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

[FINAL]

Summary Report

to

The Department of Agriculture and Fisheries Queensland

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by

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Abbreviations

BCR	Benefit-Cost Ratio
BMP	Best Management Practice
CBA	Cost-Benefit Analysis
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries (Queensland)
IPM	Integrated Pest Management
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
PVB	Present Value of Benefits
PVC	Present Value of Costs
RD&E	Research, Development and Extension
RDC	Research and Development Corporation

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), regardless of to whom they accrue.
Benefit-cost ratio:	The ratio of the present value of investment benefits to the present value of investment costs.
Discounting:	The process of relating the costs and benefits of an investment to a base year using a stated discount rate.
Internal rate of return:	The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.
Investment criteria:	Measures of the economic worth of an investment such as Net Present Value, Benefit-Cost Ratio, and Internal Rate of Return.
Modified internal rate of return:	The internal rate of return of an investment that is modified so that the cash inflows from an investment are re-invested at the rate of the cost of capital (the re-investment rate).
Net present value:	The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.
Present value of benefits:	The discounted value of benefits.
Present value of costs:	The discounted value of investment costs.

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Executive Summary

This report presents the results of a series of cost-benefit analyses 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 program investments. The project and program investments were:

- Investment 1: National Strawberry Varietal Improvement Program
- Investment 2: Fusarium Wilt Tropical Race 4 Research Program
- Investment 3: National Mungbean Breeding Program
- Investment 4: Grains Integrated Pest Management (IPM) Northern Region
- Investment 5: Grazing Best Management Practice (BMP) and ReefPlan Extension
- Investment 6: Farm Biogas Adoption by the Pork Industry

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 including those representing grains (mungbean breeding and grains IPM) and horticulture (strawberry varietal improvement and banana biosecurity). Other external funding was contributed by the Pork Cooperative Research Centre (farm biogas adoption), and the Department of Environment and Sciences and the Fitzroy Basin Association (grazing BMP and ReefPlan extension). As each of the six investments was 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, and
- The specific resource investment provided by DAF only.

Available documentation was assembled for each project with assistance from DAF personnel and others involved with the investments and associated industries. Documentation included the original project proposals, project agreements, milestone reports, final reports (where available), budget information for each investment (including variations), and other relevant reports.

Each of the six analyses provides a description of the individual project or program including objectives, RD&E input costs (cash and in-kind), outputs, activities, outcomes, and potential and/or actual impacts. Impacts are first described qualitatively according to their contribution to the triple bottom line categories 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. Impacts were estimated for up to 30 years from the year of last investment in each project. Total RD&E 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/programs varied from 28% to 69%.

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 variables that were seen to be key drivers of the investment criteria.

Some identified impacts were not quantified, this was mainly due to:

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

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

The tables below present the investment criteria for the total investment and the DAF investment in each of the six investments respectively. The investments were evaluated using a 5% discount rate, with benefits valued over 30 years from the last year of investment. All costs and benefits were expressed in 2017/18 real dollar terms and discounted to 2018/19 (the year of analysis). In addition, the bottom row in each table shows the investment criteria for the aggregate investment in all six individual projects/programs (investment areas).

Investment Criteria for Total Investment by Project/Program

Investment Area	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
National Strawberry Varietal Improvement Program	77.72	21.48	56.24	3.62	51.9	19.4
Fusarium Wilt Tropical Race 4 Research Program	147.15	12.68	134.47	11.60	24.9	14.0
National Mungbean Breeding Program	61.87	5.15	56.72	12.02	38.0	16.5
Grains IPM Northern Region	23.93	14.43	9.49	1.66	18.8	8.2
Grazing BMP and ReefPlan Extension	65.19	17.28	47.92	3.77	30.7	9.8
Farm Biogas Adoption by the Pork Industry	3.05	1.20	1.85	2.55	6.3	5.6
Aggregate (Total investment in all Project Investments)	378.91	72.22	306.69	5.25	45.5	15.2

Investment Criteria for DAF Investment by Project/Program

Investment Area	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
National Strawberry Varietal Improvement Program	48.21	13.10	35.12	3.68	64.8	21.8
Fusarium Wilt Tropical Race 4 Research Program	81.90	7.04	74.86	11.63	25.1	14.0
National Mungbean Breeding Program	34.24	2.84	31.40	12.06	37.3	17.5
Grains IPM Northern Region	13.24	7.93	5.32	1.67	19.9	8.3
Grazing BMP and ReefPlan Extension	18.68	4.91	13.76	3.80	31.4	9.8
Farm Biogas Adoption by the Pork Industry	2.09	0.83	1.26	2.53	6.3	5.6
Aggregate (DAF investment in all Project Investments)	198.37	36.65	161.72	5.41	61.4	17.1

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 other stakeholders that RD&E investments made by DAF are delivering real impacts. In addition, it can inform DAF RD&E management about performance from past investments as well as provide possible guidance for future allocation of RD&E resources.

The investments were made in six project and program areas. They were:

- Investment 1: Projects relating to the Strawberry Varietal Improvement Program
- Investment 2: Projects relating to the Fusarium Wilt Tropical Race 4 Research Program
- Investment 3: A 5-year project in the National Mungbean Breeding Program
- Investment 4: Projects relating to the Grains Integrated Pest Management (IPM) Northern Region
- Investment 5: Projects relating to Grazing Best Management Practice (BMP) and ReefPlan Extension
- Investment 6: Projects relating to Farm Biogas Adoption by the Pork Industry

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 followed 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 CBA as a primary tool. The evaluation was conducted in accord with the current guidelines of the Council of Rural Research and Development Corporations (CRRDC) (CRRDC, 2018).

Each investment was evaluated through the following steps:

1. Information from any original project documentation, including proposals and schedules, progress reports, and other relevant reports, was assembled with assistance from DAF personnel.
2. An initial description of the relevant background, objectives, RD&E costs, activities, outputs, and expected outcomes and impacts was drafted for each of the six investments. Additional information needs were then identified.
3. The actual and/or 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 personnel (i.e. Principal Investigators) and the initial draft project description sent to them for perusal and comment, together with specific information requests.
5. Further information was assembled where appropriate from publications and consultation with other project stakeholders (e.g. industry and other DAF researchers).
6. Some analyses proceeded through several drafts, both internally within the evaluation team as well as externally via Principal Investigators and other reviewers.
7. Draft reports for each investment were provided to DAF management for comment.
8. Comments on each of the draft reports were addressed and incorporated into a final report that was provided to DAF management.

In general, the factors that drive the investment criteria for RD&E include:

- The cost of the RD&E.
- 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 RD&E, 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 RD&E' scenario, referred to as the 'counterfactual'.

CBAs were conducted individually on all six investments to generate investment criteria for each project or program. 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 costs and benefits were expressed in 2017/18 real dollar terms using the Implicit Price Deflator for Gross Domestic Product and discounted to 2018/19 (year of analysis). 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 (If 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 undiscounted cash flows (benefits and costs) from each analysis were combined to provide the basis for the estimation of aggregate investment criteria, generated for the total investment and for the DAF investment separately, across 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 the investments analysed and the associated results are provided in the six individual evaluation reports presented in the Appendix (Appendices A to F).

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

Investment Area	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
National Strawberry Varietal Improvement Program	77.72	21.48	56.24	3.62	51.9	19.4
Fusarium Wilt Tropical Race 4 Research Program	147.15	12.68	134.47	11.60	24.9	14.0
National Mungbean Breeding Program	61.87	5.15	56.72	12.02	38.0	16.5
Grains IPM Northern Region	23.93	14.43	9.49	1.66	18.8	8.2
Grazing BMP and ReefPlan Extension	65.19	17.28	47.92	3.77	30.7	9.8
Farm Biogas Adoption by the Pork Industry	3.05	1.20	1.85	2.55	6.3	5.6
Aggregate (Total investment in all Project Investments)	378.91	72.22	306.69	5.25	45.5	15.2

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

Investment Area	**PVB ($m)**	**PVC ($m)**	**NPV ($m)**	**BCR**	**IRR (%)**	**MIRR (%)**
National Strawberry Varietal Improvement Program	48.21	13.10	35.12	3.68	64.8	21.8
Fusarium Wilt Tropical Race 4 Research Program	81.90	7.04	74.86	11.63	25.1	14.0
National Mungbean Breeding Program	34.24	2.84	31.40	12.06	37.3	17.5
Grains IPM Northern Region	13.24	7.93	5.32	1.67	19.9	8.3
Grazing BMP and ReefPlan Extension	18.68	4.91	13.76	3.80	31.4	9.8
Farm Biogas Adoption by the Pork Industry	2.09	0.83	1.26	2.53	6.3	5.6
Aggregate (DAF investment in all Project Investments)	198.37	36.65	161.72	5.41	61.4	17.1

The PVCs in Table 2 (DAF) compared to those in Table 1 (Total) demonstrate the importance of DAF funding in all of the six investments. As a proportion of total funding in each of the six investments, DAF funding varied from approximately 28% to 69% with a weighted average of 50.6% across all six investments.

4. Conclusions

All six of the investments analysed provided positive NPVs at a 5% discount rate. The BCRs ranged from 1.66 to 12.02 for the total investment analysis for the 30-year period from the year of last investment. The highest BCRs were provided by the Mungbean Breeding Program and the Fusarium Wilt Program at 12.02 and 11.60 to 1 respectively.

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 valuation frameworks used across the six individual evaluations.

Across the six investments the aggregate BCR for the total aggregate investment was estimated at 5.25 to 1, the aggregate internal rate of return was 45.5%, and the aggregate modified internal rate of return 15.2%.

References

CRRDC (2018), *Cross-RDC Impact Assessment Program: Guidelines*, Updated April 2018 – Version 2, April 2018, CRRDC, Canberra. Retrieved from: http://www.ruralrdc.com.au/wp-content/uploads/2018/08/201804_RDC-IA-Guidelines-V.2.pdf

Appendices

Appendix A: An Impact Assessment of DAF Investment into The National Strawberry Varietal Improvement Program

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Abbreviations

ASBP	Australian Strawberry Breeding Program
BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
NSW	New South Wales
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

This impact assessment focuses on investment in six strawberry varietal improvement projects funded jointly by Horticulture Innovation Australia Limited (Hort Innovation) and the Queensland Department of Agriculture and Fisheries (DAF) over the 20-year period July 2002 to June 2023. These six projects largely addressed the development of varieties suited to the subtropical growing regions of Australia, but in the latter period, DAF managed the entire national variety improvement program for Australia.

As the most recent of the six projects (BS17000) is only in its second year of a five year period, the quantitative analysis of investment costs and benefits refers to the first five projects. Hence, the last year of total investment costs included in the quantitative analysis is the year ended June 2018. The last year of benefits generated from the investment to 2018 is the year ended June 2026.

The total investment in all five projects subjected to benefit-cost analysis was $11.65 million with 66% contributed by DAF and 34% from Hort Innovation.

Significant expansion of the Australian strawberry industry was evident during the investment period, with the area and production of strawberries in Australia more than doubling. This was due in part to the success of the varietal improvement program. In 2017, varieties from the Australian Strawberry Breeding Program (ASBP) had captured 44% of the subtropical market and 19% of the national market.

The beneficiaries from the investment were primarily some Australian strawberry growers and Australian strawberry consumers, with only a small proportion of Australian strawberries exported. However, other participants along the strawberry input and value chains would also have benefited.

Structural change has occurred in the Queensland strawberry industry in the past few years. A number of growers (smaller growers in particular) have exited the industry or diversified into other horticultural products, while other growers have expanded their strawberry area. The increase in Queensland strawberry production and the declining strawberry price (in real terms) has been a major factor in this change.

The total investment ($11.65 million in nominal terms) was equivalent to $21.48 million in present value terms and produced benefits estimated at $77.72 million in present value terms, a net present value of $56.24 million, a benefit-cost ratio of 3.6 to 1, an internal rate of return of 51.9%, and a modified internal rate of return of 19.4%.

1. Evaluation Methods

The evaluation approach followed 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) (CRRDC, 2018).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and potential and actual outcomes and impacts. This was effected for each project. 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 investments.

2. Background and Rationale

Industry Background

The Australian strawberry industry has a five year (2013/17) annual gross farm-gate value of approximately $269 million (ABS, 2014/2018). Strawberries are grown in all states with Queensland, Victoria and Western Australia producing approximately 88% of total production. Most strawberries are consumed domestically.

Strawberries Australia Inc. is the strawberry industry's peak national agri-political organisation representing strawberry growers. All States have a Strawberry Growers Association affiliated with the national body. Total investment in research and development (R&D) associated with strawberry production in 2017/18 was $1.19 million (Hort Innovation Company, 2018, p54).

The Strawberry Industry Strategic Investment Plan 2012/2017 states that the industry's objectives are:

Objective 1 - Increase demand of the product.

Objective 2 - Increase production efficiency.

Objective 3 - Ensure an effective operating environment of industry levies by enhancing the industry's leadership, capacity and influence.

The Strawberry Varietal Improvement Assessment

Six projects addressing varietal improvement are included in this qualitative assessment, but only five projects are included in the quantitative assessment, as explained later. The six projects were managed by the Department of Agriculture and Fisheries (DAF) Queensland. Most of these projects focused on varietal improvement of strawberries grown in subtropical areas, predominantly Queensland. The wide range of Australian climates enables June to August production in warmer or sub-tropical climates, as presented in Table A1.

Table A 1: Seasonality of Strawberry Production by State

State	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	% of Total Production
Vic													32%
QLD													33%
WA													22%
SA													10%
Tas													2%
NSW													1%

Source: Strawberries Australia Inc. website http://www.strawberriesaustralia.com.au/6860050/strawberries-australia-facts-figures.htm

3. Investment Details

Summary of Projects Assessed

The six Project Codes, Titles, Project Leaders and Funding Periods are provided in Table A2. Logical frameworks describing the objectives, activities and outputs, and actual and potential outcomes and impacts for each of the six individual projects are provided in Table A3.

Table A 2: Summary of Varietal Improvement Projects Included in the Impact Assessment

Project Code	Title	Principal Investigator	Funding Period
BS01005	Australian Strawberry Breeding Program – Late Autumn Winter/Spring (LAWS) markets	Mark Herrington, DAF	July 2002 to April 2006
BS06001	Late Autumn Winter Spring strawberries for profit and consumer appeal	Mark Herrington, DAF	July 2006 to October 2008
BS08006	Late Autumn Winter Spring strawberries for profit and consumer appeal - 2008/09	Mark Herrington, DAF	February 2009 to October 2009
BS09013	National Strawberry Varietal Improvement Program - Subtropical Regions	Mark Herrington, DAF	August 2009 to November 2012
BS12021	National Strawberry Varietal Improvement Program – Subtropical Node	Mark Herrington, DAF	June 2012 to June 2017
BS17000	National Strawberry Varietal Improvement Program (2017 to 2022)	Mark Herrington, DAF	July 2017 to November 2022

The last of the six projects, the ongoing project BS17000 is included only in the qualitative assessment.

Table A 3: Logical Frameworks for the Six Projects in the Investment

BS01005: Australian Strawberry Breeding Program – Late Autumn Winter/Spring (LAWS) markets	
Project Details	Organisation: Department of Agriculture and Fisheries Period: July 2002 to April 2006 Principal Investigator: Mark Herrington
Rationale	The Australian Strawberry varietal improvement program focused on productivity, flavour, appearance and ease of harvesting. Such traits in a single variety do not always line up with one another requiring careful selective breeding to effect industry objectives.
Objectives	1. To make available very high quality and flavoursome strawberry varieties for consumption through late autumn, winter and spring via a selective breeding program.
Activities and Outputs	• The project commenced with making crosses from 23 parents, resulting in several lines being identified that were to enter on-farm trials in the next season. • It was decided that a focus for future crosses would be on combining lower acidity with early season production and bruise-resistant fruit. • A 10-week study tour to the University of Florida was organised to exchange information that would increase the efficiency of parental selection. The ensuing trip was highly relevant to the later-autumn, winter and spring sector of the Australian varietal improvement initiative. • Further crossing and evaluation of promising lines (including time of planting) were continued during 2002, 2003, 2004, and 2005. • Naming and application of Plant Breeding Rights (PBRs) for some earlier lines was instigated (e.g. Crimsonglow, Harmony, Brighteyes, Sugarbaby, Rubygem and Twotwelve). Preferred planting times were assessed using then current varieties as controls. • The first of the new varieties, DPI Rubygem, was released in 2003. • Consumer taste panels managed by DAF found that current and new varieties were mostly in the ‘acceptable’ and ‘liked’ status. • Liaison and interactions took place with the Queensland Strawberry Growers Association (QSGA), the Strawberry Commercialisation Advisory Team (SCAT), and the Strawberry Breeding Steering Committee (SBSC).
Outcomes	• Since the commencement of the project Rubygem, Harmony, Brighteyes, Sugarbaby and Twotwelve have been commercialised. • Rubygem has been the best performer but has shown deficiencies in rain damage, transportability, and tolerance to fumigation. • Interaction and exchanges with University of Florida breeding program were ongoing.
Impacts	• Consumer appeal for the new varieties has increased as well as some increase in yield and profitability. • An increase in the efficiency of parental selection due to increased exchanges and learnings with the Florida breeding program

BS06001: Late Autumn Winter Spring strawberries for profit and consumer appeal	
Project details	Organisation: Department of Agriculture and Fisheries Period: July 2006 to October 2008 Principal Investigator: Mark Herrington
Rationale	This investment was required to continue variety improvement in Late Autumn Winter Spring (LAWS) strawberry production under Project BS01005, as well

	as commence more innovative methods of selection.
Objectives	1. To develop closer national integration between northern and southern breeding programs. 2. To improve profitability of growers in the long term by enhancing innovation in the LAWS breeding program via protecting against wilt diseases, increasing early production, improving selection efficiencies, and maximising consumer appeal and choice. 3. To continue cultivar development within the LAWS breeding program in the short term.
Outputs	• In this project, breeding and selection systems were similar to those used previously, with modifications for fruit shape, visual impact and parental evaluation. • A variety known as Parisienne Belle (highly flavoured) performed sufficiently well to progress to provisional PBR stage. • Parisienne Belle was released during this project. • Including the earlier project BS01005, seven cultivars were reported being produced from the program up to this stage. • Interstate trials demonstrated good performance of some advanced selections made in the subtropical region. • By the end of the project, evaluation of advanced lines was proceeding at field site trials as well as farmer located trials.
Outcomes	• This two year project made a significant contribution to the subtropical bred cultivar releases. • Parisienne Belle initially captured less than 1% of plantings but mostly for home gardens; however, there was a 30% increase in sales of this variety later in 2011/12, • Rubygem was the most successful of the early cultivar releases but was released during BS01005 and before project BS06001 commenced. • Rubygem and Festival (an overseas variety) were more profitable to grow than other varieties and dominated early plantings during the period of this project. • Progress was made towards increased productivity in future via improved breeding strategies. • LAWS developed cultivars that are superior to others e.g. in 2008 over 50% of runners planted in Queensland were of LAWS project bred or project facilitated introductions.
Impacts	• Contribution to increased profitability of strawberry growing in Queensland due to LAWS bred cultivars released during this early period of the varietal improvement investment in the subtropics. • Contribution to future potential for further new variety releases from the variety improvement program and a subsequent increase in industry profits and consumer satisfaction.

BS08006: Late Autumn Winter Spring strawberries for profit and consumer appeal	
Project details	Organisation: Department of Agriculture and Fisheries Period: February 2009 to October 2009 Principal Investigator: Mark Herrington
Rationale	A national program for strawberry breeding was being proposed that was intended to be a five-year project after the disinvestment of the Victorian DPI from strawberry breeding. The current 9-month project was to continue supporting the existing LAWS breeding initiative as an interim ‘business as usual’ approach.

Objectives	1. To continue cultivar development in the short term with emphasis on disease resistance and selection efficiencies. 2. To offer a transition to a longer-term strawberry genetic improvement program integrated into the supply cycle and to provide a foundation for further progress.
Outputs	• The project involved frontier technologies and smart data management including BLUP (best linear unbiased prediction), marker assisted selection, supply cycle integration, disease resistance, as well as flavour and consumer assessments. • DNA profiles were developed for identifying advanced lines entering the semi-commercial stage. • Potential sources of resistance to wilt diseases were identified; two of nine isolates (17337 and 13581) of *Fusarium oxysporum f.sp fragariae* were identified as highly pathogenic and could be used in breeding Fusarium resistant cultivars to reduce plant losses and improve industry economics. • Eighteen primary clones demonstrated significant progress towards the long-term target of equalising production from May 1 to Sept 30 at 60g/plant/week. • Progress was made towards new strawberry varieties with high consumer acceptance, larger fruit size and high productivity (e.g. lines 2006-019, 2006-215, and 2006-475 were showing particular promise). • Up to seven advanced stage lines with productivity and quality attributes were identified and were established on farms in Queensland and in other states for pre-commercial tests. • The most important output from this short project was a new project proposal entitled “National strawberry varietal improvement program – subtropical regions (BS09013)”.
Outcomes	• No new Queensland bred varieties were released during the nine-month period of this project. • The project contributed to the prospective release of new and improved cultivars in the next few years contributing to increased industry productivity and consumer satisfaction. • The technological and advanced selection outputs from this project positioned the subtropical and national strawberry industry and its genetic improvement programs in a good position for further progress. • National recognition of the transition to an effective national project proposal integrating supply cycle features and advanced technology which was likely to deliver benefits through increased use of local cultivars.
Impacts	• Contribution to potentially increased productivity and profitability for strawberry growers. • Contribution to potentially reduced breeding costs in delivering new cultivars.

BS09013: National Strawberry Varietal Improvement Program - Subtropical Regions	
Project details	Organisation: Department of Agriculture and Fisheries Period: August 2009 to November 2012 Principal Investigator: Mark Herrington
Rationale	The project continued the breeding effort for subtropical regions and followed Projects BS06001 and BS08006.

Objectives	1. To develop a range of high-quality, high-value varieties suited to production across the range of important Australian growing regions by targeting sub-tropical type environments.
Outputs	• The subtropical node's historical data between 2004 and 2009 was reformatted and entered into a database, making it available for future reference. • Part of the data set was used to assist in determining the contribution of individual plant traits to cost, income, production efficiency and profitability for the subtropical region. • It was found that the start and duration of production are under complex genetic control. • The current project derived varieties 'Suncoast Delight' (2006-475) and 'Aussiegem' (2006-019) were both released in 2010 and gained PBR in 2011. Both received commercial orders; these orders were (for 2012) estimated at covering about 1% of subtropical strawberry areas. • Progress was made towards further variety releases over the period from 2012 to 2017. • Trials of high-quality lines 2007-220, 2008-116, 2009-166 were conducted in 'preliminary-off-station' evaluations. These lines were considered sufficiently promising to advance to 'on-farm trials' in 2012. All were estimated to increase gross margins by 6 to 29%. • The 'advanced-stage' lines established on farms in 2011 were not sufficiently promising to continue evaluating. • The additional lines to carry forward for the next stage of testing included 2008-054, 2008-140, 2009-063, 2009-136, 2009-156, 2009-167, 2009-055. These produced attractive, well-flavoured and abundant fruit, and all (except for two), were indexed under the QSGA approved runner scheme protocol and cleared. • In the season to October 2012 the following lines were of interest and indexing progressed: 2010-114, 2010-064, 2010-113, 2011-227, 2010-033, 2011-049, 2011-160, 2011-174, 2011-192, 2011-214, and 2009-030. • The Western Australia node established seedlings from seed crossed by the subtropical node in 2011. They were designed to meet environmental requirements especially of the Perth area and some should carry Fusarium resistance, highly applicable to Western Australia.
Outcomes	• A successful past release 'Rubygem' is now being grown in Turkey. • Potentially increased adoption of Australian bred varieties by subtropical strawberry growers. • Potentially a significant increase in profitability of strawberry growing by 2017 via decreasing production costs, increases in production per plant, and maintaining (or ameliorating reductions in) average price/kg by providing sufficiently high-quality product. • Contribution to an increase in project developed/facilitated cultivars that are superior to others e.g. in 2012 over 70% of runners planted in Queensland were Subtropical program bred or facilitated introductions.
Impacts	• A likely increase in profitability of strawberry growing in the subtropical areas (gross margins), delivered via new varieties bred in the program.

BS12021: National Strawberry Varietal Improvement Program: Subtropical Node	
Project details	Organisation: Department of Agriculture and Fisheries Period: December 2012 to November 2017 Principal Investigator: Mark Herrington
Rationale	This project was a continuation of the Subtropical breeding program and followed BS09013. However, the project scope was extended during the course of the project to include breeding for Australia's temperate and Mediterranean production regions (which included the management of the existing Victorian Strawberry Breeding Program (Hort Innovation, 2018).
Objectives	To develop a range of high-quality, high-value varieties suited to production across the range of important Australian growing regions by targeting subtropical type environments. Specific goals were: 1. to commercialise 2 to 6 varieties of low chill - short day or day neutral with high consumer appeal and outstanding agronomic characteristics, which capture at least 25% of the total Queensland and NSW market by 2018.
Outputs	• Outputs included a series of crosses and evaluation of lines aimed at new variety releases with higher yields and improved quality and with significant gross margin increases for growers. • To produce the new varieties, individual breeding targets for each production region were set in consultation with the local industries, with desirable traits including improved resistance to the crown wilt diseases *Macrophomina phaseolina* (charcoal rot*), Colletotrichum gloeosporioides* and *Fusarium oxysporum f. sp. fragariae*. • Building on the breeding strategy developed in earlier industry work, the project incorporated quantitative genetic analysis and economic modelling of fruit and plant traits to guide crossing and selection decisions. • Progress was made towards an improved resistance to Fusarium, the most common cause of crown rot in strawberries in Western Australia, causing major losses in some crops as there was no chemical control available. • Varieties released during the project period for subtropical areas included Red Rhapsody, Parisienne Kiss, Sundrench. Scarlet Rose-ASBP, Sunglow-ASBP, Meadowsong, and Venus-ASBP. • Five varieties were also released for temperate (2) and Mediterranean (3) climates, due to the extended scope of the project.
Outcomes	• An expected increased adoption of the above varieties and other new varieties in future including some with higher disease resistance. This adoption will increase the profitability of subtropical and Western Australia strawberry production, as well as some contribution to grower profitability in other regions, and some potential contribution to a cleaner environment from the improved disease resistance. • The project team reported that, "in 2017, varieties from the Australian Strawberry Breeding Program (ASBP) captured 44% of the subtropical market and 19% of the national market. These plantings had a farm-gate value of approximately $78 million and contributed approximately 2,700 jobs in production." • Indications from runner growers suggest that 2018 sales of ASBP varieties were substantially higher than 2017 levels. • It was reported that there was still more work to be done for the

	temperate and Mediterranean regions, with other potential new varieties projected. • Breeding work was to continue through the investment in the National strawberry varietal improvement project 2017/2023 (BS17000).
Impacts	• An increase in profitability of strawberry growing in subtropical, as well as a more limited contribution to other Australian regions. • A potential reduction of chemical export to the off-farm environment.

BS17000: National Strawberry Varietal Improvement Program (2017-2023)	
Project details	Organisation: Department of Agriculture and Fisheries Period: December 2017 to June 2023 Principal Investigators: Mark Herrington and Jodi Neal
Rationale	This project was a continuation of the subtropical variety improvement program and is currently ongoing. This new phase of the ASBP was to ensure that the Australian strawberry industry has access to improved, locally-adapted varieties into the future, and to continue the development and commercial release of superior varieties for targeted environments including temperate, subtropical, and Mediterranean environments.
Objectives	1. The project is aiming to develop and commercially release superior strawberry varieties adapted for production in subtropical, temperate and Mediterranean environments. The project continued with the existing successful breeding strategies developed in earlier projects but was further enhanced by incorporating genomic prediction and marker assisted selection methods.
Outputs	• Variety development has been taking into account the new substrate culture production system. • Disease resistance screenings of advanced lines and parents were extended from wilt diseases to powdery mildew. • Commercialisation agreements and plans were developed and are being implemented.
Outcomes	• Continued adoption of new varieties released during the previous projects. • During the current project period, it was expected that varieties from the ASBP would capture up to 50% of the subtropical growing market and 20% of the temperate and Mediterranean market in Australia. However, 2018 sales ended up capturing around 70% of the subtropical market and 30% of the national market (Jodi Neal, pers. comm., 2019). • It was reported that there was still more work to be done for the temperate and Mediterranean regions, with other potential new varieties projected.
Impacts	• A likely continuing increase in profitability of strawberry growing in the subtropical areas (gross margins), delivered via new varieties developed in the program. • Some increase in profitability of strawberry growing in the non-subtropical areas (gross margins), delivered via new varieties developed in the program; however, attribution to the investment in the DAF led projects considered in this assessment will be lower than for the subtropical focus, as a significant DAF project contribution commenced only in the past few years.

4. Project Investment

Nominal Investment

Table A4 shows the nominal, annual investment (cash and in-kind) for each of the five projects. The investment in Project BS17000 has not been included in the quantitative analysis as it is current and only in its second year of a five year period.

Table A 4: Annual Investment by Project and Source of Funds (nominal $)

Project	Year ending 30th June	DAF	Hort Innovation	Total
BS01005	2002	197,713	150,000	347,713
	2003	209,183	153,048	364,434
	2004	216,882	155,251	372,133
	2005	230,041	158,118	388,159
	2006	242,068	159,671	401,739
Subtotal	**BS01005**	**1,095,887**	**776,088**	**1,871,975**
BS06001	2007	331,451	231,931	563,381
	2008	259,996	181,931	441,927
	2009	71,454	50,000	121,454
Subtotal	**BS06001**	**662,901**	**463,862**	**1,126,762**
BS08006	2009	464 579	266 447	731,026
Subtotal	**BS08006**	**464 579**	**266 447**	**731,026**
BS09013	2010	592,943	275 000	867,943
	2011	592,944	275,000	867,944
	2012	237,177	110,000	347,177
	2013	355,766	165,000	520,766
Subtotal	**BS09013**	**1,778,830**	**825,000**	**2,603,830**
BS12021	2013	664,327	292,165	956,792
	2014	1,058,953	465,718	1,524,671
	2015	363,737	159,968	523,705
	2016	815,588	358,688	1,174,276
	2017	61,225	26,926	88,151
	2018	729,588	320,866	1,050,454
Subtotal	**BS12021**	**3,693,417**	**1,624,331**	**5,317,748**
Total	**All five projects**	**7,695,615**	**3,955,728**	**11,651,343**

Program Management Costs

For the DAF investment the management and administration costs for the project are assumed already built into the nominal $ amounts appearing in Table A4. 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 Hort Innovation investment, a management cost multiplier (1.12) was applied to the Hort Innovation contributions shown in Table A3. This multiplier estimate was based on information in the Hort Innovation Annual Report (2018).

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2017/18 $ terms using the Implicit Gross Domestic Product (GDP) Deflator index (ABS, 2018). No additional costs of extension were included as the project already involved a high level of industry participation through growers and Strawberries Australia Inc.

5. Past Industry Data and Performance 2001 to 2017

The following table (Table A5) provides area, yield, production and total value data for Australian strawberry production for each financial year ended 30th June from 2001 to 2017. Further, the tables following (Tables A6 to A8) provide tonnage, area, yield and value data by Australian state.

Table A 5: Areas, Yields, Production and Value for Australian Strawberry Industry Performance by Year

Year ended June	Area (ha)	Yield (t/ha)	Production (t)	Value ($m)
2001	919	16.9	15,566	95.2
2002	986	20.4	20,088	107.7
2003	1,479	15.4	22,834	130.5
2004	999	20.2	20,219	135.3
2005	865	27.5	23,737	122.3
2006	1,247	21.9	27,336	170.0
2007	1,240	23.0	28,559	200.7
2008	1,298	18.9	24,505	162.5
2009	1,183	23.9	28,246	183.2
2010	1,384	21.2	29,334	212.4
2011	2,220	13.9	30,897	223.6
2012	1,562	19.7	30,809	233.5
2013	1,917	16.9	32,405	234.0
2014	2,123	18.1	38,394	242.0
2015	2,240	20.4	45,604	272.6
2016	1,995	24.3	48,401	310.2
2017	2,265	20.0	45,251	287.5
Average	1,525	20.2	30,128	195.5

Source: ABS (2018) (Various)
n/a: not available
2008 onward: area = bearing age

Table A 6: Tonnages of Australian Strawberry Production by State (t)

Year ended June	QLD	NSW	VIC	TAS	SA	WA	Australia
2001	5,275	188	5,868	243	1,600	2,390	15,566
2002	5,795	81	8,488	397	1,693	3,635	20,088
2003	7,480	223	10,440	309	1,366	3,016	22,834
2004	6,153	166	8,157	214	2,192	3,337	20,219
2005	10,146	222	8,069	282	1,557	3,461	23,737
2006	12,929	281	6,618	421	2,216	4,870	27,336
2007	17,363	737	5,673	318	2,096	2,373	28,559
2008	12,669	320	6,788	327	1,400	3,001	24,505
2009	13,692	198	8,574	451	2,494	2,837	28,246
2010	13,085	277	10,740	319	2,397	2,516	29,334
2011	11,110	213	12,431	417	2,652	4,074	30,897
2012	12,188	188	11,533	282	2,764	3,855	30,809
2013	13,998	143	10,665	840	3,593	3,165	32,405
2014	16,576	61	13,506	1,464	3,422	3,364	38,394
2015	19,041	164	16,911	1,676	3,044	4,769	45,604
2016	23,663	190	12,724	3,295	3,417	5,112	48,401
2017	19,949	129	15,069	2,604	2,608	4,892	45,251

Source: ABS (2018) (Various)
n/a: not available
2008 onward: area = bearing age

Table A 7: Areas of Australian Strawberries by State (ha)

Year ended June	QLD	NSW	VIC	TAS	SA	WA	Australia
2001	356	32	334	25	71	101	919
2002	324	32	400	41	56	132	986
2003	418	n/a	768	32	61	160	1,479
2004	329	12	405	29	88	136	999
2005	330	12	321	26	63	114	865
2006	568	51	335	31	84	172	1,241
2007	712	46	287	20	86	89	1,240
2008	669	36	390	23	63	117	1,298
2009	582	22	350	26	83	120	1,183
2010	647	28	474	40	80	115	1,384
2011	717	27	1,121	43	134	179	2,220
2012	692	23	562	33	84	169	1,562
2013	741	24	818	39	128	167	1,917
2014	1,014	18	788	61	130	113	2,123
2015	905	13	909	75	142	194	2,240
2016	947	25	623	93	155	153	1,995
2017	903	18	969	66	153	156	2,265

Source: ABS (2018) (Various)
n/a: not available
2008 onward: area = bearing age

Table A 8: Value of Production of Australian Strawberries by State ($m)

Year ended June	QLD	NSW	VIC	TAS	SA	WA	Australia
2001	31.7	1.2	35.3	1.4	13.3	12.4	95.2
2002	29.5	0.4	45.5	2.5	13.1	16.8	107.7
2003	39.8	1.3	61.2	1.7	12.1	14.4	130.5
2004	34.2	1.2	58.0	1.5	22.5	17.8	135.3
2005	48.6	1.1	40.3	1.5	14.1	16.8	122.3
2006	73.4	1.9	43.6	2.5	21.6	26.9	170.0
2007	116.3	5.2	41.7	2.3	22.4	12.9	200.7
2008	83.1	2.1	44.4	2.2	12.7	18.0	162.5
2009	87.4	1.2	53.4	3.5	21.4	16.4	183.2
2010	92.5	1.8	72.3	3.3	23.1	19.3	212.4
2011	74.2	1.6	93.9	4.3	25.3	24.3	223.6
2012	80.9	1.5	93.5	2.9	24.9	29.8	233.5
2013	71.6	1.3	87.8	9.3	37.4	26.6	234.0
2014	102.8	0.4	82.8	6.3	28.6	21.3	242.0
2015	114.2	1.0	91.8	12.3	22.5	30.8	272.6
2016	146.8	1.2	69.2	24.9	25.7	42.5	310.2
2017	121.3	0.8	85.6	19.8	19.3	40.8	287.5

Source: ABS (2018) (Various)
n/a: not available
2008 onward: area = bearing age

The ABS statistical trend data for area, production, yield, and price of Australian strawberries are presented in Figures A1 to A4:

Figure A 1: Area of Australian Strawberries (2001/2017)

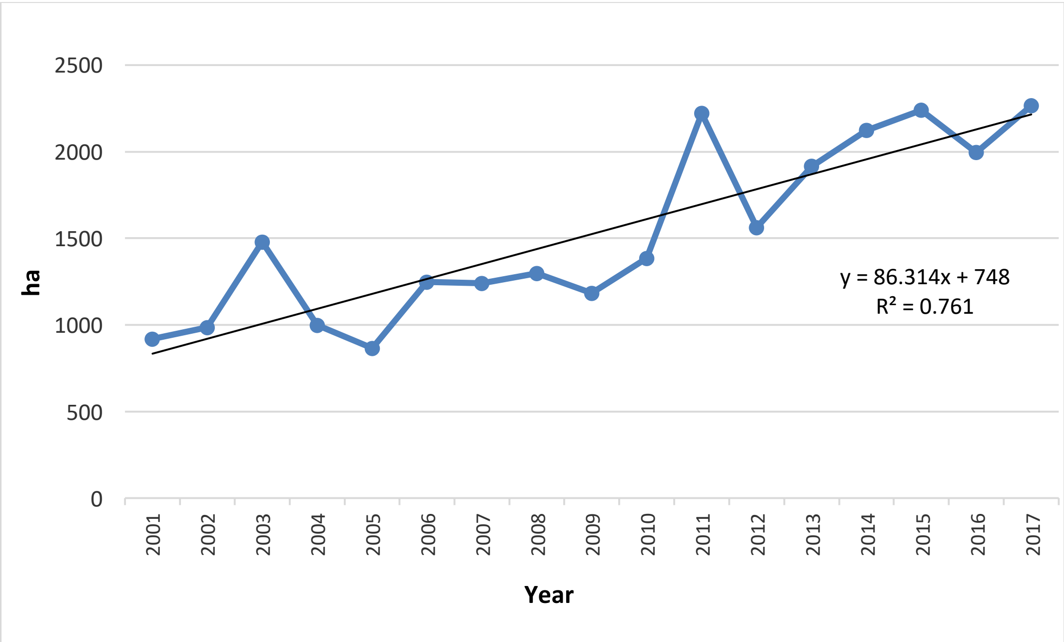
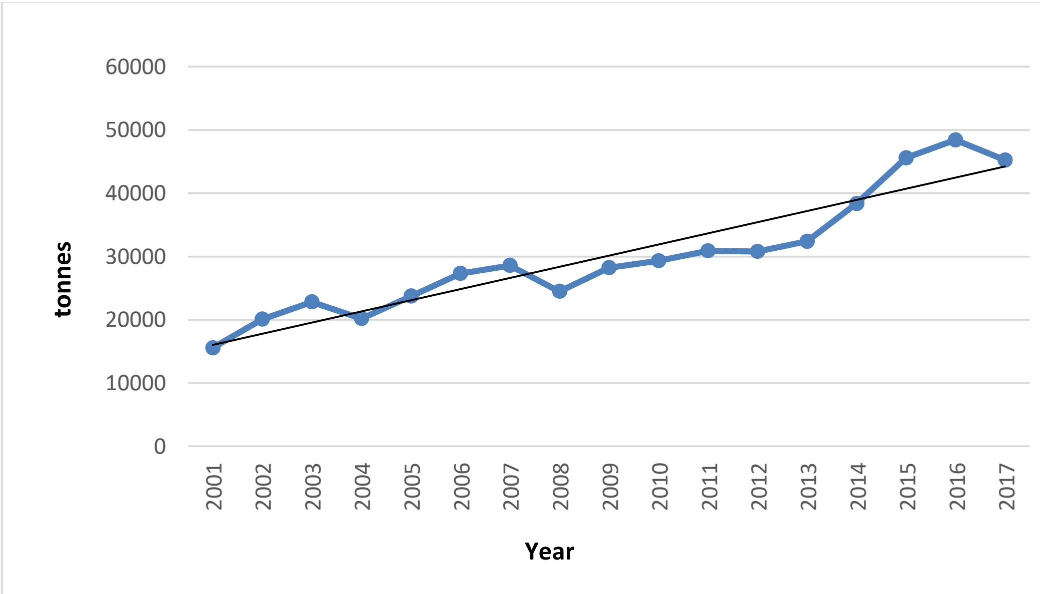


Figure A 2: Production of Australian Strawberries (2001/2017)



Two other associated drivers of the profitability of strawberry production are yield per ha and price per kg; relevant trends are shown in Figures A3 and A4. Figure A3 (yield per unit area) has been flat. Figure A4 (price per kg) shows that, in nominal terms, there has been a small price rise over the period. However, in constant dollar terms, there has been a price fall.

Figure A 3: Yield of Australian Strawberries

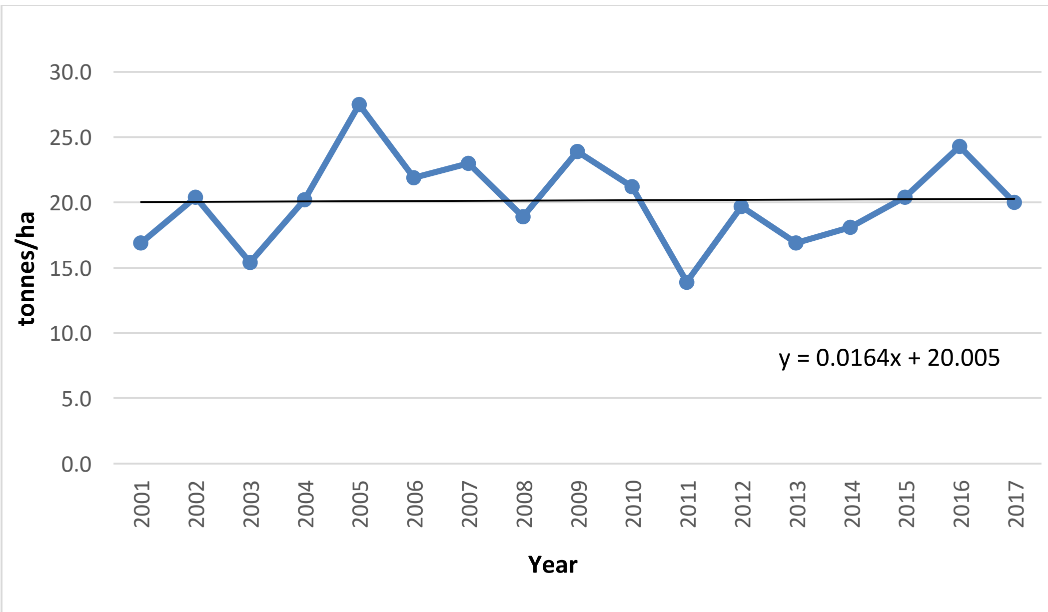
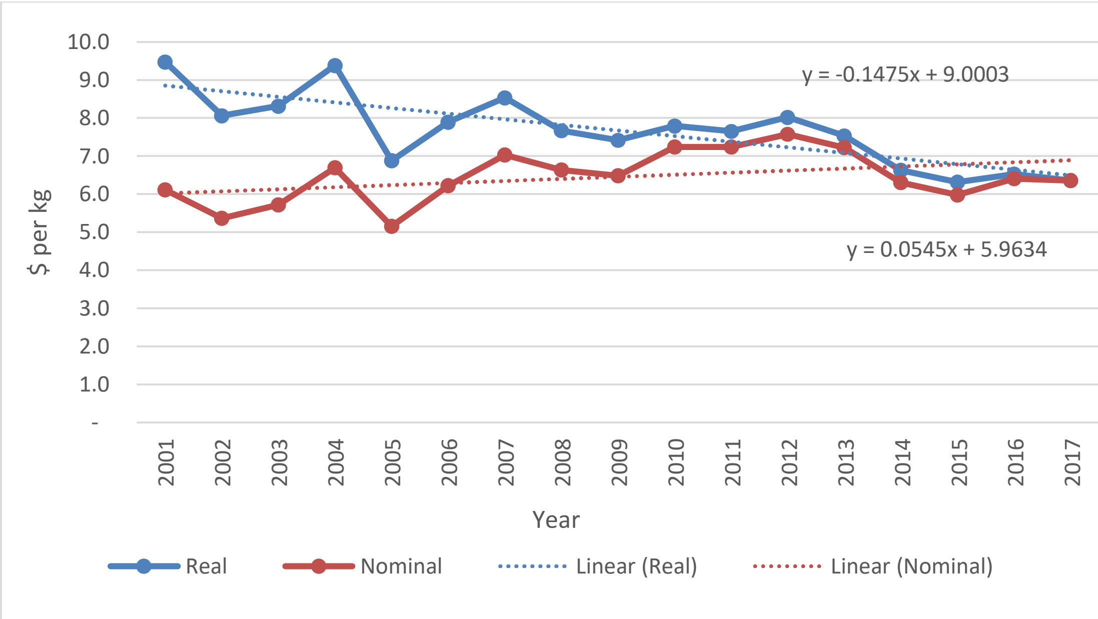
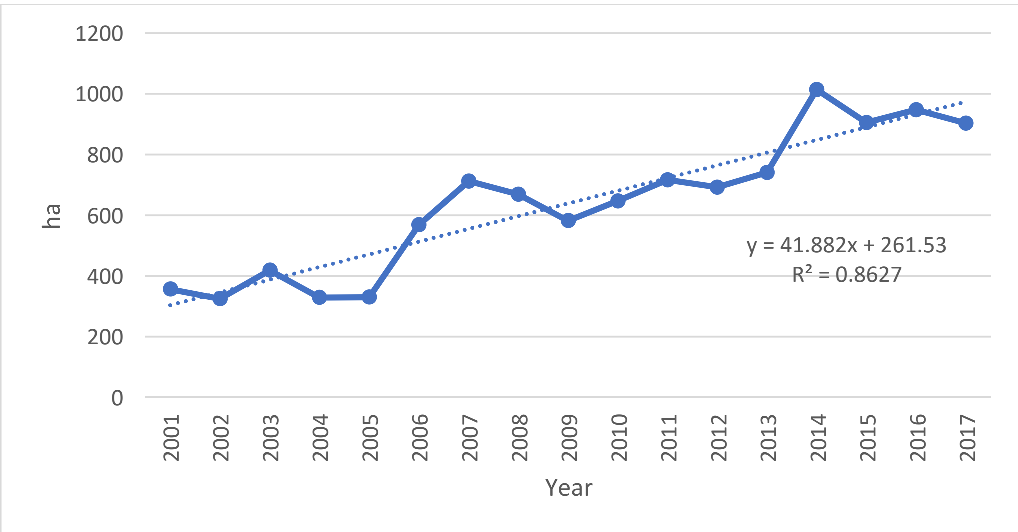


Figure A 4: Price of Australian Strawberries



A graphical representation of the area of Queensland strawberries over the period 2001 to 2017 is provided in Figure A5. The area statistical trend is highly significant.

Figure A 5: Area of Queensland Strawberries



In summary, the area and total Australian production of strawberries has more than doubled over the 17 year period. The crop area increase has been the major driver of the crop production/tonnage increase rather than yield per ha. Nominal prices have increased slightly despite the doubling of production, but in constant dollar terms prices have fallen slightly.

6. Impacts

The principal impact from the investment in improved varieties has been increased consumer satisfaction and associated increased demand contributing to an increased area of strawberries being grown in Queensland (and Australia). This increased demand may have been due, at least in part, to the new varieties (e.g. increased size, and improved taste, appearance, firmness and overall quality).

It is most likely that the significant increase in strawberry area in Queensland has been driven by increased consumer demand, and not by increased profitability of all producers. There is not much evidence of increased yield over time or higher prices for the improved quality of strawberries produced. In fact, the increased area and resulting increased production of strawberries may have negated any additional profits that would have been captured by growers if production had remained constant.

There is evidence that nominal prices to growers have remained much the same or have only slightly increased over the past 15 years. This price stagnation is probably a result of increased supply. In real dollar terms (taking into account inflation), prices to growers have actually fallen somewhat over the past 15 or so years. See Figure 4 presented earlier.

Structural change has occurred in the Queensland strawberry industry in the past few years. A number of growers (smaller growers in particular) have exited the industry or diversified into other horticultural products, while other growers have expanded their strawberry area. The declining strawberry price (in real terms) has been a major factor in this change.

On the other hand, some of the larger growers may have increased their overall farm profitability due to:

- an increase in their strawberry area has led to some reduction in fixed costs per ha.
- an increase in strawberry area possibly leading to a reduction in some variable costs.
- an increase in productivity from new varieties such as Red Rhapsody
- a higher profit from the increased area of strawberries compared to the previous land use (e.g. grazing, other horticultural crops).
- Some larger strawberry growers becoming horizontally structured across Australian growing regions in order to reduce supply variability.

Apart from the increase in consumer satisfaction as evidenced by increased consumption, some other social impacts may have been derived from increased community spillovers via the increased production of strawberries.

Principal Economic Impacts

The principal economic impacts in subtropical areas from the investment in improved varieties have been:

(a) Improved profitability for subtropical growers from the new varieties compared with the varieties that would have been grown had they not been replaced. Also, some new varieties have been released in other climatic zones including temperate and Mediterranean climatic zones where producers also have gained.
(b) Increased consumer satisfaction from improved subtropical strawberry appearance, size and colour, flavour and flavour range, and extended availability of product.

(c) Increased demand for strawberries across Australia (including subtropical areas) due to competitive prices and improved characteristics of new varieties valued by consumers.
(d) The increased demand has driven an increased area of strawberries being grown in subtropical areas and in other Australian strawberry growing areas; however, the increased area and resulting increased production of strawberries may have negated any significant additional profits that would have been captured by growers if the strawberry area had remained constant. Some growers may have increased their farm profitability due to an increase in their strawberry area and reduction in costs.

Improved Genetic Capital

The value of the germplasm capital existing in the program at the end of the investment period is likely to be greater than that at the start. This impact can be interpreted as the value of the germplasm in the program that will exist in 2022/2023 having a greater potential to produce improved varieties in the future than the germplasm existing at the beginning of the investment in 2001/2002.

Social and Environmental Impacts

Social impacts have been delivered in the form of consumer satisfaction, regional income spillovers, and increased employment. A potential environmental impact may have been delivered via reduced chemical use due to the new varieties released with increased disease resistance.

Summary of Impacts

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

Table A 9: Categories of Impacts from the Investment

Economic	Environmental	Social
Increased demand for strawberries across Australia, partly due to improved characteristics of new varieties valued by consumers Increased supply of strawberries to delivering consumer-desirable characteristics, particularly from strawberries growing in subtropical environments, but also to some extent in temperate, and Mediterranean environments Reduced breeding costs and /or improved resource allocation in breeding Increase in capital value of strawberry germplasm in the program between 2002 and the end of the investment in 2023	Increased disease resistance of new varieties may have resulted in reduced chemical use and hence a reduction in chemical export to the off-farm environment	Increased consumer satisfaction and utility due to improved aroma, flavour and quality Spillovers from increased farm incomes to regional communities and along the input and product supply chains Increased employment associated with increased strawberry supply

Public versus Private Impacts

The impacts identified from the investment are largely private accruing to strawberry consumers and some strawberry producers. The increased supply has negated any price increase so some negative impacts have been experienced by some growers.

Public benefits have been produced in the form of spillovers to regional communities from the increase in strawberry production leading to higher regional economic activity and employment.

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 strawberry breeding has been relevant to Rural RD&E Priorities 1 and 4 and to Science and Research Priority 1.

Table A 10: 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 (OCS), 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 maintained or increased strawberry growing profitability. The project was well supported and funded by others external to the QLD Government and had a distinctive angle as the subtropical strawberry production industry will be a major recipient of the impacts.

Table A 11: 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

7. Valuation of Impacts

Australian Production of Strawberries 2001 to 2023

The production of strawberries in Australia has increased significantly since 2001. A high proportion of this increase has been due to new varieties emanating from a series of projects funded in the investment carried out in the varietal improvement program funded by DAF Queensland and supported by Hort Innovation. The increase in area, production and value of Australian strawberries since 2001 has been described earlier (see Section 5).

Impacts Valued in Monetary Terms

The impact valued from this series of variety improvement investments was an increase in subtropical grower profitability largely from 2003 onwards due to the new and improved Australian subtropical varieties.

The smaller component of the added profitability was assumed to be replacement of areas of older varieties of strawberries with the newly released varieties (hereafter termed Impact 1). The larger component was the increased area and production of strawberries as supported by Figures 1 and 2. Given that the increased area of strawberries has been a significant driver of the crop production increase, Impact 2 has emanated from changing land use and an assumed gross margin increase over the former land use.

Impact 1: Adoption and Gross Margin Increase in Subtropical Areas

The assumptions that drive the gross margin increases of new varieties over the replaced varieties are provided in Table A12. The table shows an increasing proportion of the subtropical strawberry area populated by project-developed varieties over time, together with an increase in the gross margin over time when each of the new varieties are used.

It should be noted that the Queensland area of strawberries does not precisely represent the subtropical area of strawberries as there is a small subtropical area also in northern NSW; however, the area in Queensland around Stanthorpe can be considered temperate and not subtropical; for purposes of this valuation, the two areas are assumed to cancel one another out and therefore Queensland statistics are considered representative of subtropical performance.

The probabilities of the above profitability gains and adoption assumptions having been achieved are regarded as quite high. Hence, an impact probability factor of 90% for the gross margin and adoption parameters assumed has been applied (Table A12). The constituent assumptions for the base gross margin are also provided in Table A12.

Table A 12: Summary of Assumptions for Valuing Impact 1: Subtropical Variety Benefits

Year	**Subtropical Strawberry Area (QLD ha) (a)**	**Proportion of area assumed that is replaced with new Project derived varieties (%) (b)**	**Gross margin increase assumed (%) (b)**
2002	324	0	0
2003	418	0	0
2004	329	1	5
2005	330	2	5
2006	568	3	5
2007	712	4	5
2008	669	6	10
2009	582	8	10
2010	647	12	10
2011	717	14	10
2012	692	16	25
2013	741	20	25
2014	1,014	25	25
2015	905	30	25
2016	947	35	25
2017	903	40	25
From 2018	2017 benefit linearly reduced to zero by 2032 (c)		
Gross Revenue, Variable Costs, Gross Margin and Probability of Impact			
Average yield (t/ha) (d)			20.4
Average price ($/kg) (e)			7.50
Gross revenue ($/ha) (f)			$153,000 (20.4 x 7.50 x 1000
Total variable costs in 1997$ (DAFF, 1997) ($/ha)			$90,000
Total variable costs in 2018$ (GDP price index 1997 to 2018 =1.77)			$159,300
Total variable cost adjustment for productivity gain (10%) (g)			$143,370
Gross margin ($/ha) (h)			$9,630
Probability of Impact (i)			90%

Sources and Notes for Table 12:

(a) ABS (see Table A8)
(b) Agtrans Research, based on pers. comm., Mark Herrington, 2012, for assumptions from 2002 to 2012; also supported by trials in project BS09013 where lines were estimated to increase gross margins by from 6 to 29%; further, in 2017 the varietal improvement initiative reported

the new varieties from the ASBP had captured 44% of the subtropical market and 19% of the national market.
(c) No new releases have been assumed since the end of Project 12021; the benefits assumed after 2017 are assumed to gradually dissipate due to disease, consumer preferences etc.
(d) Based on Tables A7 and A8
(e) Based on Table A8 and Table A9, Figure A4, DPIPWE (2018), and DAFF QLD (1997) updated to 2017/18 terms.
(f) The gross revenue of $153,000 per ha has been estimated from 20.4t per ha x price of $7.50 per kg.
(g) The variable cost per ha of $143,370 per ha has been estimated from variable cost estimate of $90,000 per ha (DAFF, 1997) inflated by a factor of 1.77 (GDP deflator price index increase from 1997 to 2018) and then reduced by 10% for productivity cost reduction.
(h) The gross margin of $9,630 per annum has been estimated from gross revenue of $153,000 per ha (d), less variable costs of $143,370 per ha (e).
(i) Agtrans Research estimate

Impact 2: Increased Area of Strawberries grown in the Subtropical Areas

The assumptions that drive this impact are provided in Table A13.

Table A 13: Summary of Assumptions for Valuing Impact 2: Increased Area of Subtropical Strawberries due to New Varieties

Variable	**Assumption**	**Source**
Average annual area increase from 2001 to 2017 for Queensland	41 ha per annum	Based on Figure A5
Proportion of assumed increase due to subtropical varietal improvement program	75%	Agtrans Research
Average yield for Queensland strawberry growers	20.4 tonnes per ha	See Table A12
Average price for Queensland strawberry growers	$7.50 per kg	See Table A12
Gross revenue	$153,000 per ha	See Table A12
Total variable costs	$143,370 per ha	See Table A12
Gross margin	$9,630 per ha	See Table A12
Gross margin of enterprises assumed replaced	$3,000 per ha	Based on DAF AGBIZ (2019)

Impacts Not Valued in Monetary Terms

The impacts identified but not valued include:

- Some increase in grower profitability in temperate and Mediterranean climates, mostly as a result of the second half of the latter part of the investment period after the DAF involvement and management of the National Program increased significantly.
- Improved selection techniques and resource allocation in strawberry varietal improvement.
- Improvement in capital value of yet-to-be-exploited germplasm.
- Increased regional community spillovers.

The reasons for not valuing these impacts were as follows.

An increase in grower profitability in temperate and Mediterranean areas
The focus of the investment was on new varieties for the subtropical areas; other non-DAF projects addressed breeding investment in non-subtropical areas during the period of the DAF investment. However, as DAF led the national breeding program during project BS12021, the DAF project investment could be assigned at least part of the benefits delivered in the Mediterranean and temperate strawberry growing regions.

Improved selection techniques and resource allocation in strawberry varietal improvement
The two early project investments increased the efficiency of parental selection, especially of the later-autumn winter spring sector of Australian strawberry growing. However, an efficiency dividend was not applied on the grounds that such impacts could be captured in the impacts valued later in the program, so any separate impact valued posed the danger of double counting benefits. The difficult question to answer is what would have happened without these efficiencies?

Gain in Unexploited Germplasm from the beginning to end of the investment.
Any increase in the genetic capital of unexploited germplasm at the end of the investment period compared to at the commencement, suggests an additional unrealised impact from the investment that has not been valued. This unrealised impact will be delivered once further varieties based on the unexploited impact will be released at some time in the future.

Increased regional community spillovers
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 and any community spillover differences between strawberry and displaced land uses. Valuation of this impact was beyond the scope of the current assessment.

Counterfactual

Continued importation of varieties developed overseas which have been proven to be not as successful as locally bred varieties.

8. Results

All past costs were expressed in 2017/18 dollar terms using the Implicit Price Deflator for GDP (ABS, 2018). All costs and benefits were discounted to 2018/19 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.

Investment Criteria

Tables A14 and A15 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 A15, has been estimated by multiplying the total PVB by the DAF proportion of real investment (62.0%).

Table A 14: Investment Criteria for Total Investment in the Five Projects

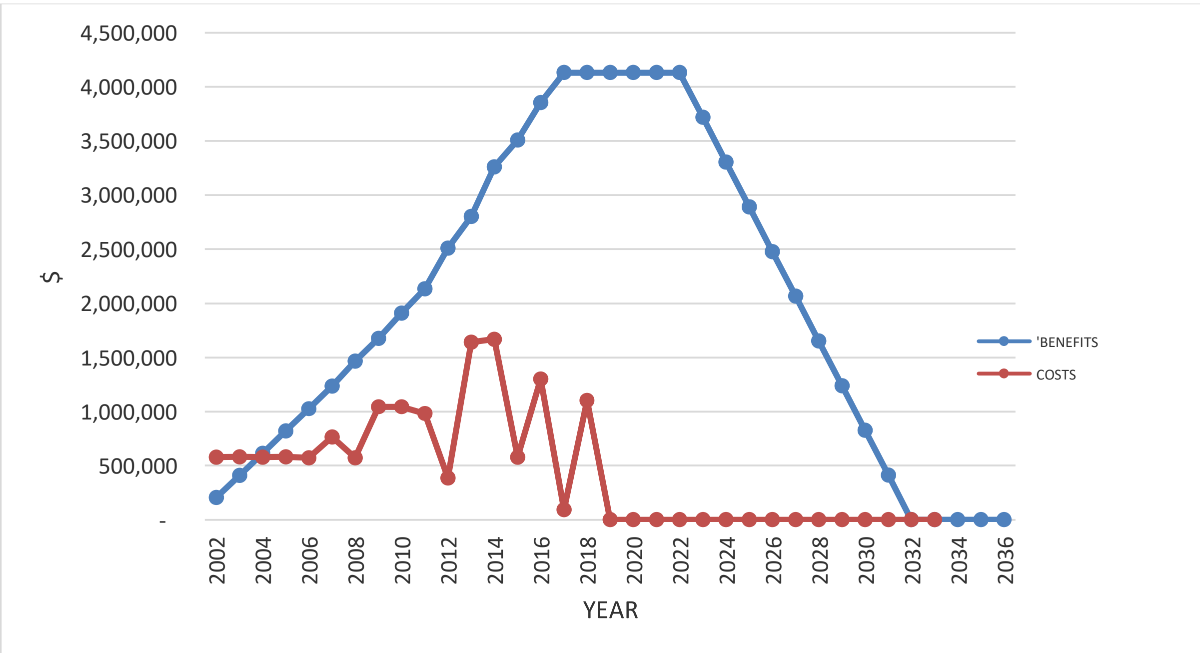
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	48.84	67.28	76.25	77.72	77.72	77.72	77.72
Present value of costs ($m)	21.48	21.48	21.48	21.48	21.48	21.48	21.48
Net present value ($m)	27.35	45.80	54.77	56.24	56.24	56.24	56.24
Benefit-cost ratio	2.27	3.13	3.55	3.62	3.62	3.62	3.62
Internal rate of return (IRR) (%)	51.4	51.9	51.9	51.9	51.9	51.9	51.9
Modified IRR (%)	negative	162.6	59.2	36.9	27.7	22.6	19.4

Table A 15: 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 ($m)	30.29	41.73	47.30	48.21	48.21	48.21	48.21
Present value of costs ($m)	13.10	13.10	13.10	13.10	13.10	13.10	13.10
Net present value ($m)	17.19	28.63	34.20	35.12	35.12	35.12	35.12
Benefit-cost ratio	2.31	3.19	3.61	3.68	3.68	3.68	3.68
Internal rate of return (IRR) (%)	64.6	64.8	64.8	64.8	64.8	64.8	64.8
Modified IRR	negative	204.2	70.0	42.8	31.7	25.7	21.8

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 A6.

Figure A 6: 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 A16 shows the relative contributions to the PVB from each impact valued.

Table A 16: Contribution to Total Benefits from Each Impact

Relative Sources of Benefits	Contribution to PVB ($m)	Share of benefits (%)
Impact 1 (individual varieties)	11.75	15%
Impact 2 (Increased area)	65.97	85%
Total	77.72	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 A17 presents the results that show the sensitivities of the investment criteria to the discount rate.

Table A 17: Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	70.81	77.72	93.00
Present value of costs ($m)	14.07	21.48	33.73
Net present value ($m)	56.75	56.24	59.27
Benefit-cost ratio	5.03	3.62	2.76

A sensitivity analysis was then carried out on the gross margin assumption. Table A18 presents the results.

Table A 18: Sensitivity to Gross Margin Assumption (Total investment, 30 years)

Investment Criteria	Gross Margin		
	-25% ($7,222)	$9,630 per annum (base)	+25% ($12,038)
Present value of benefits ($m)	50.82	77.72	104.62
Present value of costs ($m)	21.48	21.48	21.48
Net present value ($m)	29.34	56.24	83.14
Benefit-cost ratio	2.37	3.62	4.87

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 A19). 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 A 19: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Medium-High	Medium

Coverage of benefits was assessed as medium to high. Most benefits were economic in nature and related to profitability changes for Australian strawberry growers. Also, social impacts (e.g. community spillovers) were not valued.

9. Conclusion

The investment in the series of strawberry varietal improvement projects has been critical in facilitating growth in the strawberry industry in Australia over the past 17 years. During the investment period (years ending June 2001 to 2018), a number of improved strawberry varieties have been released from the breeding program with considerable success. The varietal improvement program was strongly targeted at the subtropical growing regions (represented by Queensland), resulting in a contribution to a near doubling of Australian strawberry production and consumption. Varietal success has varied with the varieties released and has included both favourable strawberry consumer and producer characteristics.

The benefits identified from the investment are predominantly private benefits for strawberry consumers and producers, but with a strong bias to increasing demand for the product as well as production efficiency, including the extension of the season for the subtropical region. There are also likely to be some public benefits captured with community spillovers from increased strawberry production and the generation of increased regional infrastructure and employment.

Structural change has occurred in the Queensland strawberry industry in the past few years. A number of growers (smaller growers in particular) have exited the industry or diversified into other horticultural products, while other growers have expanded their strawberry area. The declining strawberry price (in real terms) has been a major factor in this change.

The total investment in the five projects has produced a number of benefits some of which were valued in monetary terms. The total investment of $21.48 million (present value terms) was estimated to produce total benefits of $77.7 million (present value terms) providing a net present value of $56.2 million, a benefit-cost ratio of 3.62 to 1 (using a 5% discount rate), an internal rate of return of 51.9%, and a modified internal rate of return of 19.4%.

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

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Appendix B: An Impact Assessment of DAF Investment into the Fusarium wilt Tropical Race 4 Research Program (June 2015 to August 2019)

Acknowledgments

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Abbreviations

ABGC	Australian Banana Growers' Council (Incorporated)
ABS	Australian Bureau of Statistics
BMP	Best Management Practice
CRRDC	Council of Rural Research and Development Corporations
cv.	Cultivar
DAF	Department of Agriculture and Fisheries (QLD)
dpi	days post inoculation
Fe	Iron
FMS	Farm Management System
Foc	Fusarium oxysporum g. sp. Cubense or Fusarium wilt
GCTCV	Giant Cavendish Tissue Culture Variant
GDP	Gross Domestic Product
GPS	Global Positioning System
GVP	Gross Value of Production
HACCP	Hazard Analysis and Critical Control Point
Hort Innovation	Horticulture Innovation Australia Limited
ISHS	International Society for Horticulture Science
NDP	National Diagnostic Protocols
NDVI	Normalised Difference Vegetation Index
NGIA	Nursery and Garden Industry Australia
NIASA	Nursery Industry Accreditation Scheme Australia
NSW	New South Wales
NT	Northern Territory
PCR	Polymerase Chain Reaction

PHA	Plant Health Australia
PRG	Project Reference Group
QBAN	Quality Approved Banana Nursery
QLD	Queensland
R1	Race 1 (a race of the Fusarium wilt pathogen)
R2	Race 2 (a race of the Fusarium wilt pathogen)
R3	Race 3 (a race of the Fusarium wilt pathogen)
R4	Race 4 (a race of the Fusarium wilt pathogen)
R&D	Research and Development
RAT	Risk Assessment Tool
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
SARDI	South Australian Research and Development Institute
SR4	Sub-tropical Race 4 (a race of the Fusarium wilt pathogen)
TR4	Tropical Race 4 (a race of the Fusarium wilt pathogen)
WA	Western Australia

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 projects to improve the understanding and control of Fusarium wilt Tropical Race 4 (*Foc* TR4) for the Australian banana industry. The projects are jointly funded by DAF and the Australian Government and the Australian banana industry via Horticulture Innovation Australia from June 2015 to August 2019.

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 (2019/20). Past and future cash flows in 2017/18 dollar terms were discounted to the year 2018/19 (year of analysis) 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 (2018).

Impacts

The major impacts identified were economic/financial in nature. However, some social and environmental impacts also were identified but not valued. It is expected that Australian banana growers, particularly those in north Queensland, will be the major beneficiaries. Benefits focus on adoption of biosecurity best practice for the improved containment and control of *Foc* TR4.

Investment Criteria

The total investment of approximately $12.7 million (present value terms) has been estimated to produce total net benefits of approximately $147.2 million (present value terms) providing a net present value of $134.5 million, a benefit-cost ratio of approximately 11.6 to 1 (over 30 years, using a 5% discount rate), an internal rate of return of 24.9% and a modified internal rate of return of 14.0%.

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 as its principal tool. The approach includes both qualitative and quantitative methods that are in accord with the current evaluation guidelines of the Council of Research and Development Corporations (CRRDC) (CRRDC, 2018).

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

The Australian Banana Industry

Horticulture is Australia's second largest crop production industry after wheat, with fruit and nuts comprising 52%, vegetables 31% and nursery/ornamental crops 17% of the gross value of production (GVP) for horticulture (Australian Society of Horticultural Science, n.d.).

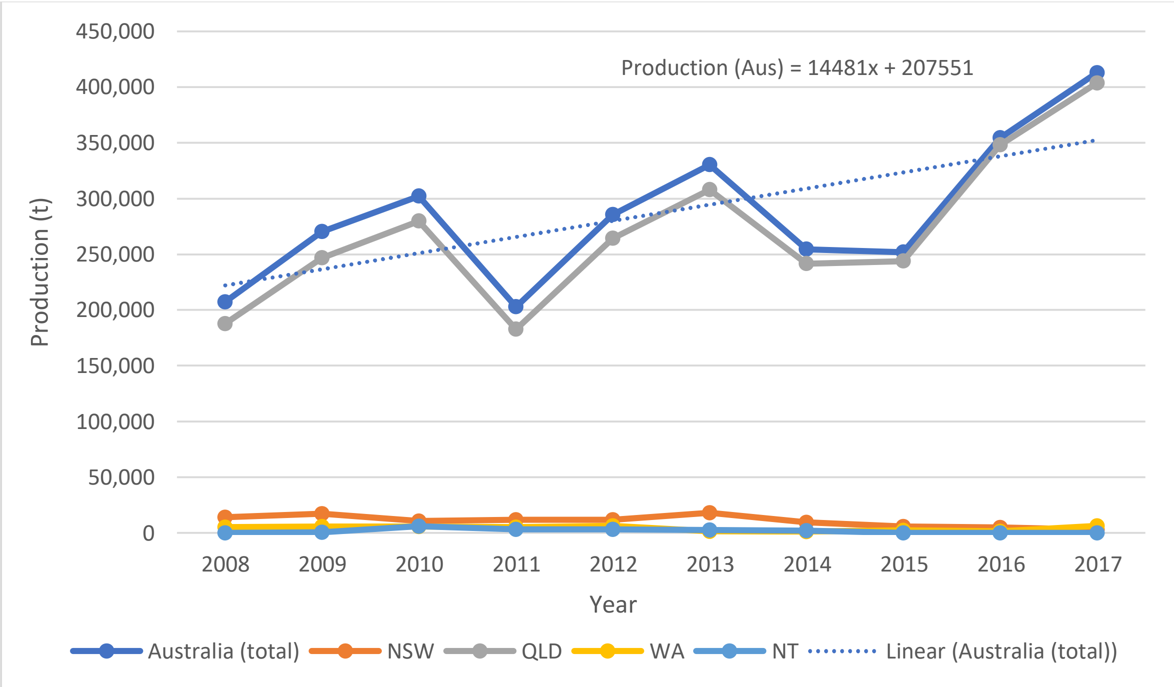
In the fruit category, bananas are Australia's number-one selling supermarket product (by volume) and the number two product in terms of total value (ABGC, 2019a). In 2016/17 Australian growers produced approximately 413,000 tonnes of bananas across 14,000 hectares (ABS, 2018a) with a GVP of $538.5 million (ABS, 2018b).

The vast majority of Australian bananas are sold as fresh fruit, with less than 1% of total production going to processing (e.g. dried fruit). Australia does not import or export fresh bananas. Production of Australian bananas is concentrated in Queensland (QLD) (94%) with a small proportion of production occuring in New South Wales (NSW) (4%), Western Australia (WA) (2%) and the Northern Terriroty (NT) (less than 1%).

Bananas are grown year round with the peak growing season between May and August. Although there are more than 500 varieties of banana plants wordwide (Hort Innovation, 2019a), production in Australia is dominated by the Cavendish variety that makes up 97% of total production. The remaining 3% is largely made up of the Lady Finger variety (Hort Innovation, 2019b).

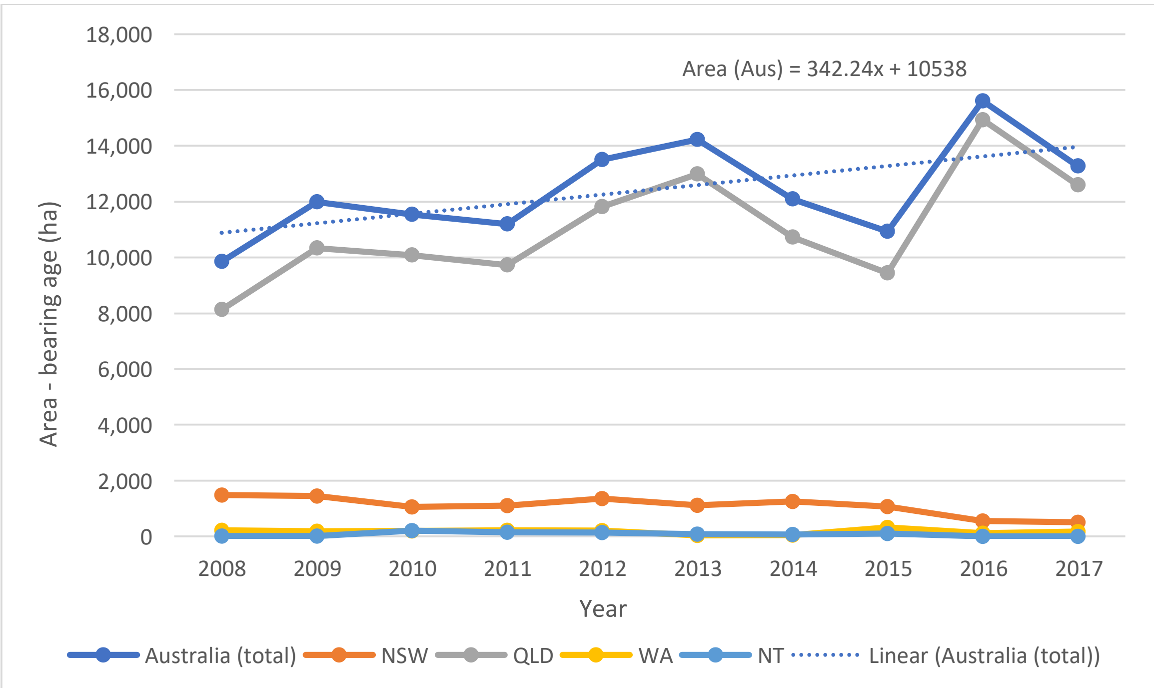
Figures B1 to B4 show the production, area, average yields, and gross value statistics for the Australian banana industry over the period 2007/08 to 2016/17 (10 years). The data show that production of Australian bananas has doubled from approximately 200,000 tonnes in 2007/08 to over 400,000 tonnes in 2016/17. This increase was largely due to the increase in the Queensland production area (from just under 10,000 hectares to just over 14,000 hectares over the 10-year period) although average yields also have increased marginally over the same period.

Figure B 1: Australian Banana Production (2007/08 to 2016/17)



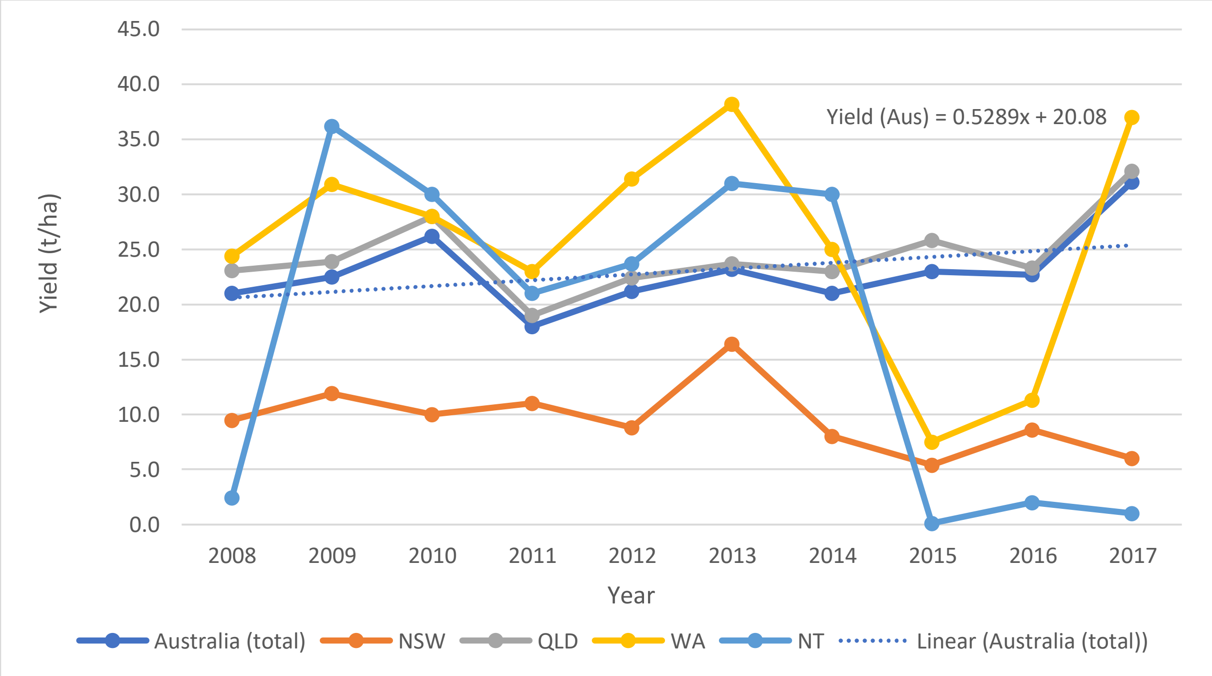
Source: ABS Catalogue 7121.0 Agricultural Commodities

Figure B 2: Production Area for Australian Bananas (2007/08 to 2016/17)



Source: ABS Catalogue 7121.0 Agricultural Commodities

Figure B 3: Average Australian Banana Yields (2007/08 to 2016/17)

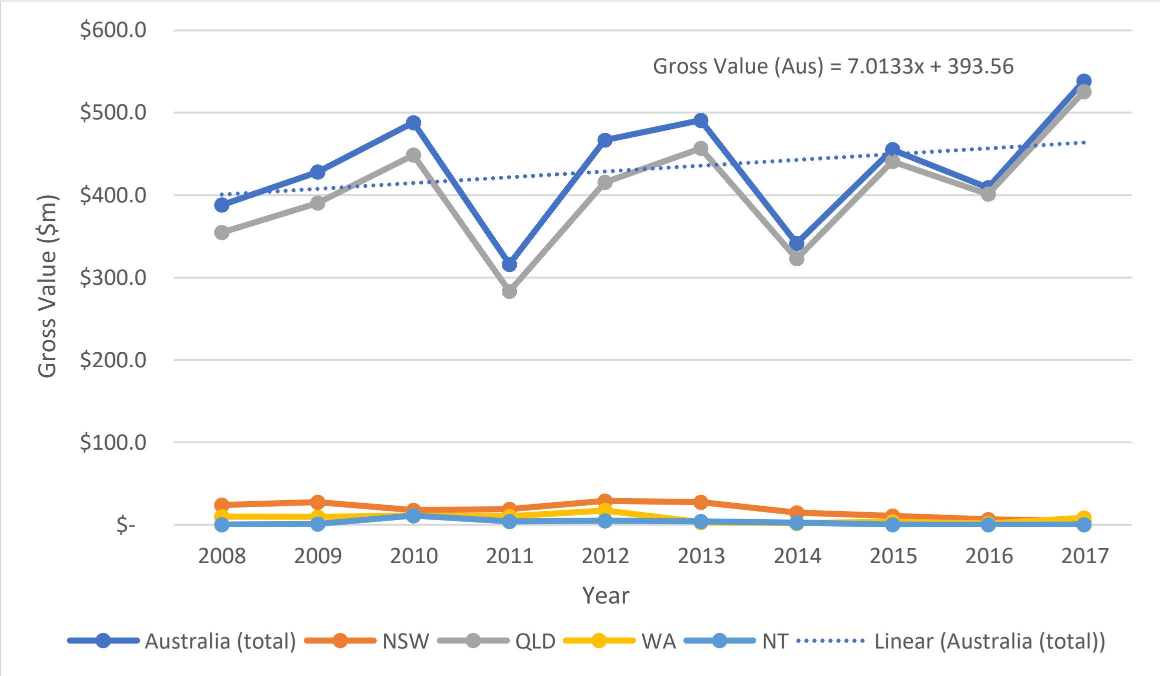


Source: Agtrans Research, derived from ABS data 2008 to 2017

In 2015, Cyclone Olwyn devastated production in Carnarvon (WA) leading to the sharp decline in yield (ABGC, 2019b).

Production in the NT has been very volatile. Fusarium wilt Tropical Race 4 (*Foc* TR4) was detected in 1997 and devasted the NT banana industry (Northern Territory Government, 2017). Banana production areas and yields remained negligible in the NT for the next decade. Some recovery from the disease occurred thanks to the Darwin Banana Farm. The Farm was able to manage the disease by rotating their soil and stringently managing biosecurity protocols (Walmsley, 2015). However, Banana Freckle (*Phyllosticta cavendishii*, a serious fungal disease affecting banana plants and fruit) was detected in the NT in 2013. As a result, the NT government, in partnership with the NT banana industry, implemented a three-year plan known as the Banana Freckle Eradication Program (ABGC, 2019c). Under the program, all NT banana production was destroyed. The NT was declared Banana Freckle free on 1 February 2019 (Northern Territory Government of Australia, 2019).

Figure B 4: Gross Value of Production for Australian Bananas (2007/08 to 2016/17)



Source: ABS Catalogue 7503.0 Value of Agricultural Commodities

Disease Risks to the Australian Banana Industry

The banana industry worldwide is subject to serious disease events, with Australia being no exception despite the fact that no fresh bananas are currently imported into the country. Biosecurity risks to Australian bananas are recognised by the industry in the Australian Banana Strategic Investment Plan (Hort Innovation, 2017). Pest and disease management (including broader industry biosecurity issues) is recognised as a key strategic outcome under the current Plan.

National research, development and extension (RD&E) investment for the Australian banana industry is guided by the National Primary Industries RD&E Framework for Horticulture (2010). Biosecurity also is recognised as a major investment priority under the Framework. The Framework states:
"Biosecurity RD&E is a key driver with potential threats if the import of bananas from South east asia is approved."

There are currently three major biosecurity threats challenging the Australian banana industry (PHA, n.d.):

1) Banana freckle,
2) *Foc* TR4, and
3) Banana bunchy top virus.

Rationale for the Current Investments

Fusarium wilt

Fusarium wilt (*Foc*), also known as Panama disease, is a destructive fungal disease of banana plants. It is caused by the fungal plant pathogen *Fusarium oxysporum f. sp. cubense*. It first became epidemic in Panama in 1890 and proceeded to devastate the Central American and Caribbean banana industries that were based on the ‘Gros Michel’ variety in the 1950s and 1960s.

There are four recognised races of the *Foc* pathogen which are separated based on host susceptibility (Daly & Walduck, 2006):

- Race 1 (*Foc* R1), was responsible for the epidemics in ‘Gros Michel’ plantations, and also attacks ‘Lady Finger’, ‘Silk’, and ‘Ducasse’ varieties.
- Race 2 (*Foc* R2) affects cooking bananas such as ‘Bluggoe’.
- Race 3 (*Foc* R3) affects *Heliconia spp.*, a close relative of banana, and is not considered to be a banana pathogen.
- Race 4 (*Foc* R4) is capable of attacking ‘Cavendish’ as well as the other varieties of banana affected by R1 and R2. Races 1, 2 and 4 have been present on the east coast of Australia for many years and R1 also is present in WA.
  R4 is further divided into ‘sub-tropical’ (SR4) and ‘tropical’ (TR4) strains.

Foc TR4 is a more virulent form of the pathogen and is capable of causing disease in ‘Cavendish’ growing under any conditions. *Foc* TR4 was first identified in Taiwan in 1989 and has since spread rapidly.

The soilborne *Foc* TR4 fungus enters the plant through the roots and blocks the plant's vascular system, causing it to wilt and die. *Foc* TR4 can't be eradicated and can survive dormant in the soil for decades without host plants. It is easily spread by movement of contaminated soil and water and infected planting material (Queensland Government, 2018).

TR4 was discovered in Darwin’s rural area in 1997 and has since spread to most banana growing areas of the Top End. In March of 2015, *Foc* TR4 was also identified on a property in the Tully area (QLD) where a large percentage of Australian bananas are grown (O'Neill, et al., 2016).

Very few varieties are resistant to the *Foc* TR4 strain of the pathogen and despite years of breeding no commercially acceptable varieties have proven to be fully resistant, although selections of Cavendish (Giant Cavendish Tissue Culture Variant (GCTCV)) have been used in Taiwan since the early 1990s (Hwang & Ko, 2004). With 94% of Australian production based in Queensland, the spread of *Foc* TR4 (or other *Foc* races) has the potential to devastate the Australian banana industry.

Rationale

In 2015, the Department of Agriculture and Fisheries (DAF) QLD, in partnership with Horticulture Innovation Australia Limited (Hort Innovation) funded a series of projects, collectively known as the Fusarium wilt Tropical Race 4 Research Program, to support successful containment of the disease and prevent further spread of the pathogen. The Program also was funded to investigate options to facilitate the development of economically viable production systems capable of minimising inoculum build up, that are suitable for use on infected or ‘at risk’ farms.

3. Project Details

Summary of Projects

Project Code	Project Title	Project Leader	Funding Period
BA14013	Fusarium wilt Tropical Race 4 – Biosecurity and sustainable solutions	Stewart Lindsay, Department of Agriculture and Fisheries, Queensland	June 2015 to June 2020 (Tony Pattison, pers. comm., 2019)
BA14014	Fusarium wilt Tropical Race 4 Research Program	Tony Pattison, Department of Agriculture and Fisheries, Queensland	June 2015 to August 2019
ST15011	Child 10 – DAF – Multi-scale monitoring tools for managing Australian Tree Crops: Industry meets Innovation	Trevor Parker, Department of Agriculture and Fisheries, Queensland	August 2015 to April 2019

Logical Frameworks

Tables B1 to B3 provide a description of the each of the projects using a logical framework approach.

Table B 1: Logical Framework for Project BA14013

Objectives	The overall aim of the project was to provide new science, information and practices that addressed key areas of need in the banana industry. The project was delivered with five main objectives, each with several interrelated components. The specific objectives of the project were to: 1. Conduct research to underpin improved biosecurity practices on farm 1.1 Rapidly identify solutions for early uptake in biosecurity practice: reducing inoculum movement from around banana plants, within plantations and between plantations. 1.2 Develop tools that provide early indications of infection and allow for prompt interventions. 1.3 Improve monitoring, early detection and responses to disease incursion. 1.4 Manage inoculum load in pseudostems, soil and water. 2. Improve access to new cultivars and build capacity in propagation 2.1 Review capacity to increase industry access to tissue-cultured, resistant varieties and cultivars. 2.2 Assess options for industry investment in banana breeding. 3. Develop resilient disease management options 3.1 Assess use of cover crops to reduce inoculum levels. 3.2 Assess use of microbes to suppress TR4. 3.3 Assess how root exudates affect TR4 populations. 3.4 Understand the role that plant stress place plays in relation to TR4. 4. Update biosecurity protocols for banana production to reflect project outcomes.

	4.1 Research becomes biosecurity protocol. 4.2 The economics of banana biosecurity. 4.3 Review industry practice to develop an industry-led code of practice. 5. Facilitate rapid adoption of the research findings 5.1 Develop an engagement and communication plan that links to existing programs. 5.2 Deliver education and training to implement the plan.
Activities	Activities were organised according to the five overarching objectives: **Conduct research to underpin improved biosecurity practices on farm** • A modified HACCP (Hazard Analysis and Critical Control Point) process was used to identify the most likely movement pathways for *Foc* TR4 associated with north Queensland production systems. • An interactive workshop process was implemented and led by the Australian Banana Growers' Council (ABGC). The workshops focused on farm biosecurity practices for *Foc* TR4. The workshops were rolled out to the industry via an ABGC-led biosecurity extension project[1] from July 2015 to February 2016. • Project BA14013 contributed significant content to the workshop modules addressing disease biology, identification and reporting, identification of risk pathways, and biosecurity practice options. • Thirty-one sanitiser/ disinfectant products were tested for their efficacy against a range of spore and fungal material produced by *Foc* R1 and *Foc* TR4. • The impact of soil quantity and type on sanitiser/disinfectant efficacy, product longevity, practical on-farm methods of monitoring product concentration, and the corrosion potential of the most effective products against a range of metals were investigated. • A quantitative Polymerase Chain Reaction (PCR) assay for identifying *Foc* TR4 in soil and water samples was developed by the South Australian Research and Development Institute (SARDI). • Assay sensitivity was assessed against soil samples that were either naturally or artificially infected with *Foc* TR4 to test the ability of the assay to detect the organism at a range of spore concentrations. • The development of a reliable test provided the ability to check if inoculum reduction practices were successful. • Project BA14013 also planned activities to update and streamline *Foc* diagnostics. However, during the project, it was discovered that there was an existing initiative through Plant Health Australia (PHA) encompassing the development, review and updating of National Diagnostic Protocols (NDPs) for high priority pests, including *Foc* TR4 as part of the National Plant Biosecurity Diagnostics Strategy. • To avoid duplication the project established contact with PHA to establish and report on the status of the activity. Project BA14013 provided an overarching structure for DAF personnel to have input to the PHA process (Stewart Lindsay, pers. comm., 2019).

[1] The ABGC-led biosecurity extension project was a separate initiative funded by the Commonwealth Government and the QLD State Government. Total funding was approximately $600,000 (Stewart Lindsay, pers. comm., 2019).

	• Activities for objective 1.3 (improve monitoring, early detection and responses to disease incursion) were transferred to project ST15011 (see Table B3 for details). • Laboratory and field trials were undertaken to identify effective chemical or biological treatments to destroy disease inoculum in infected plants and infested soil. • Lab and field trials also were conducted to test chemical and biological treatments to enhance decomposition of banana pseudostem material to prevent saprophytic colonisation by *Foc*. • The status of potential alternative host plants was tested with sampling of weeds from known *Foc* R1 sites in north Queensland. **Improve access to new cultivars and build capacity in propagation** The Australian banana industry currently invests significantly in identifying, importing and screening banana cultivars with potential pest and disease resistance (BA16001 – separate to the Fusarium wilt Research Program investment) and in developing resistant varieties with improved agronomic and organoleptic qualities through mutagenesis and somaclonal selection (BA14014 – see • Table B2 for further details). • A review of the current, global banana breeding activities, outlining their origins, objectives, methodologies, current status, and progeny suitable for the Australian industry, was undertaken to ensure the industry's investments were, and continue to be, focused in priority areas. **Develop resilient crop management options** • The efficacy of cover crops in reducing inoculum in infested soils was investigated. • The role of root exudates profiles (e.g. carboxylic acids) in controlling *Foc* was investigated under banana and cover crops to determine if they induce or reduce chlamydospore germination for *Foc,* and whether certain root exudates attract beneficial micro-organisms to the root systems. • The characteristics of a suppressive soil microbiome were investigated by analysing the metagenomics of soil organisms and assessing the influence of crop management practices on the banana microbiome. • Next generation DNA sequencing was used to characterise the microbial community around the rhizosphere of banana plants, as well as to identify *Foc*-suppressive micro-organisms. • Field and glasshouse trials were undertaken to investigate how plant stress interacts with *Foc* infection and the role of plant stress in reducing plant defence mechanisms and increasing susceptibility to *Foc*. • The study investigated the use of rapid plant physiological assessment methods (proline accumulation in leaf tissue, chlorophyll fluorescence, chlorophyll content, stomatal conductance and thermal imaging). This was to determine the potential for effectively detecting plant stress induced from abiotic factors and disease prior to the appearance of visual symptoms.

	• The study also used the tools developed to quantify the severity of stress and objectively measure leaf function and plant health. **Update biosecurity protocols for banana production to reflect project outcomes** • Project outcomes were communicated to banana growers, industry service business and key members of the Biosecurity Queensland Panama Response program team at a number of program meetings, research and development (R&D) update meetings, discussion groups and industry activities (e.g. the Banana Industry Roadshows). • The costs of implementing identified biosecurity practices and/or implementing new production systems were modelled to improve grower decision making. • The work included modelling the relative productivity of alternative Cavendish varieties in possible alternative production systems. • A Best Management Practice (BMP) guide for on-farm biosecurity was developed with input from banana growers and Biosecurity Queensland. • The guide includes a self-assessment checklist for growers to audit their adoption of effective biosecurity practices, a management plan template that can be populated with gaps identified from the audit, and comprehensive resource material that can assist in identifying what improved practices are available. • Networks with international scientists were created to facilitate communication and the sharing of research related to *Foc* TR4. This was achieved through Australian personnel participating in industry and scientific conferences (e.g. the International Society for Horticulture Science (ISHS) ProMusa Conference, October 2016) and the sharing of project findings with international banana researchers (Stewart Lindsay, pers. comm., 2019). **Facilitate rapid adoption of the research findings** • An engagement and communication plan was developed. The plan identified the key stakeholders for project information and results. • The plan also identified the key messages to be relayed to stakeholders and described the activities and channels for extension and communication to occur. • Extension and communication activities were delivered to assist banana growers and other target audiences to prepare for the critical *Foc* TR4 scenarios identified. • Extension and training activities were undertaken in collaboration with banana growers and key Australian banana client groups, particularly the ABGC. • Such extension and training activities were targeted at supporting the implementation of effective biosecurity practices for the Australian banana industry. • As project BA14013 progressed, project findings were communicated through industry events (e.g. the Australian Banana Industry Congress) and through banana industry publications 'Australian Bananas' and the ABGC e-Newsletter.
Outputs	**Conduct research to underpin improved biosecurity practices on farm**

	• The HACCP process resulted in the development of the Panama disease risk assessment tool (RAT). • The ABGC led component of the project delivered 37 interactive workshops involving 246 banana growers, partners and farm managers (representing 228 farms). • This represented participation of 77% of banana farms and 82% of the banana-producing area in north Queensland. • A range of effective biosecurity methods were identified for the north Queensland banana industry. The foundation principle for effective biosecurity adoption was described as the exclusion of all non-essential vehicles/ machinery/tools/people/planting material from a property. • Risk management practices identified to manage movement or access across zones/ farms included: i) use of dedicated vehicles, footwear and tools within specific zones, ii) procedures and facilities for footwear change at zone boundaries, iii) use of footbaths and vehicle washing and disinfection procedures, iv) physical barriers to minimise people and animal movement across zones, drainage to intercept surface water movement from external sources, and v) use of certified clean planting material. • Trials of the 31 sanitiser/ disinfectants found that quaternary ammonium-based compounds were effective at achieving a ‘zero detectable’ level of *Foc* R1 at rates of 1% across a range of contact times and in the presence of soil. • The trials also identified that the ‘Precision Laboratories high Level 0-1500ppm test’ (a quaternary ammonium test kits that measures the active ingredient concentration) provided consistent and accurate results and is an effective tool for routine monitoring of quaternary ammonium compounds. • Quaternary ammonium products also were found to maintain complete efficacy, with zero colony growth of *Foc* R1 detected, after eight months exposure to field conditions (without the addition of soil). • The addition of soil reduced the concentration of the active ingredients of the quaternary ammonium compounds over time. Inoculation results showed that, at the four month mark, *Foc* colony growth was detected. • The study also found that painted and unpainted steel, commonly used for biosecurity infrastructure, were the most susceptible metals to rust development. • The disinfectant trials also identified options for managing wash down water. It was shown that a number of disinfectant products could be used to successfully treat wastewater that contained disease affected soil for up to 24 hours. • Further, it was found that bleach and a product known as Steri-Max® were effective at eliminating *Foc* colony development present on field sampling equipment (e.g. cane knives). • A quantitative PCR assay was developed for identification of *Foc* TR4 in soil and water samples. • The assay detected most *Foc* TR4 with a high sensitivity but cross reacted at a low level with most other *Foc* races and requires further investigation. • However, project results indicated that the quantitative PCR assay preferentially detects *Foc* TR4. The limit of detection of the new assay is approximately 2.5 spores/gram of soil.

	• Support was provided to PHA for the development, review and updating of NDPs, particularly *Foc* TR4. • A revised manual (National Diagnostic Protocol for *Fusarium oxysporum f. sp. cubense*, the cause of *Foc TR4* of bananas) was submitted to the subcommittee on plant health diagnostic standards for review in May 2017[2]. • The research results suggested that urea, applied at a rate of 5 t/ha, was an effective treatment for *Foc* contaminated banana pseudostems. • Specifically, the study found that urea at rates greater than 0.031 kg/m^2 were effective at preventing *Foc* from being recovered from the soil. Ammonia was identified as the effective component of the urea breakdown cycle. • It was found that ammonia from any source that produced a concentration equal to or greater than 2,500 parts per million was effective at preventing *Foc* from being recovered from the soil. • *Trichoderma* spp. isolates were found to effectively suppress the production of *Foc* R1 inoculum in the decomposition of banana pseudostems. • The most common weed and groundcover species co-habiting banana farms were found to be: Sour Grass (*Paspalum conjugatum*), Crowsfoot Grass (*Eleusine indica*), Mullumbimby Couch (*Cyperus brevifolius*), Cinderella Weed (*Synedrella nodiflora*), Broadleaf Carpet Grass (*Axonopus compressus*), and Pennywort (*Centella asiatica*). • The analysis found that all the weed and groundcover species tested had the potential to host *Foc* SR4 as a proxy for *Foc* TR4. **Improve access to new cultivars and build capacity in propagation** • A report was produced that outlined the breeding objectives, the breeding methodologies being used, the likelihood of accessing progeny for testing in Australia, and a list of identified varieties that the study team wish to import into Australia for testing. • The review found that there are relatively few breeding programs actively breeding or selecting Cavendish style replacements. • Most programs developing hybrid crosses are focused on Lady Finger or Silk type varieties, with only limited success in developing replacement varieties with *Foc* resistance and market acceptable fruit quality. **Develop resilient crop management options** • Information was produced on: i) the efficacy of cover crops in reducing inoculum in infested soils, ii) the role of root exudates in controlling *Foc,* iii) the influence of banana crop management practices on the banana microbiome and the characteristics of suppressive soil microbiomes, iv) the interaction between plant stress and *Foc* susceptibility/infection.

[2] At the time of the current evaluation, the manual was still in draft form awaiting review (Stewart Lindsay, pers. comm., 2019.

	• Project results indicated that *Leucaena leucocephala* is a tropical pasture species worthy of further investigation as a suitable groundcover species for suppressing *Foc*. • Soil taken from *Leucaena* plots completely suppressed the recovery of *Foc* from soil and altered the microbial community. • The survey of pasture species for suppression of *Foc* and changes in soil microbial activity requires further validation. • Experiments associated with the influence of root exudates on chlamydospore germination found that carboxylic acids (the most common root exudates) resulted in the greatest activity of *Foc* R1, with citric acid utilised the most. • Results from field trials indicated that soil type and time are important factors in microbial community activity. Indications were that it may take up to two years for microbial community activity to increase. • Suppression of *Foc* R1 indicated that less *Foc* was recovered from soil with increased microbial activity. • Further analysis and correlations are required to link disease suppression with changes in the soil microbial community. • A number of methods were identified as potentially useful for quantitative assessment of stress in bananas. The methods identified were: i) Leaf chlorophyll content, ii) Chlorophyll fluorescence, iii) Proline accumulation, iv) Cell membrane stability, v) Thermography, and vi) Gas exchange parameters. • The research found that that measuring the concentration of plant pigments (particularly chlorophyll) assisted in determining the severity of stress or *Foc* infection. • The instrument and method used to measure chlorophyll fluorescence needs to be improved if this is to be a tool for pre-symptomatic disease detection. • Stomatal conductance, levels of proline accumulation and thermography could not be verified as useful measurements for stress quantification or disease detection in banana plants. • Project findings regarding resilient crop options were shared directly with *Foc* TR4 affected growers in QLD and with the remaining banana producers in the NT (Stewart Lindsay, pers. comm., 2019). **Update biosecurity protocols for banana production to reflect project outcomes** • The BMP guide for on-farm biosecurity was produced. The hard copy was launched at the Panama R&D Open Day on 12 May 2017. • The low res pdf of the resource can be found at: http://horticulture.com.au/wp-content/uploads/2017/06/On-farm-Biosecurity-Manual.pdf • The project found that key characteristics of banana growing properties has a major influence on the ability to effectively implement exclusion and zoning to manage the spread of *Foc* TR4. • The cost modelling found that, based on the application of identified effective practices, the cost of capital investment ranged from $3,070

	to $8,500 per hectare for a contiguous and non-contiguous scenario respectively. • Estimates of operating costs for crossing zone boundaries safely (washing vehicles/machinery, changing boots, provision and maintenance of disinfectant products) ranged from $134 to $546 per hectare per year for contiguous and non-contiguous scenarios respectively. • Comparison of modelled productivity outputs for alternative Cavendish production systems showed that none of the alternative systems yielded more than 50% of the industry standard 'Williams' Cavendish in a disease-free situation. • The value of the productivity modelling was to allow the manipulation of key variables such as bunch mass, crop cycle times and population mortality to identify the key requirements and productivity drivers that any potential production system must achieve. • A number of international banana scientists and producers were hosted in north Queensland to undertake field visits to inspect biosecurity practices and share project activities, methodologies and results. • Project personnel travelled to Taiwan in February 2016 to discuss collaborative research opportunities and access to cultivars that are being developed. • A number of papers and articles were produced and published or presented internationally. • Note: the costs of travel and attendance at various international conferences and events were funded under BA14014 (see Table B2 for further information). **Facilitate rapid adoption of the research findings** • An engagement and communication plan for banana biosecurity research was produced. • Various extension, communication and training activities to promote implementation of effective biosecurity practices for the Australian banana industry (see Appendix B1)
Outcomes	**Conduct research to underpin improved biosecurity practices on farm** • The systematic review of banana production systems with respect to the biology of *Foc* TR4 resulted in the identification of risk pathways associated with north Queensland banana production systems. • This knowledge contributed to the development of an effective extension and communication project for biosecurity adoption. • The Panama disease RAT was used to provide input to the development of content and process for the ABGC Biosecurity Extension project workshops and activities. • The RAT also was considered by Biosecurity Queensland in their development of the Panama disease Standards and Guidelines that provide banana growers with guidance on their biosecurity requirements if they become infected with the disease and are quarantined. • Recommendations have been made to industry regarding effective disinfectant use and monitoring. The project findings and recommendations were presented at the Panama R&D Open day,

	Banana Industry Roadshow 2016 and at local producer association meetings. The results also were published in the 'Australian Bananas' magazine as a fact sheet. • The information has been requested by both Nursery and Garden Industry Australia and Sugar Research Australia to assist their industries' efforts at maintaining effective biosecurity practices. • Trial quaternary ammonium test kits were developed based on the Precision Laboratories test. Approximately 90 test kits have been supplied to growers and industry stakeholders to promote monitoring of quaternary ammonium concentrations. • The research resulted in 100% adoption of quaternary ammonium products for disinfectant treatment by the north Queensland banana industry (Stewart Lindsay, pers. comm., 2019). • Improved management and monitoring of disinfectant concentrations also has been adopted by industry. One major banana producer reported that the use of the high range test had refined their replenishment program and reduced the product use and labour inputs for changing solution by 75%. • The quantitative PCR assay was confirmed as sensitive and specific enough for *Foc* TR4 detection in soil. • It was recommended that, where a new incursion is detected, the incursion be confirmed by sequencing to confirm identification. • The assay now is commercially available through the SARDI Molecular Diagnostics Centre. • This improved diagnostic capacity has accelerated the investigation and development of management practices fundamental to the development of an integrated crop management system for banana production in the presence of the disease. • The data on urea/ammonia use for managing contaminated banana pseudostems were used to inform field trials undertaken by Biosecurity Queensland to confirm the efficacy of their destruction protocol. • The urea destruction protocol was adopted by the Lapanday Food Corporation in the Philippines where the disease already is widespread. • Common weed and ground cover species were identified and provided to an inoculated 'alternative host' glasshouse trial conducted at the Eco-sciences Precinct (Brisbane) using *Foc* SR4 as a surrogate for *Foc* TR4. • Results showed that the standard destruction protocol is effective at destroying *Foc* in infected pseudostem material and can reduce the level of inoculum in soils associated with the infected plant to very low levels. • Further, the investigation of weeds and groundcovers as hosts of *Foc* R1 and SR4 informed further trial work with *Foc* TR4 conducted in the Northern Territory under project BA14014 (see Table B2 for further information). **Improve access to new cultivars and build capacity in propagation** • The review has assisted with decisions regarding banana variety importation, screening and development for *Foc* TR4 resistance. • The review provided a basis for the Variety Committee of project BA16001 (Improved plant protection for the banana industry) to

	develop recommendations around importing and screening, and variety development and commercialisation. **Develop resilient crop management options** • *Leucaena leucocephala* and other tropical pasture and groundcover species that were shown to significantly change the soil microbial community and potentially confer some suppression of *Foc* has informed further research in rotation crops in BA14014 (see Table B2). • Assessment of root exudates and their effect on *Foc* TR4 populations has assisted with future screening of potential rotation crops and alternative varieties. Further investigation was undertaken in BA14014 (see Table B2). • Data from BA14013 were used to inform further research on the link between microbial activity and suppression of *Foc* undertaken as part of project BA14014 (Stewart Lindsay, pers. comm., 2019). • The assessment of plant stress measurement has informed more detailed early detection work under project ST15011 (see Table B3). • The study highlighted the importance of having well-trained biosecurity staff for surveying properties at risk of contracting Panama disease and having farm staff who are on the lookout for suspicious plants. **Update biosecurity protocols for banana production to reflect project outcomes** • Key project outputs have been integrated into on-farm biosecurity practices for the Australian banana industry. In particular, the effective use of sanitiser products, decontamination of tools and soil, and effective destruction of infected plants have been adopted by growers and regulatory authorities. • BQ uses the destruction protocol for every confirmed *Foc* TR4 infected plant and has adopted quaternary ammonium-based sanitiser products in its protocols (Stewart Lindsay, pers. comm., 2019). • Specifically, the following items have been incorporated into new or amended biosecurity protocols (Stewart Lindsay, pers. comm., 2019): i) confirmation of the urea destruction protocol as effective in reducing inoculum, ii) identification of the most effective sanitiser agents, their effective rate, the influence of soil and organic matter, the impact on materials (metals) and simple monitoring methods, and iii) the application of zoning and other planning tools to assist producers to implement the principles of effective biosecurity practices for individual circumstances. • Current evaluation of adoption estimates effective biosecurity system adoption at 40% of banana growers (Stewart Lindsay, pers. comm., 2019). • The implementation cost and alternative production system productivity modelling have informed policymakers and managers at both ABGC and the Queensland Government on the relative value of different investment scenarios. • The productivity modelling information also was used to inform a more detailed assessment of individual grower expenditure on biosecurity as part of a banana industry benchmarking project. The results from this

	project were presented at the 2018 national banana roadshow (Stewart Lindsay, pers. comm., 2019). • The modelled data reinforced that cost was a major constraint to adoption, particularly for farms with non-contiguous parcels of land. • More than 140 copies of the BMP biosecurity guide have been distributed to key industry stakeholders. • Plans have been progressed to develop an online based version of the BMP biosecurity guide under project BA14014 (see Table B2) for further information). • The project built significant links with international researchers working in *Foc* TR4, particularly in Taiwan and South Africa, leading to increased international collaboration and information sharing between banana scientists and banana industry participants. **Facilitate rapid adoption of the research findings** • Development and implementation of the communication and engagement plan resulted in a coordinated and effective communication and extension effort for the project outputs. • Project outputs were widely and rapidly disseminated to banana industry stakeholders through extensive networking, communication and extension activities. • This facilitated the rapid adoption of up to date *Foc* TR4 biosecurity information and practices. • Overall the project was successful in achieving the objective of providing new science, information and practices to address the need for robust, science-based biosecurity measures to contain *Foc* TR4, prevent further spread and manage new incursions. • Assessments conducted during various project workshops showed that 91% of workshop participants improved their knowledge of *Foc* TR4 'quite a lot' or better (4 or 5/5 rating), 81% understood the risk pathways associated with the disease 'quite a lot' or better, and 84% understood suitable, effective on-farm biosecurity practices for their farms 'quite a lot' or better. • Follow up evaluations of workshop participants found that 92% rated their current biosecurity practice implementation as moderate to high. • Further, at the Panama R&D Open Day in May 2017 (attended by 109 people) 96% of participants indicate that they would change something in their business as a result of attending the event.
Potential Impacts	• Reduced risk of the incursion (new incursions) and/or spread (existing infestations) of *Foc* TR4 for the Australian banana industry, particularly the north Queensland production region. • More efficient implementation of on-farm biosecurity practices (e.g. disinfectant usage and monitoring). • Improved efficiency of investment in banana breeding through improved prioritisation • Improved efficiency of *Foc* TR4 RD&E investment • Increased scientific and industry capacity through the creation of new knowledge, biosecurity education and training, and facilitation of international collaborative networks. • Some contribution to reduced risk of pest and/or disease incursion and spread for the Australian nursery industry and the Australian sugar industry.

Table B 2: Logical Framework for Project BA14014

Objectives	The overall aim of the project was to provide new science, information and practices that address key areas of need in the Australian banana industry, with a medium to long-term view of developing management practices for banana growers affected by *Foc* TR4. The three themes that were addressed by this project were: 1. Development of genetic material suitable for production in TR4 affected areas and an understanding of the genetic basis for resistance to TR4. 2. Development of production systems that improve banana plant resilience through an understanding of the epidemiology of TR4 and the soil environment. 3. Tools to facilitate the adoption of biosecurity systems with particular focus on the development and implementation of a clean planting scheme for bits and suckers to complement tissue culture.
Activities	**Activity 1.1: Generation of improved banana survival to TR4** • Five banana cultivars (Goldfinger, GCTCV119, GCTCV215, CJ19, and Dwarf Nathan) were selected for mutation breeding. • All plants from the five cultivars targeted for mutagenesis were transferred to field sites for evaluation for diseases and agronomic characteristics. Cultivars were sent together with unirradiated control plants and additional plants were screened for agronomic characteristics and fruit quality in Queensland (Tony Pattison, pers. comm., 2019). **Activity 1.2: Selection of improved banana survival to Panama disease** • Inoculum production procedures were refined to ensure plants produced would be uniformly infected with the *Foc* TR4 pathogen. • 791 plants were planted in-field in 2017 for testing (10 Williams, 50 non-irradiated GCTCV119 and 731 mutant GCRCV119). • Each plant was inoculated with 200 mL of *Foc* TR4 inoculated millet. • Eight months post planting (February 2018) there were 50 plant deaths recorded with *Foc* TR4 observed in inoculated Williams plants, but no disease detected in GCTCV119 plants (controls or mutant). • Mutagenesis of the give cultivars was a continuous process, with representatives of all irradiated plants undergoing assessment at different stages • A selection of 21 improved GCRCV119 from the NT and a selection of 20 Goldfinger plants were chosen for second generation screening for *Foc* TR4 resistance, improved agronomic characteristics or improved fruit quality (Tony Pattison, pers. comm., 2019). • Also, approximately 650 mutated CJ19 plants (plus controls) were planted in the NT and on a commercial farm in far northern QLD. • A number of other cultivars were still undergoing assessment at the time of the current impact assessment (Tony Pattison, pers. comm., 2019).

	Activity 1.3: Marker assisted screening of germplasm for potential resistance to Panama disease • Banana cultivars were selected and multiplied to test for genetic markers. • Assays with *Foc* SR4 showed that the following accessions were resistant with no rhizome discolouration: i) Malaccensis (851), ii) Calcutta 4 (IV9), iii) Pahang SH3362, and iv) Madang (655 from Guadeloupe). **Activity 2.1: Epidemiology of *Foc*** • Inoculum studies of *Foc* SR4 in Williams and Malaccensis cultivars were conducted to investigate the epidemiology of *Foc*. • PCR tests were conducted to confirm the presence of the pathogen. • Banana plants were screened to determine the survival of *Foc* following treatment of the plants with an herbicide. • Cavendish plants were inoculated with *Foc* SR4 and were stem-injected with glyphosate, paraquat, atrazine, and kerosene to determine the survival of the fungus. **Activity 2.2: Survival of Panama disease on alternative hosts** • A survey of plants co-habiting banana plantations in the Northern Territory, north Queensland and the sub-tropics was conducted. • The survey was used to identify alternative hosts to *Foc* R1, SR4 and TR4. A preliminary list of the most common weed species in banana plantations was created for each region surveyed. • Identified species were sampled and fungal isolations performed. • Twelve weed species were selected to be used in an alternative host pot trial that commenced in November 2017. • Weeds were established in pots and then inoculated with 5 mL of *Foc* TR4 infested millet. • At the conclusion of the trial the root systems of surviving plants were sampled. • After the host survey and trials were completed, and results analysed, development of a guide on the host status of plants co-habiting bananas was commenced (Tony Pattison, pers. comm., 2019). **Activity 2.3: Rotation crops to reduce inoculum of Panama disease** • A 1.6 ha trial site near Darwin (NT) was identified. Due to no bananas having been grown at the site for two years, the site was planted to bananas to increase the inoculum in the soil before implementing rotation crops for testing. • Six rotation treatments were identified for investigation: i) Sugar graze sorghum, ii) Sweet jumbo sorghum, iii) Cavalcade (*Centrosema pascuorum*), iv) Envirogro Jarrah grass (*Digitaria milangiana*), v) Seca stylo (*Stylosanthes hamata*), and vi) weedy fallow.

- Trials were conducted where the treatment was grown/applied for 150 days. After the treatment period, a susceptible banana cultivar (cv. Williams) was planted.
- The rotation and ground cover treatments were planted on January 16, 2018. Bananas were then replanted on the site in June 2018.
- Prior to the planting of the rotation crops, soil samples were taken to determine *Foc* inoculum levels and soil nutrient characteristics (Tony Pattison, pers. comm., 2019).

Activity 2.4: Banana microbiome

- A survey was conducted of the north QLD banana producing region. The survey sampled 17 of the most dominant soils used in banana production, which represented 77% of soils used in overall banana production.
- Soil samples were collected from five banana fields showing differing degrees of plant growth.
- Biological screening was conducted to determine if in-plant growth was related to differences in the soil microbiome community.
- The bacteria, archaea, fungi, and other microeukarya associated with the area were characterised using phylogenetic marker gene sequencing.
- Also, the microbiomes of three banana varieties (Cavendish, Gold Finger and Lady Finger), grown in five of the most dominant banana production soils, were characterised.
- Twenty potential cover crops were sampled from a pasture trial in north QLD and also were screened for differences in soil microbial community composition.
- *Foc* suppressive isolates were identified and trialled in pot experiments.
- The project was then progressed to explore *Foc* at greater taxonomic resolution and over a larger geographical range to better understand *Foc*'s ecology and to highlight what controls the distribution of *Foc* and its diverse subspecies.
- A novel risk system was established that considered the roles of plant and soil microbiomes in the management of *Foc* (Tony Pattison, pers. comm., 2019).

Activity 2.5: Banana nutrition

- Nutrition glasshouse trials were conducted to assess the *Foc* severity in Cavendish bananas pre-conditioned to a range of nutrient treatments.
- The trials were used to determine the effect of deficient, adequate and high levels of nutrient supply on the banana plant defence mechanisms.
- Soil samples were collected for analysis from sites in the NT and north QLD.
- Nutrient manipulation studies were undertaken, focusing on boron and iron (Fe).

Activity 2.6: Banana soil physico-chemical properties

- A list of physico-chemical protocols was compiled.

	• A greenhouse pot trial was conducted using six key north QLD banana growing soil types planted with Lady Finger with and without inoculation with *Foc* R1. • Soil and plants were monitored during and at harvest. • A further investigation was conducted to determine whether Fe availability influences suppressiveness to *Foc*. • Fe availability was manipulated using chelating ligands with different strengths which have been shown to suppress *Foc* in other crops. **Activity 3.1: Developing and implementing a new, clean planting material system for the Australian banana industry** • A QBAN (Quality Approved Banana Nursery) committee was established to provide oversight of the activity. • Translation of the QBAN system of certification for clean banana planting material to the Nursery Industry Accreditation Scheme Australia (NIASA) / BioSecure HACCP was undertaken. • This involved a technical and administrational review of the QBAN Guidelines against the Nursery and Garden Industry Australia (NGIA) Nursery Production Farm Management System (FMS) programs, including the NIASA and the BioSecure HACCP Guidelines. • Two QBAN transition reference committee meetings were held, and progress on the transition was communicated to banana and production nursery industries via industry publications and industry events conducted during July 2018 (Tony Pattison, pers. comm., 2019). • Extension services also were provided to production nurseries to support implementation of the new QBAN scheme. This was achieved through development of a market access tool under the BioSecure HACCP Guidelines. Delivery of the tool is expected in August 2019 (Tony Pattison, pers. comm., 2019). **Activity 3.2: Digital tools to assist farm biosecurity for banana producers** • A project team member was selected to sit on the project reference group (PRG) for the ABGC's 'Better Bunch' record keeping mobile app. to ensure that the app could be built upon to add features that may increase adoption of on-farm biosecurity practices. • An online biosecurity BMP system was developed. Validation of the online BMP tool is continuing through industry feedback as the system is rolled-out to banana growers (Tony Pattison, pers. comm., 2019). **Activity 3.3: TR4 capacity building** • A number of project personnel presented at conferences, workshops and other information sharing events both domestically and abroad. **Activity 4: Project governance** • A PRG was established, and a shared understanding of project priorities and objectives developed. • Throughout the project, the PRG reviewed project progress against the proposed project outputs and milestones, annual work plans,

	monitoring and evaluation plan, and a communication and stakeholder engagement plan. • A mid-project review was conducted by Dr Brett Summerell from the Royal Botanic Gardens (Sydney) in March 2018.
Outputs	**Activity 1.1: Generation of improved banana survival to TR4** • 1,000 GCTCV119 plants, 960 Dwarf Nathan plants, 728 Goldfinger plants, and 1,100 CJ19 plants were distributed for screening. • Irradiation and stabilisation of approximately 1,000 GCTCV215 plants was completed. • The project found that generating mutations has been successful in changing banana cultivar appearance. **Activity 1.2: Selection of improved banana survival to Panama disease** • Unfortunately, the GCTCV119 mutagenesis trial was decimated by Cyclone Marcus in March of 2018. • However, the selection of 21 GCTCV119 plants from the NT for second generation screening has since been carried out. The new screening component will investigate *Foc* TR4 resistance, improved agronomic characteristics or improved fruit quality (Tony Pattison, pers. comm., 2019). • The Dwarf Nathan trial showed initial yellowing and wilting symptoms in Williams control plants within five months of planting, but with some recovery. • No elite plants were identified from the Dwarf Nathan trial. • Harvesting and fruit quality assessments were conducted for the Goldfinger trial and a 20 Goldfinger plants have been selected for second generation screening for either *Foc* TR4 resistance, improved agronomic characteristics or improved fruit quality (Tony Pattison, pers. comm., 2019). **Activity 1.3: Marker assisted screening of germplasm for potential resistance to Panama disease** • Both Malaccensis and Calcutta 4 were confirmed as resistant to *Foc* SR4 and TR4 in pot trials. This indicated that Calcutta 4 offers a possible alternative source of resistance to *Foc* TR4. • Resistance appears to be conferred through containment mechanisms that prevent the fungi from spreading to other parts of the plants. A manuscript has been submitted to Frontiers in Microbiology (Tony Pattison, pers. comm., 2019). • Work is continuing through the International Institute of Tropical Agriculture to fine map the marker and assessments will continue to be made using any variants of the marker as they are developed. • A manuscript was submitted to Frontiers in Microbiology (Tony Pattison, pers. comm., 2019). **Activity 2.1: Epidemiology of *Foc*** • Confocal microscopy showed the presence of *Foc* in the roots, corm and lower area of the Cavendish pseudostem from 10 dpi (days post inoculation) prior to the development of external symptoms.

	• The presence of *Foc* in the lower area of the Lady Finger pseudostem was not observed until 40 dpi, however, it was present in the roots at 10 dpi and the corm at 20 dpi. This also was prior to the development of external symptoms. • A manuscript on the epidemiology studies was submitted to the journal 'Frontiers in Microbiology' (titled *The Movement of Fusarium oxysporum f.sp. cubense (Sub-Tropical Race 4) in Susceptible Cultivars of Banana)* and subsequently published in 2018 (Tony Pattison, pers. comm., 2019). **Activity 2.2: Survival of Panama disease on alternative hosts** • From north Queensland, the following species were found to host *Foc* R1: i) *Youngia japonica*, ii) Summer grass (*Digitaria ciliaris*), iii) Crowsfoot grass (*Eleusine indica*), and iv) Spiny spider flower (*Cleome aculeate*). • From northern NSW, *Foc* was detected from: i) Paragrass, ii) Weeping grass, iii) Horse weed, iv) Miniature stonecrop, and v) Clover sour. • In the NT two species tested positive for *Foc* TR4: i) *Euphorbia hirta*, and ii) *Cyanthillium cinereum*. Other *Foc* species were detected in two other weed species, but further testing found that they were *F. solani* and *F. equiseti*. • All weed species showed some level of infection by TR4, with some species showing a lower frequency of *Foc* TR4 from root isolation than others. • A grower manual, depicting weeds of bananas and their host status for *Foc*, was developed. Currently, 30 potential alternative hosts have been included with two weeds (*Euphorbia heteophylla* and *Cyanthillium cinereum*) rated as high host potential to TR4. • Five weeds were rated as medium-high, five as medium, nine as low, five as very low, and five as non-hosts based on the field and pot trial surveys. • Fifty alternative host species were found in banana plantations and characterised based on their ability to host *Foc* R1, *Foc* SR4 and *Foc* TR4 from the field surveys and glasshouse experiments (Tony Pattison, pers. comm., 2019). • At the time of the current evaluation, validation of rotation crops in glasshouse experiments were still underway and the banana grower guide to plant host status was still under development. **Activity 2.3: Rotation crops to reduce inoculum of Panama disease** • Eighteen different potential rotation crops were ultimately screened for their ability to supress *Foc* TR4. • In the first trial it was shown that none of the trialled rotation crops was significantly better at reducing *Foc* than bare soil or having disease levels similar to uninoculated soil.

	• Bananas (cv. Williams) grown after rotation crops started showing *Foc* TR4 symptoms from December 2018 (Tony Pattison, pers. comm., 2019). • However, two legumes *Macroptilium bracteatum (*Burgundy bean) and *Leucaena leucocephela* (Leucaena), and two grasses *Paspalum dilatum* and *Digitaria didactyla* had *Foc* recovery levels similar to uninoculated soil and are currently (as of June 2019) undergoing further evaluation. • The experiments were extended, and sugarcane lines were sourced for further investigation to determine growth and persistence of *Foc* in their roots using *Foc* SR4. **Activity 2.4: Banana microbiome** • Results of the microbiome experiments indicated that fungal and bacterial community composition differed strongly between soils. • The difference in infection rates between soils, which may be considered representative of differences in *Foc* suppressiveness, was significantly associated with shifts in the composition of both bacterial and fungal communities. • A significant influence of banana genotype was also found for fungal, but not bacterial, communities, and found that there were distinct communities associated with different plant compartments. • *Fusarium oxysporum* was found to be among the most dominant fungal taxa in all soils and plants studied. • The BA14014 research team demonstrated that elimination of the soil microbiome can increase *Foc* colonization rates of soil by up to x10,000. This highlighted the importance of soil microbiomes in mitigating *Foc* risk. **Activity 2.5: Banana nutrition** • 81 different soil and plant characteristics were determined. • Bioassays of soils from field trials with different nitrogen rates showed that tolerance of bananas was enhanced in soil with low application of nitrogen compared to a high rate of nitrogen. This was demonstrated by a lack of external symptom development with increasing rhizome necrosis in soils that had a history of low nitrogen application. • Further, there was some evidence that high applications of nitrogen reduced the tolerance of bananas to *Foc* by changing the microbial community within the soil (Tony Pattison, pers. comm., 2019). • Recommendations on nutrient application from aeroponics trials found that a deficiency in boron may increase plant susceptibility to *Foc,* possibly through loss of cell wall strength (Tony Pattison, pers. comm., 2019). **Activity 2.6: Banana soil physico-chemical properties** • The study found that a significant reduction in disease severity was achieved by addition of the strong chelating agents Fe-EDDHA and Fe-FHBED, which reduce the availability of Fe. However, the effect was small (approximately 10% reduction in discoloration of corm). A further experiment was conducted to determine the effects of chelator application rate.

- Experiments manipulating the physiochemical properties of soil using Fe-chelating agents had no consistent effect on growth of bananas and severity of *Foc* (Tony Pattison, pers. comm., 2019).
- Further work is planned to examine the effect of nitrogen application rate, the effect of soil pH, and the effect of optimising several soil parameters at once (Tony Pattison, pers. comm., 2019).
- A number of papers were submitted and published in several academic journals (e.g. Applied Soil Ecology)

Activity 3.1: Developing and implementing a new, clean planting material system for the Australian banana industry

- The review concluded that the NGIA Nursery Production FMS provides a stable platform for inclusion of the QBAN Scheme within its Guidelines.
- Progress on the transition of the QBAN Accreditation Scheme into NIASA and BioSecure HACCP scheme requirements continues to meet project milestones.
- NIASA High Health Banana Plantlet Production requirements have been translated into the NIASA Guidelines and software updates were completed. Requirements will be included as ‘Appendix 14’ to the Guidelines.
- The appendix provides banana high health best practice guidance in relation to collection of banana material from mother blocks, tissue culture production, and nursery production of banana plantlets.
- Further, it was determined that the existing BioSecure HACCP Guidelines would not need amendment or addition of specific project related procedures to facilitate market access related movement control requirements.
- The majority of QBAN accredited businesses expressed strong support for the continuation of a scheme to provide an ongoing source of clean banana planting material for the Australian banana industry.
- The transition of the QBAN into NIASA/BioSecure HACCP was due to be finalised in August 2019 (Tony Pattison, pers. comm., 2019).

Activity 3.2: Digital tools to assist farm biosecurity for banana producers

- The online biosecurity BMP system was developed to mirror the existing environmental BMP used in the banana industry and utilise the questions in the self-assessment checklist and information resource of the on-farm biosecurity BMP.
- The system was designed to auto-populate a current management plan based on the answers that growers provide and based on current biosecurity practices they have in place.

Activity 3.3: TR4 capacity building

- David East (DAF), attended a *Foc* workshop hosted by Forestry and Agricultural Biotechnology Institute, University of Pretoria, South Africa.
- Tony Pattison and Anna McBeath travelled to Montpellier, France for the ProMusa conference focusing on agroecological management of banana plantations (October 2016).
- A Panama disease field day was undertaken in May 2017 with smaller field days for banana growers in November 2017 and February 2018.

	• Articles were published in 'Australian Bananas' magazine with a summary of the mid-project achievements. • Components of the project were disseminated to 140 banana industry personnel through the Banana Roadshows in July and August of 2018. • Presentations were made at the 22nd ACORBAT International Banana Congress in Miami (USA, May 2018), the 11th International Congress of Plant Pathology in Boston (USA, July-August 2018), and the 10th Australasian Soilborne Disease Symposium (Adelaide, September 2018). • Stewart Lindsay attended the World Banana Forum and had discussions with the Food and Agriculture Organisation of the United Nations (Rome, Italy) and CIRAD[3] researchers (Montpellier, France) about accessing global TR4 research. • Negotiations were undertaken with Dr Philppe Tixier of CIRAD (the French agricultural research and international cooperation organisation) for international collaboration on developing modelling systems to investigate how an integrated approach to managing *Foc* TR4 can best be deployed to the Australian banana industry. **Activity 4: Project governance** • The mid-project review was produced and stated that: "*the project was proceeding well and meeting all expected outputs and associated key performance indicators. The project governance and management is excellent and all the documentation provided of a high quality. The science and research methodology is appropriate and effective but expectations must be tempered to reflect the difficulty of working with this pathogen and the time scales necessary to achieve industry goals. It can be expected that the project will deliver a range of excellent science, a number of management practices to recommend to the industry, and an excellent cohort of scientists to lead and develop future research on this pathogen and the disease that it causes*".
Outcomes	• Elements of the project were ongoing at the time of this evaluation. The project is due for completion in June 2020. • Scientific interest in the project has been high due to the multi-disciplinary approaches used that incorporated plant-pathology, plant science, soil science, microbiology, soil ecology and horticulture science (Tony Pattison, pers. comm., 2019). • The selection and breeding of banana cultivars for *Foc* resistance, improved agronomic characteristics and improved fruit quality has been improved. No formal banana improvement program existed in Australia prior to project BA14014 (Tony Pattison, pers. comm., 2019). • There has been a shift in how banana cultivars are screened based on the initial outcomes from the first cultivar that underwent mutagenesis (GCTCV119). This cultivar maintained its resistance to *Foc* TR4 after irradiation, therefore greater emphasis now is being placed on agronomic characteristics (Tony Pattison, pers. comm., 2019). • The epidemiology work has allowed a re-focus of research on when *Foc* spores are being produced in banana plants which, in turn, may

[3] CIRAD: the French agricultural research and international cooperation organisation working for the sustainable development of tropical and Mediterranean regions. For more information see: https://www.cirad.fr/en

	allow a refinement in activities used to suppress the production of *Foc* spores (Tony Pattison, pers. comm., 2019). • Researchers and industry stakeholders now are more aware of which soils are likely to have *Foc* develop at a rapid rate if allowed to go unmanaged and there is increased awareness of the value of vegetated ground cover to reduce soil movement and the spread of disease (Tony Pattison, pers. comm., 2019). • Australian banana growers have continued to adopt *Foc* TR4 Research Program outputs (such as the grower manual on weeds and their Foc host status, information regarding rotation crops, and the biosecurity BMP app/online system) to improve the on-farm biosecurity practices and improve the containment of existing *Foc* TR4 infestations. • The project built significant links with international researchers working in *Foc* TR4, particularly in France and the United States of America. • The research team are working to identify which microbes live in association with bananas, what they do, and how they can be controlled to manage *Foc* in the future (Tony Pattison, pers. comm., 2019). • The BA14014 team have, to date, identified a core set of bacterial and fungal taxa that are associated with Musa spp. across different soils, genotypes and plant ages (Tony Pattison, pers. comm., 2019).
Potential Impacts	• Reduced risk of the incursion (new incursions) and/or spread (existing infestations) of *Foc* TR4 for the Australian banana industry, particularly the north Queensland production region. • More efficient implementation of on-farm biosecurity practices (e.g. through use of the biosecurity BMP online system). • Improved efficiency of investment in banana breeding through improved prioritisation. • Improved efficiency of *Foc* TR4 RD&E investment. • Increased scientific and industry capacity through the creation of new knowledge (e.g. knowledge of the banana microbiome), biosecurity education and training, and facilitation of international collaborative networks.

Table B 3: Logical Framework for Project ST15011

Objectives	ST15011 was one of 11 ‘Children Projects’ linked to the parent project *ST15016 – Multi-scale monitoring tools for managing Australian Tree Crops: Industry meets innovation* awarded to Hort Innovation in May 2015 as part of the Commonwealth Government’s Rural R&D for Profit Program. The project aimed to apply more innovative technologies to help growers improve their production and profitability. The goal of the project was to combine the latest high-resolution satellite imaging systems, cloud-based computing, data discovery and analytics, together with on-ground robotics and an increasingly ‘connected’ producer base, to support Australia’s tree crop producers’ decision making. The parent project had two components:

	1. A national audit capability framework identifying the location, area and tree population of every commercial avocado, macadamia orchard and banana plantation across Australia. The audit will integrate novel satellite image analysis with existing industry and government crop databases, regional surveys and on-ground evaluations. A Geographic Information System database integrating a web delivery and data discovery platform will support grower auditing, seasonal and longer-term production forecasts, product traceability and facilitate productivity gains through improved understanding of the spatial and temporal distribution of cultivars, geographic regions, climate trends and production bases. The database will also support biosecurity and post-disaster monitoring at state and federal level and complement existing systems and programmes. 2. A farm-level decision support tool using satellite image data and novel on-ground sensors and robotics for mapping fruit yield and quality, tree health and inflorescence counts. Data will assist grower yield forecasting and optimisation, harvest segregation based on quality and fruit size, tree health monitoring including early detection of pest and disease outbreaks, support product traceability (tree-to-plate), and reduce input costs through judicious management of water, fertiliser and pesticides, and genotype evaluation. ST15011 outlined the services provided by DAF. The DAF QLD component of the project was aligned with the remote sensing requirements of the banana industry to support the management of Panama disease. The work was delivered in conjunction with BA14013 and BA14014 (see Table B1 and B2) The specific objectives of Child project ST15011 were to: 1. Determine effective remote sensing tools to monitor the nitrogen status and productivity of banana plantations. 2. Determine effective in-field tools to identify potential disease infection.
Activities	• A PhD candidate was appointed to investigate the potential for early detection of *Foc* infection in bananas. • Preliminary assessment of *Foc* R1 inoculated and uninoculated plants was conducted using a portable field spectrometer. • Following an extensive literature review, a pot trial was conducted to validate stress detection using chlorophyll concentration, chlorophyll fluorescence, proline accumulation, cell membrane stability, thermography, and gas exchange parameters to assess stress-inflicted plants. • Spatial locations (Global Positioning System (GPS) waypoints) of past disease detections were received from the Biosecurity Queensland Panama disease response team. • A review of quantitative methods for measuring plant stress was undertaken. • Preliminary assessments were undertaken of the potential for hand-held NDVI (Normalised Difference Vegetation Index) equipment (known as Greenseeker) to investigate the impact of different nitrogen application rates. • High-resolution, multi-spectral imagery was captured for cooperating Lakeland and Tully banana farms in January and July 2016.

	• 90 plants were identified as low, medium or high productivity via classified NDVI imagery. • The 90 selected plants were geo-tagged using a GPS. • Plant stress and productivity measurements were then completed for the 90 plants. These included: height (plant and emerging sucker), leaf area, basal diameter (plant and emerging sucker), bunch weight and quality, ground temperature, relative humidity, neighbouring plant density, leaf flavonol, leaf anthocyanin, leaf chlorophyll, leaf Nitrogen Balance Index, soil microbiology, soil carbon and leaf macro- and micro-nutrient status. • Monitoring, harvesting and measuring yield of study plants was conducted on a weekly basis. • LiDAR (Light Detection And Ranging) data were obtained for the study area which allowed the development of hydrological and topographic indices for inclusion in the analysis. • WorldView-3[4] imagery was captured in 2016 and SPOT-6 and SPOT-7[5] imagery was captured in late 2017 and early 2018. • Whole of farm NDVI classifications of WorldView-3 time series data and other archive data were conducted. • Also, an electro-magnetic (EM38) ground conductivity survey was completed in conjunction with soil sampling and nutrient analysis for the 90 plants. • Initial Greenseeker crop sensor tests were conducted. • Time-series image combinations were trialled at several resolutions to best describe variation of banana blocks and to remove land management practices and harvesting complications. • Extensive ground-truthing of the study plants was undertaken in late 2017 to correspond with an October 2017 UAV (unmanned aerial vehicle) flight and November 2017 WorldView-3 image capture. • During the study, a total of three WorldView-3 images were captured (July 2016, November 2016, and October 2017). • Where possible (dependent on weather), monthly Planet lab imagery was sourced covering the period of research). Six images were obtained that were suitable. • Dualex meter[6] chlorophyll measurements were modelled against the leaf nitrogen percentage using simple linear models with the growth stage as a grouping factor for each banana block sampled. • Further imagery was captured using a Parrot Sequioa camera fitted to a DJI Phantom 4 Pro Drone in 2018. A series of grey scale calibration targets was constructed to calibrate the imagery for conversion from digital numbers to surface reflectance values. • On ground sampling of a further 48 banana plants was conducted between July and September 2018.

[4] Launched in August 2014, WorldView-3 is a multi-payload, super-spectral, high-resolution, commercial satellite featuring 16 multispectral bands and the ability to capture imagery at 31cm resolution. The satellite offers opportunities for remote sensing analysis of vegetation, coastal environments, agriculture, geology and many other applications. For more information see: https://www.geoimage.com.au/satellite/worldview-3

[5] SPOT-6 (Système Pour l'Observation de la Terre) is an optical satellite built by Astrium and launched in September 2012. For more information see: https://www.geoimage.com.au/satellite/spot-6

[6] The Dualex meter is a sensor that measures flavonol, anthocyanin and chlorophyll indices. A leaf-clip allows it to perform real-time and non-destructive measurements. Its internal GPS is used for the geolocalisation of the blocks. Its embedded datalogger brings large capabilities for data acquisition and storage. For more information see: http://www.dynamax.com/products/optics-for-polyphenol/dualex-scientific-polyphenol-chlorophyll-meter

	• Project progress and findings were communicated to the banana industry, stakeholders and the broader scientific community through a number of one-on-one presentations, poster presentations, articles and other mediums (e.g. industry meetings, conferences, interviews, etc.).
Outputs	• Preliminary results indicated that electrical potential showed significant change around seven days after treatment at a time when visible yellowing was minimal. • Two satellite imaging systems, Planet and SPOT-6 (with different spatial resolutions to WorldView-3), were found to reliably identify broad variability similar to that of WorldView-3. • Image algorithms were created for 21 significant, different vegetation indices with bunch weight, days to harvest and plant height as the dependent variable. • A number of maps were produced from the WorldView-3 modelling. • Leaf nitrogen maps were developed for targeted management, or to create a variable rate application program, for the more efficient application of nitrogen based on plant requirements. The leaf nitrogen mapping would add value to current point based information, provide opportunity for a more targeted approach to nitrogen management or sub-block nitrogen management, and can be used to understand nitrogen application efficiency. • Banana bunch weight or yield maps provide useful information for growers seeking to determine the causes and possible remediation for low yielding areas. • Plant height maps provide information on variation of plant height across a block and allow calculation of an average height for the block. This information can be used to aid the development of a nurse suckering management program. • Nurse suckering is a management practice used by farmers to manipulate the crop timing based on plant height and harvest maturity. • Analyses of data from the Dualex meter were promising and provided encouraging results for use of the Dualex meter as an in-field tool for plant nitrogen assessment. • The approach of the project of amalgamated time-series imagery into maximum classified NDVI, could be used as a practice to assess maximum productivity achieved for a given area by removing the variation due to growth stage, harvest status and land management complexities. • Growers could use this information to investigate why such variation occurs and to aid decisions as to how, or if, remediation action is required.
Outcomes	• Elements of the project were ongoing at the time of this evaluation. The project is due for completion in April 2019. • Australian banana growers have shown increased interest in precision agriculture as a management tool to improve productivity. • The project provided a first step for the implementation of precision agriculture on banana plantations through satellite mapping and identified a suitable methodology to use satellite imagery systems as a decision support tool. • At an R&D field day, 46% of grower attendees said they would change some of their practices due to the field day, although which practices were not specified.

	• Particular interest was shown in the identification of disease. The project made progress towards disease assessment through the identification of a methodology to evaluate banana productivity and stress.
Potential Impacts	• Increased scientific and industry capacity through the creation of new knowledge and methodologies (such as validation of stress detection methods, implementation of new image algorithms for satellite imagery analyses, and development of hand-held NDVI equipment) used to improve the management of Australian banana plantations. • Some contribution to improved productivity and profitability for Australian banana growers through the increased adoption of precision agriculture practices (e.g. use of plant height, leaf nitrogen, and/or yield mapping to determine causes and potential remediation options for low yielding banana areas at a farm-scale). • Some contribution to reducing the risk of the incursion and/or spread of key banana industry diseases through improved detection and monitoring. • Some contribution to reduced chemical and/or nutrient export off-farm through the increased adoption of precision agriculture practices.

4. Project Investment

Nominal Investment

Tables B4 to B6 show the annual investment (cash and in-kind) for each of the projects funded by DAF, Hort Innovation and other partners. Table B7 shows the total annual investment in all three projects by funding contributor.

Table B 4: Annual Investment in Project BA14013 (nominal $)

Contributor	2014/15	2015/16	2016/17	2017/18	Totals
DAF QLD	0	712,475	825,369	115,988	1,653,832
Hort Innovation	359,979	100,106	100,000	140,021	700,106
Others	0	0	0	0	0
Totals ($)	**359,979**	**812,581**	**925,369**	**256,009**	**2,353,938**

Source: Project documentation (i.e. project agreements and variations).

Table B 5: Annual Investment in Project BA14014 (nominal $)

Contributor	2015/16	2016/17	2017/18	2018/19	2019/20	Totals
DAF QLD	2,795,984	269,500	276,002	282,679	86,985	3,711,150
Hort Innovation	1,731,583	17,172	17,172	17,174	20,035	1,803,136
Others	358,127	358,127	358,127	358,127	0	1,432,508
Totals ($)	**4,885,694**	**644,799**	**651,301**	**657,980**	**107,020**	**6,946,794**

Source: Project documentation (i.e. project agreements and variations).

Table B 6: Annual Investment in Project ST15011 (nominal $)

Contributor	2015/16	2016/17	2017/18	2018/19	Totals
DAF QLD	113,079	170,692	213,384	195,918	693,073
Hort Innovation	44,077	40,070	24,382	17,115	125,643
Others	60,000	50,000	31,877	35,469	177,346
Totals ($)	**217,156**	**260,762**	**269,643**	**248,502**	**996,063**

Source: Project documentation (i.e. project agreements and variations).

Table B 7: Total Annual Investment in All Three Projects (nominal $)

Contributor	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	Totals
DAF QLD	0	3,621,538	1,265,561	605,374	478,597	86,985	6,058,055
Hort Innovation	359,979	1,875,766	157,242	181,575	34,289	20,035	2,628,885
Others	0	418,127	408,127	390,004	393,596	0	1,609,854
Totals ($)	**359,979**	**5,915,431**	**1,830,930**	**1,176,953**	**906,482**	**107,020**	**10,296,795**

Source: Project documentation (i.e. project agreements and variations).

Program Management Costs

For the DAF investment, the management and administration costs for the project are already built into the nominal dollar amounts appearing in Tables B4 to B7. A salary multiplier of 2.85 was used (Wayne Hall, pers. comm., 2017).

A 16.2% management cost was included to account for overheads associated with Hort Innovation's contribution. This cost is in addition to the Hort Innovation contribution shown in Tables B4 to B7. This multiplier was based on the share of 'payments to suppliers and employees' in total Hort Innovation expenditure (3-year average) reported in the Hort Innovation's Statement of Cash Flows (Hort Innovation Annual Report, various years).

A 10.0% management and administration cost was included to account for overheads associated the contribution of others to the total project investment. This cost is in addition to the other contribution amounts shown in Tables B4 to B7.

Real Investment, Commercialisation and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2017/18 dollar terms using the Implicit Gross Domestic Product (GDP) Deflator index (ABS, 2019). No additional costs of extension were included as the project encompassed a range of communication and extension components.

5. Impacts

The principal impact from adoption of project results was:

- Reduced risk of the incursion (new incursions) and/or spread (existing infestations) of *Foc* TR4 for the Australian banana industry.

Table B8 provides a summary of the types of impacts identified, categorised into economic, environmental and social impacts.

Table B 8: Triple Bottom Line Categories of Potential Impacts from the Foc TR4 Research Program (June 2015 to August 2019)

Economic	• Reduced risk of the incursion (new incursions) and spread (existing infestations) of *Foc* TR4 for the Australian banana industry, particularly the north Queensland production region. • More efficient implementation of on-farm biosecurity practices. • Improved efficiency of investment in banana breeding through improved prioritisation. • Improved efficiency of *Foc* TR4 RD&E investment • Some contribution to improved productivity and profitability for Australian banana growers through the increased adoption of precision agriculture practices. • Some contribution to reduced risk of pest and/or disease incursion and spread for the Australian nursery industry and the Australian sugar industry.
Environmental	• Some contribution to reduced chemical and/or nutrient export off-farm through the increased adoption of precision agriculture practices (ST15011 only)
Social	• Increased scientific and industry capacity

Public versus Private Impacts

Most of the impacts identified in this evaluation were industry related and therefore the benefits are considered private benefits. Some public benefits may be delivered in the form of the social benefit of increased scientific and industry capacity, and, potentially, the environmental benefit of reduced chemical and/or nutrient export off-farm.

Distribution of Private Impacts

The primary beneficiaries of the Fusarium wilt TR4 Research Program (June 2015 to August 2019) are Australian banana growers. Particularly those growers in the Queensland production region and/or those growing Cavendish banana varieties.

It can be assumed that the benefits from the project findings will be distributed between participants along commercial banana supply chains according to the relevant supply and demand elasticities.

Impacts on other Australian industries

It is possible that impacts from the project will, with further research, be relevant to growers in other, related Australian industries such as the nursery industry and the sugar industry. This is particularly true for R&D related to biosecurity BMPs.

Impacts Overseas

No significant impacts to overseas parties was identified. However, improved international scientific and industry networks that improve *Foc* information sharing may have some impact on foreign banana industries dealing with *Foc* infestations.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural Research, RD&E priorities are reproduced in Table B9. The Fusarium wilt TR4 Research Program (June 2015 to August 2019) investment has contributed primarily to Rural RD&E Priority 2, with some contribution to priorities 3 and 4, and to Science and Research Priority 1.

Table B 9: 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 B10. The Fusarium wilt TR4 Research Program investment (June 2015 to August 2019) addressed Queensland Science and Research Priority 1, with some contribution to priorities 6 and 10. In terms of the guides to investment, the investment is likely to deliver real future impact with the improved control and management of *Foc* TR4.

Table B 10: 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.

One principal impact of the Fusarium wilt TR4 Research Program investment (June 2015 to August 2019) was valued in monetary terms.

- Reduced risk of the incursion (new incursions) and spread (existing infestations) of *Foc* TR4 for the Australian banana industry, particularly for the north Queensland production region.

This impact was assumed to contribute to reduced potential industry losses through improved detection, containment and management of *Foc*.

Impacts Not Valued

Not all impacts identified in Table B8 could be valued in the assessment.

The economic impacts identified but not valued included:

- More efficient implementation of on-farm biosecurity practices.
- Improved efficiency of investment in banana breeding through improved prioritisation.
- Improved efficiency of *Foc* TR4 RD&E investment.
- Potentially, some contribution to improved productivity and profitability for Australian banana growers through the increased adoption of precision agriculture practices.
- Potentially, some contribution to reduced risk of pest and/or disease incursion and spread for the Australian nursery industry and the Australian sugar industry.

The environmental impacts identified but not valued included:

- Potentially, some contribution to reduced chemical and/or nutrient export off-farm through the increased adoption of precision agriculture practices (ST15011 only).

The social impacts identified but not valued included:

- Increased scientific and industry capacity

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

<u>More efficient implementation of on-farm biosecurity practices</u>

Since the outbreak of *Foc* TR4 in Tully (QLD) a large number of banana growers have implemented on-farm biosecurity practices to varying degrees. As improved information has become available in terms of best management practice for on-farm biosecurity, some growers will have amended their biosecurity practices while others will have adopted practices that they were not carrying out before.

As of March 2019, Panama disease was considered contained (Queensland Government, 2019). The initial outbreak detected on a single farm in Tully in 2015 did spread to a further two farms in 2017 (Johnston, 2018) but there have been no further detections of *Foc* TR4 in north Queensland to date.

The net impact of these potential practice changes is difficult to value. Data on the range of biosecurity measures practiced across Australian banana plantations and the costs of such practices was not readily available. Further, the counterfactual, that is, what would have happened in terms of biosecurity practice change without the Fusarium wilt TR4 Research Program investment, was difficult to define.

<u>Improved efficiency of investment in banana breeding and improved efficiency of *Foc* TR4 RD&E investment</u>

The coordination, collaboration and sharing of R&D through the investment in the Fusarium wilt TR4 Research Program is a strong element of banana disease R&D investments including breeding for disease resistance.

The general dissemination of information regarding banana disease research and the interactions of an international network of banana experts are likely to generate benefits through improved prioritisation and working towards the best use of available research monies.

These impacts were not valued primarily due to difficulties in forming the counterfactual, that is, what would have been the characteristics of investments and their impacts if the Fusarium wilt TR4 Research Program (June 2015 to August 2019) had not been funded (e.g. lesser impacts or the same impact but requiring a higher level of investment). Further, data on the total investment in *Foc* RD&E and banana breeding for Australia was not readily available and information on which to base credible assumptions was limited to expert opinion.

<u>Contribution to improved productivity and profitability for Australian banana growers through the increased adoption of precision agriculture</u>

Project ST15011 may make some contribution to increased adoption of precision agriculture practices in the Australian banana industry through the implementation of new and improved satellite imaging and crop measuring and monitoring systems and tools.

Further RD&E is required to progress these tools and increase adoption of precision agriculture in banana plantations to improve productivity and profitability through enhanced crop management (e.g. reducing yield variability, reducing chemical and/or nutrient inputs).

This impact was not valued due to limited evidence and/or data available regarding adoption of precision agriculture practices on-farm and the difficulty in linking the project investment to the end impact.

<u>Contribution to reduced risk of pest and/or disease incursion and spread for the Australian nursery industry and the Australian sugar industry</u>

This impact was considered a secondary, indirect economic impact. Cross-industry collaboration and information sharing is likely to result in improved biosecurity practices for other Australian agricultural industries. However, how such other industries will use information generated through the Fusarium wilt TR4 Research Program, and to what extent, is uncertain.

<u>Environmental benefits from potentially reduced use of chemicals/nutrients in banana crops with less chemical export off–farm</u>

The potential for reduced use of chemicals/nutrients as a result of increased adoption of precision agriculture practices for the Australian banana industry is likely to generate several environmental benefits. Reduced use of chemicals means a lessened likelihood of chemical run-off into water sources and a reduction in adverse effects on downstream ecosystems, particularly that of the Great Barrier Reef. Fewer sprays also means that resistance build-up to chemicals is reduced. Difficulties exist in quantifying the value of such environmental benefits and also in linking the investments in the analysis to such impacts.

<u>Increased scientific and technical capacity</u>

The Fusarium wilt TR4 Research Program (June 2015 to August 2019) supported various PhD projects, international scientific and industry collaborations and networks, and contributed to the wider body of scientific knowledge. The investments have also consistently worked towards developing general scientific capacity (e.g. developing new, validated research methodologies and conducting researcher training), some of which will enhance the availability of expertise in future responses to *Foc* outbreaks.

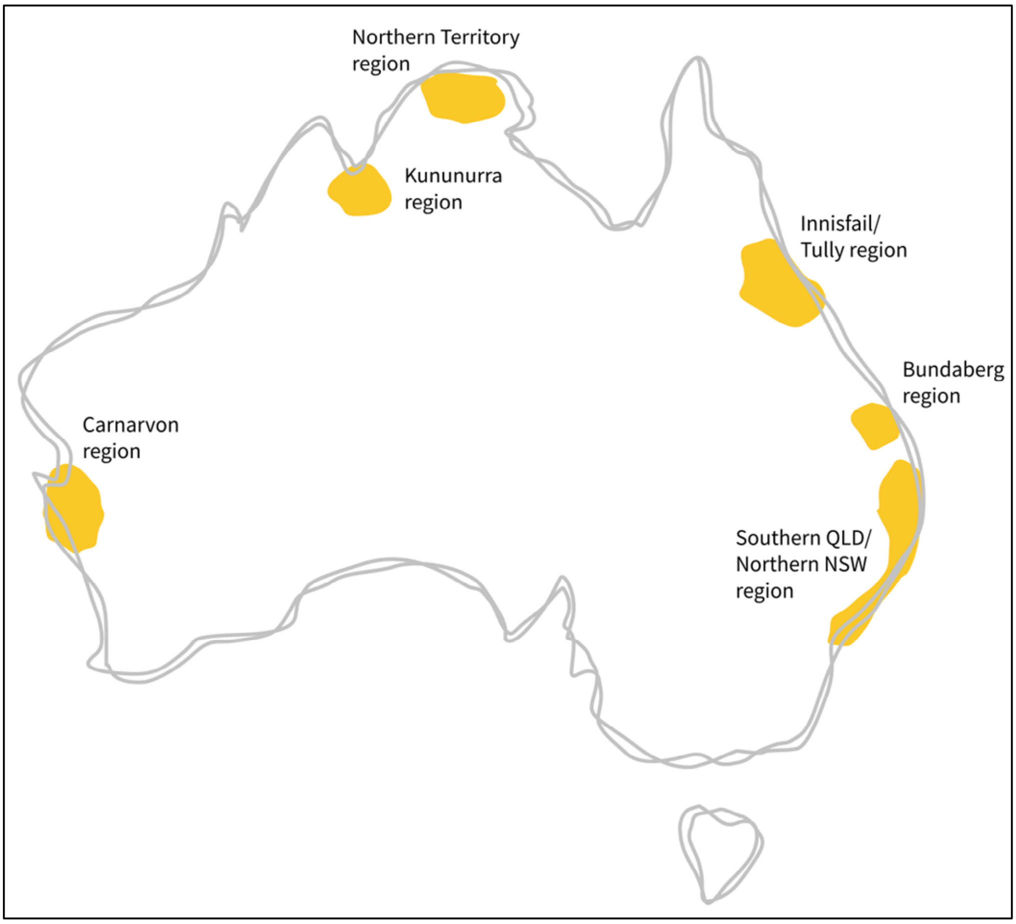
It is difficult to quantify the magnitude of such capacity enhancement because the initial level of capacity was unknown and placing a monetary value on human capacity requires the application of non-market valuation techniques that were beyond the scope of the current impact assessment.

Valuation of Impact 1: Reduced potential production losses for the Australian banana industry

Foc TR4 is named 'tropical race 4' because the TR4 strain of the fungus is capable of infecting Cavendish banana varieties growing in tropical conditions (Biosecurity Queensland, 2016). The wet tropical coast of northern QLD between Babinda and Cardwell (shown in Figure B5) is Australia's main banana growing area, accounting for between 70% and 80% of the Australia's national production (Deuter, White, & Putland, 2012; Stewart Lindsay, pers. comm., 2019).

Once a plantation becomes infected with *Foc* TR4, prevention of spread can only be achieved by the destruction of infected plants, maintenance of a surrounding buffer zone with no banana plants, limiting water run-off and restricting access using fence s and long-term fallow of affected land. There are no known long-term chemical options for management of *Foc* TR4 (Cook, Taylor, Meldrum, & Drenth, 2015).

Figure B 5: Map of Australian Banana Growing Regions



Source: https://australianbananas.com.au/Pages/all-about-bananas/the-banana-story

Potential industry losses WITHOUT the investment (counterfactual)

It was assumed that, without the investment in the Fusarium wilt TR4 Research Program (June 2015 to August 2019), including disease risk pathway identification, biosecurity BMPs, *Foc* mitigation and containment information and activities, grower engagement (e.g. workshops), and cultivar data provided by the investment, there would be a greater risk of future *Foc* TR4 incursions becoming established and spreading to a proportion of the tropical QLD banana industry causing significant economic losses. Without the investment, it also was assumed that quarantine efforts for future incursions would be less effective, therefore the potential spread of *Foc* TR4 would be faster than it would with the investment.

Industry losses WITH the investment

It was assumed that with the investments the risk of future incursion, establishment and spread of *Foc* TR4 would be lower and that quarantine efforts would be more effective therefore slowing the spread of the disease by half.

Specific assumptions used in the valuation are detailed in Table B11.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table B11.

Table B 11: Summary of Assumptions

Variable	Assumption	Source[(a)]
General Assumptions		
Australian banana production (5-year average, 2013-2017)	320.8 kt	ABS Agricultural Commodities Statistics (various)
Australian banana production area (5-year average, 2013-2017)	13,225 ha (bearing age)	
QLD production and area as a proportion of the total Australian banana industry	96% production 92% area	
QLD banana yield (average 2010-2015)	25.5 t/ha	
Australian banana industry value – gross value of production (5-year average 2013-2017)	$446.9 million	ABS Value of Agricultural Commodities (various)
Impact 1: Reduced potential industry losses from *Foc* TR4 in Australia		
WITHOUT the investment		
Probability of *Foc* TR4 spreading to the rest of the tropical QLD banana industry	10% in any year	Agtrans Research
Proportion of QLD production potentially affected by the spread of *Foc* TR4	45% (approximately 60% of the production occurring in the tropics at 75% of total Australian production)	Agtrans Research after consultation with Stewart Lindsay (DAF)
Time to reach maximum spread and impact	10 years	Stewart Lindsay (pers. comm., 2019)
Impact cost of *Foc* TR4 to the Australian banana industry should the disease become widespread	$138 million p.a.	Cook *et al.*, 2015
WITH the investment		
Probability of *Foc* TR4 spreading to the rest of the tropical QLD banana industry	9% in any year (reduction of 1%)	Agtrans Research
First year of impact of reduced risk of spread	2016/17	Year 2-3 of Fusarium wilt TR4 Research Program – assumes investment outputs begin to be adopted prior-to completion of BA14013.
Proportion of QLD production potentially affected by the spread of *Foc* TR4	45% (approximately 60% of the production occurring in the tropics at 75% of total Australian production)	Agtrans Research after consultation with Stewart Lindsay (DAF)
Time to reach maximum spread and impact	20 years (slows spread half)	
Risk Factors		

Probability of output	90%	Based on the existing, but partial, successful completion of the Fusarium wilt TR4 Research Program investment (June 2015 to August 2019).
Probability of outcome (usage)	80%	A large number of growers and industry stakeholders have already adopted biosecurity practices to improve the containment and control of *Foc* TR4. This probability takes into account those yet to adopt BMPs, those who will not adopt, and any dis-adoption.
Probability of impact	50%	Allows for uncertainty regarding the future control methods used to contain and control *Foc* TR4 in the tropical Australian banana industry (e.g. new technologies, resistant (non-Cavendish) banana varieties).

7. Results

All past costs were expressed in 2017/18 dollar terms using the Implicit Price Deflator for GDP (ABS, 2019). All benefits after 2017/18 were expressed in 2018/19 dollar terms. All costs and benefits were discounted to 2018/19 (year of analysis) 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 (2019/20).

Investment Criteria

Table B12 and Table B13 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 B13, has been estimated by multiplying the total PVB by the DAF proportion of real investment (55.7%).

Table B 12: Investment Criteria for Total Investment in the Fusarium wilt TR4 Research Program (June 2015 to August 2019)

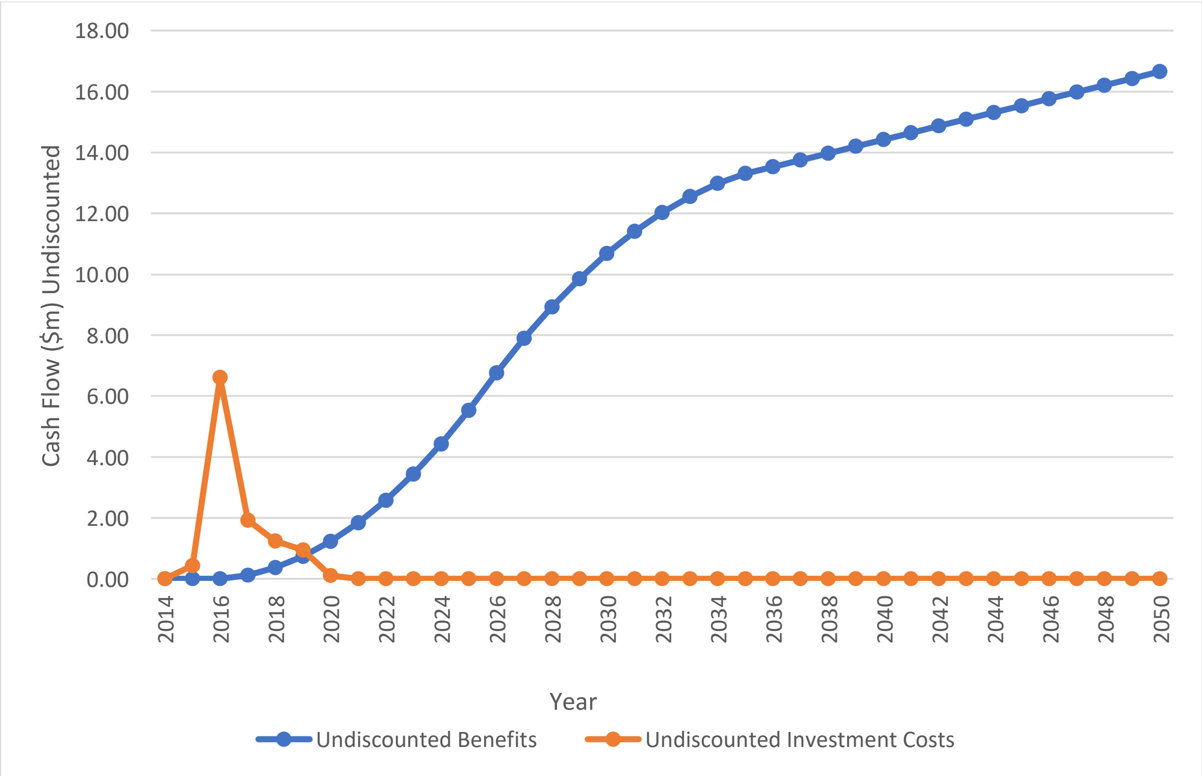
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	2.43	16.76	44.95	76.35	104.02	127.44	147.15
Present value of costs ($m)	12.68	12.68	12.68	12.68	12.68	12.68	12.68
Net present value ($m)	-10.25	4.08	32.27	63.67	91.34	114.76	134.47
Benefit-cost ratio	0.19	1.32	3.54	6.02	8.20	10.05	11.60
Internal rate of return (%)	negative	9.9	21.0	23.8	24.6	24.8	24.9
MIRR (%)	negative	10.5	18.7	18.2	16.6	15.2	14.0

Table B 13: Investment Criteria for DAF Investment in the Fusarium wilt TR4 Research Program (June 2015 to August 2019)

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	1.35	9.33	25.02	42.50	57.90	70.93	81.90
Present value of costs ($m)	7.04	7.04	7.04	7.04	7.04	7.04	7.04
Net present value ($m)	-5.69	2.29	17.97	35.45	50.85	63.89	74.86
Benefit-cost ratio	0.19	1.32	3.55	6.03	8.22	10.07	11.63
Internal rate of return (%)	negative	9.94	21.2	24.0	24.7	25.0	25.1
MIRR (%)	negative	10.6	18.8	18.2	16.7	15.2	14.0

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 B6.

Figure B 6: Annual Cash Flow of Undiscounted Total Gross 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 B14 presents the results. The results showed a moderate to high sensitivity to the discount rate. This is largely due to the fact that the benefit cash flows occur well into the future and therefore are subjected to significant discounting.

Table B 14: Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	353.00	147.15	73.34
Present value of costs ($m)	11.29	12.68	14.20
Net present value ($m)	341.71	134.47	59.13
Benefit-cost ratio	31.27	11.60	5.16

A sensitivity analysis also was carried out on the change in risk attributable to the Fusarium wilt TR4 Research Program investment. Table B15 presents the results. The results showed low sensitivity to the assumed change in risk.

Table B 15: Sensitivity to the Change in Risk Attributable to the Fusarium wilt TR4 Research Program Investment (Total investment, 30 years)

Investment Criteria	**Change in Risk**		
	0.2%	**1%** (base = 10% without less 9% with investment)	**2%**
Present value of benefits ($m)	126.12	147.15	173.43
Present value of costs ($m)	12.68	12.68	12.68
Net present value ($m)	113.44	134.47	160.75
Benefit-cost ratio	9.95	11.60	13.68

Finally, a sensitivity analysis was carried out on the proportion of the Australian banana industry (in terms of production) assumed to be impacted by the spread of *Foc* TR4. Results are shown in Table B16. The results showed a moderate sensitivity to the proportion of production assumed to be affected by the spread of the disease.

Table B 16: Sensitivity to the Proportion of the Australian Banana Industry Impacted by the Spread of Foc TR4 (Total investment, 30 years)

Investment Criteria	**Proportion of Production**		
	20%	**Base (45%)**	**90%**
Present value of benefits ($m)	65.40	147.15	294.30
Present value of costs ($m)	12.68	12.68	12.68
Net present value ($m)	52.72	134.47	281.61
Benefit-cost ratio	5.16	11.60	23.21

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 B17). 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 B 17: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Low-Medium	Medium

Coverage of impacts was assessed as low-medium. Although the principal economic impact was valued, a number of other impacts including environmental and social impacts, were not valued in monetary terms. This was largely due to a lack of available of data/evidence, poor linkages between the Program investment and the impacts, and the relative significance of the impacts compared to the principal impact valued. Thus, the investment criteria as provided by the valued impact are likely to be underestimated to some degree.

Confidence in assumptions was rated as medium. Data for this analysis were drawn from credible, published sources with supplementary data/information provided by the projects' Principal Investigators.

8. Conclusions

The analysis demonstrates that the investment in *Foc* TR4 biosecurity best practice has provided a positive return. However, it is important to note that the assumptions related to probability of disease spread are uncertain and so the benefits identified and valued in this analysis also are somewhat uncertain. The positive investment criteria are consistent with previous economic evaluations of R&D investments in banana disease diagnostics and biosecurity.

Some impacts were identified and described qualitatively, but not valued in monetary terms. A more comprehensive study could be conducted in the future to attempt to quantify some of these other benefits. Given the scope of the current analysis, it is likely that the benefits valued are an underestimate of the full potential benefits that may accrue because of the Fusarium wilt TR4 Research Program investment.

The primary impact that was quantified was the potential for reduced economic losses to the

Australian tropical and sub-tropical banana industry through reducing the risk of *Foc* TR4 spreading from the NT and Tully (QLD) and slowing the spread of the disease should it occur.

The current assessment revealed that the quantitative analysis of the impact Australian biosecurity RD&E for the banana industry is somewhat uncertain. Conceptually, future analyses would benefit from the availability of improved information regarding the current and potential future risk of disease incursion and/or spread each year, and the likely alternative land use by region should *Foc* spread more widely.

The total investment of approximately $12.7 million (present value terms) has been estimated to produce total net benefits of approximately $147.2 million (present value terms) providing a net present value of $134.5 million, a benefit-cost ratio of approximately 11.6 to 1 (over 30 years, using a 5% discount rate), an internal rate of return of 24.9% and a modified internal rate of return of 14.0%.

The results are consistent with previous analyses conducted by Agtrans regarding banana diseases and biosecurity RD&E. Given the coverage of impacts valued and conservative assumptions made for the valuation, the investment criteria reported may be an underestimate of the total value of the impact of the Fusarium wilt TR4 Research Program investment.

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Appendix B1: Networking, communication and extension activities for BA14013

Table B18 shows the networking, communication and extension activities undertaken as part of project BA14013.

Table B 18: Networking, communication and extension activities of BA14013

Date	Activity	Stakeholder Group	Attendance
Group activities – R&D coordination			
6/4/16	UQ Fusarium Focus video-conference	Panama disease R&D staff; ABGC staff; BQ staff	30
13/5/16	UQ Fusarium Focus video-conference	Panama disease R&D staff; ABGC staff; BQ staff	40
16/8/16	DAF Panama disease R&D update seminar	Panama disease R&D staff; ABGC staff; BQ staff, NTDPI staff	40
20/9/16	Meeting with ABGC TR4 R&D Manager – update for ABGC board and CEO on project progress	ABGC Board and staff	N/A
7/12/16	Biosecurity Queensland Panama Response Program Planning Manager – update on project progress and activities	BQ staff	N/A
10/1/17	Dr E Aitken, UQ, seminar on *Foc* TR4 resistance gene marker development, South Johnstone	DAF RD&E staff; BQ staff; ABGC staff	15
14-15/2/17	Panama disease R&D Update seminar, Brisbane	DAF R&D staff; ABGC staff and board members; BQ staff; NTDPIR staff; UQ staff; QAAFI staff; NSW DPI; ACIAR; Hort Innovation; JCU; UNE	50
6/3/17	BQ response and epidemiological review, Prof A Viljoen, Stellenbosch University	DAF project staff; BQ staff	15
25/9/17	Panama disease R&D Update seminar, Brisbane	DAF project staff; ABGC staff; 3 grower representatives; BQ staff; NTDPIR staff; NSW DPI staff; UQ staff; JCU staff; UNE	35

		PhD student; Hort Innovation staff	
Group activities - industry			
13/11/15	DAF/ABGC Panama disease industry field day	Banana growers, consultants, agricultural retailers, chemical company representatives	100
10/3/16	Banana agribusiness managers discussion group – sanitiser R&D presentation	Consultants, agricultural retailers, chemical company representatives	25
13/4/16	Mareeba Banana Growers Association meeting – sanitiser R&D presentation	Banana growers	5
8/6/16 Mareeba 9/6/16 Innisfail 16/6/16 Tully 23/6/16 Carnarvon 5/7/16 Coffs Harbour 7/7/16 Murwillumbah	National Banana Industry Roadshow – presentations on project results: • Sanitiser trials – K Grice • Early detection/remote sensing – K Ferro • Soil health – T Pattison	Banana growers, consultants, agricultural retailers, chemical company representatives	165 total
30/6 & 1/7/16	ABGC Panama TR4 industry meetings	Banana growers, industry service providers	50 total
July 2016	ABGC Chairman project progress briefing – summary of project activities for his panel discussion at PHA seminar, Melbourne	ABGC Board chairman, PHA seminar attendees	N/A
22/9/16	Banana agribusiness managers discussion group – supplementary sanitiser R&D presentation on corrosion and effective concentration monitoring	Consultants, agricultural retailers, chemical company representatives	22
4/4/17	ABGC TR4 R&D manager – discussions on new sanitiser screening results including assessment against TR4	ABGC TR4 R&D manager, and ABGC CEO and Board by extension	N/A
12/5/17	DAF Panama R&D Open Day, South Johnstone	Banana growers, consultants, agricultural retailers, chemical company representatives	109
22/6/17	Presentation at Australian Banana Industry Congress 2017 on project activities and results	Banana growers, consultants, agricultural retailers, chemical company representatives, supply chain	200+

		businesses, R&D agencies	
6/7/17	Cassowary Coast Banana Growers Association meeting – update on project activities	Banana growers, ABGC staff	18
1-2/8/17	ABGC Panama TR4 industry meetings – update on new incursion (Tully, Innisfail, Mareeba)	Banana growers, industry service providers	130 total
Conference presentations			
10-14/10/16	5th ISHS-ProMusa Symposium: Agroecological approaches to promote innovative banana production systems, Montpellier, France • Integrating management practices to support banana production in the presence of Fusarium wilt (T Pattison) • Monitoring microbial functional and structural diversity for management of disease suppressive soil (A McBeath)	International banana researchers	90
14-17/11/16	9th Australasian Soilborne Disease Symposium, Lincoln University, Christchurch • Development of an integrated management system to suppress Fusarium wilt of bananas (T Pattison)	Domestic and international researchers	60
25-28/9/17	Australasian Plant Pathology Society/CRC Plant Biosecurity - Science Protecting Plant Health Conference, Brisbane (pres.) • Engineering banana cropping systems to suppress soil borne diseases • Quaternary ammonium-based disinfectants for effective on-farm biosecurity management of Panama disease in bananas Posters: • Effects of commercial disinfectants on the survival of *Foc* Race 1 and TR4 propagules • The survival of *Foc* in plants co-habiting Australian banana farms • Testing the efficacy of urea as a treatment for the destruction of *Foc* in infected soil • The assessment of physiological methods for early,	Domestic and international researchers; biosecurity agency staff and policymakers	523

	quantifiable stress detection in banana plants • Using *Trichoderma* to suppress Fusarium wilt (*Foc*) in banana cropping systems		
Written material			
Australian Bananas – Issue 45, Spring 2015	• Zoning out bad habits – making the change to effective biosecurity	Banana growers, allied service providers, R&D staff	1000
Australian Bananas – Issue 46, Autumn 2016	• Fielding ideas – growers share their TR4 innovations • Ammonium compounds clean up	Banana growers, allied service providers, R&D staff	1000
Australian Bananas – Issue 47, Spring 2016	• Early detection trials • DDAC test kits • Panama disease R&D overview	Banana growers, allied service providers, R&D staff	1000
Australian Bananas – Issue 48, Autumn 2017	• Panama R&D update summary	Banana growers, allied service providers, R&D staff	1000
Australian Bananas – Issue 49, April 2017	• Meeting of TR4 Minds – the latest update on TR4 research	Banana growers, allied service providers, R&D staff	1000
Australian Bananas – Issue 50, September 2017	• Panama Open Day report	Banana growers, allied service providers, R&D staff	1000
BQ Panama TR4 Program Update newsletter	Mar/Apr 2016 • Groundcover trials, reducing inoculum, weed host status survey, development of biosecurity BMP May/Jun 2016 • Weed host status survey, early detection, pseudostem destruction, soil ecology trials Jul/Aug 2016 • Panama R&D update seminar Sept/Oct 2016 • Disinfectant trials against TR4 from NT, new sanitiser testing in Qld, weed host trials, inoculum reduction Jan/Feb 2017 • Testing concentration of disinfectant solutions, disinfectant corrosion testing, detecting stressed banana plants	Banana growers, ABGC staff, local government, utilities	400 recipients (116 growers)

DAF Fact sheets	Panama Disease Tropical Race 4 Research Update series: • Quaternary Ammonium products aid in the management of *Foc* • Testing the efficacy of urea as a treatment for the destruction of *Foc* in infected soil • Proximal sensing tools for early, quantifiable stress and disease detection • Quaternary ammonium products: How can you monitor them? How long are they effective for and are they corrosive? • Soil management, organic matter, biological activity and disease suppression Multi-scale monitoring tools for managing Australian tree crops	Banana growers, allied service providers, R&D staff	N/A
Banana best management practices guide	On-farm biosecurity	Banana growers, allied service providers, R&D staff	142 (as at 29/9/17)
International TR4 networks/visits			
23/2/17	3 Israeli banana R&D staff visited DAF South Johnstone to discuss *Foc* TR4 R,D&E activities	DAF R,D&E staff; BQ response program staff; ABGC staff	N/A
20/6/17	Prof R Ploetz (University of Florida) & Dr F Bakry (CIRAD, France) visited DAF South Johnstone to discuss *Foc* TR4 R,D&E activities	DAF R,D&E staff; BQ response program staff; ABGC staff	N/A
27/6/17	Dr Roberto Young, Dole Honduras, visited DAF South Johnstone to discuss *Foc* TR4 R,D&E activities	DAF R,D&E staff; BQ response program staff; ABGC staff	N/A

Source: Project BA14013 Final Report

Appendix C: An Impact Assessment of DAF Investment into Project DAQ 00172 of The National Mungbean Improvement Program

Acknowledgments

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Abbreviations

AVRDC	The World Vegetable Center, previously Asian Vegetable Research and Development Center
BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries – Queensland
GRDC	Grains Research and Development Corporation
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NMIP	National Mungbean Improvement Program
NPV	Net Present Value
NSW	New South Wales
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

This impact assessment focuses on a project investment (Project DAQ00172) in the National Mungbean Improvement Program (NMIP). The project was funded jointly by the Grains Research and Development Corporation (GRDC) and the Queensland Department of Agriculture and Fisheries (DAF) over the 5-year period from 1 July 2011 to 30 June 2016. This project continued the development of varieties suited to the mungbean growing regions of Australia. The total investment in DAQ00172 was $3.84 million in nominal terms with 45% contributed by GRDC and 55% from DAF.

The NMIP released three new varieties during the period of the project and shortly thereafter. A particular highlight was the release of Jade-AU that became available to growers in 2015 and which has become one of the mainstays of the mungbean industry in the large shiny-seeded market. Also, in addition, a number of superior lines were identified that were approved to proceed to release. The project investment continued the long term development of genetic resistance to various mungbean diseases that will be captured in the release of mungbean varieties in future.

The beneficiaries from the current investment were primarily Australian mungbean growers and their cropping rotations, as well as the associated mungbean input supply and marketing chains.

The total investment was equivalent to $5.2 million in present value terms (2017/2018 $ terms). The investment produced benefits estimated at $61.9 million in present value terms, a net present value of $56.7 million, a benefit-cost ratio of 12.0 to 1, an internal rate of return of 38.0%, and a modified internal rate of return of 16.5%.

The investment criteria produced from the current analysis of project DAQ00172 were highly positive, and therefore in line with previous economic analyses of mungbean breeding investments. The evaluation of the latest project and its comparison of its investment returns with earlier periods of investment provides confidence that the positive historical returns from mungbean breeding are still continuing.

1. Evaluation Methods

The evaluation approach followed 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) (CRRDC, 2018).

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 identified impact compared to those impacts that were valued. The impacts valued therefore are deemed to represent the principal benefits delivered by the project.

2. Background and Rationale

Mungbean (*Vigna radiata*) is an annual legume grown as a spring and summer crop in subtropical areas, predominantly in Queensland and northern New South Wales. Grain yields are constrained by a short crop life cycle and can be impacted by drought, disease and severe weather damage at maturity that can reduce both yield and product quality.

The first commercial mungbean varieties grown in Australia (late 1960s and 1970s) were imported varieties. CSIRO undertook evaluation and breeding up until 2002 and bred varieties Emerald (1993) and Green Diamond (1997). The area of the mungbean crop expanded from around 10,000 tonnes in the late 1980's to 45,000 tonnes by the mid 2000's.

The Department of Agriculture and Fisheries Queensland (DAF) (then known as DEEDI) assumed leadership and refocused the breeding program in 2003 placing emphasis on expanded genetic diversity and development of new foliar disease resistance traits; the breeding program was underpinned by rigorous field evaluation throughout the northern grains region. The release of the mungbean varieties, Crystal and Satin II, in 2008 has reinvigorated the Australian industry and saw production grow to highs of 65,000 tonnes.

About 95% of mungbean produced in Australia are exported. Mungbean are mainly marketed as a vegetable rather than as bulk grain so their appearance is very important. A small proportion of mungbean seed produced is used in Australia for sprouting.

Plant breeding has been a high priority for the Australian Mungbean Association (AMA), as unreliable dryland production was considered a constraint in marketing. A target stable production of 50,000 tonnes per annum by 2014 was set by the AMA in order to support market development for Australian mungbean (AMA, 2011).

Mungbean traditionally have been produced mainly in central and southern Queensland and northern NSW. However, significant potential exists for production in northern Australia as exhibited in increasing production in the Burdekin Irrigation Area.

Mungbean are a short season spring/summer crop grown mainly as a rotation crop with cereals or cotton. There are several different types of mungbean grown in Australia including a large and a small seeded shiny type, and a dull seeded type grown for niche markets.

3. Project Investment

This assessment addresses the investment in Project DAQ00172: National Mungbean Improvement Program that extended from 2011 to 2016. The following table shows the nominal, annual investment (cash and in-kind) for the project. The project was funded jointly by DAF and the Grains Research and Development Corporation (GRDC).

Table C 1: Annual Investment and Funding Source for DAQ00172 (nominal $)

Year ending 30th June	**DAF**	**GRDC**	**Total**
2012	373,300	327,000	700,300
2013	395,400	300,000	695,400
2014	423,800	300,000	723,800
2015	446,700	300,000	746,700
2016	480,900	300,000	780,900
Total	**2,120,100**	**1,527,000**	**3,647,100**

Program Management Costs

For the DAF investment the management and administration costs for the project are assumed already built into the nominal $ amounts appearing in Table C1. 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 the GRDC investment, a management cost multiplier of 1.12 was applied to the GRDC contributions shown in Table C1. This multiplier estimate was based on information in the GRDC Annual Report (GRDC, 2017).

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2017/18 $ terms using the Implicit Gross Domestic Product (GDP) Deflator index (ABS, 2018). Costs of extension and communication by GRDC were assumed to be already included within the 1.12 management cost multiplier. The CRRDC guidelines state that communication and extension costs need to be accommodated explicitly.

Extension and communication costs for DAF and AMA were included by a multiplier of 1.075 applied to the annual DAF R&D cost. The multiplier was estimated by Agtrans based on knowledge of other information dissemination and communication costs associated with variety management and promotion/marketing.

4. Project Description

Table C2 following provides a description of Project DAQ00172 in a logical framework format.

Table C 2: Logical Framework for Project DAQ00172

DAQ00172: National Mungbean Improvement Program (2011-2016)	
Project Details	Organisation: Department of Agriculture and Fisheries, Queensland Period: July 2011 to June 2016 Principal Investigator: Col Douglas, DAF
Objective	The broad objective was to develop and release new mungbean varieties that, with superior grain yield, foliar disease resistance (halo blight, tan spot, powdery mildew) and grain quality, will improve productivity, profitability and reliability for mungbean farmers and the Australian industry.
Activities and Outputs	• Pure seed (125 kg of M07213) was handed over to the AMA for seed increase in northern Australia. • Line M07213 was approved for release by the Mungbean Management Group and the DAF variety release committee (November 2011). Seed was available for the 2013 spring planting. • M07213 was at least nine per cent higher yielding than Crystal (9-26% over four years and 28 sites), with superior grain quality and foliar disease resistance; Crystal provisionally had been rated resistant/moderately resistant to powdery mildew and tan spot. • Small seeded halo blight resistant lines (M09235, M09246 and M09350) had high yield under halo blight disease pressure (170% yield of Celera and Green Diamond) and were yield competitive with Crystal). A single line was to be identified after the 2011-2012 season. • It was realised that new markets may need to be identified for small seeded mungbean if a new variety release was made and production increased thereafter. • Potential new resistance sources were identified from germplasm from the AVRDC (The World Vegetable Center, previously known as the Asian Vegetable Research and Development Center) including sources against halo blight and tan spot. • Thirty two tonnes of M07213 seed was produced and M07213 was licensed to the AMA. • M07213 had a 12% higher yield than Crystal (38 trials over last five years) and had higher powdery mildew resistance than Crystal and slightly better for tan spot. • M09246 was proposed at the time to be the next new variety release, combining two sources of halo blight resistance. M09246 is a small-seeded type that has a significantly higher yield than Celera and Green Diamond and yields similar to Crystal under halo blight pressure. M09246 entered commercial bulk-up with AMA in 2013. • Some halo blight resistance was incorporated into large seeded lines as well. • Further crosses of disease resistant lines were made with AVRDC germplasm. • On-farm trials were extended to the Liverpool Plains in NSW and in the Burdekin Irrigation Area in QLD.

	- A new approach to analysis allowed for partitioning of heritable and non–heritable yield performance among breeding lines. Selection of crossing parents was then based on objective genetic potential for yield and disease resistance. - Jade-AU (previously known as line M07213) was considered to have a yield gain of 12% over Crystal, as well as improved resistance to powdery mildew and improved grain quality compared to Crystal. - Celera II-AU (previously line M09246) was approved for release in 2013 and was first sown in the spring of 2014. - Celera II-AU was the first National Mungbean Improvement Program (NMIP) variety to address halo blight (the major foliar disease of mungbean. It also has improved powdery mildew and tan spot resistance compared to the varieties it will replace. Grain quality has been approved by grain exporters and end users. It is an early flowering variety and hence its exposure to drought during grain fill is reduced compared to Crystal and Jade-AU. - Celera II-AU was higher yielding than the varieties it replaced and will also out-yield Crystal under conditions of high disease pressure. In the absence of halo blight, the yield of Celera II-AU is intermediate between current large and small shiny seeded varieties. - Evaluation of a series of black gram varieties with improved yield over the commercial variety Regur has taken place; these lines also have outstanding disease resistance and could be used as a source of resistance for improving mungbean resistance to halo blight. - Release decisions were made for a black gram variety after yield trials and results of market testing for taste and appearance. - Three sets of new germplasm (shiny large seeded and shiny small seeded) were imported from AVRDC (also some from a Thai breeding program) and new resistance donors for halo blight and tan spot have been identified and incorporated into the crossing program. - A new strain of halo blight was identified and reported. However, material in the most recent germplasm imported from AVRDC shows immunity type resistance to both the new (K strain) and the old strain (T strain) of halo blight as well as to tan spot. - Crop surveys were conducted from 2014 onwards to determine the distribution and pathogenicity of the two halo blight strains. - New large seeded genotypes that combine resistance to the main halo blight strain with high yield potential, performed well in early trials and could potentially be released at, or following, the end of the project. - A new association mapping project commenced that will allow fast tracking the introgression of new foliar disease resistance into existing lines. - Following a scoping study for mungbean production in north Queensland, selection trials commenced in the Burdekin (Ayr Research Station) in 2014 and were further developed in 2015. NMIP breeding line M08019 yielded 2.9 tonnes per ha in unreplicated strip trials, as compared to a yield of 2.6 tonnes per ha for Crystal. - NMIP targeted specific adaptation for central Queensland; in particular the central highlands where Celera II-AU and the latest halo blight resistant lines have not suited as well as they have in southern environments. - NMIP also was investigating short duration lines to minimise risk (spring and autumn crops) and longer phenology to maximise yield potential under irrigation in north Queensland. **Communication**

	• A number of extension and field days were held over the period at various locations - e.g. Liverpool Plains, Hermitage Research Station (Warwick). • A road show to support the release of Jade-AU was conducted in QLD and NSW growing areas. • The project maintained linkages with GRDC agronomy projects associated with mungbean resulting in efficiencies of trials and joint inputs at field days. • Team meetings for reviewing progress and plans were held and quarterly teleconferences were held by the management croup (AMA, DAF and GRDC). • International collaboration was strengthened with AVRDC and the Australian Centre for International Agricultural Research and communication with other mungbean researchers occurred via an international symposium and Australian conferences.
Outcomes	• As a result of Project DAQ00172 and earlier investment, three new varieties of mungbean were released during, or shortly after the duration of the project. • Rapid adoption of Jade-AU was experienced on its release and thereafter and it has since become a prominent mungbean variety. For example, initial stocks of Jade-AU were sold out by September for the spring planting in 2013 and there was a high demand for seed for the 2014 spring planting. • Celera II-AU replaced Celera and Green Diamond varieties and facilitated renewed access to the small seeded shiny green market. However, the first sowing opportunity for Celera II-AU was not until December 2014 (no spring sowing possible). Yields of Celera II have been well above those of Green Diamond and quality is very good. • Black gram commands only a small market and hence the development of the new variety was a by-product from exploring genetic diversity for new disease resistance to incorporate into the key large-shiny market. The new black gram variety (Onyx), with a small yield increase over the existing variety, was released in 2017. • Introgression is a medium-long term goal for the breeding program due to (partial) infertility. Black gram is a potentially valuable source of foliar and fusarium disease resistance, and drought and waterlogging tolerance. If successfully introgressed and able to recover adapted plant types, derived lines would not be released until after 2020 (Col Douglas, pers. comm., 2015).
Impacts	• Early indications are the two new varieties first grown in in 2013-2014 and 2014-2015 respectively have provided ongoing higher performance and profitability than the varieties they replaced. • Another impact could be from any increased area of cereal rotations incorporating mungbean, where the increased area could have been driven by the advent of the new varieties. • Potentially, further yield increases and improved disease resistance may emanate from any future commercialisation of already identified superior lines. For example, Line M12036 has been targeted for release in 2019, with first production in 2020. • The genetic capital available for further exploitation has increased due to the project, particularly that associated with disease resistance.

Summary of Outputs and Outcomes

A summary of the principal outputs associated with the investment is provided by the following:

- Jade-AU was released in 2013 year and first grown in the 2014 year. Jade-AU had a 12% higher yield potential over Crystal, the then dominant shiny green type. Jade-AU also is more disease resistant and its quality is improved compared to Crystal. It has taken 50% market share from Crystal on the basis of yield, as well as some increased resistance against powdery mildew.
- Celera II-AU was released in 2014 and first grown in the 2015 year. Celera II-AU is a small seeded shiny green mungbean and has been a direct replacement for Green Diamond and Celera; it is likely to have taken 100% market share after 4 years. Its major advantage is a higher yield than the competing small seeded varieties and it has higher resistance to halo blight.
- Onyx was released in 2017 and has replaced the only former black gram variety Regur.
- Other lines with increased disease resistance have been identified and are being further trialled.

The principal short-term outcomes from the investment are the new superior varieties being grown, or expected to be grown, by mungbean producers. Some of the already released varieties have been quickly adopted by growers due to their improved varietal characteristics including some increased disease resistance, their adaptation to different environments including both dryland and irrigated production, and the extension efforts made by various organisations. However, any increase in the area of mungbean driven by the associated productivity and profitability increases generally has been masked by the recent seasonal conditions as reflected in areas and average yields provided in Table C3 following.

5. Recent Mungbean Industry Production Data 2011-2017

The following table (Table C3) provides area, yield, and production data for Australian mungbean production for each year ended 30th June from 2011 to 2017.

Table C 3: Areas, Yields, and Production for Australian Mungbean Industry by Year

Year ended June	Area (000 ha)	Yield (t/ha)	Production (000 t)
2011	86.4	0.8	65.2
2012	55.0	0.8	44.5
2013	38.0	0.9	35.0
2014	35.0	0.9	32.0
2015	35.0	0.9	32.0
2016	130.0	0.9	123.0
2017	129.0	0.8	99.0
7-year average	72.6	0.86	61.5

Source: ABARES (2017)

The above average areas grown in the year ended June 2016 was due to a combination of high prices and seasonal conditions. Prices to farmers were over $1,000 per tonne and as high as $1,400 per tonne for niche sprouting quality beans. Optimistic views on export prices and sowing intentions remained high for a period but seasonal conditions have worked against high yields and hence production levels (Col Douglas, pers. comm., 2019).

6. Summary of Impacts

The principal impact from the investment has been the continued development of improved varieties that have led to higher grower productivity and profitability of mungbean. Some regional community spillovers have been derived from improved profitability and sustainability of mungbean growing; these benefits flow to local families and businesses along the supply chain (e.g. storage, marketing, transport).

In the longer term, the breeding germplasm capital has increased during the period of DAQ00172 and this germplasm promises further variety releases in future periods.

Yield increases

The major impacts driven by the NMIP project have been the yield increases from the two mainstream new varieties that have been released during the project and the prospective yield increases from the future commercialisation of the superior line that is currently being further evaluated. These yield increases have led to, or will lead to, increased productivity and higher farm profitability.

A summary of the quality improvements and the disease resistance status of the three already released varieties and the prospective release variety is shown in Table C4.

Table C 4: Quality and Disease Resistance Improvements of Released and Prospective New Varieties

Variety	**Comparable variety (s)**	**Quality Improvement**	**Resistance to**		
			Powdery mildew	**Halo blight**	**Tan spot**
Jade-AU	Complements Crystal	Yes	Improved	Same	Slightly improved
Celera II-AU	Replaces Celera and Green Diamond	Yes	Improved	Improved	Improved
Onyx (Black Gram)	Replaces Regur	No	Same	Improved	Same/Improved
Prospective Line M12036	Complements Crystal and Jade-AU	Yes	Improved	Improved	Reduced

Source: Progress Reports and Final Project Report for DAQ00172 and inputs from Col Douglas

Potential production stability

The higher yields and quality and improved disease resistance may deliver greater confidence to grain producers in their decisions to plant mungbean. This may in turn elicit a higher total area of mungbean grown, climatic conditions permitting. If higher production occurs, this may not only provide increased profit but also may have positive export marketing implications for the Australian industry through improved stability in servicing market demand niches in the high quality end of the market

Maintaining and increasing mungbean in cropping rotations

Mungbean play an important role in providing a disease break for cereal grains in northern cropping systems. Crop rotations incorporating mungbean can be sustainable and more profitable than a cereal-cereal rotation and mungbean may also play a role in cotton-cereal rotations. Relative product prices and the stability of yields are determinants of mungbean plantings but there are other drivers apart from higher and more stable yields. Mungbean can reduce chemical use in the rotation due to improved weed and pest control and can reduce the use of nitrogen fertiliser in the cereal phase of the rotation. If the new varieties lead to an increase in the annual area of mungbean planted in rotations, then such additional impacts can be attributed to the new varieties. It is noteworthy that one of the strategies stated in the mungbean industry strategic plan (AMA, 2015) is to ensure that information is available on how the economics and sustainability of rotations may be influenced by the inclusion of mungbean.

This interaction with broader cropping systems is not restricted to grain-only rotations. Following earlier investment by GRDC and Sugar Research Australia, a recent project directed at fallow legume break crops for sugarcane demonstrated the following impacts:

- Potential Increased productivity and profitability for Burdekin sugarcane growers adopting short and long fallow grain crops such as mungbean and soybean.
- Potential reduction in fertiliser costs for Burdekin sugarcane growers and potential soil health maintenance and long-term sustainability of Burdekin sugarcane cropping soils due to the inclusion of such legume crops.

Environmental

Maintaining disease breaks and weed control in cereal crop rotations through use of mungbean can lead to less chemical usage (pesticides) in the cereal phase of the rotation. Such reduced pesticide usage may benefit the farm environment and potentially lead to reduced export of chemicals to public waterways. Nitrogen contributed by mungbean crops can reduce total nitrogen fertiliser required in the rotation, and hence reduce greenhouse gas emissions.

Genetic capital

Due to the further development of germplasm during the project, the genetic capital held by NMIP at the end of the investment period (2016) is considerably higher than at the beginning (2011). This is particularly so due to activities initiated since 2011 with the AVRDC and the continued importation of new genetic material.

Overview of Impacts

An overview of impacts in a triple bottom line categorisation is shown in Table C5.

Table C 5: Categories of Impacts Driven by the DAQ00172 Project Investment

Levy Paying Industry	**Spill overs**		
	Other Industries	**Public**	**Foreign**
Economic impacts			
Contribution to release of three varieties to date with higher yields, some with higher quality and some with improved disease resistance compared to the varieties they have replaced. Contribution to prospective variety releases that are likely to be progressed to release.	Yield increases and economic benefits to other crops such as cereals from disease and weed control from maintaining or increasing mungbean in	Nil	Prospective contribution to improved mungbean varieties overseas via testing methods and genetic loci knowledge.

Increasing the area of mungbean in rotations (through increased or maintained profitability of mungbean and more disease resistant varieties) can potentially lead to reduced chemical usage on farms (herbicides and fungicides) and fertiliser cost reduction from nitrogen supplied by mungbean compared to other crops that might be used in rotations Increase in capital value of mungbean germplasm between 2011 and 2016	rotations due to the new varieties		
Environmental impacts			
Reduced use of nitrogen fertiliser in crop rotations and associated reduction in greenhouse gas emissions Reduced use of chemicals in rotation crops	Nil	Reduced use of chemicals in rotations leading to reduced export of chemicals off farm Increasing or maintaining mungbean in rotations can potentially lead to reduced chemical/ nutrient exports in cereal/cotton growing regions	Nil
Social impacts			
Improved farmer well-being through reduced chemical use by farmers	Nil	Reduced chemical use resulting in reduced potential impact on regional well being Maintenance or improvement in community wellbeing through increased farm income and associated off-farm expenditure	Nil

Public versus private impacts

The impacts identified from the investment are predominantly private in nature, namely those accruing to mungbean producers in the northern grain growing regions of central and southern Queensland and northern NSW. There may have been some small public impacts potentially produced (or at least maintained), mainly environmental in nature, from lowered chemical usage with potential implications for water quality off-farm.

Impacts on other primary industries

Some potentially small spill over private impacts also are likely, mostly gains to cereal producers where they may have been influenced to maintain mungbean plantings, potentially due to the characteristics of the new NMIP varieties.

Distribution of impacts along the mungbean supply chain

Some of the potential benefits from more profitable production will be passed along the mungbean supply chain to processors and exporters. Part of any estimated gain achieved by producers will be transferred to plant breeders through Plant Breeders Rights.

Benefits overseas

Growers of mungbean in overseas countries will benefit to some extent from Australian contributions to testing methods and genetic loci identification. However, no seed of the new Australian varieties has been exported to date due to the difficulty of enforcing the rights held by Australians under the Plant Breeders Rights and to the AMA's dedication to protecting the competitiveness of Australian growers.

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 C6. The investment in mungbean breeding has been relevant to Rural RD&E Priorities 1 and 4 and to Science and Research Priority 1.

Table C 6: 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 C7.

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 maintained profitability of mungbean profitability. The project was well supported and funded by others (GRDC and AMA) external to the QLD Government and had a distinctive angle as the dominant Queensland mungbean production industry will be a major recipient of the impacts.

Table C 7: 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)

7. Valuation of Impacts

The impacts valued from the investment in Project DAQ00172 are:

- The yield increases and quality improvements from the actual or prospective release of improved varieties of mungbean over the years ending June 2012 to June 2018.

The impacts identified but not valued include:

- Any increased area of mungbean used in rotations that have been driven by the new varieties with associated rotational advantages to other crops (weed control, disease breaks, no additional nitrogen fertiliser required).
- Any improvements in grade out percentages for the new varieties.
- Any reduced use of chemicals (herbicides) in other crops due to increased area of mungbean grown in rotations due to the new varieties.
- The genetic capital of unexploited germplasm at the end of the investment period where it may be higher than at the beginning, suggesting an additional unrealised impact from the investment. The germplasm exchange initiated with the AVRDC in the second half of the investment period would make it most likely that a genetic capital gain would have taken place over the investment period from 2011 to 2016.

Counterfactual

If the NMIP (and specifically Project DAQ00172) had not been funded, it is assumed there would not have been any significant breeding investment by the private sector and that no yield, quality or disease resistance improvements would have occurred via new varieties.

Assumptions for Valuation

Data on areas and yields by variety by year were not available, but the areas, yields and production of mungbean since Project DAQ00172 commenced were reported up to 2016-2017 in Table 3. The annual area has averaged 72,600 ha, yield 0.86 tonnes per ha and production just under 61,500 tonnes per annum. Farm gate prices have fluctuated but have assumed to have averaged $900 per tonne (Australian Mungbean Association (AMA), 2018).

Jade-AU and Celera II-AU

Jade-AU is assumed to have contributed 50% of the area planted to large shiny green mungbean by 2017 at the expense of Crystal, largely due to its yield increase of 12% over Crystal. Celera II-AU has replaced some of the small green varieties Green Diamond and Celera due to its improved yield (20%) and resistance to halo blight.

Further to Table C4, Table C8 summarises the assumptions made for valuing the impacts of the already released varieties, and potentially to be released varieties, associated with Project DAQ00172,

Table C 8: Assumptions for Varieties Released and Prospectively to be Released

New Variety Name or Line	Year of release	First year grown	Yield gain over variety replaced (%)	Quality improvement ($/t) and/or disease resistance (a)	Years after release to maximum adoption	Maximum adoption level
Jade-AU	2013	2014	12% over Crystal	0	1	50% of large green shiny
Celera II-AU	2014	2015	20% over Celera and Green Diamond	$50/t and first variety released with resistance to halo blight	4, as slow to increase significantly in area	100% of small green shiny
Onyx-AU (niche black gram type with limited market)	2017	2017	10% yield gain over Regur	Improved disease resistance	2, but slow to increase in area	100% of black gram
Selected and developed in Project DAQ00172 and prospectively to be released in future						
M12036	2019	2020	20% over Crystal and Jade-AU for S QLD and NNSW	Improved resistance to halo blight	2	40% of large green shiny
M14070, M14383,M15084	2021	2022	Still to be identified and confirmed			

(a) Improved disease resistance has been assumed to be associated with yield impact and not quality impact.
(Source: NMIP reports and Agtrans Research discussion with Col Douglas, 2015 and 2019)

Any impacts of varieties released between the end of the investment 2015-16 and 2022-2023 could still be attributed in part to the investment period under review as any potential cross made in 2015-2016 (the last year of the investment in the project) could result in some contribution to a variety release after 8 years (up to 2022-2023).

Given the assumed yield improvements assumed in Table 8 and offered by the new varieties that are already being grown, it could have been expected that the average annual yield per hectare over the past few years for the industry as a whole would have started to show an upward trend. However, Table C3 shows that over the past few years there has been no clear upward trend in mungbean yield. Explanations for this discrepancy include:

(a) The static yields have has been largely due to the climatic conditions experienced in the past series of seasons. It could be assumed therefore that without the new varieties the yield per ha performance would have been even lower then actually achieved as reported in Table 3. If this is correct, then the assumptions on yield gains and level of industry impacts would appear sound.

(b) As the yield gains assumed were based on a series of well-managed varietal trials in different regions and over a series of years, elicited varietal differences were not possible to emulate when transferred to the commercial production arena. Alternatively, it is possible that the agronomic information required to grow the new varieties under commercial production in different regional environments and seasonal conditions was not always sufficient to extract the potential gains from the new varieties. This appears to be recognised in varying industry comments regarding the performance of Jade-AU, in particular. Also, two actions ranked very high by growers in the 2014 strategic planning workshop (AMA, 2015, p18) related to
    - Further investment in pre-commercialisation projects for all new varieties developed in the NMIP.
    - Optimising the performance of new genetics through agronomic practices across all varieties and growing regions.

This analysis rests on explanation (a) above, supported by the minimal industry production and yield data available. Hence, no adjustment has been made for translation of the trial yield improvement levels to lower commercial levels.

Matching varietal impacts to the investment being evaluated

As breeding programs are usually long-term ongoing investments, attributing benefits to specific investment periods can be difficult. For the evaluation of DAQ00172, some attribution of impacts from the new variety releases to the period of investment (2012 to 2016) has had to be made. The investment being evaluated commenced in the year ending June 2012. It is assumed that mungbean varieties are produced from an eight year breeding cycle from initial cross to variety release. Hence, the influence of the project investment in the 2012 year would have been marginal for any varieties released in that first year, as the impact for any release in 2012 would be attributed to 2012 plus the previous seven years of breeding activity. It could be argued that approximately one eighth (12.5%) of the benefit from that variety could be attributed to the investment in 2012; any cultivars released in 2013 (two years investment in the eight years) could be attributed 25% of the gain and so on.

Hence, Jade-AU could be attributed 25% of any benefit and Celera-II AU, released in 2014, a total of 3 years of project breeding activity or 37.5% of benefits realised. If Line 12036 is released in 2019, it could be attributed 50% of benefits realised. The overall schedule is exemplified in Table C9.

Table C 9: Estimated Attribution of the Impact of a Variety Released in a Specific Year to the Investment Period Evaluated (2012-2022) [(a) (b)]

Year of release (Year ending June)	2012	2013[(c)]	2014[(d)]	2015	2016[(e)]	2017	2018	2019[(f)]	2020	2021	2022	2023	2024	2025	2026	2027	2028
Relevant Investment period (Year ending June)																	
2005																	
2006																	
2007																	
2008																	
2009																	
2010																	
2011																	
2012	I	I	I	I	I	I	I										
2013		I	I	I	I	I	I	I									
2014			I	I	I	I	I	I	I								
2015				I	I	I	I	I	I	I							
2016					I	I	I	I	I	I	I						
2017																	
2018																	
2019																	
2020																	
2021																	
2022																	
2014																	
2015																	
2016																	
2017																	
2018																	
2019																	
2020																	
2021																	
% Attribution of Impact to Variety	12.5	25.0	37.5	50.0	62.5	62.5	62.5	50	37.5	20	12.5	0	0	0	0	0	.0

Notes:

(a) "I" indicates a year of investment between 2004 and 2020 that is relevant to a variety released in a particular year (horizontal axis)
(b) Shading indicates the eight year period including the year of release
(c) Jade-AU released
(d) Celera II-AU released
(e) Onyx released (black gram)
(f) Line M12036 released

Adoption

The average area and yield of mungbean was reported earlier in Table 3. The average area reported was 72,600 ha and the average yield was 0.86 t/ha. Although the proportions of mungbean types may well vary between years, for the purpose of this evaluation, the proportion of the total annual area of the different mungbean types has been assumed constant. The estimates used were:

- Shiny green large seeded type 90%
- Shiny green small seeded type 5%
- Dull seeded type 3%
- Black gram (*Vigna mungo*) 2%

Source: (Rob Anderson, pers. comm., 2015).

Past adoption of new varieties (and hence the delivery of impacts) has been very rapid as evidenced by adoption of early varieties and Crystal and Satin II. Hence, in most cases, maximum adoption of a new variety is assumed to be reached in its second year of growing.

Summary of assumptions

A summary of the key assumptions made for valuing benefits is shown in Table C10. While some of the sources of the assumptions in the table are somewhat dated but still are believed to represent valid assumptions.

Table C 10: Summary of Assumptions

Variable	Assumption	Source
General Assumptions		
Value of mungbean	$900 per tonne for large shiny	Australian Mungbean Association, 2018
Average premium for small green and dull seeded	$100 per tonne	Rob Anderson, pers. comm., 2015
Average premium for quality improvement	$50 per tonne	Based on discussions with Dale Reeves regarding Crystal, in 2011
Assumed length of breeding cycle	Eight years (may vary from 7-9 years from first cross to year of release)	Agtrans Research after discussions with Col Douglas
Attribution of varietal benefits to the investment being evaluated	Number of the eight years up to and including the variety release year that are covered in the investment period, divided by eight	Agtrans Research; See Table C9
Average area of mungbean in years ending June 2011 to June 2017	72,600 ha	Table C3
Base average yields for mungbean varieties to which percentage yield increases were applied	0.86 t per ha	Table C3
Assumptions for New Varieties		
JADE-AU		
Year released	2013 and first grown in 2014	Table C8
Yield increase over Crystal	12%	Table C8

Maximum adoption level for Variety Jade-AU	50% of large shiny green area from 2014	Agtrans Research after discussions with Col Douglas
Time to maximum adoption	1 year	Table C8
Celera II-AU		
Year released	2014 and first grown in 2015	Table C8
Yield increase over Celera and Green Diamond	20%	Table C8
Maximum adoption level for Celera II-AU	100% of small shiny green area	Agtrans Research after discussions with Col Douglas
Time to maximum adoption	4 years	Table C8
Onyx-AU (Black Gram)		
Year released	2017 and first grown in 2017	Table C8
Yield increase over Regur	10%	Table C8
Maximum adoption level for Onyx-AU	100%	Table C8
Time to maximum adoption	2 years	Table C8
Prospective Line M12036		
Year released	2019 and first grown in 2020	Table C8
Probability of release	100%	Agtrans Research after discussion with Col Douglas
Yield increase over Crystal and Jade-AU for S QLD and NNSW	20%	Agtrans Research after discussions with Col Douglas
Time to maximum adoption	2 years capturing 40% of market for large green shiny type due to resistance to halo blight	Agtrans Research after discussions with Col Douglas

Results for Analysis of Investment in DAQ00172

All past costs and benefits were expressed in 2017-2018 dollar terms using the GDP Implicit Price Deflator. All benefits after 2017-2018 were expressed in 2017-2018 dollar terms. All costs and benefits were discounted to 2018-19 using a discount rate of 5%. Investment criteria estimated included the net present value, the benefit-cost ratio, the internal rate of return (IRR) and the modified internal rate of return (MIRR).

The basic analysis used assumptions for the best estimates of each variable, notwithstanding a high level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2015-2016).

The present value of benefits (PVB) from each source of benefits was estimated separately and then summed to provide an estimate of the total value of benefits.

Investment criteria were estimated for both the total investment and for the DAF investment alone. Each set of investment criteria were estimated for different periods measured from the last year of investment. The investment criteria were all positive as reported in Tables C11 and C12.

Table C 11: Investment Criteria for Total Investment and Benefits for the Benefit Periods (Discount rate 5%)

Criterion	Years from last year of investment (2015-2016)						
	0	5	10	15	20	25	30
Present value of benefits (m$)	2.62	13.17	28.13	39.85	49.03	56.23	61.87
Present value of costs (m$)	5.15	5.15	5.15	5.15	5.15	5.15	5.15
Net present value (m$)	-2.53	8.02	22.98	34.70	43.88	51.08	56.72
Benefit-cost ratio	0.51	2.56	5.46	7.74	9.53	10.92	12.02
Internal rate of return (%)	negative	29.4	36.7	37.8	38.0	38.0	38.0
Modified internal rate of return (%)	56.6	88.3	39.6	27.8	22.2	18.8	16.5

Table C 12: Investment Criteria for DAF Investment and Benefits for the Benefit Periods (Discount rate 5%)

Criterion	Years from last year of investment (2015-2016)						
	0	5	10	15	20	25	30
Present value of benefits (m$)	1.45	7.29	15.57	22.05	27.14	31.12	34.24
Present value of costs (m$)	2.84	2.84	2.84	2.84	2.84	2.84	2.84
Net present value (m$)	-1.39	4.45	12.73	19.22	24.30	28.28	31.40
Benefit-cost ratio	0.51	2.57	5.48	7.77	9.56	10.96	12.06
Internal rate of return (%)	negative	28.7	36.1	37.1	37.3	37.3	37.3
Modified internal rate of return (%)	35.6	112.7	44.3	30.3	23.8	20.0	17.5

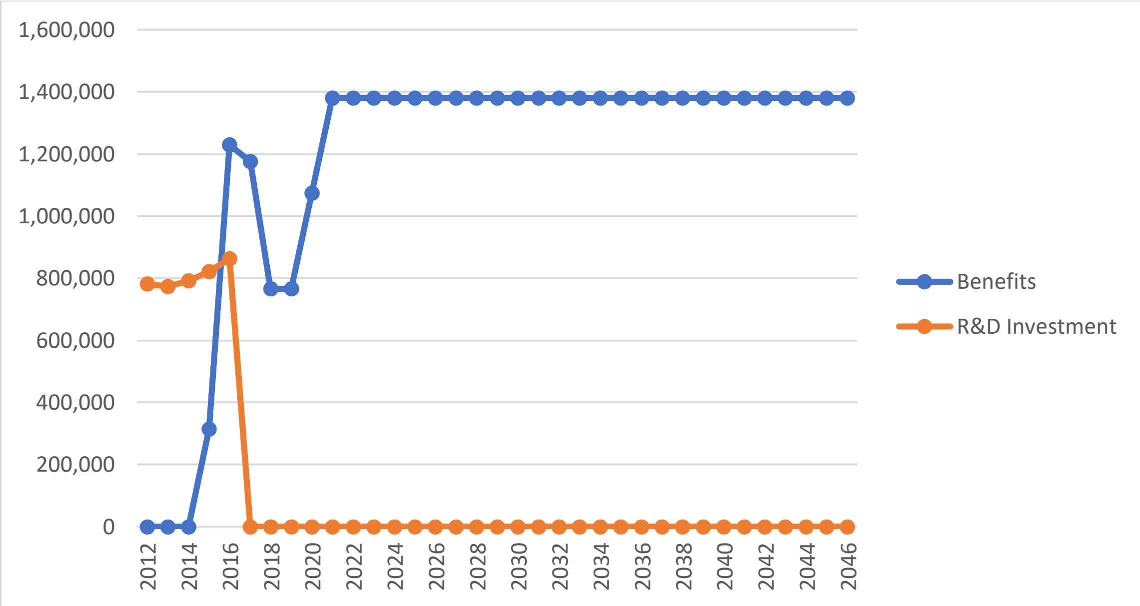
There are four sources of benefits valued in the analysis. Table C13 shows estimates of the relative contribution from each source.

Table C 13: Contribution of Source of Benefits to Present Value of Benefits (PVB) (Total investment, 30 years)

Source of Benefit	PVB (million $)	%
Variety Jade-AU (large shiny)	16.16	26.1
Variety Celera II-AU (small shiny)	7.91	12.8
Variety Onyx-AU	1.98	3.2
Prospective Line M12036	35.82	57.9
Total	61.87	100.0

The annual R&D investment costs and benefit cash flows for the 30 year period from the year of last investment are shown in Figure 1. The benefits fluctuate from year to year up to 2021 due to varying mungbean areas and the variety releases and their adoption. From 2018, the average past area of mungbean was used (Table 3C) as specific mungbean areas were not available.

Figure C 1: Annual Benefit and R&D Investment Cash Flow



Sensitivity Analyses

Sensitivity analyses were carried out on several variables and results are reported in Tables C14 and C15. The sensitivity analyses were performed on the Total Investment results using a 5% discount rate with benefits taken over the life of the investment plus 30 years from the year of last investment. All other parameters were held at their base values.

Table C14 shows the sensitivity of the investment criteria to changes in the discount rate.

Table C 14: Sensitivity of Investment Criteria to Discount Rate (Total investment, 30 years)

Criterion	0%	5% (Base)	10%
Present value of benefits (m$)	108.24	61.87	42.01
Present value of costs (m$)	4.03	5.15	6.52
Net present value (m$)	104.24	56.72	35.49
Benefit-cost ratio	26.84	12.02	6.44

Table C15 shows the sensitivity of the investment criteria to changes in the assumption regarding the maximum adoption level attained by M120369. The results show the investment performance is driven strongly by the assumption. This is because the M120369

Line contributes nearly 60% of all benefits estimated for the investment (Table C13).

Table C 15: Sensitivity of Investment Criteria to Maximum Adoption Level of M12036 (Total investment, 5% discount rate, 30 years)

Criterion	Pessimistic (20%)	Base (40%)	Optimistic (60%)
Present value of benefits ($m)	43.95	61.87	79.78
Present value of costs (m$)	5.15	5.15	5.15
Net present value (m$)	38.81	56.72	74.63
Benefit-cost ratio	8.54	12.02	15.50

It is interesting to note that the positive benefit-cost ratio estimated here for Project DAQ00172 (12.0 to 1) is similar to that reported for a GRDC mungbean breeding investment in 2015 (11.9 to 1) (Agtrans Research, 2015). However, the two evaluations are not strictly comparable as the 2015 GRDC investment evaluation covered three breeding projects over a longer period of time (2004 to 2016); one of these three projects was DAQ00172.

The investment criteria produced from the current analysis of project DAQ00172 were highly positive, and therefore in line with previous economic analyses of mungbean breeding investments. The evaluation of the latest project and its comparison of its investment returns with earlier periods of investment provides confidence that the positive historical returns from mungbean breeding investment are still continuing.

8. Confidence Rating

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 impacts it is often not possible to quantify all the 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 C16). 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 significant uncertainties in assumptions made

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

Table C 16: Confidence in Analysis of Investment in Project DAQ00172

Coverage of Benefits	Confidence in Assumptions
High	Medium-High

9. Conclusions

During the investment period of DAQ00172 (2011 to 2016), two new improved varieties (Jade-AU, and Celera II-AU) were released. A third variety (Onyx-AU) was released in 2017 and one prospective new variety was scheduled for future release.

Jade-AU has been widely adopted by the mungbean industry. Celera-II-AU and Onyx-AU have been slower to become widely adopted. The released varieties have delivered significant benefits, including yield, quality and disease resistance improvements.

In addition, a number of promising lines with higher yields and greater disease resistance have been produced from which further varietal releases are expected in the next few years.

The speed at which the new varieties have been adopted (particularly Jade-AU) by industry is an important driver of the positive results of the project. While the step improvements in the yield and quality of the varieties released were important factors in driving adoption, the cohesive approach of seed multiplication by AMA and the extension and communications efforts by the state agencies, Pulse Australia, AMA, and GRDC, must also be given credit for the rapid adoption where it occurred.

As most mungbean are grown in rotation with cereals and other crops, any future increased mungbean area driven by the new varieties will lead to spinoff benefits to the rotations by acting as a disease break potentially leading to higher yields for cereal crops as well as less pesticide use.

The continuing investment in the NMIP has produced a number of impacts some of which have been valued in this evaluation. The total investment of $5.2 million (present value terms) has been estimated to produce total benefits of $61.9 million (present value terms) providing a net present value of $56.7 million. Measures of the rate of return also were high including a benefit-cost ratio of 12.0 (over 30 years, using a 5% discount rate), an internal rate of return of 38.0%, and a modified internal rate of return of 16.5% given a reinvestment rate of 5%.

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Appendix D: An Impact Assessment of DAF Investment into Grains Integrated Pest Management – Northern Region (July 2012 to June 2019)

Acknowledgments

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Melina Miles, Principal Entomologist, Department of Agriculture and Fisheries, Queensland.

Abbreviations

ABS	Australian Bureau of Statistics
BQ	Biosecurity Queensland
cesar	Centre for Environmental Stress and Adaptation Research
CRRDC	Council of Rural Research and Development Corporations
DAF	Department of Agriculture and Fisheries (Queensland)
DAFWA	Department of Agriculture and Food Western Australia
GDP	Gross Domestic Product
GRDC	Grains Research and Development Corporation
GVP	Gross Value of Production
IPM	Integrated Pest Management
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
NPIS	National Pest Information Service
NSW	New South Wales
PNS	Push Notification Service
PVB	Present Value of Benefits
QLD	Queensland
RD&E	Research, Development and Extension
RDC	Research and Development Corporation
RWA	Russian Wheat Aphid
SA	South Australia
SARDI	South Australian Research and Development Institute
VIC	Victoria

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 projects aimed at improving industry capacity and adoption of integrated pest management for the control of invertebrate pests in the Australian grains industry. The project was jointly funded by DAF, the Australian Government via the Grains Research and Development Corporation (GRDC), and other partners from July 2012 to June 2019.

Methods

The project was first analysed qualitatively using a logical framework approach that included a description of 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 (2018/19). Past and future cash flows in 2017/18 dollar terms were discounted to the year 2018/19 (year of analysis) 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 (2018).

Impacts

The major impacts identified were economic/financial in nature. However, some social and environmental impacts also were identified but not valued. It is expected that Australian grain growers, particularly those in the GRDC's northern grains region will be the major beneficiaries. Benefits focus improved control of invertebrate pests through increased adoption, and improved implementation, of integrated pest management practices.

Investment Criteria

Total funding from all sources for the project was approximately $14.4 million (present value terms). The value of total benefits was estimated at $23.9 million (present value terms). This result generated an estimated net present value of $9.5 million, a benefit-cost ratio of approximately 1.7 to 1, an internal rate of return (IRR) of 18.8% and a modified IRR of 8.2%.

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 as its principal tool. The approach includes both qualitative and quantitative analyses that are in accord with the current evaluation guidelines of the Council of Research and Development Corporations (CRRDC) (CRRDC, 2018).

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

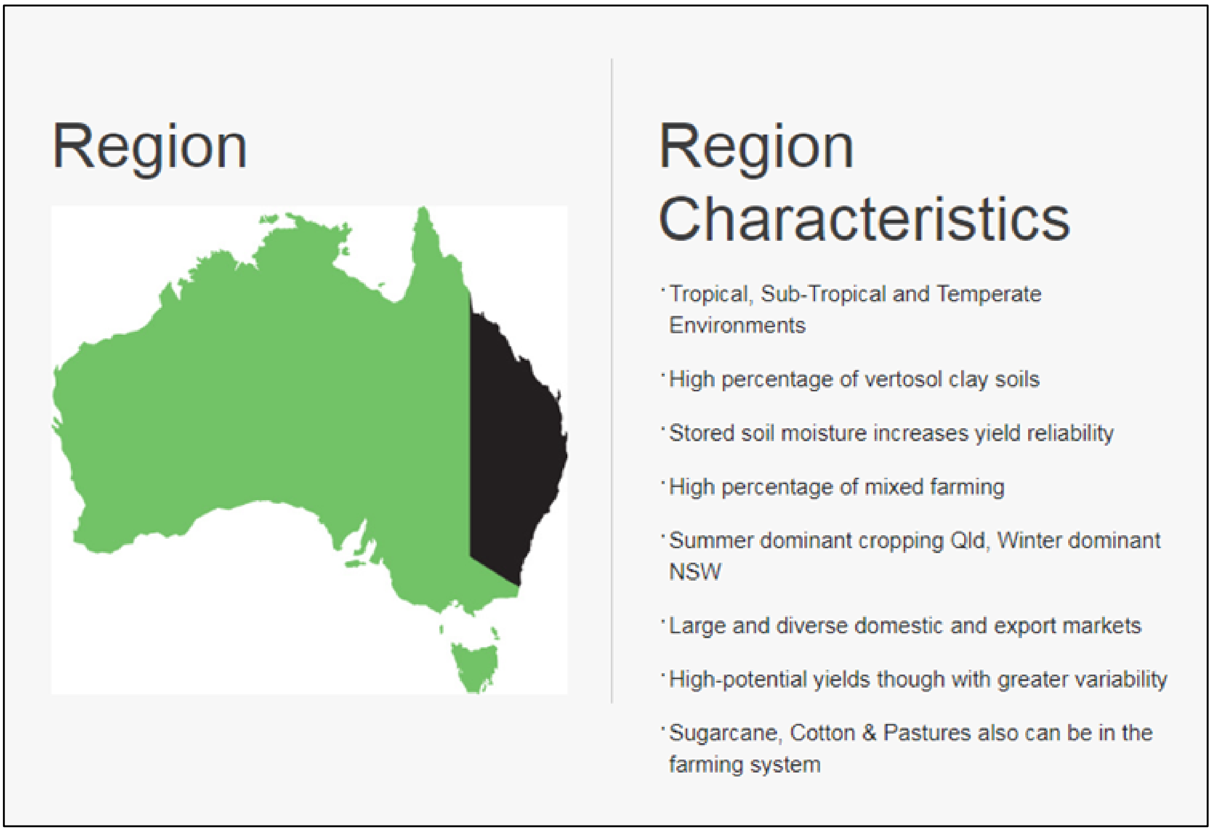
Background

The GRDC Grain Regions

The Grains Research and Development Corporation (GRDC) divides the Australian grains industry into three primary grain production regions. Research, development and extension (RD&E) for each region is governed by an advisory panel (GRDC, 2019).

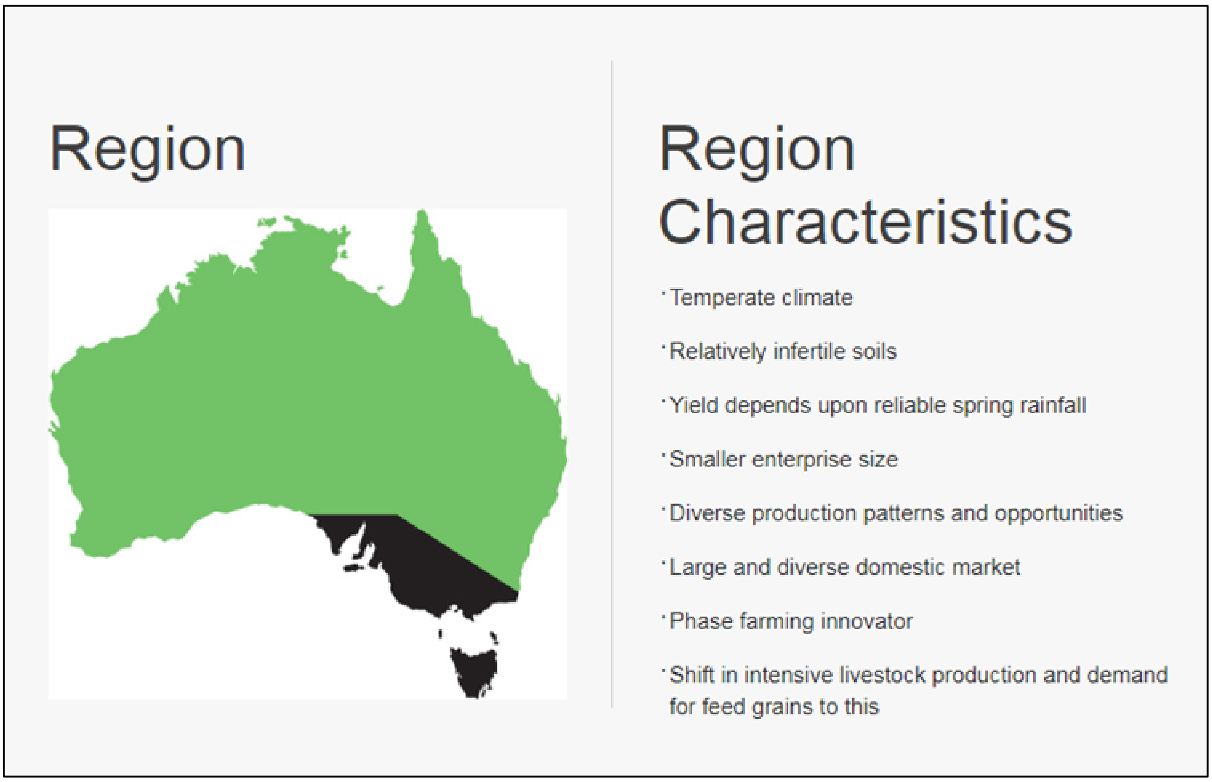
Figures D1 to D3 show maps of each of the three regions along with key regional characteristics.

Figure D 1: The Northern Grains Region (GRDC)



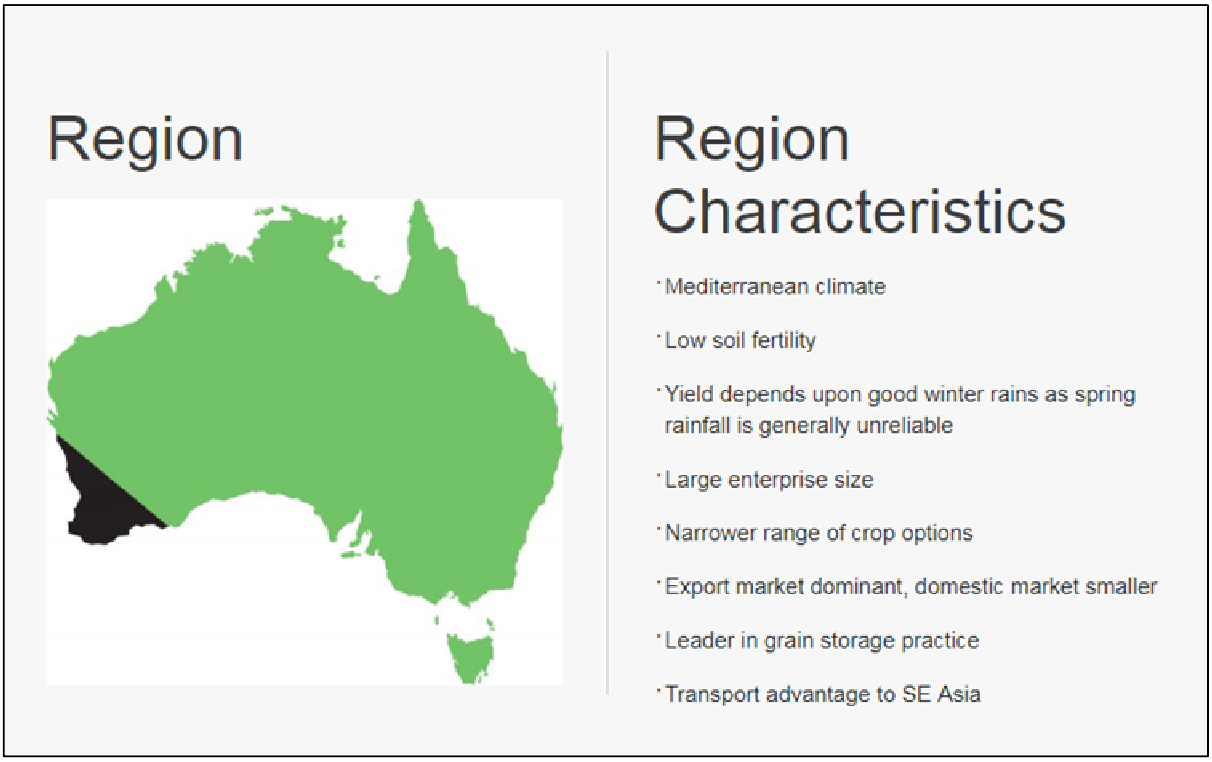
Source: https://grdc.com.au/about/what-we-do/region-panels/northern

Figure D 2: The Southern Grains Region (GRDC)



Source: https://grdc.com.au/about/what-we-do/region-panels/southern

Figure D 3: The Western Grains Region (GRDC)



Source: https://grdc.com.au/about/what-we-do/region-panels/western

Impact Costs of Invertebrate Pests for the Northern Grains Industry

In 2013, a study was conducted through GRDC to investigate and document the current and potential costs of invertebrate pests in grain crops (Murray, Clarke, & Ronning, 2013).

The study covered six key Australian grain crops (wheat, barley, oats, canola, lupins, and sorghum) across three GRDC grain production regions (northern, southern and western) and found that invertebrate pests have the potential to decrease the value of the Australian grains industry by more than $1.5 billion per annum[7] (Murray *et al.*, 2013).

Present, actual annual production losses, aggregated across the six major crop types, were estimated at $359.8 million with the associated cost of controlling invertebrate pests estimated at $159.1 million annually.

The northern grains region (see Figure D1) accounted for approximately 12.4% of production losses at $44.4 million per annum, and 10.2% of national control costs at $16.2 million per annum.

Table D1 below shows the estimated annual economic losses and costs of control for the northern grains region, and Australia, for each of the six key grain crops evaluated by Murray *et al.* (2013).

[7] Total potential impact costs of invertebrate pest for six major grain types of over $1.7 billion less current control costs of approximately $159.1 million (Murray *et al.*, 2013)

Table D 1: Current Economic Losses and Control Costs of Invertebrate Pests for Wheat, Barley, Oats, Canola, Lupins and Sorghum

Crop	**Current Value of Economic Losses**		**Current Cost of Pest Control**	
	Northern Region ($m)	**Australia ($m)**	**Northern Region ($m)**	**Australia ($m)**
Wheat	11.748	193.514	3.072	77.872
Barley	2.545	66.639	0.915	25.763
Oats	0.048	8.308	0.020	4.431
Canola	0.613	54.018	0.043	29.489
Lupins	0.000	7.811	0.000	9.349
Sorghum	29.480	29.480	12.196	12.196
Totals	**44.434**	**359.770**	**16.246**	**159.100**

Source: Murray *et al.* (2013)

The average, annual production information (including area, production, yield, price and gross value of production (GVP)) are presented in Table D2 below.

Table D 2: Average Annual Production Statistics for Six Key Australian Grain Crops

Crop	**Area ('000 ha)**	**Yield (t/ha)**	**Production ('000 t)**	**Price ($/t)**	**GVP ($m)**
Northern Region					
Wheat	2,573	1.7	4,429	253	1,120.3
Barley	508	1.8	900	221	198.8
Oats	140	0.8	106	222	23.4
Canola	47	1.3	60	510	30.6
Lupins	19	1.4	28	342	9.5
Sorghum	704	3.1	2,201	213	468.3
Australia					
Wheat	12,974	1.5	20,106	260	5,232.3
Barley	4,439	1.7	7,480	214	1,597.5
Oats	953	1.3	1,233	204	251.0
Canola	1,461	1.1	1,555	482	750.0
Lupins	724	1.1	798	256	204.1
Sorghum	708	3.1	2,209	213	469.9

Source: Murray *et al.* (2013) – 2006/07 to 2011/12 averages.

Integrated Pest Management in Australian Grains

Integrated Pest Management (IPM) combines the use of biological, cultural/ management and chemical practices to control insect pests in agricultural production (farmbiosecurity, 2019). In particular, IPM seeks to use natural predators or parasites to control pests, using selective pesticides for backup only when pests are unable to be otherwise controlled.

IPM reduces reliance on broadspectrum pesticides, limiting the opportunity for resistance and promoting populations of beneficial species (GRDC, 2009). Effective IPM can reduce production losses, decrease total input costs (through reducing unnecessary chemical spraying), slow the development of resistance to key agricultural chemicals, improve biodiversity and potentially have positive impacts on the broader environment through reduced chemical run-off.

Further, the use of more costly selective insecticides may provide the opportunity for ‘free’ biological control to occur, in some instances resulting in suppression of pests below economic thresholds (consequently not requiring treatment) (Melina Miles, pers. comm., 2019).

Rationale for the Current Investments

Since the 1950s, synthetic pesticides have been the accepted method of controlling invertebrate crop pests. Murray *et al.* (2013) estimated that, without control, the total potential economic losses caused by invertebrate pests could be upward of $1.7 billion per annum for the Australian grains industry. However, chemical resistance in target species, increasing input costs, and environmental considerations mean that relying only on traditional, chemical control methods is no longer optimal.

Implementing IPM can be daunting as effective IPM requires an understanding of pest and beneficial insect dynamics, economic control thresholds, and how various control tactics interact (GRDC, 2009).

In 2012/13 the Department of Agriculture and Fisheries (DAF) Queensland, and GRDC, funded a suite of projects to improve industry capacity in IPM, with a particular focus on the northern grains region, to increase the adoption and overall effectiveness of IPM for Australian grain growers.

3. Project Details

Summary of Projects

Project Code	Project Title	Project Leader	Funding Period
DAQ00179	IPM Training	Melina Miles, Department of Agriculture and Fisheries Queensland	July 2012 to June 2015
DAQ00196	Delivery of Improved Invertebrate Pest Management in the Northern Grains region		July 2014 to June 2019
DAQ00201	National Pest Information Service (NPIS)		July 2014 to June 2018

Logical Frameworks

Tables D3 to D5 provide a description of the each of the projects using a logical framework approach.

Table D 3: Logical Framework for Project DAQ00179: IPM Training

Objectives	The objective of the project was to increase the knowledge, skills and capacity of growers and agronomists to implement IPM on their farms. The key objectives of the project were to: • Develop training resources for the northern region equivalent to the I-Spy manual developed for the southern and western regions;

	• Develop a series of training modules that address local issues and incorporate grower and advisor preferences for content and format. The module format allows for flexibility and inclusion of key local issues in each workshop; • Deliver at least 26 workshops for growers and advisors over the life of the project with a team of experienced field entomologists and workshop facilitators; • Provide ongoing learning opportunities for workshop participants through field components and follow up field sessions and demonstrations; and • Evaluate the preferences of growers and advisors in relation to supporting technology for IPM implementation, in particular the apps for smartphones.
Activities	• Developed and delivered an IPM training course for growers and advisors in both the northern and southern grain regions. • The project team was comprised of research entomologists and extension staff from each of the states in the northern and southern regions (QLD, NSW, SA, and VIC), with coordination and training delivered by the Independent Consultants Australia Network. • A two-day pilot workshop was held in Sydney in December 2012. • Participants included 18 growers and advisors (agronomists). • At the workshop, the full complement of workshop modules was presented and discussed. • Participants provided feedback that was then used to modify and improve the workshop program. • Based on feedback from the pilot workshop, modules were developed for a full range of crops and pests in the northern and southern regions. • Between January 2013 and March 2015, 26 workshops were delivered across the northern and southern regions. • Six advisor and 20 grower workshops were conducted. • The modules formed the foundation of the workshops and were provided to participants in the form of workshop booklets, and in downloadable form from a website created for the workshops (www.ipmworkshops.com.au). • Total attendance at the grower-agronomist workshops across both regions (excluding the pilot) was 353 individuals. 81% (287) of the participants were agronomists with 19% grower attendance overall. • Field activities that focused on sampling and pest identification were run at 11 of the workshops. • Additionally, two field day/walks were conducted as well as presentations and discussions with agronomists and growers. • Post-workshop support was offered via phone and/or email. • The IPM workshop website was maintained until October 2015 and then migrated to the www.ipmguidelinesforgrains.com.au website at the end of 2015. • Web based I-Spy[8] modules were developed to support the I-Spy manual and northern region equivalent. The modules were made available on the GRDC website.

[8] I-SPY is a comprehensive resource manual for farmers and advisors covering basic taxonomy, important insect groups and identification keys, and descriptions of common species, as well as information on monitoring, IPM

	• The I-Spy modules received 232 views during the three-year project, while the crop manuals recorded 181 views and the threshold ready reckoner was downloaded 34 times. • An additional five, specific crop manuals, prepared with updated research material for chickpea, maize, sorghum, sunflower, and winter cereals, were developed. • The five crop manuals focused on the northern grains region to complement the I-Spy manuals (which are southern/western region focused) and emphasised pest management (Melina Miles, pers. comm., 2019). • Also, a threshold ready reckoner was prepared for key pests of pulses and sorghum. • IPM Best Bet strategies also were developed for major crops. • At the conclusion of all 27 workshops (26 agronomist and grower workshops, 1 pilot workshop), participants were surveyed to assess factors influencing the adoption and non-adoption of IPM principles and practices. • Also, at each workshop, participants were asked about their ongoing needs (information and training) in relation to IPM. • An evaluation of practice change was undertaken in 2014. The evaluation encompassed all participants of the six advisor workshops. • A final project evaluation was conducted in 2015.
Outputs	• IPM training modules and associated crop manuals developed for the northern and southern grain regions. • Grower and advisor awareness of pest lifecycles, drivers of outbreaks and economic thresholds. • IPM Best Bet Strategies were developed for: 1) Established Pests – Northern region 2) Established Pests – Southern region 3) Canola 4) Sorghum 5) Sunflower 6) Summer pulses 7) Winter cereals 8) Winter pulses – Southern region • Various resources were provided and made available via the IPM website, including: 1) Insectopedia – an electronic insect pest management manual for the major pests of southern Australian grain growing and grazing regions 2) I-Spy manual 3) Northern Regional Manuals 4) Links to various resources such as: - Helicoverpa pheromone trap operation - Newsletters/Blogs - Department (QLD, NSW, SA, and VIC) and cesar[9] websites - Economic threshold ready reckoners - Apps – including the GRDC insect ute guide - Sources of entomological supplies

principles, and biosecurity. For more information see: https://grdc.com.au/resources-and-publications/all-publications/publications/2018/i-spy

[9] See: http://cesaraustralia.com/

	- GRDC publications 5) Farm biosecurity information • Over 1,500 views and 340 downloads of workshop resource material occurred on the IPM workshop website. • Take home messages, articulated by workshop participants at the end of the workshops, showed that the key messages around IPM fundamentals had been effectively communicated and included: 1) importance of monitoring 2) need to consider more strategic use of chemicals 3) economic thresholds 4) importance of correctly identifying pest and beneficials 5) IPM is worthwhile 6) need to understand the lifecycle of pests 7) need to consider a wider range of control/ management options • Workshop participant surveys found that there was considerable support of further workshops (refreshers) at regular intervals of 2-3 years. • The 2014 practice change evaluation across workshop participants from both the northern and southern regions found that, in the space of 8 to 13 months, respondents reported small shifts in behaviour and attitude attributable to participation in the workshops (e.g. reduced insurance sprays, increased monitoring, awareness of beneficials, more considered insecticide selection). • Post-workshop evaluations indicated a high level of assimilation of key messages. It was found that the common themes for non-adoption included: time constraints, low/zero tolerance for damage, knowledge gaps (pest biology, beneficial impact, non-insecticide options), uncertainty around thresholds, and the reactive nature of current invertebrate pest management. • The final project evaluation found that 95% of respondents reported making some, or significant, change in management practices as a result of participation in the workshop. • Specifically, changes had been made in planning, use of thresholds, monitoring of beneficials, and awareness of the impact of insecticides on beneficials. • The evaluation included an investigation of the GRDC Insect Ute Guide app[10]. • This specific component of the evaluation found that the majority of interviewees (68%) were aware of, or had used, the app. However, only 30% of grower interviewees had used it. Agronomists with less than 10 years in the industry had a higher use/awareness (91%) than agronomists with greater than 10 years in the industry (59%).
Outcomes	• Within 6 months of the project finishing, 95% of workshop participants across both regions (northern and southern) had implemented one or more learnings from the workshops. It was estimated that the 272 agronomists (95% of the 287 workshop attendees) implementing IPM learnings would reach approximately 8 growers each, therefore the workshops may have a reach of up to 2,176 growers.

[10] GRDC Ute Guides App is a mobile information resource for farmers and agronomists working in the Australian Grains Industry. It provides searchable library topics with extensive high-resolution images on subjects relevant to grain-growers. It complements and extends GRDC's paper-based Ute Guide series by linking all resources under a single app. For more information see: https://grdc.com.au/resources-and-publications/apps/grdc-ute-guides

	• Thresholds, monitoring and increased consideration of beneficials were the three key areas that respondents were found to be addressing in their pest management after the workshop program. • Project personnel noted that there was little systematic implementation of the learnings from the project. • It was recommended that future investments consider program designs that better facilitate adoption through effective practice change programs incorporated elements such as refresher workshops, seasonal field activities, and direct communication with entomologists (Melina Miles, pers. comm., 2019). • Adoption of project outputs has led to a greater understanding of the risks of insecticide resistance and how appropriate management can increase the longevity of existing chemistry and reduce likelihood of ineffective insecticide treatments being applied. • Growers have increased the use of selective, rather than broadspectrum, insecticides and implemented the use of economic thresholds to underpin decisions that potentially reduce the number of unnecessary sprays. • There now is increased interest from growers and agronomists in preserving beneficial insects (predators and parasitoids) that protect non-target species. • This improved/increased adoption of IPM practices has increased the likelihood that invertebrate pests are controlled before they can cause yield or quality loss. • The project also improved collaboration and created networks between researchers and grain industry advisors. This provided a platform for future grower/agronomist education. • Regular contact between growers and agronomists and entomologists has continued. • Entomologists take phone call enquiries and present at industry events each year. There are also involved in regular field days and workshops which provide opportunities for grower/agronomist-entomologist interactions (largely funded by separate GRDC investments in a range of organisations) (Melina Miles, pers. comm., 2019).
Impacts	• Some contribution to increased productivity and profitability for the northern and southern region grains industry through increased adoption of IPM. This impact will be driven by: 1) improved control of invertebrate pests through more effective implementation of IPM resulting in decreased losses in grain yield and quality, 2) increased adoption if IPM practices, and 3) potentially, reduced insecticide costs achieved through better targeted treatments and fewer unnecessary or poorly timed applications. These reduced costs may, however, be offset by increased costs of monitoring and expenditure on selective, rather than broadspectrum, insecticides. • Potentially, some contribution to reduced rates of longer-term resistance to agricultural insecticides in target pest species. • Enhanced industry capacity to manage grain pests. • Increased scientific knowledge and research capacity. • Reduced insecticide load in the environment leading to reduced chemical export off-farm and, potentially, improved biodiversity outcomes (reduced impact on non-target species).

	• Increased grower well-being attributable to improved confidence in on-farm invertebrate pest management and potentially reduced exposure and handling of highly toxic broadspectrum insecticides.

Table D 4: Logical Framework for Project DAQ00196: Delivery of Improved Invertebrate Pest Management in the Northern Grains Region

Objectives	The overall aim of the project was to deliver reduced economic losses caused directly by invertebrate pests or poorly implemented management in the northern grains region. New knowledge and tools for key pests, including six economic case studies, will be delivered by the project and increase grower and advisor understanding of, and confidence in, IPM. Changes in levels of confidence, and practice change, will be measured through repeated National GRDC surveys. Initially, the major species on which the project was to focus were those identified as causing in excess of $1 million in losses per annum in sorghum and/or winter cereals: 1) Helicoverpa, 2) False wireworm, 3) Armyworm, 4) Cereal aphids, 5) Sorghum midge, and 6) Rutherglen bug. For summer pulses, the suite of pests that the project initially was to address included: 1) Helicoverpa, 2) Pod sucking bugs, 3) Bean podborer, 4) Mirids, 5) Etiella, and 6) Soybean stem fly.
Activities	• Industry stakeholder consultation was conducted to identify key IPM priorities and knowledge gaps for the project, this included input from the workshops conducted under project DAQ00179 (see Table D3 above). • The consultation was used to develop and deliver an annual priority list of pests based on economic impacts in the northern region, with identified knowledge gaps. • The pests and issues identified through the stakeholder consultations were used to prioritise project activities. • A number of trials then were conducted to investigate some of the priority pests and issues identified. • Seventeen trials were conducted in 2014, with a further 18 undertaken in 2015, to investigate the following topics: 1) Canola aphid and helicoverpa thresholds and damage potential. 2) Helicoverpa control options in faba beans and linseed. 3) Rutherglen bug control option screening. 4) Mirid damage in faba beans. 5) Sampling efficiency in faba beans.

	6) Screening of new, soft options for efficacy against sorghum midge 7) Calibration of sweepnet and beatsheet in chickpeas. 8) Management options for scarabs in summer crops. 9) Soft midge control in sorghum. 10) Determination of potential impact of parasitoid on cereal aphid populations. • Further trials were then conducted that targeted: 1) Use of sulfoxaflor against mirids at cost-effective rates. 2) Evaluation of fipronil seed treatment for Zygrita in soybeans. 3) The impact of narrower (25cm) row spacing of pulses on beatsheeting. 4) Evaluation and documentation of unusual pest outbreaks. 5) Efficacy of chlorantraniliprole for Etiella. 6) Investigation of phytoplasma impact on soybeans. • An additional 16 trials were undertaken on: 1) Rutherglen bug population dynamics, sampling, barrier treatments and impact on canola. 2) Helicoverpa and green mirid pest status and damage characterisation for wheat, barely, and lupins. 3) Early aphid impact on faba beans. 4) Evaluation of repeated low rate nucleopolyhedrovirus (also known as NPV) in chickpeas. 5) Broadspectrum impact on natural enemies. • Helicoverpa in faba beans and aphids in canola were identified as two key species where confidence in crop monitoring was low. This information was then used to develop an improved method to inform management decisions. • In 2015, trials were established to determine the accuracy of edge sampling of canola for estimating aphid infestations. At the same time, trials to evaluate the efficacy of beatsheet, sweep net and visual sampling for Helicoverpa in faba beans were conducted. • Six focus species were identified to develop case studies on IPM issues for the project. • The case study topics were (Melina Miles, pers. comm., 2019): 1) bio-economic threshold for podsucking bugs in soybeans, 2) benefits and risk of controlling podsucking bugs in crushing soybeans, 3) bio-economic model for black soil scarabs, 4) risk bio-economic framework for Lucerne crownborer in soybeans, 5) sorghum midge control and host plant resistance, and 6) natural enemy contribution to pest control. • The manuals for accredited workshops on mungbean, soybean, sunflower, and chickpea were updated. • Project team members were involved in delivery of the insect pest management components at the Pulse Australia and Better Sunflower workshops across the northern region. • Discussions around priority pest issues were undertaken at least annually with the Australian Mungbean Association, Australian Oilseed Federation, Grain Orana Alliance, and the Northern Grower Alliance. • Project personnel participated in a number of meetings with the Grains Pest Advisory Committee, National Insecticide Resistance Management, and National Invertebrate Pest Initiative throughout the project and participated in the Practice Change in IPM workshop in 2015.

	• A number of workshops, field walks, and presentations to industry stakeholders through 'GRDC Updates' were conducted. • The project team also provided assistance to GRDC writers in the production of 15 media releases, industry newsletter articles and technical publications. • Further extension was achieved through the Beatsheet blog[11] and associated social media communications. • Project personnel also participated in planning meetings for the Push Notification Service (PNS) under the National pest Information Service project (DAQ00201) (see Table D5 for more information).
Outputs	• The trials on aphid damage potential in canola demonstrated that canola plants are susceptible earlier than thought (at stem elongation). • Consequently, assessment of the proportion of infestation based on plants (rather than racemes) was simplified due to the earlier monitoring requirement. • The project found that canola can compensate for significant simulated aphid damage. • The trials on Etiella in soybeans resulted in new thresholds being developed for Etiella in late-podfill soybeans that were relatively high at 35-40 larvae per meter squared. • The damage potential of mirids in faba beans was confirmed. • A preliminary threshold for Helicoverpa in canola was proposed at 2.4g grain loss/larva. • Sulfoxaflor was found to be effective against mirids at cost-effective rates in conjunction with the application of salt. • The research on helicoverpa in faba beans showed that a visual inspection of terminals was essential for detecting small larvae, and that the visual inspection should be done in addition to beatsheeting for larger larvae and other pests. • A rate reduction for seed treatment for Zygrita was found to be suitable for large seeded mungbeans. • Publication of 10 mungbean Tips & Tactics factsheets. • New management recommendations for scarabs in summer crops, aphids in canola, Helicoverpa in wheat, and green mirids in faba beans were produced. • Six economic case studies were delivered to increase grower and advisor understanding of, and confidence in, IPM. • 15 articles were posted on the Beatsheet blog (415 subscribers), seven videos uploaded to YouTube (4,603 channel views), and 35 tweets posted (390 followers). • Changes in levels of confidence and practice change, are to be measured through the National GRDC surveys.
Outcomes	• Negotiations were underway to extend DAQ00196 by 12 months to complete the six proposed case studies by December 2019 (Melina Miles., pers. comm., 2019). • The case studies will likely be made available through DAF communication channels. Each of the case studies will be published in peer reviewed journals, and a grower/agronomist-friendly fact sheet produced by DAF entomology (Melina Miles, pers. comm., 2019).

[11] See 'The Beatsheet blog' at http://www.thebeatsheet.com.au

	• The project, through its extension activities, has broadened the penetration of relevant and timely invertebrate pest information via social media platforms. • Integration of the blog, YouTube channel and Twitter feed enable cross-promotion of information. • There has been an increase in subscription numbers to the Beatsheet blog of approximately 20% and it was estimated that 50% of northern region advisors are subscribers. • Some growers in the grain and pulse industries across the northern region have used the new and improved IPM information to enhance their invertebrate pest management practices.
Impacts	• Some contribution to increased productivity and profitability for the northern region grains industry through improved implementation of IPM. This impact will be driven by 1) improved management of invertebrate pests through more effective implementation of IPM resulting in decreased yield and quality grain loss, and 2) increased adoption of IPM practices. • Potentially, some contribution to reduced rates of resistance to agricultural insecticides in target pest species. • Enhanced industry capacity. • Increased scientific knowledge and research capacity. • Potentially, reduced insecticide load in the environment leading to reduced chemical export off-farm and, potentially, improved biodiversity outcomes (reduced impact on non-target species). • Increased grower well-being attributable to improved confidence in on-farm invertebrate pest management and potentially reduced exposure and handling of highly toxic broadspectrum insecticides.

Table D 5: Logical Framework for Project DAQ00201: National Pest Information Service

Objectives	The four services delivering invertebrate pest management advice to the grains industry for over 10 years were PestFax (delivered by the Department of Agriculture and Food for Western Australia (DAFWA)), Pestfacts South East (delivered by cesar (originally the Centre for Environmental Stress and Adaptation Research) in Victoria and southern NSW), Pestfacts SA (delivered by the South Australian Research and Development Institute (SARDI) in SA), and the Beatsheet (delivered by DAF for QLD and northern NSW). The objective of the NPIS (DAQ00201) was to combine these services to facilitate the development of efficiencies and innovation in delivery. The specific objective of the project was to deliver to industry, timely, dynamic and responsive information and advice via a range of communication channels (electronic, web, Push Notification, social media, print, traditional media). It also aimed to deliver: • A national strategy for the delivery of pest information services for the grains industry; • Free diagnostic services for pest identification; • Technical expertise contributed to the development of resources for growers (GRDC publications);

	• An established network for the collection of intelligence on pest activity and regional seasonal conditions; and • Pest activity information for inclusion in the PNS (VIC Department of Environment and Primary Industries).
Activities	• An NPIS Strategic Plan (2014-2019) was developed focusing on four key areas: 1) Sourcing real time field information on pest incidence, 2) Analysing and interpreting pest data, 3) Advising growers and advisors, and 4) Data capture, interrogation and access. • The project team included researchers, consultants and other technical/extension staff from DAF, cesar, SARDI, and DAFWA. • The project team reviewed project outcomes on an annual basis to identify deficiencies in the services delivered. • A scoping study was conducted to evaluate the value of Helicoverpa trapping to the Australian grains industry. • A separate scoping study was carried out to investigate the prospect of developing a common platform to support a range of predictive pest development and emergence models. • A programmer was engaged in 2016 to develop a platform for running existing phenological models (and to which new models could be added). • The study identified a number of models that would run on such a platform and enable the services to provide forecasts of likely pest activity, as well as rate of pest development and timing of crop damage. • The Pestfacts services (delivered by cesar and SARDI) were re-aligned to remove overlap in western Victoria. • SA and DAFWA based teams conducted pest identification services for NPIS subscribers. • Over 700 specimens and images were identified with feedback provided over a three-year period. • Where a sample was considered to be a possible biosecurity risk (e.g. an exotic incursion) the specimens were sent to Biosecurity Queensland (BQ) for professional diagnostics (Melina Miles, pers. comm., 2019). • Each of the four service providers undertook surveys of subscribers to determine the value (qualitatively) of the NPIS. • Key members of the NPIS project team also participated in the planning of the PNS project. They contributed expertise on the feasibility of reporting processes and expectations of information on which future pest alerts may be made.
Outputs	• As a result of the Helicoverpa scoping study, a national network of traps was rolled out, including in QLD and northern NSW for the first time. • A functional, on-line version of the phenological model platform (DARABUG 2) was completed. • Pestfacts now exists as PestfactsSA and Pestfacts south-eastern. • The four services, through the NPIS, delivered high quality information to industry on: 1) pest and beneficial identification, 2) risk of crop loss,

	3) management advice, and 4) relevant recent research outcomes. • Each service delivered between 11 and 25 newsletter issues each season supplemented with images, video and links to further information. • Results from subscriber surveys indicated that subscribers valued the NPIS services highly and that management decisions for a majority of subscribers had been influenced by the information that had been sourced from the various newsletters.
Outcomes	• The information generated by the Helicoverpa trapping network is highly valued by growers and advisors. • In the southern and western regions, the trapping network data is used to guide the intensity and timing of crop monitoring for native budworm. The recent inclusion of *H. armigera* (cotton bollworm) traps in the south/west networks provides guidance as to the risk of chemical failure because of insecticide resistance in this species (Melina Miles, pers. comm., 2019). • In the northern region, the trap data is used to provide information on the relative timing and abundance of helicoverpa, and the proportional abundance of *H. punctigera* (native budworm) and *H. armigera* (Melina Miles, pers. comm., 2019). • The operation of the trapping network in the southern part of the northern region (from the QLD border to Dubbo) has highlighted the early presence of *H. armigera* – which, prior to the generation of this data, were not considered to be present in early spring. This finding has major implications of resistance management and insecticide choice (and costs of control) in these regions (Melina Miles, pers. comm., 2019). • Efficiency in data collection and analysis for the trapping program was also enhanced by the establishment of a national database for trapping data, and the development of the MothTrapVis tool that converts this data into a spatial map of pest density/activity. • The MothTrapVis tools was made available for use by the NPIS team in 2016/17 and is being further developed in a subsequent project. • Findings from the trapping network have led to the suggestion that insecticide resistance management needs to be further promoted. • Also, that remotely operated traps, with data uploaded directly to the cloud, have been piloted. • The DARABUG 2 platform has been used by entomologists to provide information to industry to guide and optimise the timing of insecticide use through predicting the rate of development of populations and juvenile stages for key pests. • The greater collaboration between Pestfacts SA and Victoria has led to increased efficiencies in delivery of pest information to grain growers. This has included the delivery of 50+ PestNotes that ensure consistency in content and remove the need to repeatedly research and re-write basic pest information. • An increased number of grains industry stakeholders (including growers and advisors) now are accessing pest updates and information via digital platforms such as online newsletters, Twitter, YouTube as well as through traditional print media. • A follow on NPIS project (NPIS 2, 2019-2022, led by cesar) was being negotiated at the time of the current evaluation. The total project budget is likely to be significantly higher than the original NPIS (NPIS

	1) budget at approximately \$0.57 million p.a. (plus in-kind contributions) (Melina Miles, pers. comm., 2019). • The new NPIS project will provide support for ongoing pest identification services in the southern and western regions. The project also will fund continuation of the national trapping network (Melina Miles, pers. comm., 2019). • In-field specimen identification by researchers, growers and agronomists are considered by BQ to be the 'front line' in terms of pest surveillance. These activities contribute significantly to QLD biosecurity outcomes (Melina Miles, pers. comm., 2019).
Impacts	• Some contribution to increased productivity and profitability for the northern region grains industry through improved implementation of IPM. This impact will be driven by: 1) improved management of invertebrate pests through more effective implementation of IPM resulting in decreased yield and quality grain loss, and 2) increased adoption of IPM practices. • Potentially, some contribution to reduced rates of resistance to agricultural insecticides in target pest species. • Enhanced industry capacity. • Increased scientific knowledge and research capacity. • Potentially, reduced insecticide load in the environment leading to reduced chemical export off-farm and, potentially, improved biodiversity outcomes (reduced impact on non-target species). • Increased grower well-being attributable to improved confidence in on-farm invertebrate pest management and potentially reduced exposure and handling of highly toxic broadspectrum insecticides.

4. Project Investment

Nominal Investment

Tables D6 to D8 show the annual investment (cash and in-kind) for each of the projects funded by DAF, GRDC and other partners. Table D9 shows the total annual investment in all three projects by funding contributor.

Table D 6: Annual Investment in Project DAQ00179 (nominal \$)

Contributor	2012/13	2013/14	2014/15	Totals
DAF QLD	187,300	202,300	215,400	605,000
GRDC	210,000	210,000	209,917	629,917
Others	53,900	56,300	59,500	169,700
Totals (\$)	**451,200**	**468,600**	**484,817**	**1,404,617**

Source: Project documentation (i.e. project agreements and variations).

Table D 7: Annual Investment in Project DAQ00196 (nominal $)

Contributor	2014/15	2015/16	2016/17	2017/18	2018/19	Totals
DAF QLD	899,611	989,486	1,026,948	1,032,894	1,092,599	5,041,538
GRDC	549,521	549,894	548,880	549,432	549,117	2,746,844
Others	0	0	0	0	0	0
Totals ($)	**1,449,132**	**1,539,380**	**1,575,828**	**1,582,326**	**1,641,716**	**7,788,382**

Source: Project documentation (i.e. project agreements and variations).

Table D 8: Annual Investment in Project DAQ00201 (nominal $)

Contributor	2014/15	2015/16	2016/17	2017/18	Totals
DAF QLD	232,432	285,272	301,321	294,809	1,113,834
GRDC	350,000	350,000	350,000	350,000	1,400,000
Others	0	0	0	0	0
Totals ($)	**582,432**	**635,272**	**651,321**	**644,809**	**2,513,834**

Source: Project documentation (i.e. project agreements and variations).

Table D 9: Total Annual Investment in All Three Projects (nominal $)

Contributor	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	Totals
DAF QLD	187,300	202,300	1,347,443	1,274,758	1,328,269	1,327,703	1,092,599	6,760,372
GRDC	210,000	210,000	1,109,438	899,894	898,880	899,432	549,117	4,776,761
Others	53,900	56,300	59,500	0	0	0	0	169,700
Totals ($)	**451,200**	**468,600**	**2,516,381**	**2,174,652**	**2,227,149**	**2,227,135**	**1,641,716**	**11,706,833**

Source: Project documentation (i.e. project agreements and variations).

Program Management Costs

For the DAF investment, the management and administration costs for the project are already built into the nominal dollar amounts appearing in Table D9. A salary multiplier of 2.85 was used (Wayne Hall, pers. comm., 2017).

A 9.7% management cost was included to account for overheads associated with GRDC's contribution. This cost is in addition to the GRDC contribution shown in Table D9. This multiplier was based on the share of 'payments to suppliers and employees' in total GRDC expenditure (3-year average) reported in the GRDC's Statement of Cash Flows (GRDC, Annual Report, 2016-2018).

A 10.0% management and administration cost was included to account for overheads associated with the contribution of others to the total project investment. This cost is in addition to the other contribution amounts shown in Table D9.

Real Investment, Commercialisation and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2017/18 dollar terms using the Implicit Gross Domestic Product (GDP) Deflator index (ABS, 2019). No additional costs of extension were included as the project encompassed a range of communication and extension components.

5. Impacts

The principal impacts from the three DAF project investments were identified as:

- Contribution to increased productivity and profitability for the Australian grains industry (particularly the northern region) through increased implementation of IPM. This impact will be driven by:
  1) improved management and control of invertebrate pests through more effective implementation of IPM resulting in decreased losses in grain yield and quality,
  2) increased adoption of IPM practices, and
  3) potentially, reduced insecticide costs achieved through better targeted treatments (more effective treatment and the potential for 'free' natural biological control) and fewer unnecessary or poorly timed applications. These reduced costs may, however, be offset by increased costs of monitoring and expenditure on selective, rather than broadspectrum, insecticides.
- Contribution to reduced rates of insecticide resistance development in target pest species.
- Enhanced industry capacity to assess risk and manage insect pests.
- Increased scientific knowledge and research capacity.
- Reduced insecticide load in the environment leading to reduced chemical export off-farm and, potentially, improved biodiversity outcomes (reduced impact on non-target species) and associated ecosystem services (biocontrol, pollination).
- Increased grower well-being attributable to improved confidence in on-farm invertebrate pest management and potentially reduced exposure and handling of highly toxic broadspectrum insecticides.

Table D10 provides a summary of the types of impacts identified, categorised into economic, environmental and social impacts.

Table D 10: Triple Bottom Line Categories of Potential Impacts from DAF Investment into Grains Integrated Pest Management – Northern Region (July 2012 to June 2019)

Economic	• Potentially, increased productivity and profitability for the Australian grains industry (particularly the northern region) through implementation of IPM. • Potentially, reduced rates of resistance to agricultural insecticides in target pest species.
Environmental	• Potentially, reduced insecticide load in the environment leading to reduced chemical export off-farm and, potentially, improved biodiversity outcomes (reduced impact on non-target species) and associated ecosystem services (biocontrol, pollination).
Social	• Enhanced industry capacity. • Increased scientific knowledge and research capacity. • Potentially, increased grower well-being attributable to improved confidence in on-farm invertebrate pest management and potentially reduced exposure and handling of highly toxic broadspectrum insecticides.

Public versus Private Impacts

The primary impacts identified in this evaluation were industry related and therefore the benefits are considered private benefits. Some public benefits may be delivered in the form of the social benefit of increased industry capacity, and, potentially, the environmental benefits of reduced chemical export off-farm and improved biodiversity outcomes.

Distribution of Private Impacts

The primary beneficiaries of the DAF IPM investment are Australian grain growers (including pulses), particularly those growers in the northern grain production region.

It can be assumed that the benefits from the project findings will be distributed between participants along commercial grains supply chains according to relevant supply and demand elasticities.

Impacts on other Australian industries

It is possible that impacts from the project will, with further research, be relevant to growers in other, related Australian industries such as the cotton industry or other cropping industries that deal with the key invertebrate pests targeted by this investment in grains RD&E.

Impacts Overseas

No significant impacts to overseas parties were identified. However, the sharing of important project outputs and scientific findings through published material and online resources may have some impact on cropping industries abroad through improved IPM research and implementation.

Match with National and State Priorities

The Australian Government's Science and Research Priorities and Rural Research, RD&E priorities are reproduced in Table D11. The DAF IPM investment has contributed primarily to Rural RD&E Priorities 4, with some contribution to priorities 2 and 3, and to Science and Research Priority 1.

Table D 11: 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 D12. The DAF IPM addressed Queensland Science and Research Priority 1, with some contribution to priority 3 and 6. In terms of the guides to investment, the investment is likely to have real future impact through improved control of invertebrate pests in the northern grains industry.

Table D 12: 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.

One principal impact of the DAF IPM investment was valued in monetary terms.

- Contribution to increased productivity and profitability for the Australian grains industry (particularly the northern region) through implementation of IPM.

This impact was assumed to contribute to reduced potential industry losses through improved management of invertebrate grain pests primarily in the northern Australian grains region, as well as in the southern and western Australian grains regions to a lesser extent.

Impacts Not Valued

Not all impacts identified in Table D10 could be valued in the assessment.

The economic impacts identified but not valued included:
- Contribution to reduced rates of resistance to agricultural insecticides in target pest species.

The environmental impacts identified but not valued included:
- Reduced insecticide load in the environment leading to reduced chemical export off-farm and, potentially, improved biodiversity outcomes (reduced impact on non-target species).

The social impacts identified but not valued included:
- Enhanced industry capacity.
- Increased scientific knowledge and research capacity.
- Increased grower well-being attributable to improved confidence in on-farm invertebrate pest management and potentially reduced exposure and handling of highly toxic broadspectrum insecticides.

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

<u>Contribution to reduced rates of resistance to insecticides</u>

Over time, and with frequent exposure, invertebrate pests may develop resistance to important agricultural chemicals used to control the damage they cause to crops. This means that chemicals applied frequently, particularly broadspectrum insecticides/pesticides, become less effective over time potentially leading to increasing economic losses and an uncertain future for control of key pest species, particularly where no suitable replacement is available.

GRDC and the Cotton RDC invest significant resources to monitor, measure and manage resistance of key pest species in various broadacre crops. However, the DAF IPM investment was not directly involved in resistance management (Melina Miles, pers. comm., 2019), however the projects are likely to contribute to reduced rates of resistance in the future through more effective implementation, and increased adoption, of IPM leading to reduced reliance on broadspectrum chemicals for pest control.

The impact was not valued in monetary terms because of the range of invertebrate pests and crop types covered by the DAF IPM investment and uncertainty about the level and value of the DAF IPM investment's contribution to future changes to invertebrate pest chemical resistance.

<u>Environmental benefits from potentially reduced use of chemicals in Australian/northern grain crops</u>

The potential for reduced use of chemicals as a result of increased adoption of, and more effective implementation of, IPM practices for the Australian grains industry is likely to generate some environmental benefits. Reduced use of chemicals means a lessened likelihood of chemical run-off into water sources and a reduction in adverse effects on downstream ecosystems. Further, increased use of species-specific insecticides (as opposed to broadspectrum insecticides) and a greater understanding and consideration of beneficials also may reduce the negative impact of chemicals on non-target species.

Difficulties exist in quantifying the value of such environmental benefits and also in linking the investments in the analysis to such impacts.

<u>Increased industry capacity</u>

The DAF IPM investment supported a significant number of IPM workshops, field days, publications and other extension activities and materials. The project outputs have likely contributed to an increase in capacity for grains industry stakeholders, particularly growers and advisors, to implement effective IPM across the northern grains region.

It is difficult to quantify the magnitude of such capacity enhancement because the initial level of capacity was unknown and placing a monetary value on human capacity requires the application of non-market valuation techniques that were beyond the scope of the current impact assessment. However, some of this capacity increase is captured by the valuation of potentially reduced economic losses (see Section 6.3 below).

<u>Increased scientific knowledge and research capacity</u>

The scientific knowledge and capacity built within the DAF RD&E team created by the IPM investment, as well as the establishment and maintenance of national IPM teams that operate collaboratively is likely to contribute to improved efficiency and effectiveness of RD&E in the future (Melina Miles, pers. comm., 2019). The improved research capacity also provides confidence to industry that future pest challenges can, and will be, addressed. This increased confidence enhances industry capacity and also may encourage increased industry investment in priority pest RD&E areas.

However, like industry capacity (described above), given the inherent uncertainty about the initial and future level of any capacity change, and the difficulty attributing a monetary value to such a change, the increased scientific knowledge and research capacity impact was not valued in this assessment.

<u>Increased grower well-being</u>

Increased adoption of IPM practices, as well as more effective implementation of IPM by growers who had already adopted, may contribute to increased grower and community well-being through improved confidence in on-farm pest management and potentially reduced exposure and handling of highly toxic broadspectrum insecticides.

Within the scope of the current assessment, it was not possible to estimate the potential change to well-being.

Valuation of Impact 1: Reduced potential economic losses for the Australia grains industry

As described in Section 2 above, invertebrate pests cause economic losses through reduced crop yields, quality downgrades, and control costs, worth millions of dollars each year in the Australian grains industry.

The DAF IPM investment has likely contributed to reduced production losses and reduced control costs for invertebrate pests in the Australian grains industry through:

1) improved management and control of invertebrate pests through more effective implementation of IPM,
2) increased adoption of IPM management practices, and

3) potentially, reduced insecticide costs achieved through better targeted treatments and fewer unnecessary or poorly timed applications. These reduced costs may, however, be offset by some increased costs of monitoring and expenditure on selective, rather than broadspectrum, insecticides.

Impact 1 was valued in two parts. The first part consisted of the value of potentially reduced impact damage costs of invertebrate pests in the northern grains region. The second part included the benefits of reduced impact costs of invertebrate pests, to a lesser extent, in the southern and western grains regions.

Specific assumptions used in the valuation are detailed in Table D13.

Summary of Assumptions

A summary of the key assumptions made for the valuation of impacts is shown in Table D13.

Table D 13: Summary of Assumptions

Variable	Assumption	Source[a]
General Assumptions		
Northern grain production area, yield, total production, and value by major crop type	See Table D2	Murray *et al.* (2013)
Australian grain production area, yield, total production, and value by major crop type (southern and western only)	Based on Australian statistics less the northern region data (See Table D2 above)	
Impact 1: Reduced potential economic losses from invertebrate pests in the northern grains industry		
WITHOUT the investment		
Current impact costs of invertebrate pests on the northern grains sector (including yield, quality and control costs)	See Table D1 above	Murray *et al.* (2013)
Current impact damage costs of invertebrate pests on the southern and western grains sectors (including yield, quality and control costs)	Based on Australian statistics less the northern region data (See Table D1 above)	
WITH the investment		
Likely reduction in economic losses attributable to the DAF IPM investment for the northern grain region (valuation part 1)	3%	Agtrans Research
Likely reduction in economic losses attributable to the DAF IPM investment for the rest of Australia (southern and western grain regions only) (valuation part 2)	1%	
First year of impact	2013/14	Based on evidence of usage of early project outputs

Year of maximum impact	2019/20	Based on final year of DAF IPM investment
Period of maximum impact	5 years (2019/20 to 2023/24)	Agtrans Research based on a linear decline of impact due to dis-adoption and/or decreasing effectiveness of IPM assuming no further investment in IPM extension beyond the investment evaluated or research outputs being superseded.
Last year of impact	2028/29	
Net additional cost to growers to effectively implement IPM	Nil. It was assumed that any additional costs of monitoring/ management would be offset by savings through reduced chemical use.	
Risk Factors		
Probability of output	100%	Agtrans Research
Probability of outcome	50%	Conservative estimate based on the assumed increased adoption, and improved implementation, of IPM in the three grains region.
Probability of impact	80%	Allows for exogenous factors that may affect the impact of IPM (e.g. environment/ climate factors).

7. Results

All past costs were expressed in 2017/18 dollar terms using the Implicit Price Deflator for GDP. All benefits after 2017/18 were expressed in 2017/18 dollar terms. All costs and benefits were discounted to 2018/19 (year of analysis) 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 (2018/19).

Investment Criteria

Table D14 and D15 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 D15, has been estimated by multiplying the total PVB by the DAF proportion of real investment (55.4%).

Table D 14: Investment Criteria for Total Investment in Grains IPM

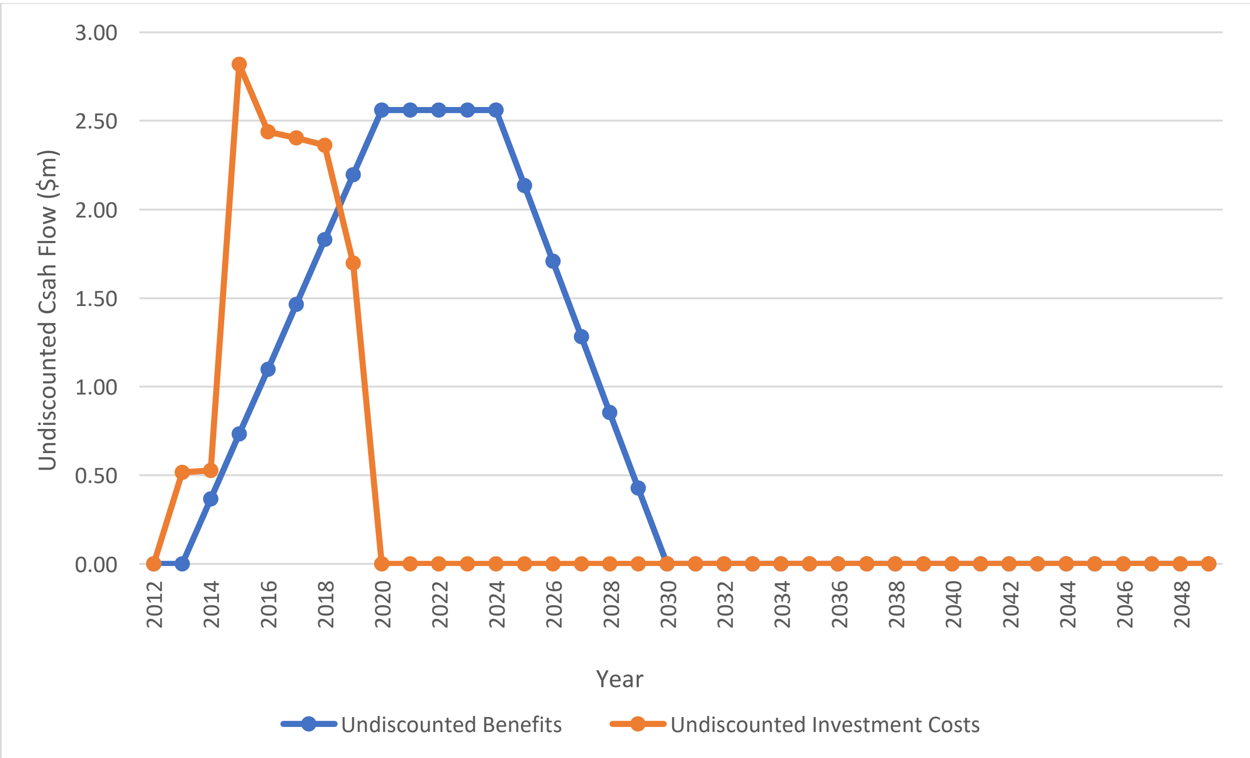
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	8.36	19.44	23.93	23.93	23.93	23.93	23.93
Present value of costs ($m)	14.43	14.43	14.43	14.43	14.43	14.43	14.43
Net present value ($m)	-6.08	5.01	9.49	9.49	9.49	9.49	9.49
Benefit-cost ratio	0.58	1.35	1.66	1.66	1.66	1.66	1.66
Internal rate of return (%)	negative	15.1	18.8	18.8	18.8	18.8	18.8
MIRR (%)	negative	17.6	14.8	11.4	9.8	8.8	8.2

Table D 15: Investment Criteria for DAF Investment in Grains IPM

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	4.63	10.76	13.24	13.24	13.24	13.24	13.24
Present value of costs ($m)	7.93	7.93	7.93	7.93	7.93	7.93	7.93
Net present value ($m)	-3.30	2.84	5.32	5.32	5.32	5.32	5.32
Benefit-cost ratio	0.58	1.36	1.67	1.67	1.67	1.67	1.67
Internal rate of return (%)	negative	16.0	19.9	19.9	19.9	19.9	19.9
MIRR (%)	negative	18.5	15.3	11.8	10.0	9.0	8.3

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 D4.

Figure D 4: Annual Cash Flow of Undiscounted Total Gross 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 D16 presents the results. The results showed a low sensitivity to the discount rate. This was largely because the benefit cash flows occur in the first 10 to 15 years after the last year of investment and, therefore, are not subjected to substantial discounting.

Table D 16: Sensitivity to Discount Rate (Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	26.89	23.93	22.01
Present value of costs ($m)	12.76	14.43	16.33
Net present value ($m)	14.13	9.49	5.68
Benefit-cost ratio	2.11	1.66	1.35

A sensitivity analysis also was carried out on likely reduction of impact costs assumed for both the northern, and other grain producing regions. Table D17 presents the results. The results showed moderate to low sensitivity to reduction in impact damage costs assumed.

Table D 17: Sensitivity to the Likely Reduction to Impact Costs (Total investment, 30 years)

Investment Criteria	**Likely Reduction in Invertebrate Pest Impact Damage Costs**		
	1.5% Northern Region 0.5% Other Regions (Half Base)	**3% Northern Region 1% Other Regions (Base)**	**6% Northern Region 2% Other Regions (2x Base)**
Present value of benefits ($m)	11.96	23.93	47.86
Present value of costs ($m)	14.43	14.43	14.43
Net present value ($m)	-2.47	9.49	33.42
Benefit-cost ratio	0.83	1.66	3.32

A break-even analysis then was conducted on the joint proportion of the assumed reduction in impact damage costs across all three regions (northern, southern and western). The analysis showed that the investment criteria are positive with a reduction in impact damage costs of 1.8% for the northern region and 0.6% for the other (southern and western) regions.

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 D18). 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 D 18: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Medium-High	Medium-Low

Coverage of impacts was assessed as medium to high. The impact valued (reduced potential economic losses for the Australian grains industry) was considered the primary benefit of the investment.

A number of other impacts, including environmental and social impacts, were identified but not valued in monetary terms. This was largely due to a lack of available of data/evidence, poor linkages between the investment and the impacts, and the relative significance of the impacts compared to the principal impact valued. Thus, the investment criteria as provided by the valued impact are likely to be underestimated to some degree.

Confidence in assumptions was rated as medium-low. Data for this analysis were drawn from credible, published sources with supplementary data/information provided by the projects' Principal Investigators. However, much of the data on invertebrate pest impact costs is marginally outdated and the broad range of pests and crops covered by the investment necessitated a generalised approach to impact valuation.

8. Conclusions

The analysis demonstrates that the investment in the improvement and extension of IPM for the Australian grains industry has provided a positive return. However, it is important to note that the assumptions related to reduction of invertebrate pest damage costs (e.g. magnitude of the impact attributable to the investment) are somewhat uncertain and so the benefits identified and valued in this analysis also are uncertain.

The primary impact that was quantified was the potential for reduced impact costs of invertebrate pests in the Australian grains industry (including losses of yield and quality, and expenditure on pest control). The benefit was driven by the adoption and improvement of IPM practices, particularly in the northern grains region.

The total investment of approximately $14.4 million (present value terms) has been estimated to produce total net benefits of approximately $23.9 million (present value terms) providing a net present value of $9.5 million, a benefit-cost ratio of approximately 1.7 to 1 (over 30 years, using a 5% discount rate), an internal rate of return of 18.8% and a modified internal rate of return of 8.2%.

The results are consistent with previous analyses conducted by Agtrans regarding IPM RD&E for the Australian grains industry. Also, given the coverage of impacts valued and conservative assumptions made for the valuation, the investment criteria reported are likely to be an underestimate of the total value of the impact of the grains IPM investment.

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Appendix 1D: DAQ00179 Workshop Content

Table D19 shows the workshop content provided to growers and agronomists as part of project DAQ00179.

Table D 19: Workshop Content Provided During DAQ00179

Table 4. The content of each workshop was based on a number of pre-prepared modules

Modules used during the workshop	IPM overview/toolbox	Canola	Sorghum	Maize	Sunflower	Summer pulses	Winter cereals	Winter pulses	Pastures and lucerne	Establishment Pests	Insect ID	Monitoring, thresholds	Natural enemies	Management strategies	Insecticides	Slugs & snails	Virus in canola
Dubbo & Wagga Wagga	✓	✓					✓	✓		✓		✓			✓		
Horsham & Adelaide	✓	✓					✓	✓		✓		✓	✓		✓		
Dalby & Moree*	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓		
Wellington, Forbes & Griffith	✓	✓				✓	✓	✓	✓	✓		✓	✓				
Pittsworth & Goondiwindi	✓	✓	✓			✓	✓										
Casino & Grafton	✓											✓		✓			
Kadina, Kapunda, Albury, Bendigo & Horsham		✓					✓	✓		✓	✓	✓				✓	
Campbell Town, Lake Bolac & Cummins	✓	✓					✓	✓		✓			✓			✓	✓
Narromine, Gunnedah & Warialda	✓	✓	✓		✓	✓		✓									✓
Moura & Emerald			✓		✓	✓	✓	✓									

Source: Project DAQ00179 Final Report 2015 Supplementary Information

Appendix E: An Impact Assessment of DAF Investment into Grazing Best Management Practice and Reef Plan Extension

Acknowledgments

Robert Karfs, Science Director, Beef and Sheep, Animal Science, Agri-Science Queensland, Department of Agriculture and Fisheries.

Abbreviations

ABS	Australian Bureau of Statistics
BCR	Benefit Cost Ratio
BMP	Best Management Practice
BMRG	Burnett-Mary Regional Group
CBA	Cost Benefit Analysis
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
DAF	Queensland Department of Agriculture and Fisheries
DES	Queensland Department of Environment and Science
FBA	Fitzroy Basin Association
GDP	Gross Domestic Product
GLM	Grazing Land Management
GRB	Great Barrier Reef
MIRR	Modified Internal Rate of Return
MLA	Meat and Livestock Australia
NPV	Net Present Value
NQDT	North Queensland Dry Tropics
NRM	Natural Resource Management
OHS	Occupational Health and Safety
QLD	Queensland
PVB	Present Value Benefits
PVC	Present Value Costs
RDC	Research and Development Corporation
SEQ	South East Queensland
SWOT	Strengths, Weaknesses, Opportunities and Threats Analysis

Executive Summary

The Report

This report presents the results of an impact assessment of a Queensland Department of Agriculture and Fisheries (DAF) investment in three phases of a project to deliver grazing best management practice (BMP) in three river catchments draining to the Great Barrier Reef (GBR). The project was funded by the Department of Environment and Sciences (DES) with in-kind support from the Fitzroy Basin Association (FBA). DAF contributed in-kind support. Potential impacts are analysed for the funding period July 2011 to June 2018.

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 in 2017/18 dollar terms were discounted to the year 2018/19 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, 2018).

Impacts

The major impacts identified were both economic and environmental. Social impacts including capacity building were also identified. It is expected that the Queensland beef cattle industry and people who value the GBR will be the primary beneficiaries of the investment. The lack of data linking grazing BMP adoption to reduction in sediment runoff, improved GBR outcomes and quantification of people’s willingness to pay for the improvement meant that potential environmental impacts remained unquantified.

Investment Criteria

Given the counterfactual scenario assumed, total funding from all sources for the project was approximately $17.28 million (present value terms). The value of total benefits was estimated at $65.19 million (present value terms). This result generated an estimated net present value (NPV) of $47.92 million, a benefit-cost ratio (BCR) of 3.77 to 1, an internal rate of return (IRR) of 30.7% and a modified internal rate of return (MIRR) of 9.8%.

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 CRRDC (CRRDC, 2018).

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 benefits delivered by the project.

2. Background and Rationale

Background

Since 2003 the Queensland (QLD) and Australian Governments have partnered with industry, Natural Resource Management (NRM) and conservation organisations to deliver a series of Reef Water Quality Action Plans (Reef Plan) to reverse the decline in water quality in the GBR World Heritage Area. The primary objective of Reef Plan was to reduce the level of nutrients, sediments and pesticides from agricultural lands entering the GBR by encouraging landholders to adopt better land management practices. This was to be achieved by a variety of mechanisms including incentives, regulation and extension services.

The development of Grazing BMPs as part of Reef Plan commenced in 2009; the timeline was as follows:

- 2009 to 2011 – project design in a partnership that included DAF, FBA and the Australian Government.
- 2011 – project partnership expanded to include DES with a particular focus on the Burdekin rangelands – a known source of sediment impacting GBR inshore coral reefs and seagrass meadows.
- 2012 to 2014 – initial project rollout in the Fitzroy (Rockhampton), Burdekin (Townsville), Mary-Burnett (Bundaberg) and South East Queensland (SEQ) Catchments. AgForce assisted with Reef Plan project rollout.
- 2014 to 2017 – additional landholder participation in project rollout in the Fitzroy, Burdekin, Mary-Burnett and SEQ Catchments.
- 2017 to 2018 – additional project rollout in catchments draining to the GBR (Fitzroy, Burdekin and Mary-Burnett), expansion to additional catchments and planning for further investment.

Rationale for the Investment

Grazing BMP is a voluntary program. Its aim is to help beef cattle grazers to identify practices to enhance profitability, natural resource management and ethical production. The Grazing BMP program includes:

- Graziers strategically reviewing their properties to develop business action plans.
- Fine tuning business performance through extension and training support.
- Graziers developing an understanding of their legal obligations (e.g. Occupational Health and Safety (OHS), animal welfare).
- Demonstration of land and animal stewardship and enterprise self-regulation.
- Obtaining Accredited Producer status through an external audit.

The Grazing BMP program consists of five modules that address:

1) Soil Health.
2) Grazing Land Management (GLM).
3) Animal Production.
4) Animal Health and Welfare.
5) People and Business.

Individual producers benefit through the introduction of holistic management to their enterprise, enterprise SWOT analysis, business improvement plans and benchmarking of management practices against industry peers. The grazing industry benefits through industry wide benchmark and baseline measures, data to inform policy development and stronger individual businesses contributing to a stronger QLD industry.

By participating in the Grazing BMP program, beef producers help the QLD grazing industry to demonstrate to State and Federal Governments and the wider Australian community, the good environmental stewardship of graziers and that QLD beef is produced ethically and sustainably. Ultimately public investment is to contribute to reduced sediment laden runoff, improved water quality and ecosystem health in the GBR.

Evaluation Coverage

At DAF's request the focus of investment has been on DES and FBA investment and DAF in-kind support along with the subsequent activities, outputs, outcomes and impacts delivered with this funding. The period of investment covered is 2010/11 to 2017/18. DAF has also suggested that though highly successful, Grazing BMP projects in Western QLD (Grazing Futures) and SEQ should not be formally considered in this evaluation (Robert Karfs, written comm., February 2019). Hence, this evaluation focusses on river catchments which drain directly to the GBR.

As a consequence, data have been provided and analysed for the Burdekin, Fitzroy and Burnett-Mary river catchment regions. Table E1 summarises Grazing BMP activities 2014/15 to 2017/18 for these three river catchment regions. Activity data were not available to the analyst for the period 2010/11 to 2013/14. Table E2 summarises Grazing BMP achievements 2010/11 to 2017/18 for the Burdekin, Fitzroy and Burnett-Mary river catchment regions.

Table E 1: Grazing BMP Activity Numbers Burdekin, Fitzroy and Burnett-Mary (2014/15 to 2017/18)

	Module workshops	**Businesses attending**	**Participants**	**Module one on ones**	**Extension events**	**Businesses attending**	**Participants**	**One on one engagements**	**Businesses accredited**
Burdekin	10	133	151	54	62	1,880	2,057	277	48
Fitzroy	80	676	929	1	81	955	1,669	239	42
Burnett-Mary	37	225	303	1	57	1,253	1,702	90	14
Total	**127**	**1,034**	**1,383**	**56**	**200**	**4,088**	**5,428**	**606**	**104**

Source: DAF records provided by Robert Karfs

Table E 2: Grazing BMP Achievements Burdekin, Fitzroy and Burnett-Mary (2010/11 to 2017/18)

	Total QLD area under grazing (ha)	**Total area under Grazing BMP (ha)**	**No. of Grazing BMP modules completed**	**No. of soil and GLM modules completed**	**No. of businesses completing a module**	**No. of businesses completing all 5 modules and NOT re-assessing**	**No. of businesses completing all 5 modules and re-assessing**	**No. of independently accredited businesses**	**Area of accredited businesses (ha)**
Burdekin	12,647,762	7,594,267	1,334	529	381	184	142	52	1,375,519
Fitzroy	12,159,080	5,063,754	2,276	933	813	266	254	39	1,236,023
Burnett-Mary	3,626,998	746,386	1,112	454	310	159	58	11	37,497
Total	**28,433,840**	**13,404,407**	**4,722**	**1,916**	**1,504**	**609**	**454**	**102**	**2,649,039**

Source: FBA Contract Variation Report July 2017 - June 2018, extract provided by Robert Karfs

3. Project Details

Summary

Project Title: Grazing BMP and Reef Plan Extension
Research Organisation: Department of Agriculture and Fisheries, Queensland
Principal Investigator: Robert Karfs
Period of Funding: 1 July 2010 to 30 June 2018

Objectives

The aim of the Grazing BMP and Reef Plan Extension project was to work with beef cattle producers and support them through the adoption of grazing systems that are productive and profitable with improved water quality outcomes for the GBR. Program objectives were:

1) To provide landholders with the tools, experience and knowledge to allow them to better manage their properties at or above industry standard.
2) To provide the QLD grazing industry with a mechanism for benchmarking their practices and to demonstrate to the wider grazing community that environmental stewardship and ethical production methods are integral to a profitable and sustainable grazing industry.
3) To identify a mechanism whereby improved grazing management practices will result in a minimisation of sediment from grazing land impacting water quality, particularly to the GBR.
4) To secure comprehensive and effective sector and stakeholder engagement and consultation.

Logical Framework

Table E3 provides a description of the project in a logical framework developed for the project.

Table E 3: Logical Framework for Grazing BMP & Reef Plan Extension Project

Activities and Outputs	• Developed 157 industry standards in a database covering soil and land management, animal production and welfare, business practices and people management relevant to most QLD beef grazing enterprises. • Created a database that allows grazers to self-report and compare their own performance to industry standards. To ensure grazier confidentiality the database was held and maintained by producer representative body AgForce. • The database provides industry with a tool that allows it to demonstrate adoption of best practice and areas for practice improvement. • Delivery of workshops, field days, producer meetings and property visits backed with online information and tools to improve grazing, environmental and human resource performance.

	• DAF-led extension activities incorporating recent R&D and tailored to accommodate regional differences and the level of producer skill. DAF-led activities used to shift graziers from current to industry best practice. • 13.4 million hectares, 47% of the total grazing area of the Burdekin, Fitzroy and Burnett-Mary river catchments, covered by the Grazing BMP & Reef Plan Extension project by 30 June 2018. • 1,504 grazing businesses completing at least one of the Grazing BMP program's five self-assessment modules. A total of 1,916 Soil and Grazing Land Management modules completed. 609 businesses completing all five Grazing BMP modules and 454 businesses completing all five modules and assessed on their content. 102 businesses independently assessed and attaining Accredited Producer status. Accredited Producers control 2.6 million ha of grazing land in the Burdekin, Fitzroy and Burnett-Mary river catchments. • In 2016 an independent survey of 92 participating producers found 84% considered changes to management practices post participation in the project, and 73% had commenced or completed practice change. • The grazing BMP program expanded to non-Great Barrier Reef catchments in 2017 to include delivery of self-assessment modules, training and accreditation in SEQ and Western QLD; however, this evaluation does not specifically include these regional impacts.
Outcomes	• Graziers in the Burdekin, Fitzroy, Burnett-Mary and other river catchments shifting from current to best practice with improvements in property performance, environmental and human resource management.
Impacts	• Economic – improved profitability for participating beef cattle graziers in the Burdekin, Fitzroy and Burnett-Mary river catchments. • Economic – improved profitability for participating beef cattle graziers in other QLD areas e.g. SEQ and Western QLD; however, this evaluation does not specifically value these regional impacts. • Environment – reduced sediment laden runoff, improved water quality and protection for GBR inshore reefs and seagrass meadows. • Environment – maintenance of healthy rangelands on properties managed by participating graziers. • Social – improved human resource management including participating grazier occupational health and safety. • Social – increased community well-being through the spill-over effects of increased farm productivity and profitability. • Capacity – beef producers with additional land, animal, people and enterprise management skills across three coastal catchments and other parts of QLD. • Capacity – regional NRM groups, primary producer organisations and government agencies with additional skills in data generation, data management, communication and extension.

4. Project Investment

Nominal Investment

Table E4 shows the annual investment (cash and in-kind) for the project by DES, FBA and DAF.

Table E 4: Annual Investment in the Grazing BMP and Reef Plan Extension Project (nominal $)

Contributor	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	Totals
DES ($)	0	750,000	960,000	985,000	1,040,000	1,000,000	1,106,000	950,000	6,791,000
FBA ($ in-kind)	122,000	169,000	229,000	486,000	322,000	549,000	561,000	519,000	2,957,000
DAF ($ in-kind)	108,000	316,000	335,000	523,000	485,000	763,000	738,000	687,000	3,955,000
Totals ($)	**230,000**	**1,235,000**	**1,524,000**	**1,994,000**	**1,847,000**	**2,312,000**	**2,405,000**	**2,156,000**	**13,703,000**

Source: Project documentation (including written material provided by Robert Karfs).

Program Management Costs

For the DES and DAF investment, the management and administration costs for the project are already built into the nominal $ amounts appearing in Table E4 (Robert Karfs, Principal Investigator, DAF, pers. comm., March and April 2019). For FBA a management cost multiplier of 1.03 was estimated after reviewing online copies of the Association's annual reports.

Real Investment, Commercialisation and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2017/18 $ terms using the Implicit GDP Deflator index (ABS, 2019).

No allowance has been made for cattle producer time associated with contributed data and participating in extension activities. Gain to producers from adopting Grazing BMP recommendations has been measured as a change in profit and is inclusive of adoption costs.

5. Impacts

The principal potential impacts from Grazing BMP include:

- Improved profitability for participating beef cattle graziers in the Burdekin, Fitzroy and Burnett-Mary river catchments.
- Reduced sediment laden runoff, improved water quality and protection for GBR inshore reefs and seagrass meadows.

Table E5 provides a summary of the types of potential impacts categorised into economic, environmental and social impacts.

Table E 5: Triple Bottom Line Categories of Potential Impacts of Grazing BMP

Financial	• Improved profitability for participating beef cattle graziers in the Burdekin, Fitzroy and Burnett-Mary river catchments. • Improved profitability for participating beef cattle graziers in other QLD areas e.g. SEQ and Western QLD; however, this evaluation does not specifically value these regional impacts.
Environmental	• Reduced sediment laden runoff, improved water quality and protection for GBR inshore reefs and seagrass meadows. • Maintenance of healthy rangelands on properties managed by participating graziers.
Social	• Social – improved human resource management including participating grazier OHS. • Social – increased community well-being through the spill-over effects of increased farm productivity and profitability. • Capacity – beef producers with additional land, animal, people and enterprise management skills across three coastal catchments of QLD. • Capacity – regional NRM groups, primary producer organisations and government agencies with additional skills in data generation, data management, communication and extension.

Public versus Private Impacts

Potential impacts identified in this evaluation are split between those benefiting private and public stakeholders. Private benefits will accrue to beef cattle graziers adopting Grazing BMPs, including improved profitability. Public benefits will be realised when adoption of Grazing BMPs results in reduced sediment runoff and improved GBR environmental outcomes.

Distribution of Private and Public Impacts

The primary beneficiaries of private impacts are beef cattle producers with some of this benefit being captured by those along the beef cattle supply chain (e.g. transporters, processors and consumers). The primary beneficiaries of public environmental benefits are Queenslanders who enjoy the reef and others who visit the GBR.

Impacts on other Australian industries

Grazing BMP tools and materials are relevant to cattle production in other states (e.g. Northern NSW and the Northern Territory) and other livestock industries (e.g. sheep grazing).

Impacts Overseas

It is possible that Grazing BMP tools and materials will be relevant to overseas rangeland management and may even be incorporated into Australian aid projects.

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 E6. The delivery of

Grazing BMPs contributes primarily to Rural RD&E Priority 3 and Priority 4 and to Science and Research Priorities 1, 2 and 7.

Table E 6: 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 E7. Grazing BMP addressed Queensland Science and Research Priorities 1 and 3 (Table E7). In terms of the guides to investment, the project is likely to have a real future impact, had external commitment and has scaled toward critical mass.

Table E 7: 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 impacts that included future expected impacts. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. The impact on graziers participating in the project, in the three river catchments that drain to the GBR – improved profitability, was valued.

Impacts Not Valued

Impacts not valued included increased grazier profitability in non-reef catchments. At the request of DAF, the analysis confined itself to reef related activities. The impact on the environment - reduced sediment laden runoff, improved water quality and protection for the GBR was not valued. Consistent with DAF (2015) this evaluation found that information and data relating to environmental benefits are difficult to access and a direct correlation between Grazing BMPs, reef recovery and the value of recovered reef could not be credibly established. Maintenance of healthier rangelands on properties managed by graziers participating in Grazing BMPs could not be valued for these same reasons. Quantification of social and capacity building were also beyond the scope of this impact assessment.

Valuation of Benefit: Improved Profitability for Participating Beef Cattle Graziers

The impact on the profitability of graziers participating in Grazing BMP activities in the three river catchments that drain to the GBR was quantified. The impact on profit was assessed using the results of a monitoring and evaluation survey, internal case studies and expert opinion. Profitability improvement was quantified at 12.54% across graziers participating in Grazing Land Management, Herd and Business Management activities (DAF, 2015).

Profitability improvement as a result of participating in the project is realised through improved pasture production, reduced fodder supplementation costs, higher calving percentage and heavier weight gains in cattle (Barry O'Sullivan, Glenalpine Station, Burdekin reported in written material provided by Robert Karfs, DAF, February 2019).

The improvement in profitability is measured across average per head gross margin for each of the Burdekin, Fitzroy and Burnett-Mary river catchments. In each case data were sourced from the Northern Beef Report Situation Analysis (McLean, *et al*., 2014). The Northern Beef Situation Analysis provided a long term view of beef grazing enterprise profitability in each river catchment prior to roll-out of the project.

A summary of these and other relevant assumptions is provided in Table E8.

Counterfactual

In the absence of project investment, a forecast increase in the increased profit of graziers participating in Grazing BMPs in the three river catchments that drain to the GBR has been assumed to be delayed for 5 years. This is the same counterfactual developed by DAF (2015).

Table E 8: Summary of Assumptions

Variable	Assumption	Source
General assumptions		
Increase in gross margin attributable to grazier participation in project.	12.54%	DAF (2015) and predicated on achieving project objectives and productivity benefits estimated through internal case studies and expert opinion which reported an average 12.54% improvement in profitability from graziers completing GLM, Herd and Business Management modules.
Graziers who will follow through project participation with practice change.	73%	Independent survey of producers in 2016 results provided by Robert Karfs, DAF.
Year of first impact with project in place.	2018/19	Consultant assumption – some benefits achieved through changes to business management activities that yield immediate results.
Counterfactual: Year of first impact with no Grazing Best Management Practice and Reef Plan Extension Investment.	2023/24	Consultant assumption – 5 year delay in realisation of benefits in the absence of project investment.
Benefit 1: Improved profitability for participating beef cattle graziers – Burdekin		
Average per head beef cattle gross margin increase in the Burdekin due to the investment	$97.72/head	Average long term gross margin for the QLD Central North as reported in McLean *et al*., 2014). NB: gross margin increase takes into account situation before project impacts were realised.
Cattle per property in the Burdekin.	3,828 head	McLean *et al*., 2014.
Number of Burdekin graziers completing 5 project self-assessment modules between 2011 to 2018.	184	FBA Contract Variation Report July 2017 – June 2018 provided by Robert Karfs, DAF.
Benefit 2: Improved profitability for participating beef cattle graziers – Fitzroy		
Average per head beef cattle gross margin in the Fitzroy due to the investment.	$172.43/head	Average long term gross margin for the QLD Southern Inland and Central as reported in McLean *et al*., 2014). NB: gross margin increase takes into account situation before project impacts were realised.
Cattle per property in the Fitzroy.	1,388 head	McLean *et al*., 2014.
Number of Fitzroy graziers completing 5 project self-assessment modules between 2011 to 2018.	266	FBA Contract Variation Report July 2017 – June 2018 provided by Robert Karfs, DAF.
Benefit 3: Improved profitability for participating beef cattle graziers – Burnett-Mary		
Average per head beef cattle gross margin in the	$141.40/head	Average long term gross margin for the QLD Southern Coastal as reported in McLean et al., 2014). NB: gross margin

Burnett-Mary due to the investment.		increase takes into account situation before project impacts were realised.
Cattle per property in the Burnett-Mary.	1,075 head	McLean *et al*., 2014.
Number of Burnett-Mary graziers completing 5 project self-assessment modules between 2011 to 2018.	159	FBA Contract Variation Report July 2017 – June 2018 provided by Robert Karfs, DAF.

7. Results

All past costs were expressed in 2017/18 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP). All benefits after 2017/18 were expressed in 2017/18 dollar terms. All costs and benefits were discounted to 2018/19 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.

Investment Criteria

Tables E9 and E10 show the investment criteria estimated for different periods of benefits for the total investment and DAF investment respectively. The present value of benefits (PVB) attributable to DAF investment only, shown in Table E10, has been estimated by multiplying the total PVB by the DAF proportion of real investment (28.7%).

The reason the investment criteria are similar for the different number of years from the year of last investment is because of the counterfactual assumption of a 5-year lead time for the with investment scenario.

Table E 9: Investment Criteria for Total Investment in Grazing BMP Project

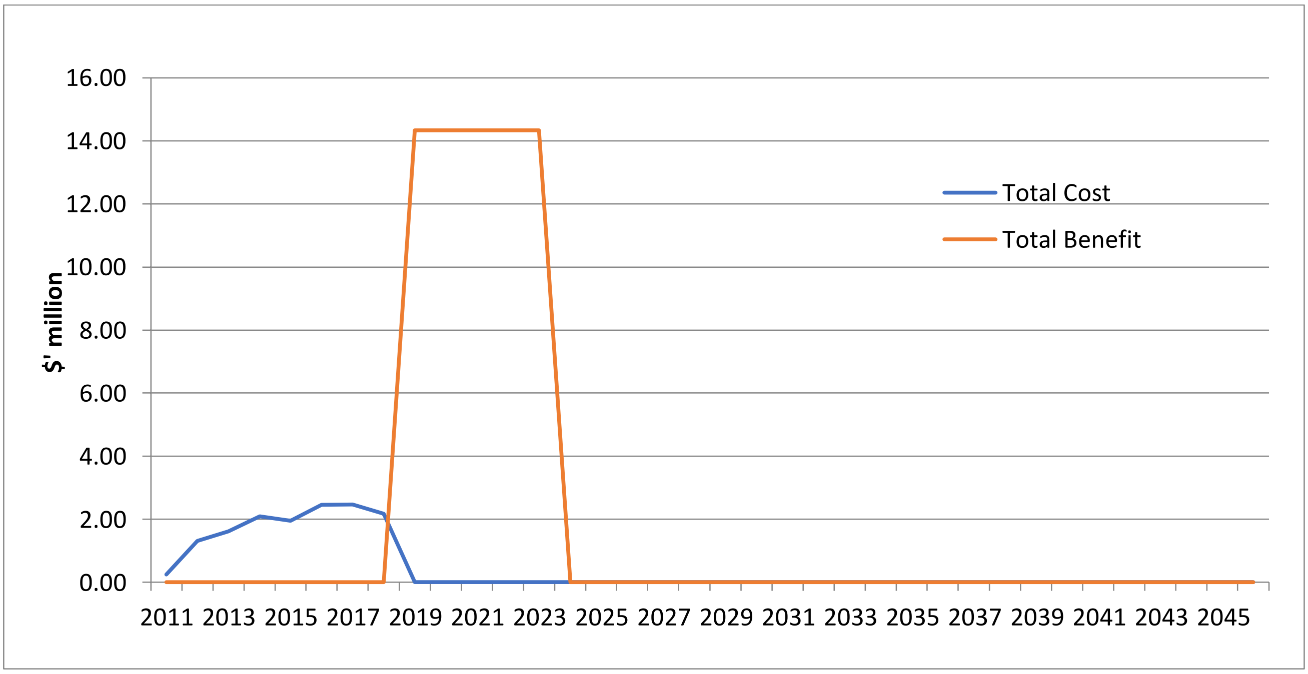
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	65.19	65.19	65.19	65.19	65.19	65.19
Present value of costs ($m)	17.28	17.28	17.28	17.28	17.28	17.28	17.28
Net present value ($m)	-17.28	47.92	47.92	47.92	47.92	47.92	47.92
Benefit-cost ratio	0.00	3.77	3.77	3.77	3.77	3.77	3.77
Internal rate of return (IRR) (%)	negative	30.7	30.7	30.7	30.7	30.7	30.7
Modified IRR (%)	negative	36.9	19.9	14.7	12.2	10.7	9.8

Table E 10: Investment Criteria for DAF Investment in Grazing BMP Project

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	18.68	18.68	18.68	18.68	18.68	18.68
Present value of costs ($m)	4.91	4.91	4.91	4.91	4.91	4.91	4.91
Net present value ($m)	-4.91	13.76	13.76	13.76	13.76	13.76	13.76
Benefit-cost ratio	0.00	3.80	3.80	3.80	3.80	3.80	3.80
Internal rate of return (IRR) (%)	negative	31.4	31.4	31.4	31.4	31.4	31.4
Modified IRR (%)	negative	37.1	20.0	14.8	12.3	10.8	9.8

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 E 1: Annual Cash Flow of Undiscounted Total Benefits and Total Investment Costs



Sources of Benefits

There are three sources of benefits valued in the analysis – one for each of the river catchments participating in the Grazing BMP project that drain to the GBR lagoon. Table E11 shows the relative contributions to the Present Value of Benefits (PVB) from each source. The improved profitability for participating beef cattle graziers in the Burnett-Mary (Benefit 3) provides the smallest contribution to total benefit as this catchment has the least number of participating grazing properties.

Table E 11: Contribution to Total Benefits from Each Source

Source of Benefit – Improved Profitability for Participating Beef Cattle Graziers	**Contribution ($m)**	**Share of benefits (%)**
Burdekin (Benefit 1)	28.64	43.9
Fitzroy (Benefit 2)	26.49	40.6
Burnett-Mary (Benefit 3)	10.06	15.4
Total	**65.19**	**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 E12 presents the results. The results showed limited sensitivity to the discount rate, largely due to the short period of benefits driven by the counterfactual.

Table E 12: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	71.71	65.19	59.80
Present value of costs ($m)	14.32	17.28	20.84
Net present value ($m)	57.38	47.92	38.96
Benefit-cost ratio	5.01	3.77	2.87

A sensitivity analysis was also carried out on the estimate of graziers who follow through project participation with practice change (adoption rate). Table E13 presents the results. If only 50% of graziers completing BMP training follow through with practice change on farm, then the project still delivers a healthy return on investment (BCR 2.58:1).

Table E 13: Sensitivity to Assumed Level of Practice Change
(Total investment, 30 years)

Investment Criteria	**Graziers Completing 5 Modules and Implementing Practice Change**		
	50%	**73% (base)**	**90%**
Present value of benefits ($m)	44.65	65.19	80.38
Present value of costs ($m)	17.28	17.28	17.28
Net present value ($m)	27.38	47.92	63.10
Benefit-cost ratio	2.58	3.77	4.65

Finally, a sensitivity analysis was carried out on the increase in profitability attributable to Grazing BMP training and adoption. Table E14 presents the results. The results showed a high level of sensitivity to the increase in profit assumed for participating graziers. Nevertheless, halving the net increase in profit attributable to adopting Grazing BMPs still results in a positive return from project investment (BCR 1.89:1).

Table E 14: Sensitivity to Increase in Profit as a Result of Grazing BMP
(Total investment, 30 years)

	Increase in Enterprise Profitability		
	6.27%	**12.54%(base)**	**25.08%**
Present value of benefits ($m)	32.60	65.19	130.39
Present value of costs ($m)	17.28	17.28	17.28
Net present value ($m)	15.32	47.92	113.11
Benefit-cost ratio	1.89	3.77	7.55

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 E15). 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 E 15: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Medium	High

Coverage of benefits was assessed as medium. While the economic benefit to graziers participating in the Grazing BMP project was quantified, the environmental benefit of reduced sediment laden runoff, improved water quality and protection for the GBR, the principal driver for the project, was 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 high. The data supporting the assumptions leant heavily on project data. The approach used was consistent with an internal Cost Benefit Analysis completed by DAF for the first phase of Burdekin river catchment investment (DAF, 2015).

8. Conclusions

Grazing BMP is a voluntary program that aims to help beef cattle graziers to identify practices to enhance profitability, natural resource management and ethical production. The survey evidence indicates that participating graziers have lifted soil health, land management, animal production and business performance. Ultimately public investment has been made in the project to contribute to reduced sediment laden runoff, improved water quality and ecosystem health in the GBR.

Given the counterfactual scenario assumed, total funding from all sources for the project was approximately $17.28 million (present value terms). The value of total benefits was estimated at $65.19 million (present value terms). This result generated an estimated net present value (NPV) of $47.92 million, a benefit-cost ratio (BCR) of 3.77 to 1, an internal rate of return of 30.7% and a modified internal rate of return of 9.8%.

Sensitivity analyses carried out on key variables used in the valuation of impacts indicate that even if only half the graziers completing the BMP program make positive practice change on their property or if the assumed increase in profit is only half that assumed in the base analysis, investment criteria for the project remain positive. Results also remained positive for the higher (10%) discount rate.

The analysis has demonstrated that research, development and extension aimed at improving the performance of beef cattle grazing enterprises in river catchments that drain to the GBR has the potential to generate economic, environmental and social benefits for property owners and the QLD community.

References

ABS (2019) 5404.0 Australian System of National Accounts Table 4 Expenditure on Gross Domestic Product (GDP), Implicit Price Deflators

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Appendix F: An Impact Assessment of DAF Investment into Bioenergy-RD&E projects supporting adoption of on-farm biogas systems by the Australian pork industry

Acknowledgments

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Abbreviations

ABS	Australian Bureau of Statistics
ACCU	Australian Carbon Credit Units
ALFA	Australian Lot Feeders Association
AM2MA	Australian Methane to Markets Program
APL	Australian Pork Limited
BCR	Benefit-Cost Ratio
BSP	Bioenergy Support Program
CAL	Covered Anaerobic Lagoon
CHP	Combined Heat and Power
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
DA	Dairy Australia
DAF	Department of Agriculture and Fisheries – Queensland
DAFF	Department of Agriculture, Fisheries and Forestry – Aust. Government
EOI	Expression of Interest
GDP	Gross Domestic Product
GHG	Greenhouse Gas
H_2S	Hydrogen Sulphide
IRR	Internal Rate of Return
kWh	Kilowatt Hour (of electricity)
LPG	Liquid Petroleum Gas
MIRR	Modified Internal Rate of Return
MLA	Meat and Livestock Australia
NPV	Net Present Value
PPM	Parts Per Million
PVB	Present Value of Benefits
PVC	Present Value of Costs
QLD	Queensland

R&D	Research and Development
RD&E	Research, Development and Extension
RECs	Renewable Energy Certificates
RIRDC	Rural Industries Research and Development Corporation
SPU	Standard Piggery Units
UQ	University of Queensland

Executive Summary

The primary purpose of this assessment is to demonstrate that benefits have accrued from specific DAF investments. The positive results in terms of both the number and range of impacts identified and valued demonstrate that the investment in the four projects delivered significant value to pork producers and the environment, and provided a healthy return on research, development and extension (RD&E) investment.

The RD&E investment assessed covered the period 2013 to 2018 and totalled $0.94 m in nominal terms. The specific RD&E projects were undertaken within the Queensland Department of Agriculture and Fisheries (DAF) and the University of Queensland (UQ) but covered pig producers in all Australian States. The projects were supported by the Cooperative Research Centre for High Integrity Australian Pork (Pork CRC) via its Bioenergy Support Program (BSP) that commenced in 2012.

The investment of $1.20 m in present value terms was assessed as providing monetary impacts of $3.05 m (present value terms), a net present value of $1.85 m, a benefit cost ratio of 2.55 to1, an internal rate of return of 6.3%, and a modified internal rate of return of 5.6%

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, Cooperative Research Centres, State Departments of Agriculture, and some Universities. This impact assessment uses Cost-Benefit Analysis 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, 2018).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, and potential and actual outcomes and impacts. This was effected for each project. 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

Background

Methane is considered the dominant agricultural greenhouse gas (GHG) in Australia, with methane from livestock emissions representing 12% of Australia's total emissions (Department of Agriculture, Fisheries and Forestry, 2011). Livestock emissions include those from enteric fermentation and from manure. These emissions respectively arise from the digestive process of livestock and the decomposition of animal wastes in manure management systems.

The National Agriculture and Climate Change Action Plan 2006-2009 identified methane capture and use as a priority area for emission reductions in the livestock sector. The potential for capture and use of methane from livestock was considered greatest in the intensive livestock industries where manure management is estimated to contribute three per cent of emissions from Australian agriculture (Rose, 2008).

The early Methane to Markets Partnership was a multilateral partnership, the purpose of which was to create a voluntary, non-binding framework for international cooperation to reduce methane emissions and advance the recovery and use of methane as a valuable clean energy source (Global Methane Initiative, undated). The Australian Methane to Markets in Agriculture (AM2MA) Program was established in 2007 by the Australian Government and industry as part of Australia's involvement in the Methane to Markets Partnership.

The AM2MA Program was managed by the Rural Industries Research and Development Corporation (RIRDC). A Steering Committee guided the Program and comprised representatives from the Commonwealth Government, RIRDC, Dairy Australia (DA), Australian Pork Limited (APL), Meat and Livestock Australia (MLA) and the Australian Lot Feeders' Association (ALFA). The goal was to encourage and enable development, adaptation and use of methane capture technology in the Australian intensive livestock industries.

The AM2MA evolved into the Global Methane Initiative, a multilateral partnership, the purpose of which was to create a voluntary, non-binding framework for international cooperation to reduce methane emissions and advance the recovery and use of methane as a valuable clean energy source (Global Methane Initiative, undated).

Covered Anaerobic Lagoon (CAL) systems offer the potential to reduce GHG emissions and provide a source of renewable energy. A number of Australian piggeries have installed such systems; however, improvements were needed in their safety and efficiency – removal of hydrogen sulphide from the raw biogas and an increase in the number of on-farm energy uses for which biogas could be applied. Extension was needed to increase pig producer knowledge of CAL biogas systems before industry-wide adoption could occur.

The Cooperative Research Centre for High Integrity Australian Pork (Pork CRC) was particularly active in further researching and extending information on biogas production and use from piggeries across Australia via its Bioenergy Support Program (BSP) that commenced in 2012. The investment addressed in this impact assessment was made by the Pork CRC via a joint project with the Queensland Department of Agriculture and Fisheries (DAF) and the University of Queensland (UQ) over the period from April 2013 to June 2018.

As of 2018, the manure effluent of approximately 15% of the total Australian pig herd was being directed to biogas systems. This is the equivalent of 29% of the national herd housed in conventional sheds at piggeries larger than 500 sow farrow-to-finish (the Pork CRC's estimated cut-off for feasibility). Prior to project investment, manure from only about 2% of the national Australian herd was being directed to biogas systems (Pork CRC Annual Report, 2018).

3. Investment Details

Summary of Projects

Four DAF projects completed between April 2013 and June 2018 are the subject of this impact assessment. Project Codes, Titles, Principal Investigators and Funding Periods are provided in Table F1.

Table F 1: Summary of Projects Included in the Impact Assessment

Project Code:	**Title**	**Principal Investigator(s)**	**Funding Period**
4C-104	Bioenergy Support Program (Sub-project assessed was Alan Skerman's Master of Philosophy '*Cost effective options for piggery biogas treatment*)'.	Stephan Tait (UQ) Alan Skerman (DAF).	2013-2016.
4C-114	Options for Cost Effective and Efficient Use of Piggery Biogas Energy.	Alan Skerman (DAF).	2014-2015.
4C-116	Bioenergy Support Program - DAF Transition.	Alan Skerman (DAF).	2015-2018.
4C-122	Installation of instrumentation for remote monitoring of biogas composition and operational data at commercial piggeries.	Alan Skerman (DAF) and Stephan Tait (UQ).	2018.

Logical frameworks for the four DAF projects are presented in Table F2.

Table F 2: Logical Frameworks

Code and Title	**4C-104 sub-project: Cost effective options for piggery biogas treatment.**
Project Details	Organisation: DAF. Period: April 2013 to June 2016. Principal Investigator: Alan Skerman (*Master of Philosophy project*).
Rationale	The concentration of hydrogen sulphide (H_2S) in raw biogas captured in CALs at Australian piggeries ranges from 500 to 3,000 ppm. These relatively high concentrations of H_2S present a major obstacle to biogas technology uptake by the industry due to toxicity and corrosion considerations. The Safe Work Australia 8-hour average and short term exposure limits for H_2S are 10 and 15 ppm. When H_2S dissolves in condensed moisture, it forms sulphuric or sulphurous acid which is highly corrosive, limiting the life of biogas burning appliances and causing serious corrosion in metallic fittings. The cost of using commercial biogas filter media to remove H_2S from piggery biogas may affect the economic viability of biogas systems, limiting technology uptake and the accompanying reduction in energy costs and greenhouse gas emissions. It is estimated that a 1,000 sow piggery may need to spend $20,000 annually to reduce average biogas concentrations from 2,000 to 200 ppm which is a substantial 20% of the total revenue/cost savings from using the biogas.
Objectives	Identify and test low-cost options for on-farm cleaning of piggery biogas of H_2S.
Activities and Outputs	• Literature review to identify novel low cost gas cleaning options for testing. Options identified included granulated steel furnace slag, red soil, compost, composted beef feedlot manure, granulated activated charcoal and biochar. • Fabrication of laboratory scale experimental apparatus for testing sorption capacity and kinetics of H_2S on various solid media. • Testing of media and modelling in laboratory trials at UQ and DAF Toowoomba. Completion of experiments testing the performance of ten alternative biogas scrubbing media and two commercial media, some with dry and moisture-saturated test gas. • Upgrade of equipment and completion of on-farm pilot-scale scrubber trials and theoretical modelling. • A trial testing H_2S oxidation added small amounts of air to biogas upstream of a low-cost enhanced surface treatment vessel which was made on-farm with intrinsic safety measures. CAL effluent provided a convenient, low-cost nutrient source for the biofilm of naturally occurring microorganisms in the packed column. This treatment was effective, removing 90%+ of H_2S in a single pass and reducing H_2S concentrations from 4,000 ppm to <400 ppm. • Another trial tested commercial media against low cost alternatives. Commercial media provided the best performance. However, red soil exposed to air and mixed with ground sugar cane mulch may be useful for final polishing after an oxidation step has removed most of the H_2S. • A Master of Philosophy thesis was prepared, submitted and the qualification duly awarded to Alan Skerman. • Findings were presented to a student workshop in May 2014, a DAF seminar in June 2014 and a Bioenergy Australia Conference in December 2014. Two scientific journal articles were published.
Outcomes	• Lower cost techniques for reducing H_2S levels in biogas were identified, increasing the financial viability and uptake of piggery biogas production.
Impacts	• Additional capital and operating cost of biogas systems at piggeries encouraged to adopt the technology as a result of project outcomes.

	• Additional adoption of biogas systems and hence contribution to reduced GHG emissions – methane is captured and burnt for electricity or heat production reducing its GHG potential. • The increased uptake of biogas systems will reduce piggery operating costs – biogas is substituted for purchased electricity, heat energy or sold to the electricity grid. • Capital equipment associated with biogas production at piggeries adopting the technology lasts longer with biogas cleaned of corrosive H_2S. • Increased pork industry resilience to rising energy costs with adoption of biogas systems. • Staff working in piggeries with biogas cleaned of H_2S have safer working conditions. • The increased uptake of biogas systems improved community and worker amenity due to reduced odour emissions. • Enhanced social licence for the pork industry with less threat of piggery closures, more opportunity to expand and less restrictive regulation. • Increased farm profitability some of which flows to local families and businesses in regional areas. • Increased biogas management and research capacity.

Code and Title	**4C-114: Options for Cost Effective and Efficient Use of Piggery Biogas Energy.**
Project Details	Organisation: DAF. Period: August 2014 to September 2015. Principal Investigator: Alan Skerman.
Rationale	A number of Australian pork producers have recently adopted on-farm anaerobic digestion systems producing biogas which is generally used in combined heat and power (CHP) systems. Large piggeries typically produce biogas in excess of the volume required to satisfy on-site electrical power use. Rather than flaring the unutilised biogas or low priced sales of electricity back to the grid, a project was required to examine the feasibility of adopting a range of alternative uses of biogas which could potentially improve on-farm energy use efficiency, in a cost effective manner.
Objectives	1. Review options for use of excess biogas generated with CHP systems. 2. Prepare case studies to demonstrate how absorption cooling could be used in tri-generation (electrical energy, heating and cooling) systems to supply the electrical, heat and cooling energy requirements of typical piggeries.
Activities and Outputs	• Literature review to identify alternative uses for biogas including absorption heating and cooling, space and water heating, gas turbines, transport fuel. • Collect data on farm characteristics and energy use at case study piggeries. • Complete feasibility studies in partnership with commercial provider Simons Green Energy on four piggeries including designs/costings for tri-generation systems suitable for maximising biogas energy use efficiency. • Options identified for use of excess biogas included boilers, internal combustion engines, electrical generators, micro-turbines, Stirling motors, organic Rankine cycle systems, fuel cells, tri-generation and vehicle fuel. • On-farm uses for additional energy included odour mitigation, shed space heating, underfloor hot water circulation, radiators, radiant heaters, shed cooling, absorption chilling, drinking water chilling and snout cooling. • Preferred options included hot water boilers and co-generation units. Return on investment ranged between 12% and 25%. Returns did not include the cost of installing CALs, associated control equipment or returns from sale of Australian Carbon Credit Units.

	• A report detailing the literature review and feasibility study findings was prepared. • Findings presented to conferences; articles published in industry magazines.
Outcomes	• Additional cost-effective on-farm uses for biogas were identified increasing the financial viability and uptake of piggery biogas production.
Impacts	• Additional capital and operating cost of biogas systems at piggeries adopting the technology. • Reduced GHG emissions – methane is captured and used for electrical energy, heating and cooling. • Reduced piggery operating costs - biogas may be substituted for purchased electricity, heat energy and cooling rather than flaring or low value sales to the electricity grid (typically electricity is purchased from the grid at $0.25/kWh but returned to the grid at a value of $0.025/kWh). • Increased pork industry resilience to rising energy costs. • Improved community and worker amenity due to reduced odour emissions. • Enhanced social licence for the pork industry with less threat of piggery closures, more opportunity to expand and less restrictive regulation. • Increased farm profitability some of which flows to local families and businesses in regional areas. • Increased biogas management and research capacity.

Code and Title	**4C-116: Bioenergy Support Program – DAF Transition.**
Project Details	Organisation: DAF. Period: July 2015 to June 2018. Principal Investigator: Alan Skerman.
Rationale	The Pork CRC Bioenergy Support Program (BSP) has encouraged extensive uptake of biogas technology and coordinated the development of a relevant research program. A project was required to fund Alan Skerman to take over the BSP's technical extension role. The role required: promoting the outcomes of relevant Pork CRC research; keeping existing biogas extension material up-to-date; and offering technical support for adoption of biogas technology at commercial piggeries which have been designated as Pork CRC demonstration sites. Dr Stephan Tait, UQ would continue to deliver and coordinate the research component of the BSP Program.
Objectives	1. To effectively extend the outcomes from research projects 4C-104, 4C-109, 4C-111, 4C-113 and 4C-114 across the pork industry and contribute to meeting Pork CRC sub-program 4C milestones relating to Carbon Neutral Pork Production. 2. To continue to promote adoption of biogas by offering technical support to early adopter producers, and by keeping Pork CRC biogas-related extension materials up-to-date as an information resource to support adoption. 3. To provide the Pork CRC with up-to-date information about ongoing activities and adoption of new technologies at the Pork CRC biogas demonstration sites.
Activities and Outputs	• Provide ongoing extension updates on projects 4C-104, 4C-109, 4C-111, 4C-113 and 4C-114 as articles in the Australian Pork Newspaper. • Keep technical information up-to-date including case study site information and descriptions and the Pork CRC Technical Talking Topic series. • Maintain the existing phone and email based inquiry line to support producers investigating biogas capture, treatment and use systems.

	• Keep up-to-date industry adoption statistics to allow Pork CRC to communicate on its contribution to meeting industry adoption targets. • Develop/maintain basic laboratory analytical services at DAF Toowoomba to support producers contemplating new biogas developments. • Support early adopter producers trialling low-cost on-farm biogas systems. • The project delivered four Talking Topics booklets, eight Australian Pork Newspaper 'It's a gas' articles, a YouTube video, five peer-reviewed journal articles, three conference papers and several industry talks. Face-to-face meetings were held with biogas producers and those contemplating uptake.
Outcomes	• Additional take-up of biogas systems in Australian piggeries.
Impacts	• Additional capital and operating cost of biogas systems at piggeries adopting the technology. • Reduced GHG emissions – methane captured at more Australian piggeries. • Reduced piggery operating costs – more Australian piggeries adopting biogas systems. • Increased pork industry resilience to rising energy costs. • Improved community and worker amenity due to reduced odour emissions. • Enhanced social licence for the pork industry with less threat of piggery closures, more opportunity to expand and less restrictive regulation. • Increased farm profitability some of which flows to local families and businesses in regional areas. • Increased biogas management and research capacity.

Code and Title	**4C-122: Installation of instrumentation for remote monitoring of biogas composition and operational data at commercial piggeries.**
Project Details	Organisation: DAF. Period: July 2017 to June 2018. Principal Investigators: Alan Skerman and Stephan Tait.
Rationale	There was a need to facilitate and provide incentives to pig producers to install instrumentation to remotely monitor biogas composition and other operational data, at up to three commercial piggeries with existing on-farm biogas systems. The high quality data available through these installations would be used for: (i) early diagnosis of operational irregularities or system faults, (ii) evaluation of a range of operating strategies and biogas treatment methods, (iii) manage changes in biogas composition resulting from co-digestion feed stock variations, (iv) validate the energy and economic value of the biogas, (v) assess short and long-term seasonal variations in biogas production and quality, and (vi) manage biogas use options to maximise economic benefit. These data were to be readily accessible to the piggery managers for daily biogas system management purposes and key Pork CRC BSP researchers/technical support officers involved in documenting system performance and carrying out strategic applied research. These initial installations were to provide a pilot resource for long-term evaluation and possible modification prior to more widespread deployment across the industry.
Objectives	To facilitate and provide incentives for producers to install instrumentation to enable Pork CRC BSP officers and piggery managers to remotely monitor biogas composition and other operational data at up to three existing on-farm biogas systems operating at commercial piggeries.
Activities and Outputs	• Call for EOI from piggeries for grants of $10,000 for use on installation of biogas monitoring instruments. Three most suitable applications selected. • Each producer incurred a cost of $50,000 to have biogas monitoring instruments installed/commissioned. $10,000 grant deducted from this total. • Data collected over a three month period, analysed and a report produced.

	• Final report included findings to help producers and industry service providers deploy similar systems at additional piggeries. • Ongoing data used for technical papers and extension material. • Producers assisted in the daily operation of their biogas plants. • BSP able to offer improved support to producers. • Accurate, consistent and timely data for R&D projects. • Comprehensive evaluation of biogas system operation and viability.
Outcomes	• More efficient biogas systems, improved financial viability and additional uptake of systems in Australian piggeries.
Impacts	• Additional capital and operating cost of biogas systems at piggeries adopting the technology. • Reduced GHG emissions – methane captured at more Australian piggeries. • Reduced piggery operating costs – more Australian piggeries adopting biogas systems. • Increased pork industry resilience to rising energy costs. • Improved community and worker amenity due to reduced odour emissions. • Enhanced social licence for the pork industry with less threat of piggery closures, more opportunity to expand and less restrictive regulation. • Increased farm profitability some of which flows to local families and businesses in regional areas. • Increased biogas management and research capacity including effective monitoring systems.

4. Project Investment

Nominal Investment

Table F3 shows the annual investment (cash and in-kind) for each of the four projects.

Table F 3: Annual Investment (nominal $)

Project	Year ending 30th June	DAF	Pork CRC	Other	Total
4C-104	2013	65,000#	0	0	65,000
	2014	65,000#	5,500	0	70,500
	2015	65,000#	8,250	0	73,250
	2016	65,000#	8,250	0	73,250
	Total	***260,000***	***22,000***	***0***	***282,000***
4C-114	2015	57,613	33,372	16,000*	106,985
	2016	21,124	6,500	4,000*	31,624
	Total	***78,737***	***39,872***	***20,000***	***138,609***
4C-116	2016	64,170	38,975	0	103,145
	2017	65,678	38,992	0	104,670
	2018	67,221	39,530	0	106,751
	Total	***197,069***	***117,497***	***0***	***314,566***
4C-122	2018	157,145	50,000	0	207,145
	Total	***157,145***	***50,000***	***0***	***207,145***
All Projects	2013	65,000	0	0	65,000
	2014	65,000	5,500	0	70,500
	2015	122,613	41,622	16,000	180,235
	2016	150,294	53,725	4,000	208,019
	2017	65,678	38,992	0	104,670
	2018	224,366	89,530	0	313,896
	Totals ($)	**692,951**	**229,369**	**20,000**	**942,320**

Source: project proposals and Pork CRC Annual Report 2018
Agtrans estimate of DAF in-kind contributions based on Alan Skerman salary (0.11FTE) + overheads
* Project contribution made by Simons Green Energy

Program Management Costs

For the DAF investment, the management and administration costs for the project are assumed already built into the nominal dollar amounts appearing in Table F3. 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 the Pork CRC investment, a management cost multiplier of 1.3 was applied to the CRC contributions shown in Table F3. This multiplier was based on information in the Pork CRC Annual Report (2018).

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2017/18 dollar terms using the Implicit GDP Deflator index (ABS, 2018). No additional costs of extension were included as the project already involved a high level of industry participation through individual pork businesses and a project that targeted industry extension (4C-116).

5. Impacts

Research and extension to improve the efficiency of piggery biogas systems has delivered the following impacts.

Capital and operating costs on-farm

Construction and operation costs are incurred at piggeries that adopted CAL biogas systems following project related RD&E. Costs are also incurred for auxiliary units to maximise the benefit from biogas generation and use.

Reduced greenhouse gas emissions

The anaerobic digestion process that takes place in CALs generates biogas which is otherwise released into the atmosphere. Biogas mostly consists of methane, a strong GHG that is far more potent than carbon dioxide. When biogas is burned, the methane in the gas is converted to carbon dioxide and consequently the impact of the GHG emissions is reduced. Burning methane on-farm in biogas systems creates energy that can substitute for purchased energy (e.g. electricity generated from fossil fuels). This in turn further reduces GHG emissions. GHG emission reductions are able to earn Australian Carbon Credit Units (ACCUs) which were valued by Skerman *et al*. (2015) at \$10/tonne of CO_2 equivalent under the Australian Government's Emissions Reduction Fund. Projects analysed in this impact assessment increase the safety (4C-104), efficiency (4C-104, 4C-114, 4C-122) and uptake (4C-116) of CAL-based biogas systems.

Reduced piggery operating costs

Biogas captured by CALs can be burnt to generate electricity, heat energy or used for absorption cooling. This will lead to reduced operating costs if the electricity/ heat/ cooling energy generated is consumed on-site and consequently reduces other energy inputs such as electricity purchased from the grid. Operating cost savings identified in project 4C-114 include operation of piglet heating pads, provision of chilled sow drinking water, reduced 'grid sourced' electricity for heat lamps and reduced LPG use for shed space heating. Electricity can also be generated for general use on-farm (valued at \$0.25/kWh) with surpluses sold to the grid (valued at \$0.025/kWh). Electricity generated from biogas also earns Renewable Energy Certificates (RECs) (valued at \$0.0395/kWh). CAL biogas systems are only relevant to larger operations with 500 or more sows.

Increased industry resilience

Generation of energy on-farm at least partially isolates the pork industry from a major source of cost pressure (rising energy prices) at a time when the industry has faced strong competition from low-cost imported pig meat.

Improved community and worker amenity due to reduced odour emissions

Anaerobic effluent ponds tend to produce offensive (rotten egg gas) odours as a result of the anaerobic digestion process that occurs in the ponds. Odour emissions can potentially reduce the quality of life of workers and surrounding neighbours. Impermeable pond covers used to capture methane can also be used to reduce odour emissions from anaerobic ponds. Therefore, improved community and worker amenity can be achieved by covering anaerobic ponds for methane capture and use.

Enhanced social licence for the Australian pig industry

CAL installation may enhance the social licence of piggeries which have attracted odour complaints, allow the development of new or expanded piggery operations at a site which would otherwise be unsuitable for development and relax regulatory pressure on pork producers due to odour and impact on nearby residents.

Spillovers from increased farm incomes to regional communities

Some social impact may be derived from improved profitability and sustainability of piggeries that have installed biogas systems via the maintenance or increase of farm profitability, some of which flows to local families and businesses.

Increased piggery management and research capacity

Completion of all four projects analysed in this impact assessment has increased skill level in piggery managers managing CAL biogas systems and added to the skill base of DAF staff including the completion of a Master of Philosophy by Alan Skerman. As a result of the projects analysed, researchers also have access to effective biogas monitoring systems in commercial piggeries.

Summary of Impacts

An overview of impacts in a triple bottom line categorisation is shown in Table F4.

Table F 4: Categories of Impacts from the Investment

Economic	Environmental	Social
Capital and operating costs incurred on-farm for piggeries adopting CAL biogas systems. Reduced large piggery operating costs via the generation of electricity. Additional piggery income streams from ACCUs and RECs.	Reduced GHG emissions.	Increased industry resilience. Improved community and worker amenity due to reduced odour emissions. Enhanced social licence for the pork industry with less threat of piggery closures, more opportunity to expand and less restrictive regulation. Spillovers from increased farm incomes to regional communities. Increased piggery management capability and increased research capacity.

Public versus Private Impacts

The impacts identified from the investment are both private and public in nature. Private impacts accrue to pork producers – capital and operating costs for CAL biogas systems, reduced piggery operating costs and additional income streams from carbon credits. Public/social benefits include a more pleasant and safer workplace, environmental benefits from lowered GHG emissions to the atmosphere, as well as spillovers to regional communities from increased industry resilience, enhanced producer incomes and increased biogas infrastructure leading to higher regional economic activity and employment. Some community amenity benefits may be captured due to reduced odour emissions and increased piggery management and research capacity.

Impacts Accruing to other Primary Industries

Improvements in the safety and efficiency of CAL biogas systems will be relevant to other large intensive animal operations including dairy, beef cattle feedlotting and intensive poultry production. The use of CAL biogas systems in meat processing facilities is assumed not to be financially viable due to the alternative uses of meat processing waste.

Distribution of Benefits along the Pork Supply Chain

Some of the potential benefits from the higher profile green, 'carbon neutral' image of pork will be shared along the supply chain with processors, distributors and consumers.

Impacts Overseas

Technological developments pertaining to CAL biogas systems will be relevant to intensive animal industries in other countries. Techniques to improve the safety and efficiency of systems will be most relevant to large scale production in technologically advanced countries. It is noted that the New Zealand pork industry was a partner in the Pork CRC and has priority access to research findings. Also, it is understood that adoption of simplified systems, potentially using low cost biogas cleaning techniques developed as part of 4C-104, will be relevant to developing communities.

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 F5. The investment in biogas adoption is relevant to Rural RD&E Priorities 1 and 4 and to Science and Research Priority 1, 5 and 7.

Table F 5: 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 (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 F6.

The investment addressed QLD Science and Research Priorities 1, 4 and 6. In terms of the guides to investment, the investment is likely to have a real future impact on pork production profitability, as well as deliver environmental benefits. The DAF investments were well supported by others external to the QLD Government and had a distinctive angle via delivery of both industry and environmental impacts.

Table F 6: 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

Table F4 impacts valued in the quantitative analysis were:

- Additional capital and operating costs incurred on-farm for piggeries adopting CAL biogas systems as a result of project RD&E.
- Reduced piggery operating costs via the generation of electricity.
- Additional piggery income streams from reducing GHG emissions including sale of ACCUs and the redemption of RECs.

Impacts not Valued in Monetary Terms

The impacts identified but not valued included:

- Increased industry resilience.
- Improved community and worker amenity due to reduced odour emissions.

- Enhanced social licence for the pork industry.
- Spillovers from increased farm incomes to regional communities.
- Increased piggery management capability and increased research capacity.

Social impacts were not quantified due to a lack of evidence/data, difficulty in quantifying the causal relationship and pathway between the projects and the impact and the complexity of assigning monetary values to the impact.

Quantification of Benefits

Additional Capital and Operating Costs
Capital and operating costs will be incurred on large piggeries adopting CAL biogas systems as a result of project RD&E. Capital and operating costs will include the CAL, electricity generation equipment, boilers to generate heat and thermal integration equipment. Costs will vary by piggery size and the type of production activity undertaken. For analysis purposes an average of data assembled for four large piggeries as part of 4C-114 has been used (Skerman *et al*., 2015).

Reduced Piggery Operating Costs
Installation and operation of a CAL biogas system will save the adopting large piggery electricity purchase costs. Cost savings have been estimated using average data from the four large piggeries assembled as part of 4C-114 (Skerman *et al*., 2015). Estimates were prepared using an assumed average value of $0.25/kWh.

Income Earned from Electricity Sales
Even with additional on-farm uses for energy generated by the CAL biogas system there will be a small surplus of electricity that can be fed back into the electricity grid. The value of this surplus has been estimated using average data from four large piggeries assembled as part of 4C-114 (Skerman *et al*., 2015). Estimates were prepared using the low but realistic price of $0.025/kWh.

Income Earned from ACCUs
Under the Emissions Reduction Fund piggeries adopting CAL biogas systems are eligible to earn ACCUs. The value of piggery ACCUs has been estimated using average data for four large piggeries assembled as part of 4C-114 (Skerman *et al*., 2015). Estimates were prepared using a value of $10/tonne of CO_2 equivalent.

Income Earned from RECs
Piggeries adopting CAL biogas systems are eligible to claim Renewable Energy Certificates. The value of piggery ACCUs has been estimated using average data for four large piggeries assembled as part of 4C-114 (Skerman *et al*., 2015). Estimates were prepared using a value of $0.0395/kWh.

Timing and Extent of Adoption
Australian Government estimates in 2012 suggested 690 Australian piggeries may be able to capture and destroy methane (DAFF, 2011). Research also suggested that by 2017, methane emitted by 15-20% of the Australian pig herd will be captured and destroyed, increasing to 25-30% by 2020 (DAFF, 2011). The 2017 estimate is the equivalent of 21 large piggeries having CAL biogas systems (Tait, 2014). With the four DAF projects analysed in this impact assessment in place and additional knowledge on safety and efficiency generated and communicated to piggery owners, two additional piggeries that would not otherwise have adopted a CAL are assumed to adopt the technology every year for eight years starting in 2017.

Other Assumptions
For the purposes of this analysis, the first year of investment by a piggery as a result of the projects analysed is assumed to be 2017.

Counterfactual

The four DAF projects analysed in this impact assessment have increased the safety, efficiency and uptake of CAL biogas systems. As a result, it is assumed the investment will increase the number of piggeries that adopt the technology in comparison to a scenario without the investment (i.e. two additional piggeries every year for eight years).

Table F 7: Summary of Assumptions for Valuing Benefits

Variable	**Assumption**	**Source**
CAL biogas system costs and returns at a large scale piggery		
Capital cost of CAL biogas system.	$830,000 one-off.	Average of data collected from four large piggeries for the preparation of case studies (Skerman *et al*., 2015).
Operating cost of CAL biogas system.	$65,000 per year.	
Reduced piggery operating costs via the generation of electricity.	$60,000 per year.	
Piggery income – sale of surplus electricity	$12,000 per year.	
Piggery income – sale of ACCUs	$37,000 per year.	
Piggery income – redemption of RECs	$22,600 per year.	
Timing and extent of adoption		
First year of investment by a piggery	2017	Consultant assumption.
Additional adoption with DAF investment in place	2 large piggeries every year for 8 years	Consultant assumption.

7. Results

All past costs were expressed in 2017/18 dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP) (ABS, 2018). 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 (2047/48).

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 present value of benefits (PVB) attributable to DAF investment only, shown in Table F9, has been estimated by multiplying the total PVB by the DAF proportion of real investment (68.6%).

Table F 8: Investment Criteria for Total RD&E Investment in Four CAL Biogas Projects

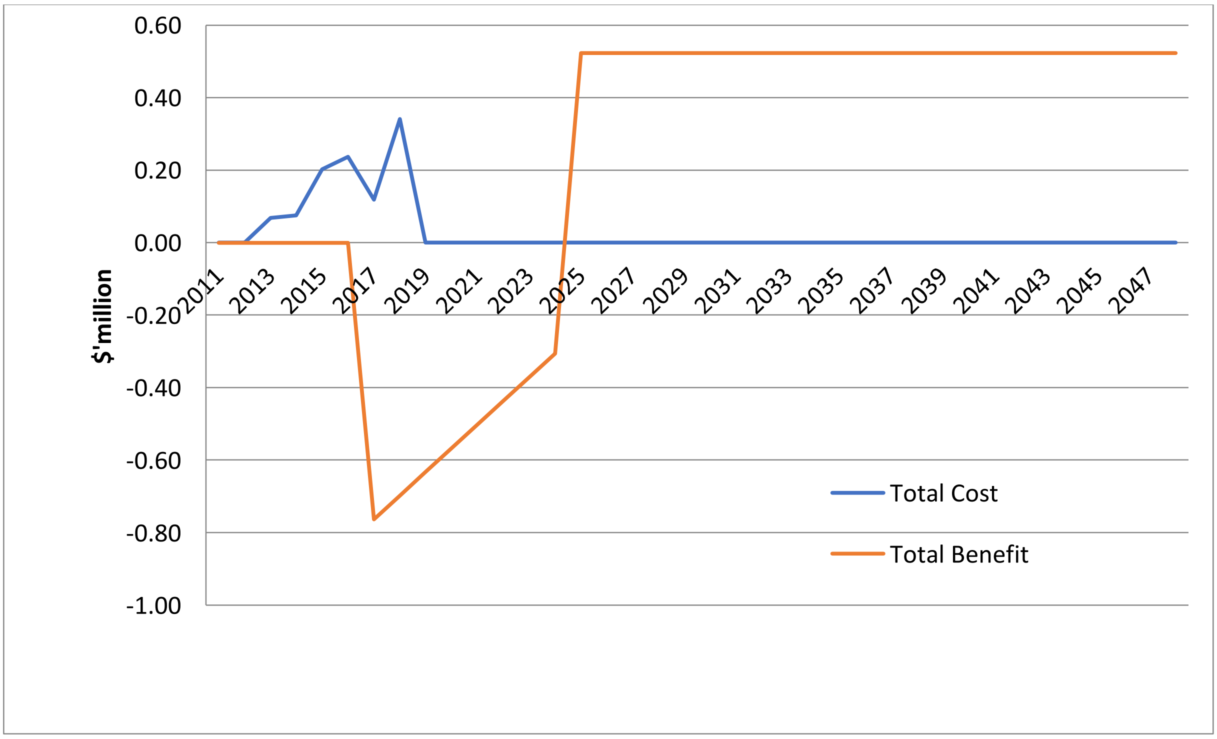
Investment criteria	Number of years from year of last investment						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	-3.15	-7.78	-5.35	-2.43	-0.15	1.65	3.05
Present value of costs ($m)	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Net present value ($m)	-4.35	-8.98	-6.55	-3.63	-1.34	0.45	1.85
Benefit-cost ratio	-2.63	-6.50	-4.47	-2.03	0.03	1.38	2.55
Internal rate of return (IRR)	negative	negative	negative	negative	3.6%	5.4%	6.3%
Modified IRR	negative	negative	negative	1.8%	4.2%	5.2%	5.6%

Table F 9: Investment Criteria for DAF RD&E Investment in Four CAL Biogas Projects

Investment criteria	Number of years from year of last investment						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	-2.16	-5.34	-3.67	-1.67	-0.10	1.13	2.09
Present value of costs ($m)	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Net present value ($m)	-2.99	-6.17	-4.50	-2.50	-0.93	0.30	1.26
Benefit-cost ratio	-2.61	-6.44	-4.43	-2.02	-0.12	1.36	2.53
Internal rate of return (IRR)	negative	negative	negative	negative	3.6%	5.4%	6.3%
Modified IRR	negative	negative	negative	1.8%	4.2%	5.2%	5.6%

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 F 1: Annual Cash Flow of Undiscounted Total Net Benefits and Total RD&E 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 F10 shows that investment criteria are sensitive to the discount rate. This is because there are significant costs 'up front' at the beginning of the analysis period including CAL capital costs and there is a delay before project benefits accrue.

Table F 10: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	16.54	3.05	-2.23
Present value of costs ($m)	1.04	1.20	1.37
Net present value ($m)	15.50	1.85	-3.60
Benefit-cost ratio	15.87	2.55	-1.62

A sensitivity analysis was completed on the number of additional piggeries adopting CAL biogas systems as a result of the projects (Table F11). Results show that with a halving of adoption from two piggeries to a single piggery per year, returns from the investment remain positive.

Table F 11: Sensitivity to Number of Piggeries Adopting CAL Biogas Systems
(Total investment, 30 years)

Investment Criteria	**Additional Piggeries Adopting CAL Biogas Systems as a Result of the Projects**		
	1 every Year for 8 Years	**2 every Year for 8 Years (base)**	**4 every Year for 8 Years**
Present value of benefits ($m)	1.52	3.05	6.10
Present value of costs ($m)	1.20	1.20	1.20
Net present value ($m)	0.33	1.85	4.90
Benefit-cost ratio	1.27	2.55	5.10

A final sensitivity analysis was completed on the reduction in piggery operating costs achieved via the generation of electricity (Table F12). Results show that if electricity cost saving is halved to $30,000 per year, then investment costs exceed investment benefits.

Table F 12: Sensitivity to Reduction in Piggery Operating Costs
(Total investment, 30 years)

Investment Criteria	**Reduction in Piggery Operating Costs**		
	$30,000 per year	**$60,000 per year (base)**	**$120,000 per year**
Present value of benefits ($m)	-5.32	3.05	15.97
Present value of costs ($m)	1.20	1.20	1.20
Net present value ($m)	-6.51	1.85	14.77
Benefit-cost ratio	-4.44	2.55	13.34

Confidence Ratings and other Findings

The investment analysis results 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 F13). 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 F 13: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
Medium	Medium-High

Coverage of benefits was assessed as medium. While key economic benefits were quantified, social/public benefits were not.

Confidence in assumptions was rated as medium-high. Assumptions applied in valuing impacts (costs and prices) were extracted from real situations.

8. Conclusion

The investment in this group of biogas projects has increased the safety, efficiency and awareness of CAL biogas production in large Australian piggeries. This change is expected to provide benefits to pork producers as well as the public. Public benefits will be realised through improved environmental and social outcomes.

In summary, the total investment in the four projects has produced a number of impacts and some of the key benefits have been valued. The total investment of $1.20 million (present value terms) has been estimated to produce total gross benefits of $3.05 million (present value terms) providing a net present value of $1.85 million, a benefit-cost ratio of 2.55 to 1 (using a 5% discount rate), an internal rate of return of 6.3% and a modified internal rate of return of 5.6%.

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