries paid for by other parties

The USC management and administration costs for the project are included in Table F2 as an in-kind contribution from USC calculated as 1.3 multiplier on salary (Helen Nahrung, pers. comm., 2018).

Real Investment and Extension Costs

For the investment analysis, the investment costs of all parties were expressed in 2016/17 dollars using the Implicit Gross Domestic Product (GDP) Deflator index (ABS, 2018). No additional costs of extension were included.

5. Impacts

The principal potential impacts from the positive results exhibited by the project include:

- Increased effectiveness in detecting pine pests and disease at post-border locations through:
    - Better trained local council staff to detect pests and disease post border, both at pine locations around greater Brisbane and at import facilities.
    - More effective monitoring for pests and diseases through better placed traps at prioritised locations of trees around import facilities.
    - Baseline health data of trees enabling knowledge of when pest and disease incursions and establishment are most likely to occur.

- Reduction in the probability of impact on Southern Pine plantations in Queensland leading to avoided productivity losses and lowered management and eradication costs through a lower probability of pest and diseases entering Queensland that are transferred to plantation forests.

Table F3 provides a summary of the potential types of impacts categorised into economic, environmental and social impacts.

Table F3: Triple Bottom Line Categories of Potential Impacts

Economic	• Increased effectiveness in detecting pine pests and disease at post-border locations. • Reduction in the probability of pest impacts and disease on pine forestry plantations in south-east Queensland leading to avoided productivity losses and lowered management and eradication costs • Potential reduced negative impacts on the Australian pine estate outside of the Queensland Southern Pine plantations. • Increase in effectiveness in national biosecurity surveillance. • Maintained market access for south-east Queensland pine timber exporters.
Environmental	• Lowered probability of negative biodiversity impacts from invasive pine pests.
Social	• Increased scientific research capacity

Public versus Private Impacts

Most impacts identified in this evaluation are industry related, and therefore the impacts are generally considered to be private. Some public benefits may be delivered as softwood plantations in Queensland are generally located on government owned land that is leased to private interests. There are also public benefits through increased biosecurity capacity of DAF and the staff of the six local councils through receiving training as part of the project. Both private and public benefits may be delivered via the enhanced national surveillance strategy.

Distribution of Private Impacts

For private impacts, it can be assumed that the positive impacts from the project will accrue mainly to growers of Southern Pine and their associated input and product supply chains.

Impacts on other Australian industries

Because of the project was solely Queensland focused, it is assumed that the impacts will accrue mainly to Southern Pine in south-east Queensland (both *Pinus Taeda* and hybrids), but there may be spillovers to pine industries in other parts of Queensland and other States due to lower risk of disease incursion from Queensland Southern Pine plantations. There may be wider implications to other Australian industries via the project’s contribution to an improved national surveillance strategy.

Impacts Overseas

There are no foreseeable overseas impacts from this project.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural Research Development & Extension (RD&E) priorities are reproduced in Table F4. The biosecurity project contributes primarily to Rural RD&E Priority 2 and Science and Research Priority 1.

Table F4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities[a] (est. 2015)	**Science and Research Priorities[b] (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food (includes fibre) 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

(a) Source: Commonwealth of Australia (2015)
(b) Source: Office of the Chief Scientist (2015)

The Queensland Government's Science and Research Priorities, together with the four decision rules for investment that guide evaluation, prioritisation and decision making around future investment, are reproduced in Table F5. The project addressed Queensland Science and Research Priorities 1 and 3. Regarding the guides to investment, the project is likely to have a real future impact through improved confidence in the management of the sustainability of softwood plantations in south-east Queensland. The project has a Queensland biosecurity focus.

Table F5: Queensland Government Research Priorities

Queensland Government	
Science and Research Priorities (est. 2015)	**Investment Decision Rule Guides (est. 2015)**
1. Delivering productivity growth 2. Growing knowledge intensive services 3. Protecting biodiversity and heritage, both marine and terrestrial 4. Cleaner and renewable energy technologies 5. Ensuring sustainability of physical and especially digital infrastructure critical for research 6. Building resilience and managing climate risk 7. Supporting the translation of health and biotechnology research 8. Improving health data management and services delivery 9. Ensuring sustainable water use and delivering quality water and water security 10. The development and application of digitally-enabled technologies.	1. Real Future Impact 2. External Commitment 3. Distinctive Angle 4. Scaling towards Critical Mass

Source: Office of the Chief Scientist Queensland (2015)

6. Valuation of Impacts

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, mainly when some uncertainty was involved. Sensitivity analyses were conducted on variables that were considered key drivers of the investment criteria or that were considered uncertain. Three impacts were valued, the increased effectiveness in detecting pine pests and disease at post border locations in South East Queensland and a reduction in the probability of impact of pests/disease on pine forestry plantations in Queensland's Southern Pine plantations (avoided productivity losses and lowered management and eradication costs). These impacts were valued as one impact. The third impact valued was the expected maintenance of market access for some exports of forest products from Southern Pine producers in south-east Queensland.

Reduction in Probability of Establishment

As a result of the project, improved trapping and monitoring of high-risk sites has, and will, take place. The additional training of staff has already resulted in further knowledge of pest-host associations with a pest incursion being found in street trees at the Sunshine Coast (Helen Nahrung pers comm., 2018). The project has led to better placement of traps as the project produced maps of high-risk sites around import facilities and near local pine trees. Tree health assessments from the project have provided baseline data on tree health. This allows more effective monitoring of trees to improve recognition of pest or disease presence.

The above outcomes have been assumed to reduce the probability of a pest or disease establishment in south-east Queensland Southern Pine plantations in any given year from 5% (based on Carnegie et al, 2017) to 4.5%.

Impact 1: Cost of Pest/Disease Establishment

Specific assumptions for estimating this cost are provided in Table F6.

Gross Operating Surplus (GOS) for the Queensland Southern Pine industry is $44.7 million p.a., with an output of $438 million p.a. and net expenditure of $393.3 million p.a. (Schirmer et al., 2018).

The analysis assumes the valued benefit for south-east Queensland plantations, focused in Tuan-Toolara and Beerburrum, as the project looked only at pine pest and disease entry points in greater Brisbane. Therefore, a probable pest incursion will occur in south-east Queensland first. North Queensland and Northern NSW pine plantations are not included as pest and disease spread from south-east Queensland will have a different probability of pest establishment. Including the spread to other regions of Australia for pests and diseases established in south-east Queensland Southern Pine Plantations cannot be reasonably assumed in the analysis.

The proportion of Queensland Southern Pine grown in South East Queensland is 77.77% (ABARES, 2018). As the GOS for south-east Queensland Southern Pine Plantations is not available separately, the proportion of Southern Pine grown in south-east Queensland is applied to Queensland Southern Pine output value and net expenditure to estimate south-east Queensland Southern Pine GOS, output value, and net expenditure.

Eradication

It is assumed that an eradication attempt will be undertaken if there is an establishment of a pine pest or disease in South East Queensland Southern Pine Plantations. An eradication strategy is assumed to be attempted only in the first year of the pest establishment. There is a probability assumed of 60% that the eradication will be successful. No further action is assumed to be taken for that specific pest or disease establishment if eradication is successful. From Carnegie et al. (2017), a pest eradication is assumed to take the form of destroying infected and surrounding trees, resulting in lost production, and increased costs due to extra labour. The increased costs are assumed to be $6 million. The area of Southern Pine Plantation destroyed by eradication is assumed to be 2,181 hectares (based on Carnegie et al., 2017). This area represents 1.88% of the south-east Queensland Southern Pine plantation, so lost output is estimated at $6.42 million.

Ongoing management

If eradication is not successful, it is assumed there will need to be further management of the pine pest or disease. Any management costs due to the outbreak are assumed to be part of existing expenditure, with the lost wood output being the primary impact from dying trees. For simplicity, it is assumed that infected timber cannot be sold.

The pest or disease is assumed to spread $2km^2$ per year, with a tree mortality rate of 10% per year within infected areas. The lost production from a 10% loss of $2km^2$ per year is estimated at $58,831. The $2km^2$ is cumulative per year minus the area lost due to pest or disease.

Impact 2: Maintained Market Access

Table F7 provides the supporting assumptions.

As of 2016, 20% of harvested logs in Beerburrum are exported, while no harvested logs in Tuan-Toolara are exported (Carnegie et. al, 2018). The GOS for south-east Queensland Southern Pine plantations is $34.76 million per annum. The area of plantation pines in Beerburrum is 22,079 hectares, while Tuan-Toolara covers 67,171 hectares (Carnegie et. al., 2017). Therefore, the proportion of south east Queensland plantation forest in Beerburrum is 24.47%. Therefore, 4.95% of the south-east Queensland Southern Pine plantation logs are destined for export. Assuming the GOS is distributed evenly between logs for local processing and export processing, the GOS for exported logs is $1.72 m per annum.

If there is a pest establishment in south-east Queensland Southern Pine plantations, there may be loss of export market access (Carnegie et.al., 2017). Local industry currently does not have a use for the forest products destined for export (Carnegie et. al, 2017). Depending on the particular pest that establishes, there may still be market access to some export markets. Local processors may also take some of the logs meant for export. For these reasons, it is assumed that 20% of forest products previously exported can still be exported or used locally.

As with Impact 1, there is a 4.5% per annum probability of a pest establishment with the project. In the first year of the pest establishment, eradication will be attempted. During the eradication attempt, it is assumed that there is no export market access. With the project there is a 60% probability of eradication being successful. If eradication is successful, it is assumed export market access will be restored after proof of freedom from the pest is provided. If eradication is not successful, lost export market access will continue. It is assumed that after six years of export market access loss, local producers will use the logs meant for export in their production.

Impacts not Valued

Not all impacts identified in Table F3 could be valued in the assessment.

The economic, environmental, and social impacts not valued include:

- The impact of less pest and disease risk to other parts of Australia outside of South East Queensland. This impact is not valued due to:
    - The project conducted surveys only around greater Brisbane, mainly locations close to the Port of Brisbane
    - Other states are undertaking their own surveillance programs
    - While there is a decreased risk to other parts of Australia due to the project from a pest or disease spreading from south-east Queensland, it is not the same risk factor as for south-east Queensland Southern Pine and cannot be estimated with any confidence.
- Increased effectiveness in national biosecurity surveillance.
- Lowered probability of negative biodiversity impacts on native pine trees.
- Increased scientific research capacity in plantation forest biosecurity.

The second, third, and fourth impacts above were not valued due to lack of time and resources and the greater uncertainty of assumptions required in estimating such secondary impacts.

Additional Costs

Other sources provided inputs into some of the activities of the project. These costs are not accounted for directly as additional costs as such inputs still would have occurred without this project being funded.

The final report of the project stated that there would be no additional funds made for enhancing biosecurity via strategic surveillance. Improvement in biosecurity is assumed to occur due to re-direction of existing resources.

Extension

There may be further extension activity through increased training of staff into the future. The additional training may occur at other locations outside of south-east Queensland or for other tree species. The impacts valued are not dependent on such future extension investment.

Counterfactual

The assumptions for the counterfactual are the same as the impact valued except the percentage risk of establishment. Without the project, it is assumed that there is a 5% probability per year that a pest establishment can occur. The reduction from 5% to 4.5% can be considered to be a conservative estimate as the enhanced surveillance strategy has already detected new pests at high-risk sites. The probability of eradication is 50% without the project as the project improved the probability of eradication being successful.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table F6.**Error! Reference source not found.**

Table F6: Summary of Assumptions for Impact 1

Variable	Assumption	Source
Base assumptions		
GOS for Queensland Southern Pine plantations	$44.7 million per annum	Schirmer et al., 2018
Value of Output for Queensland Southern Pine plantations	$438 million per annum	Schirmer et al., 2018
Net Expenditure for Queensland Southern Pine plantations	$393.3 million per annum	Schirmer et al., 2018
Proportion of Southern Pine plantations in South East Queensland	77.77%	ABARES, 2018
GOS assumed for South East Queensland Southern Pine plantations	$34.76 million per annum	$44.7 million x 77.77%
Value of Output for South East Queensland Southern Pine plantations	$340.63 million per annum	$438 million x 77.77%
Net Expenditure for South East Queensland Southern Pine plantations	$305.87 million per annum	$393.3 million x 77.77%
Area of South East Queensland Southern Pine plantations	115,800 hectares	ABARES, 2018
Area of South East Queensland Southern Pine plantations	1,158 km^2	ABARES, 2018
Risk of pest establishment with and without the changed surveillance strategy		
Without project probability per annum of undetected threat becoming established within Southern Pine plantations	5% per annum	Agtrans Research based on Carnegie et al. (2017)
With project probability per annum of undetected threat becoming established within Southern Pine plantations	4.5% per annum	Agtrans Research
Year of first incidence of possible pest incursion	2018/2019	Agtrans Research
Cost of pest establishment to Southern Pine plantations in South East Queensland both with and without the project		
Eradication costs year one of incursion only- eradication attempt scenario		
Area destroyed due to eradication	2,181 hectares	Based on Carnegie et al. (2017)
Percentage of output lost due to eradication	1.88%	2,181 ha /115,800 ha
Lost output due to eradication effort	$6.42 million	340.63 million * 1.88%
Increased cost due to eradication undertaken without the project	$6 million	Based on Carnegie et al. (2017)

Probability of eradication being successful with the project	60%	Agtrans Research
Probability of eradication being successful without the project	50%	Agtrans Research
If eradication is unsuccessful, pest impact continues to spread years two to thirty		
Mortality rate of trees in infected area if pest/disease is not eradicated	10%	Agtrans Research indirectly based on Carnegie et al. (2017)
Spread of disease	$2km^2$ spread each year	Agtrans Research indirectly based on Carnegie et al. (2017)
Cost of lost trees per 2 km^2	$58,831 per 2 km^2	10% * ($340.63 million/1,158 km^2) * 2

Table F7: Summary of Assumptions for Impact 2

Variable	**Assumption**	**Source**
GOS for Queensland Southern Pine plantations	$44.7 million per annum	Schirmer et al., 2018
Proportion of Southern Pine plantations in South East Queensland	77.77%	ABARES, 2018
GOS assumed for South East Queensland Southern Pine plantations	$34.76 million per annum	$44.7 million x 77.77%
Area of plantation in Tuan-Toolara	67,171 hectares	Carnegie et. al., 2017
Area of plantation in Beerburrum	22,079 hectares	Carnegie et. al., 2017
Percentage of south-east Queensland Southern Pine located in Beerburrum	24.74%	22,079 ha / (66,171 ha + 22,079 ha)
Percentage of Beerburrum Southern Pine products exported	20%	Carnegie et. al., 2018
Percentage of south-east Queensland Southern Pine from Beerburrum used for export	4.95%	20% * 24.74%
GOS for export	$1.72 m per annum	4.95% * $34.76 m
Percentage that cannot be exported or used domestically	20%	Agtrans Research
Period when export market is replaced by domestic use due to lost market access	Six years after pest establishment	Agtrans Research
Probability of incursion without the project	5%	Agtrans Research
Probability of incursion with the project	4.5%	Agtrans Research
GOS lost in eradication period without the project	$68,799 in year of eradication attempt	5% * (1-20%) * $1.72 m
GOS lost in eradication period with the project	$61,919 in year of eradication attempt	4.5% * (1-20%) * $1.72 m
Probability of eradication being successful with the project	60%	Agtrans Research

Probability of eradication being successful without the project	50%	Agtrans Research
Probable GOS access lost per year without the project from year two to year six after establishment	$34,399 per annum	50% * $68,799
Probable GOS lost per year with the project from year two to year six after establishment	$24,768 per annum	(1-60%) * $61,919

7. Results

All past costs were expressed in 2016/17 dollars using the Implicit Price Deflator for GDP. All benefits after 2016/17 were expressed in 2016/17 dollars. All costs and benefits were discounted to 2017/18 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, including a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2017/18) to the final year of benefits assumed.

Investment Criteria

Tables F8 and F9 show the investment criteria estimated for different periods of benefits for the total investment and the DAF investment respectively. The DAF investments from different sources in Table F2 are combined.

Table F8: :Investment Criteria for Total Investment

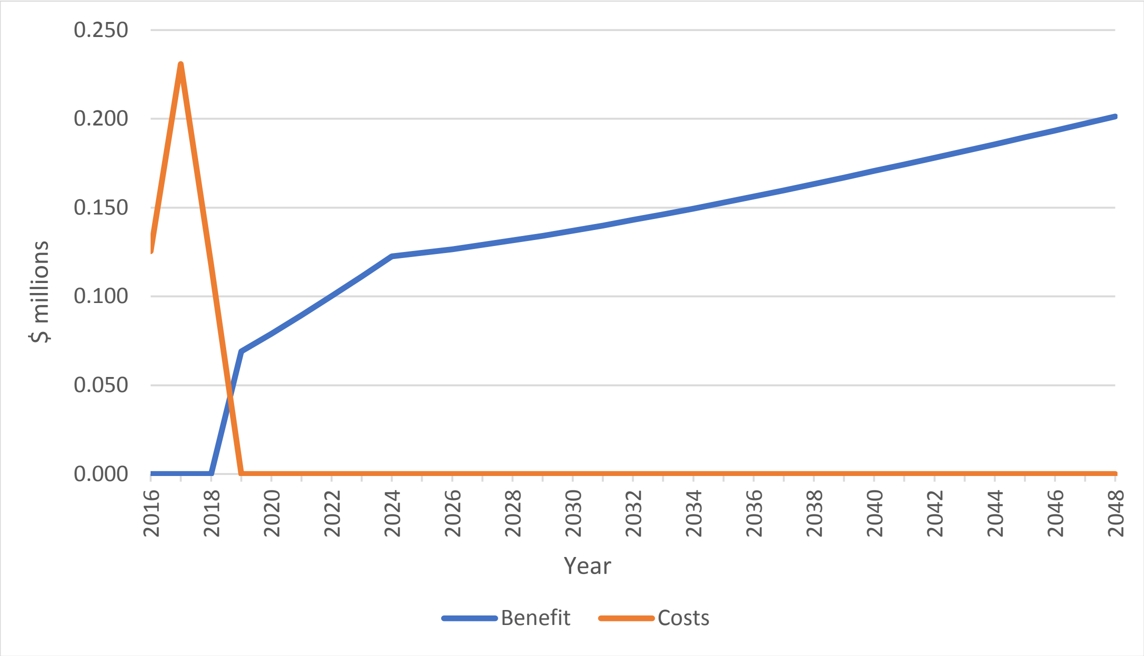
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits (PVB) ($m)	0.00	0.38	0.81	1.19	1.51	1.79	2.04
Present value of costs (PVC) ($m)	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Net present value (NPV) ($m)	-0.50	-0.11	0.32	0.69	1.01	1.30	1.54
Benefit-cost ratio (BCR)	0.00	0.77	1.63	2.38	3.03	3.60	4.09
Internal rate of return (IRR) (%)	neg.	neg.	13.31	16.82	18.02	18.51	18.70
MIRR (%)	neg.	neg.	10.27	11.24	10.98	10.52	10.05

Table F9: Investment Criteria for DAF Investment

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
PVB ($m)	0.00	0.31	0.66	0.96	1.22	1.45	1.65
PVC ($m)	0.40	0.40	0.40	0.40	0.40	0.40	0.40
NPV ($m)	-0.40	-0.09	0.25	0.55	0.82	1.04	1.24
BCR	0.00	0.77	1.63	2.38	3.03	3.60	4.09
IRR (%)	neg.	neg.	13.31	16.82	18.02	18.5	18.71
MIRR (%)	neg.	neg.	10.27	11.24	10.98	10.52	10.05

The annual undiscounted benefit and cost cash flows for the total investment for the duration of the investment period plus 30 years from the last year of investment are shown in Figure F1.

Figure F1: Annual Cash Flow of Undiscounted Total Benefits and Total Investment Costs



Source of impacts

Table F10 presents the source of impacts (Impact 1 and Impact 2). Impact 1 had the larger influence on the investment criteria. Both impacts on their own would have covered the discounted costs of the project ($0.50 m, as provided in Table F9).

Table F10: Distribution of Impacts

Impact	Present value of benefits ($)	Percentage spilt
Impact 1	1.32 m	64.71%
Impact 2	0.72 m	32.29%
Total	2.04 m	100%

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was 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. Table F11 presents the results.

Table F11: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	**5% (base)**	**10%**
PVB ($m)	4.40	2.04	1.14
PVC ($m)	0.47	0.50	0.52
NPV ($m)	3.93	1.54	0.62

BCR	9.29	4.09	2.18

A sensitivity analysis was carried out on the reduced probability of a pest or disease establishment with the project. Table F12 presents the results. The results show a high sensitivity to the reduced probability of establishment with the project.

Table F12: Sensitivity to the Probability of Pest and Disease Establishment (Total investment, 30 years)

Investment Criteria	**Sensitivity to the probability of establishment with the project**		
	4.75%	**4.5% (base)**	**4.25%**
PVB ($m)	1.37	2.04	2.71
PVC ($m)	0.50	0.50	0.50
NPV ($m)	0.87	1.54	2.21
BCR	2.75	4.09	5.44

A sensitivity analysis was carried out on the increased costs due to eradication. Table F13 presents the results. The sensitivity affects both impacts. The results show low sensitivity to the increased costs due to the eradication attempt.

Table F13: Sensitivity to Increased Cost Due to Eradication Attempt

Investment Criteria	**Sensitivity to increased cost due to eradication undertaken**		
	$10 m	**$6 m (base)**	**$4 m**
PVB ($m)	2.35	2.04	1.89
PVC ($m)	0.50	0.50	0.50
NPV ($m)	1.85	1.54	1.39
BCR	4.71	4.09	3.79

Confidence Ratings and other Findings

The results produced are highly dependent on the assumptions made, some of which are uncertain. Two factors 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 F14). 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 F14: Confidence in Analysis of Project

Coverage of Benefits	**Confidence in Assumptions**

Medium-High	Low-Medium

The coverage of benefits was rated as medium-high, as the principal impacts were valued. The confidence in assumptions was rated as low-medium, largely because of the difficulty of making sound assumptions concerning the expectations of the size and damage costs of any future pest establishment, and the uncertainly around the quantity of Southern Pine currently exported that would no longer capture a market premium.

8. Conclusions

The investment in Protecting Queensland's timber resource from pest and disease incursions was to improve biosecurity to enable pest and disease incursions to be detected earlier and so lower the possibility of establishment in plantation forests.

The impacts valued apply to Southern Pine plantations in south east Queensland. The improved methods to enhance early detection of pine pest and diseases are assumed to reduce the risk of a pest or disease establishment in south east Queensland Southern Pine plantations. The pathway to this impact is through improved mapping of high-risk sites, improved local council training, and better tree health data. The project has also informed the National Forest Biosecurity High-Risk Surveillance program that is forming the basis of national forestry biosecurity.

The PVC from all sources for the project was approximately $0.50 million. The PVB was estimated at $2.04. million using best-bet assumptions. This result generated an estimated NPV of $1.54 million, a BCR of 4.09 to 1, an IRR of 18.7% and a MIRR of 10.0%.

Sensitivity analyses were carried out on key variables affecting the value of impacts. These variables included the discount rate, the project-driven reduction in the probability of pest and disease establishment in south-east Queensland Southern Pine plantations and the increased cost of pest and disease eradication. The results demonstrated the importance of the reduced probability of pest establishment to the future value of the research investment.

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